OPERATING SYSTEMS: FILE SYSTEMS

Files, directories and file system

To remember…

Before classes

Class

After class

Prepare the prerequisites.

Study the material associated with the **bibliography**: slides alone are not enough.
Please ask questions (especially after study).

Exercising skills:

- Perform all **exercises**.
- Carrying out the **practice notebooks** and **the practical exercises** progressively.

Recommended reading

Base

1. Carretero 2020:
   1. Cap. 6
2. Carretero 2007:
   1. Cap. 9.1-9.5,
   2. Cap. 9.8-9.10 & 9.12

Suggested

1. Tanenbaum 2006:
   1. (es) Cap. 6
   2. (en) Cap. 6
2. Stallings 2005:
   1. 12.1-12.8
3. Silberschatz 2006:
   1. 10.3-10.4,
   2. 11.1-11.6 and 13

Contents

- □ Introduction
- □ File
- □ Directory
- □ File System
- □ Partitions/Volumes
- □ Devices
- □ System software
- □ File System (manager)

Contents

- □ **Introduction**
- □ File
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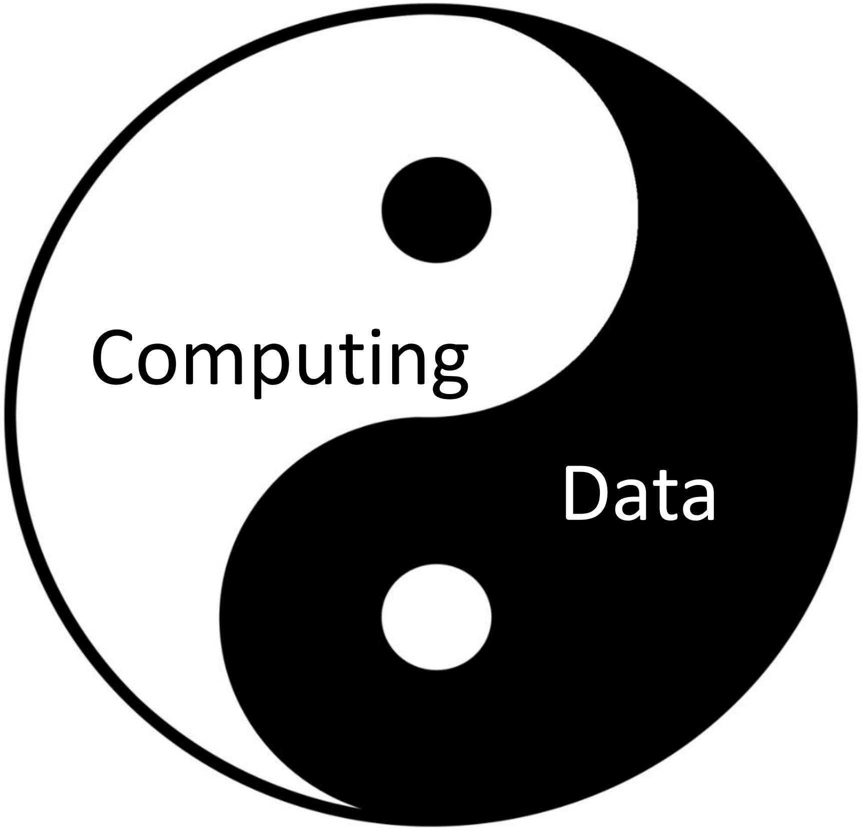
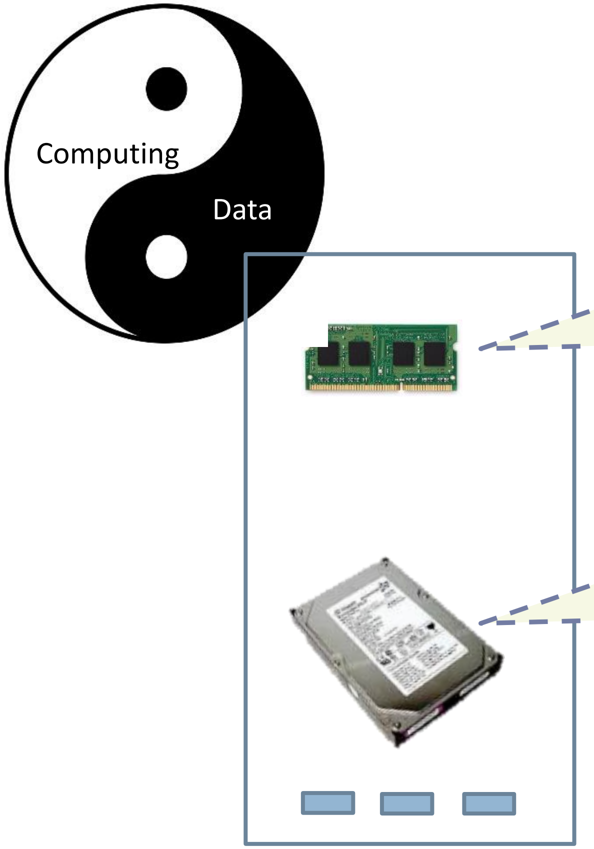
General scope

~2021



General scope

~2021

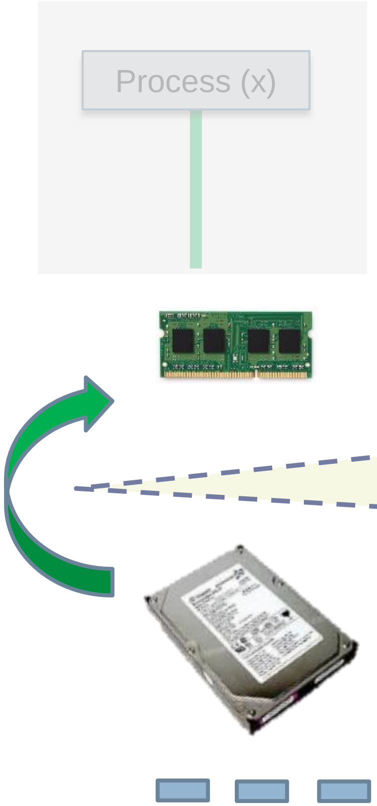


1. Main memory:
   - **NON-persistent** data
   - Works with bytes or words
   - ‘Low’ capacity: only data in use at a given moment

1. Secondary memory:
   - **Persistent** data
   - Works with **data blocks**
   - ‘High’ capacity: all possible data needed

General scope

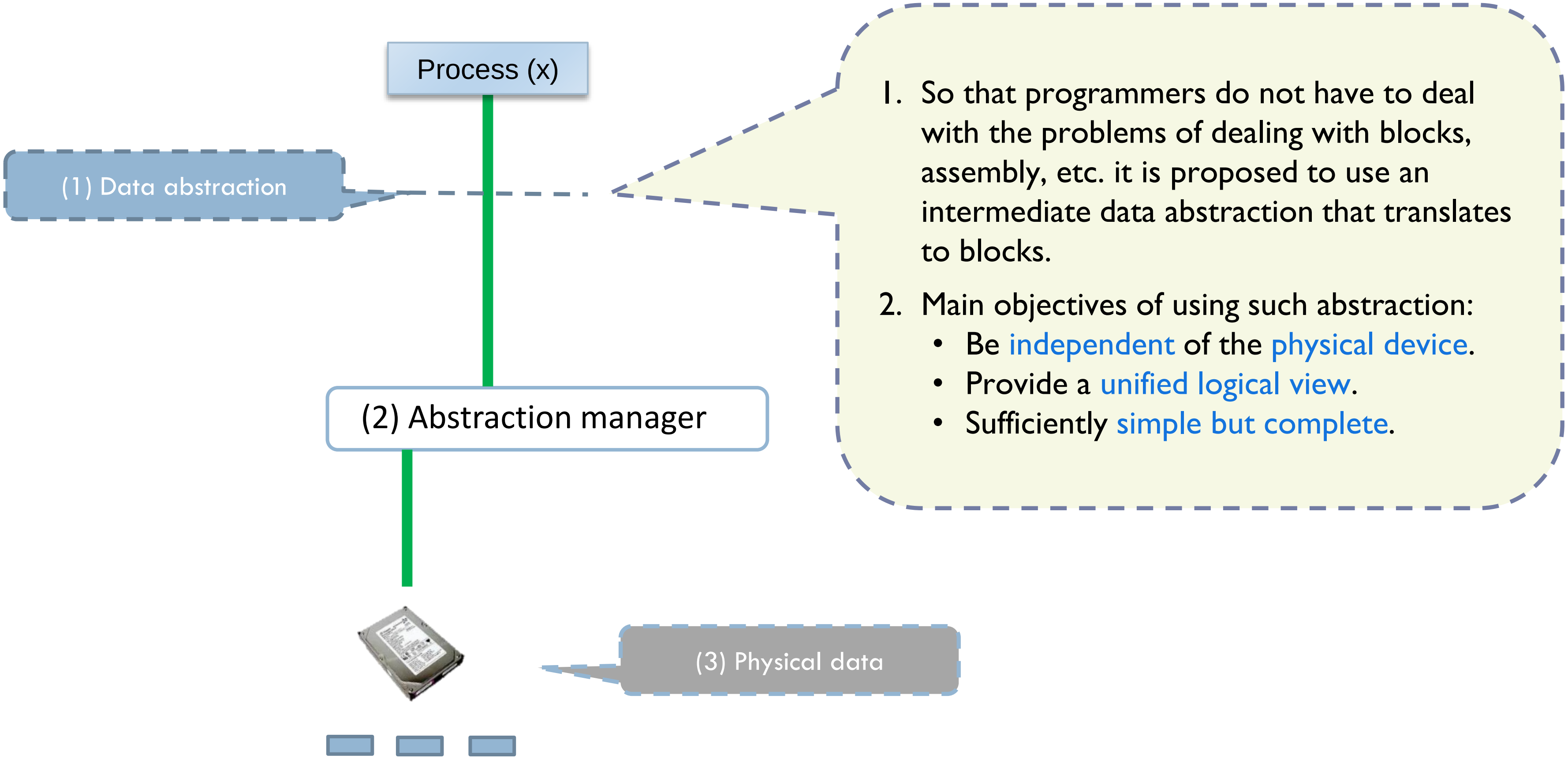
~2021



1. It is necessary to identify in which blocks the data are located and load them into main memory before using them.
2. Goal: to avoid (as much as possible) programmers having to deal with blocks to search for blocks, save or save data, etc.

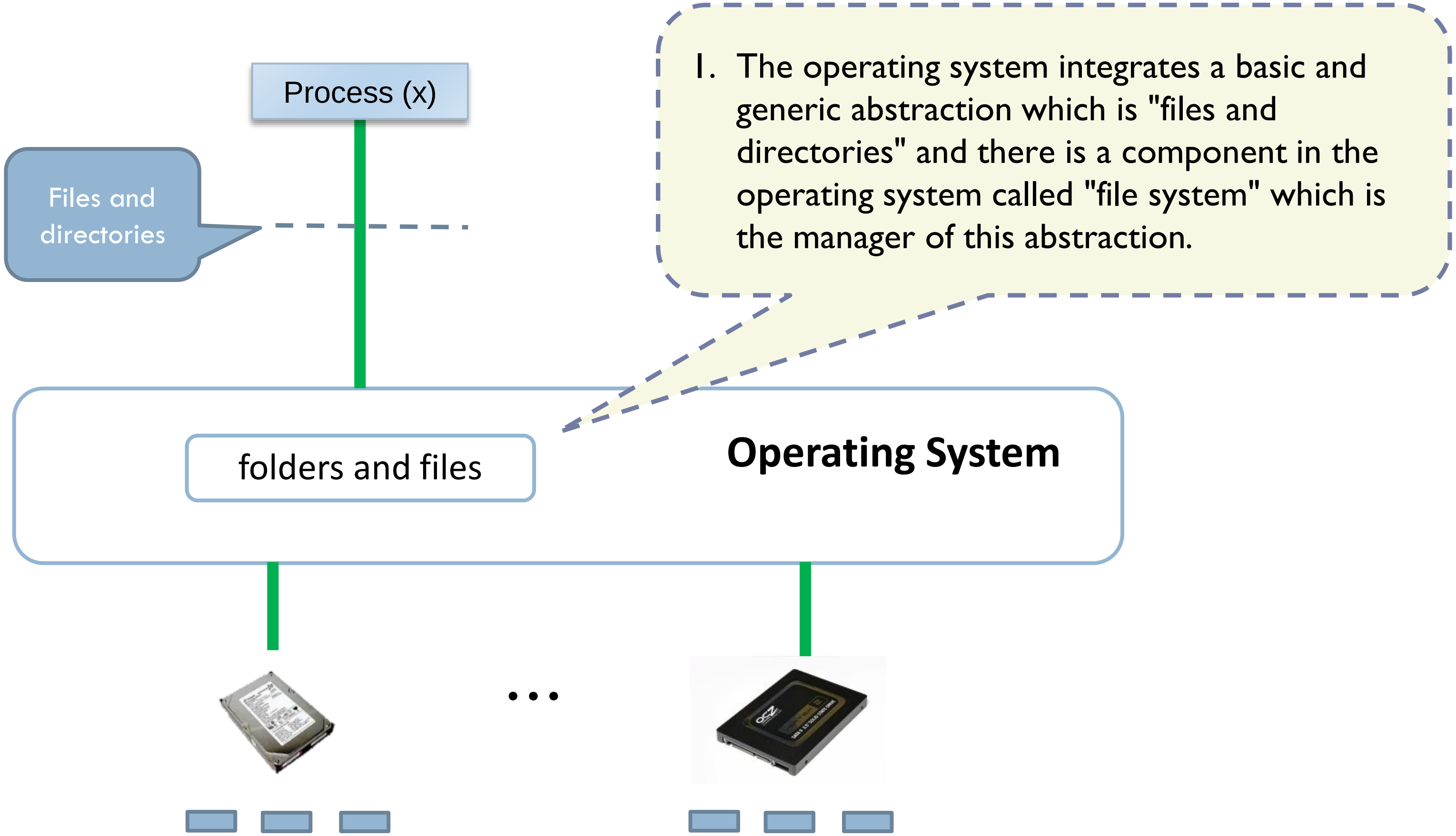
General scope

~2021



1. So that programmers do not have to deal with the problems of dealing with blocks, assembly, etc. it is proposed to use an intermediate data abstraction that translates to blocks.
2. Main objectives of using such abstraction:
   - Be independent of the physical device.
   - Provide a unified logical view.
   - Sufficiently simple but complete.

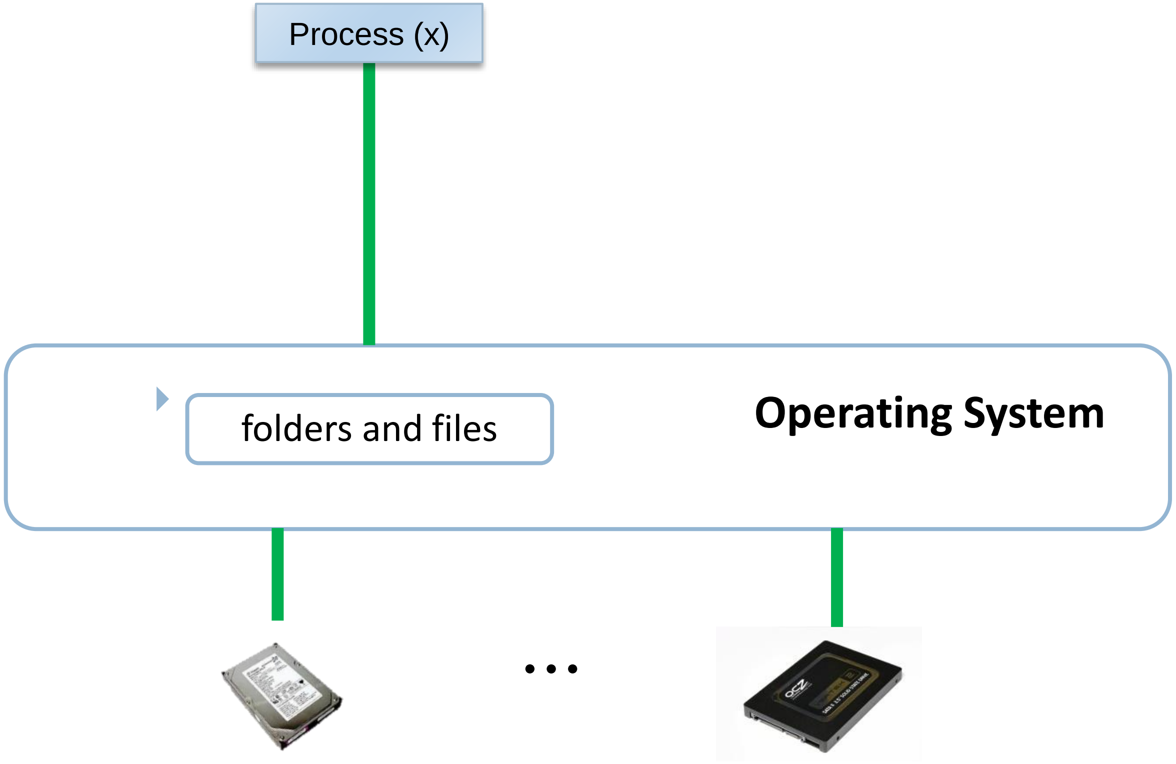
(1/2) The O.S. integrates a basic and generic abstraction: file system



1. The operating system integrates a basic and generic abstraction which is "files and directories" and there is a component in the operating system called "file system" which is the manager of this abstraction.

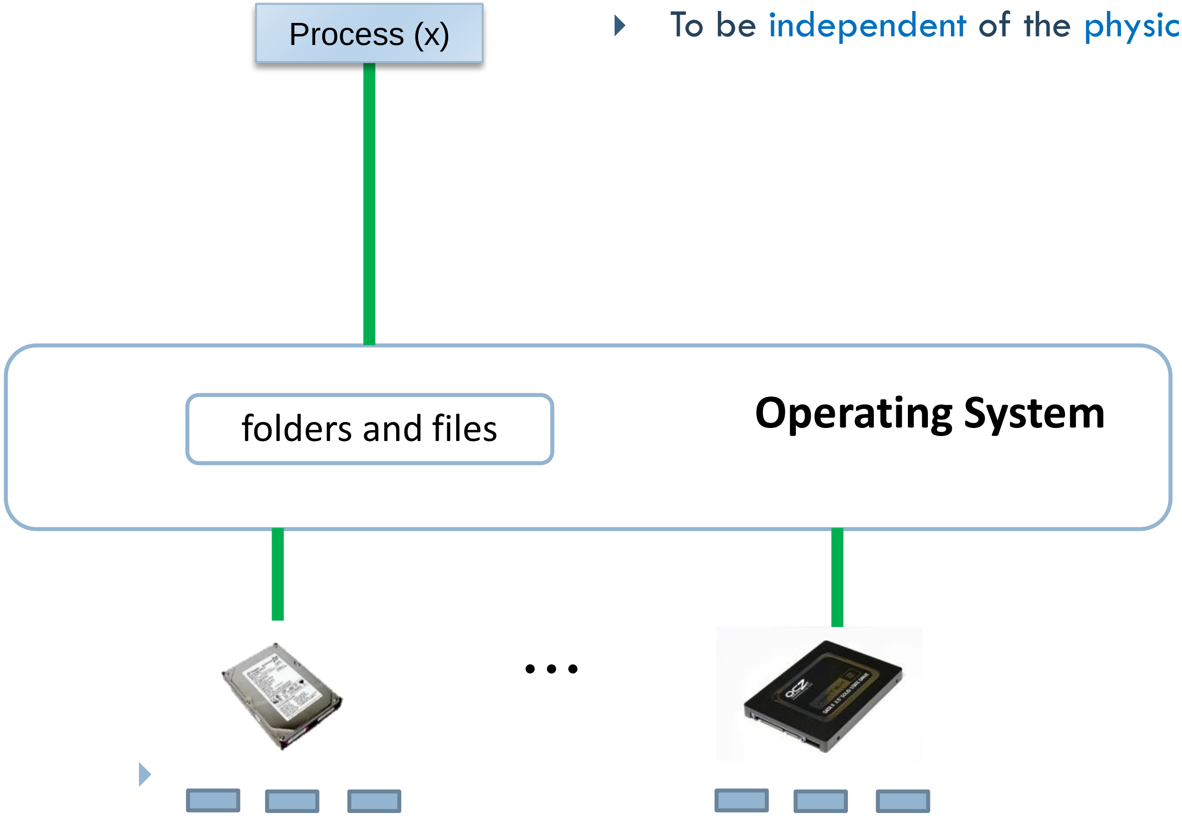
Main features of a file system

- Added functionality to facilitate secondary storage management:

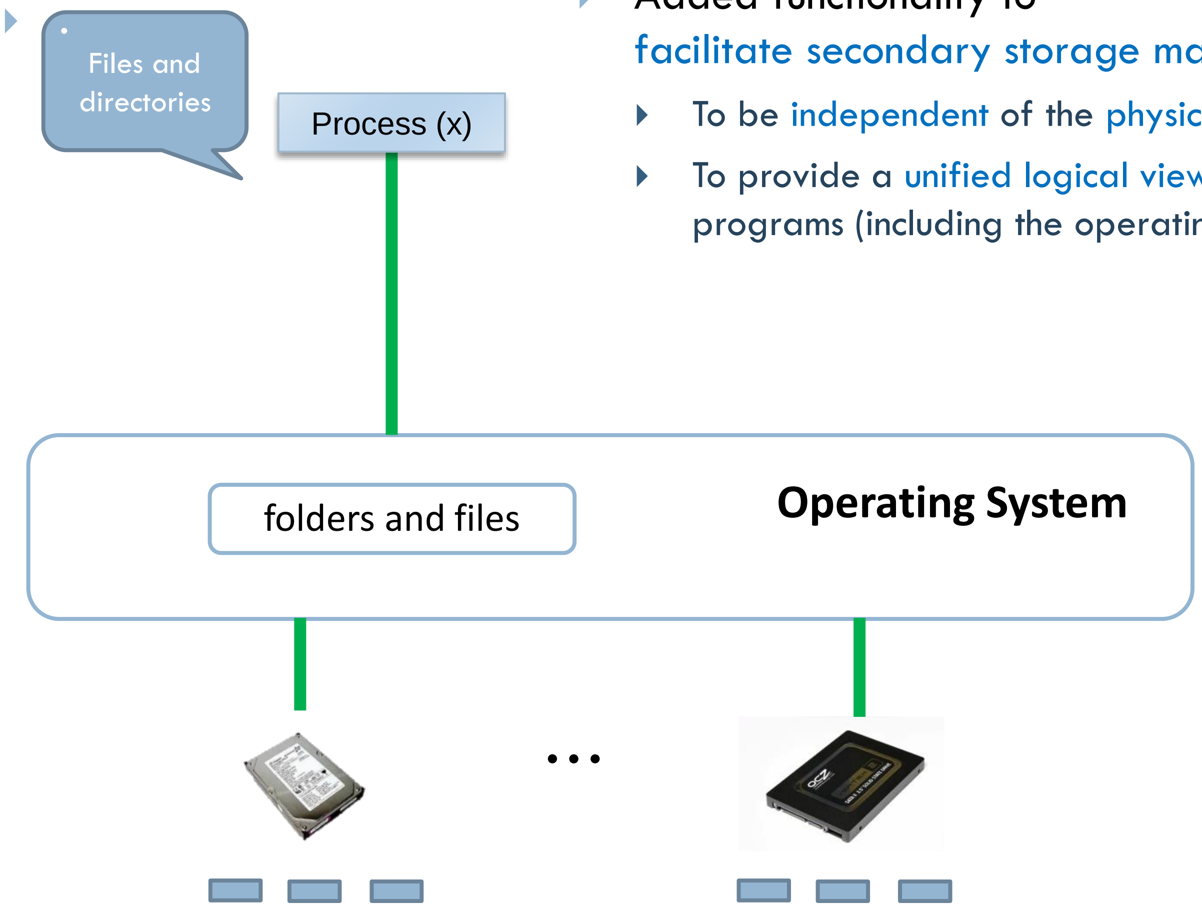


Main features of a file system

- Added functionality to facilitate secondary storage management:
  - To be independent of the physical device.

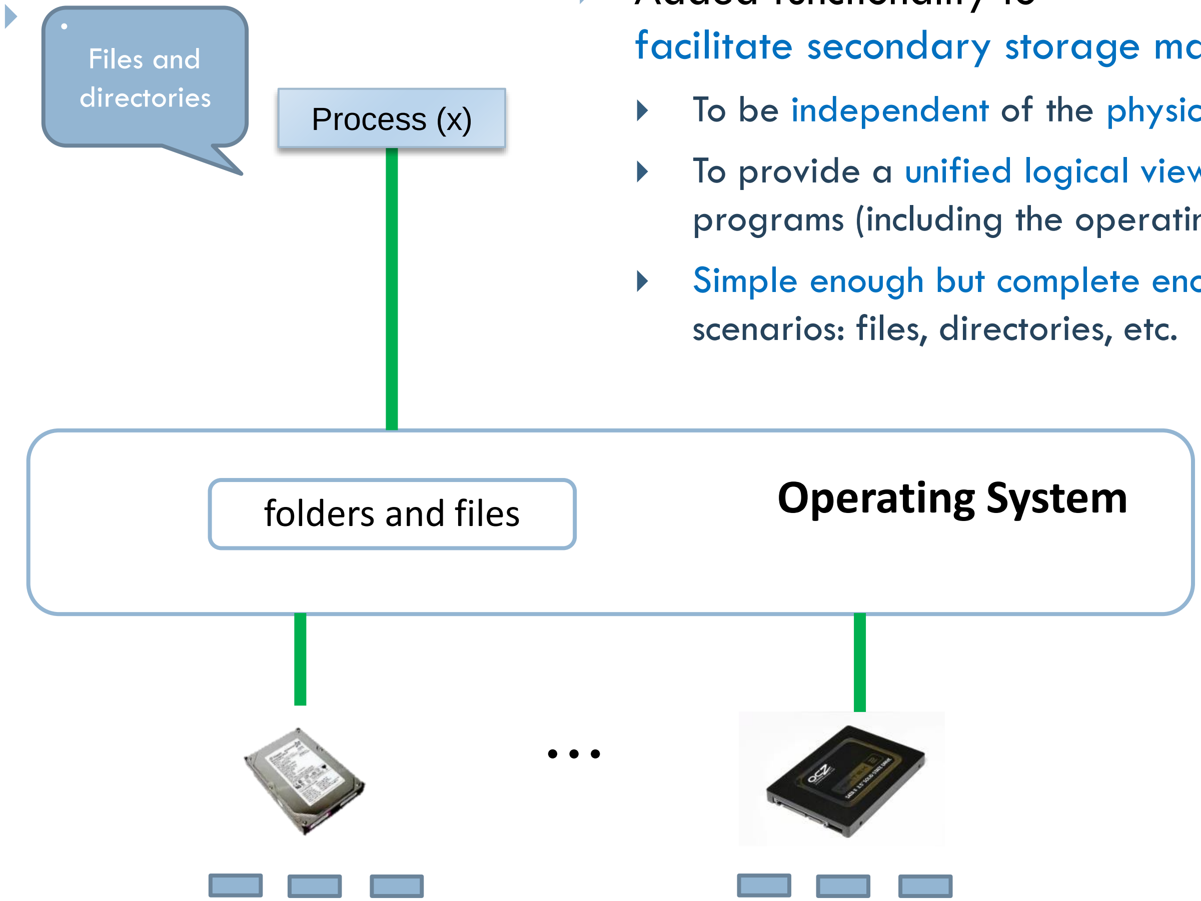


Main features of a file system



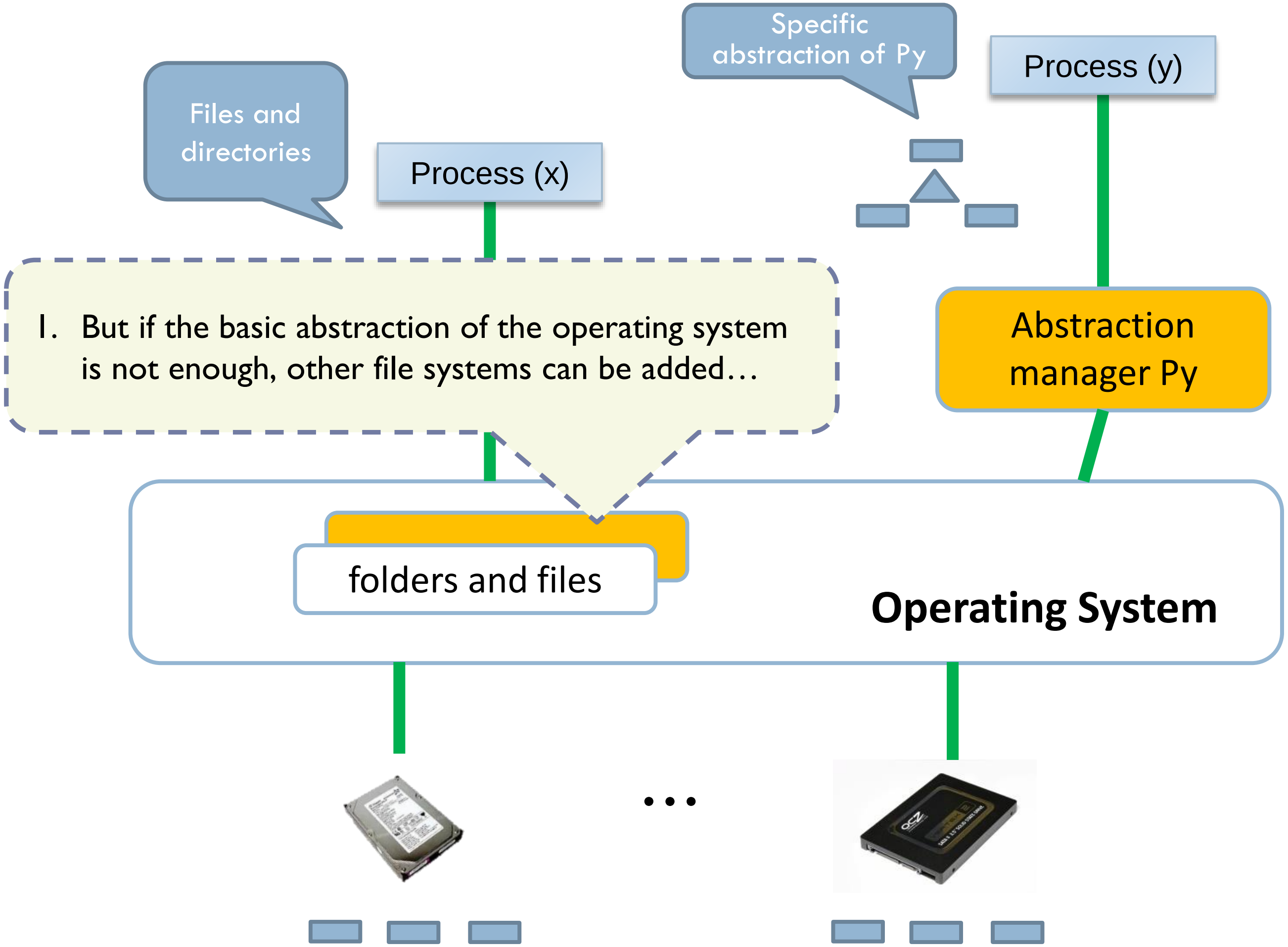
- Added functionality to facilitate secondary storage management:
  - To be independent of the physical device.
  - To provide a unified logical view for users and programs (including the operating system itself).

Main features of a file system



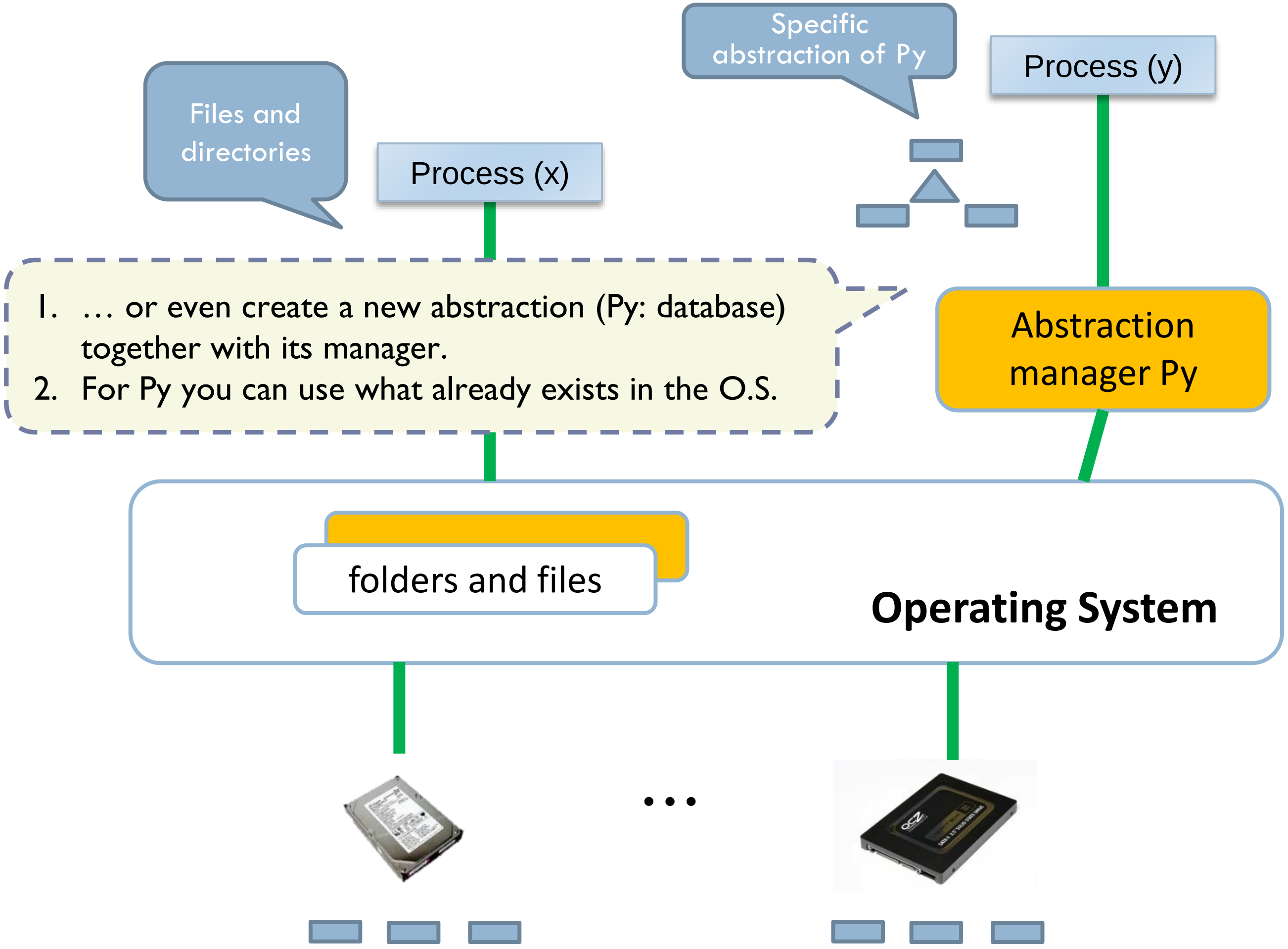
- Added functionality to facilitate secondary storage management:
  - To be independent of the physical device.
  - To provide a unified logical view for users and programs (including the operating system itself).
  - Simple enough but complete enough to cover most scenarios: files, directories, etc.

(2/2) The O.S. provides support for building even other storage systems



1. But if the basic abstraction of the operating system is not enough, other file systems can be added…

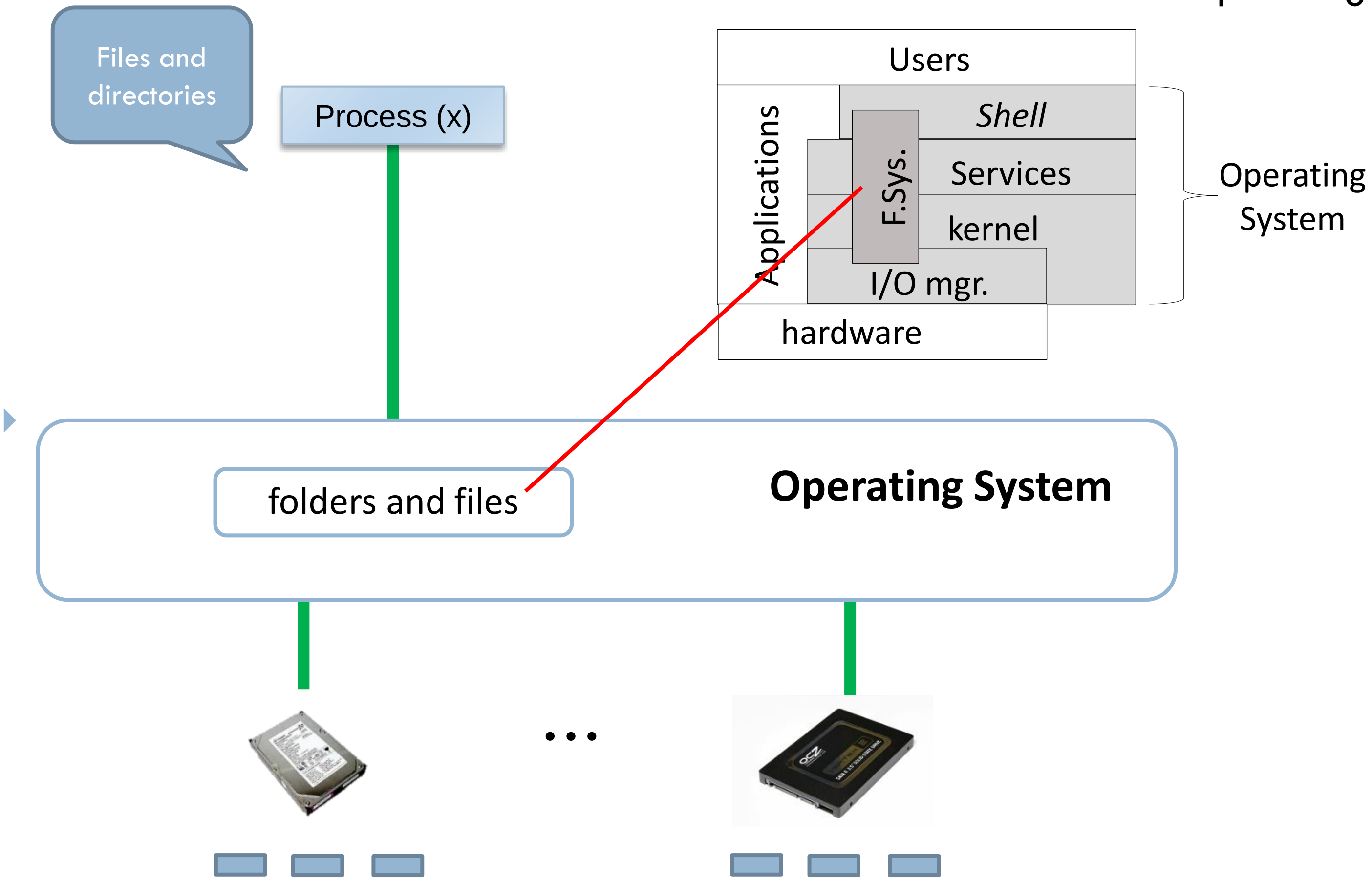
(2/2) The O.S. provides support for building even other storage systems



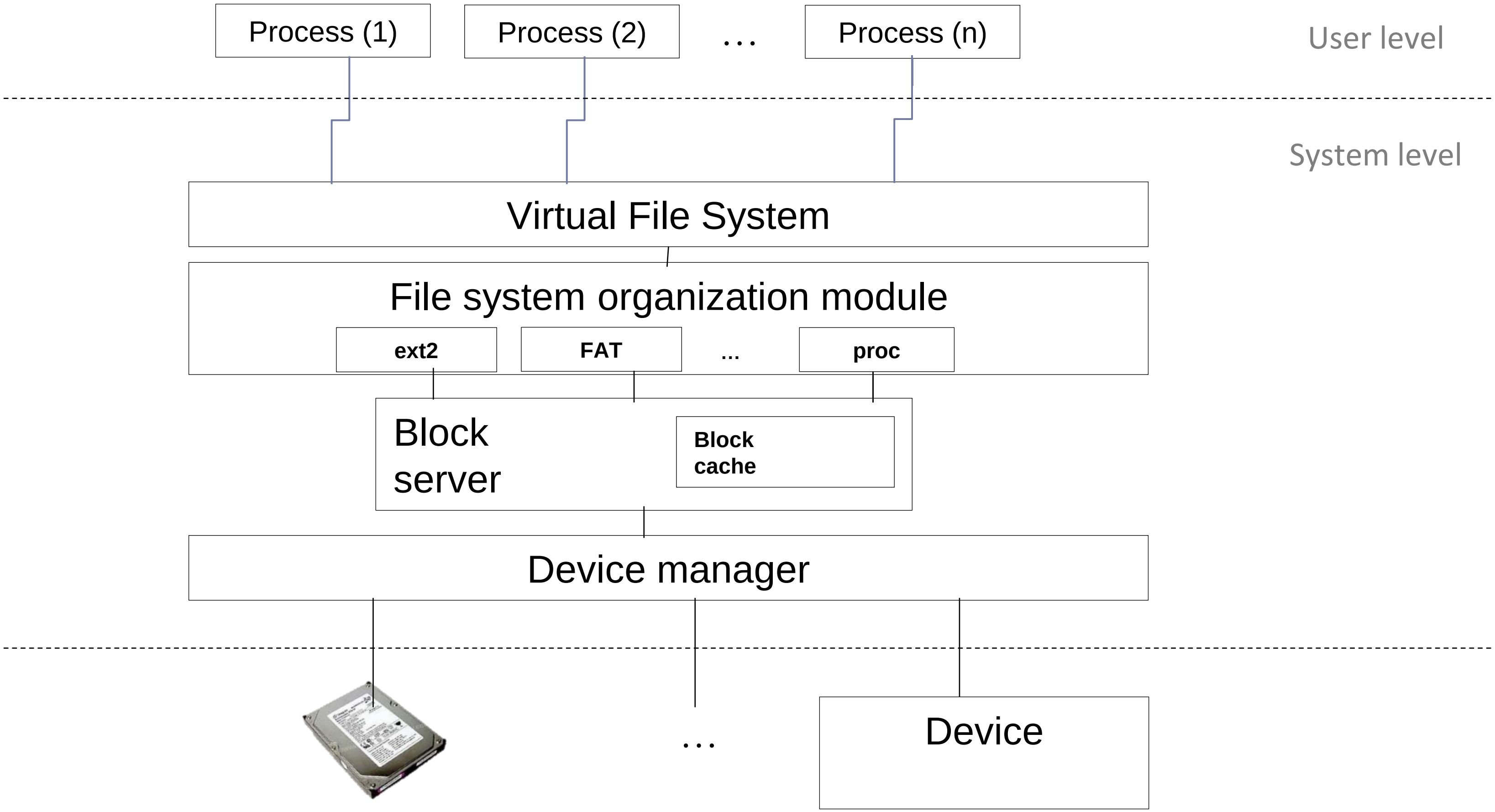
1. … or even create a new abstraction (Py: database) together with its manager.
2. For Py you can use what already exists in the O.S.

Architecture of file systems

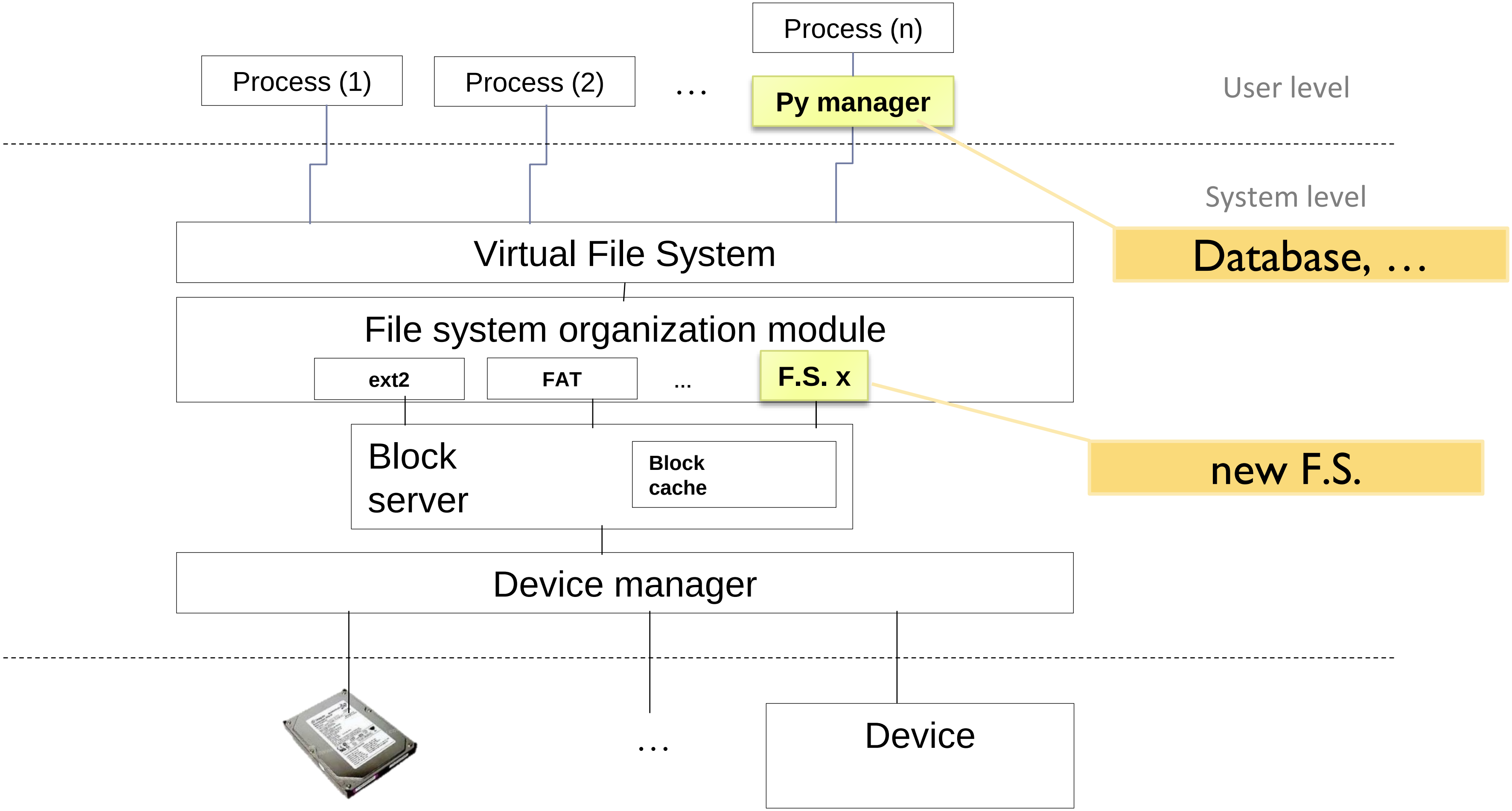
- Architecture cross-section of the operating system:



Architecture of file systems

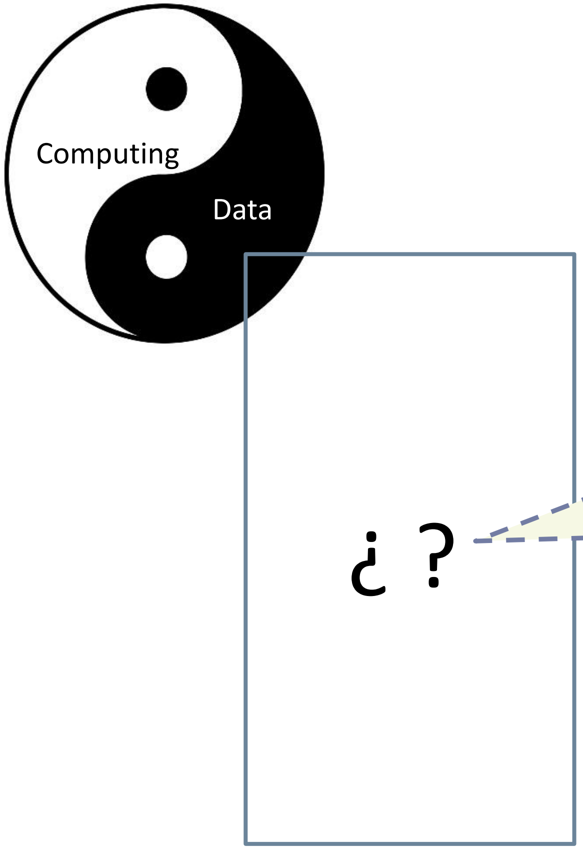


Extensible architecture
with external file systems and file managers



General scope

> 2021



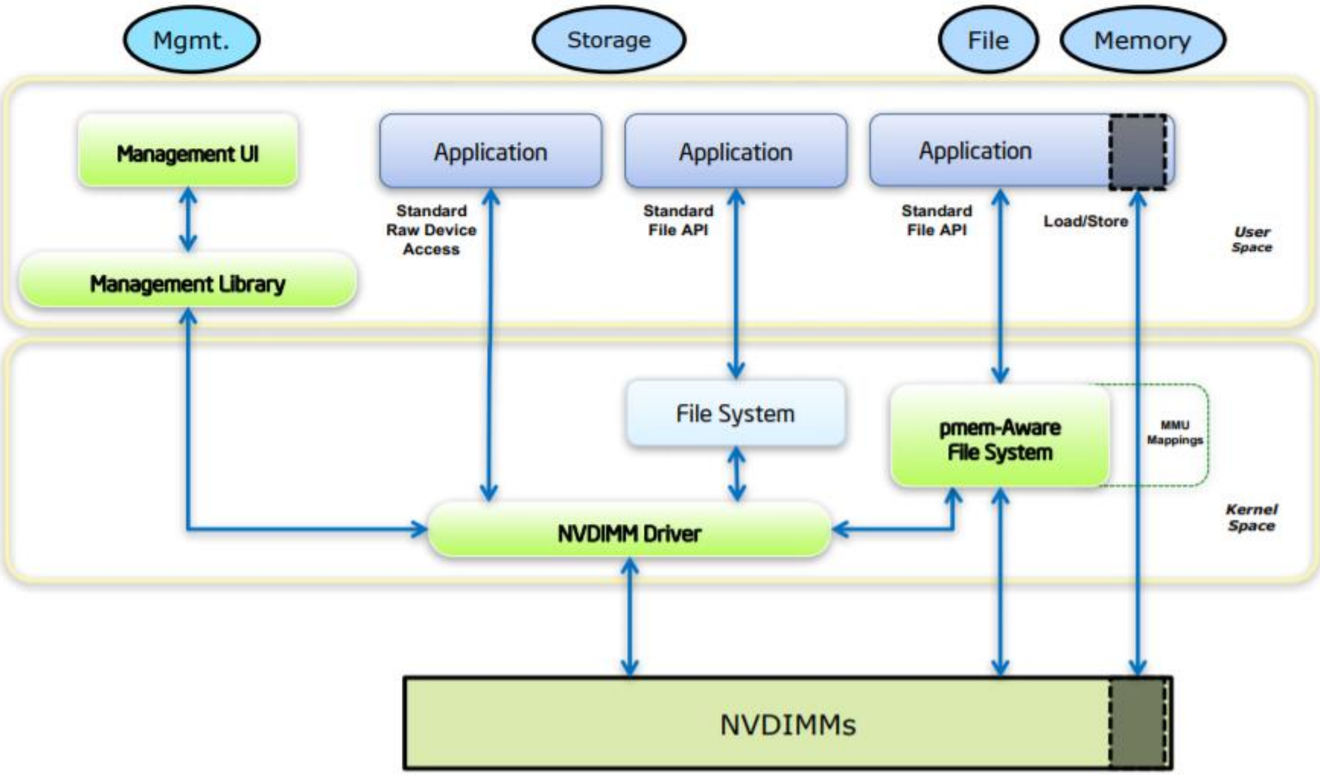
1. New memory (sum of main and secondary memory):
   - **Persistent** data
   - Works with bytes or words, or with blocks
   - ‘High’ capacity

General scope

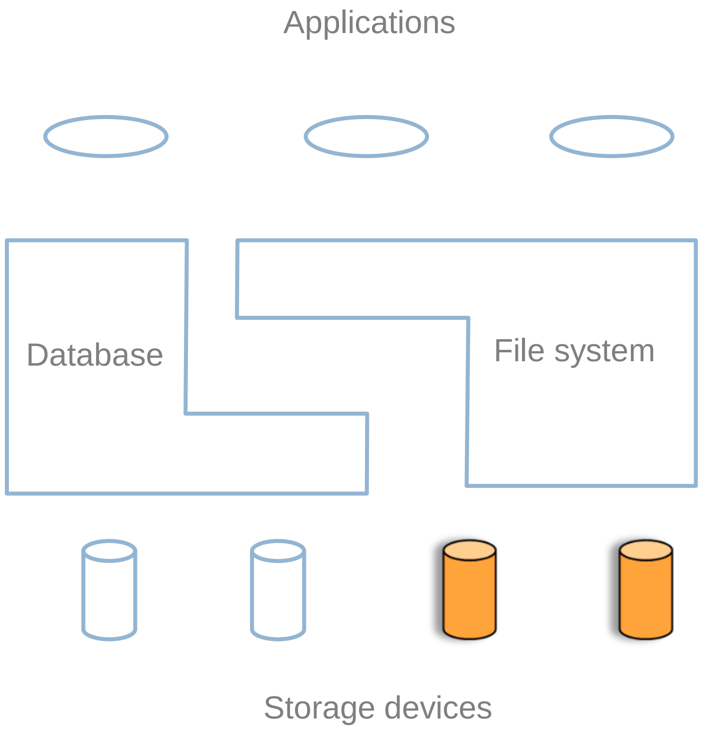
> 2021

https://www.snia.org/tech_activities/standards/curr_standards/npm, http://pmem.io/

The SNIA NVM Programming Model

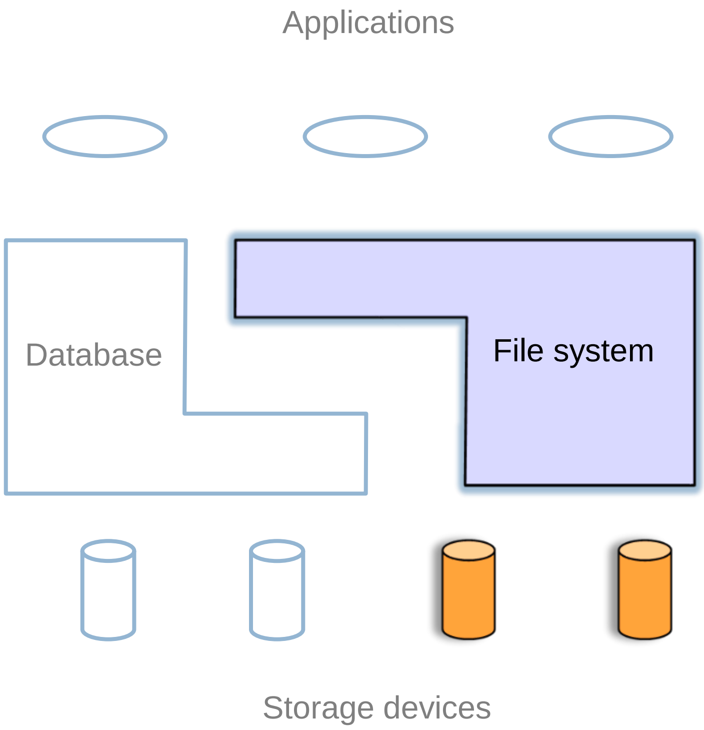


Summary: architecture



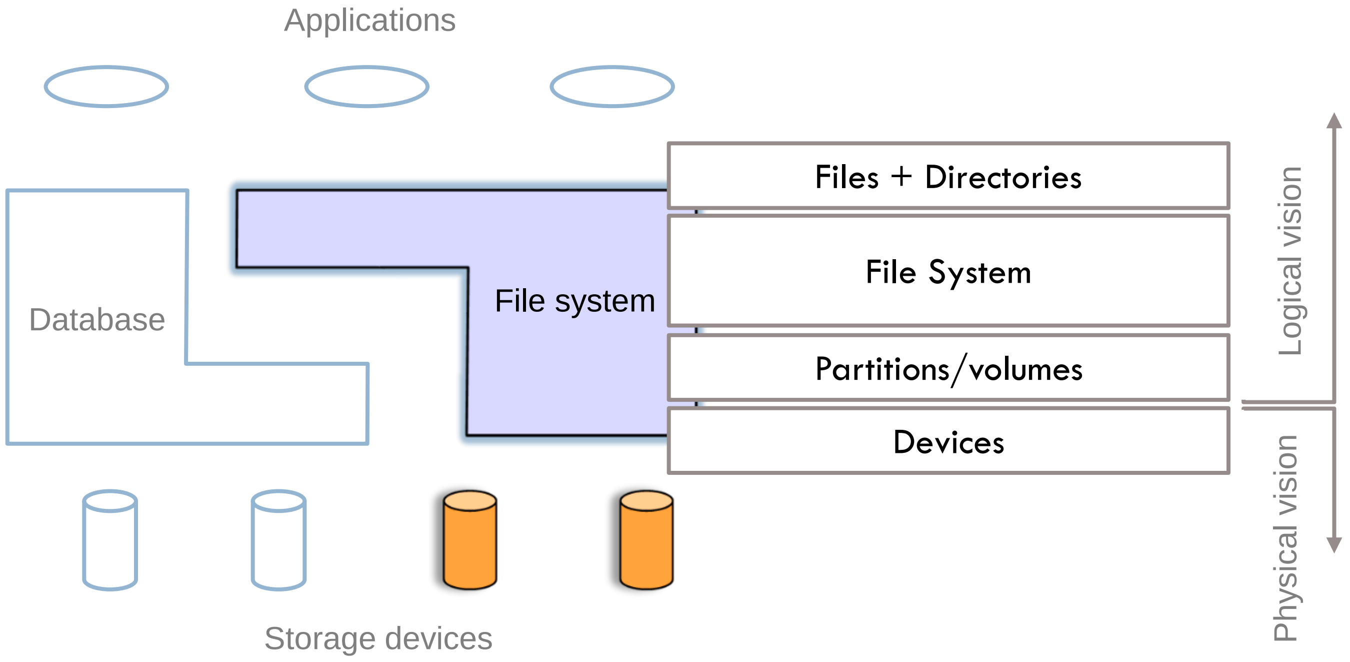
- □ We have both possibilities in illustration proposed by SNIA:
  - *Storage Networking Industry Association*
  - http://www.snia.org
- □ Applications access data stored on storage devices using DB and/or file systems.

Summary: architecture



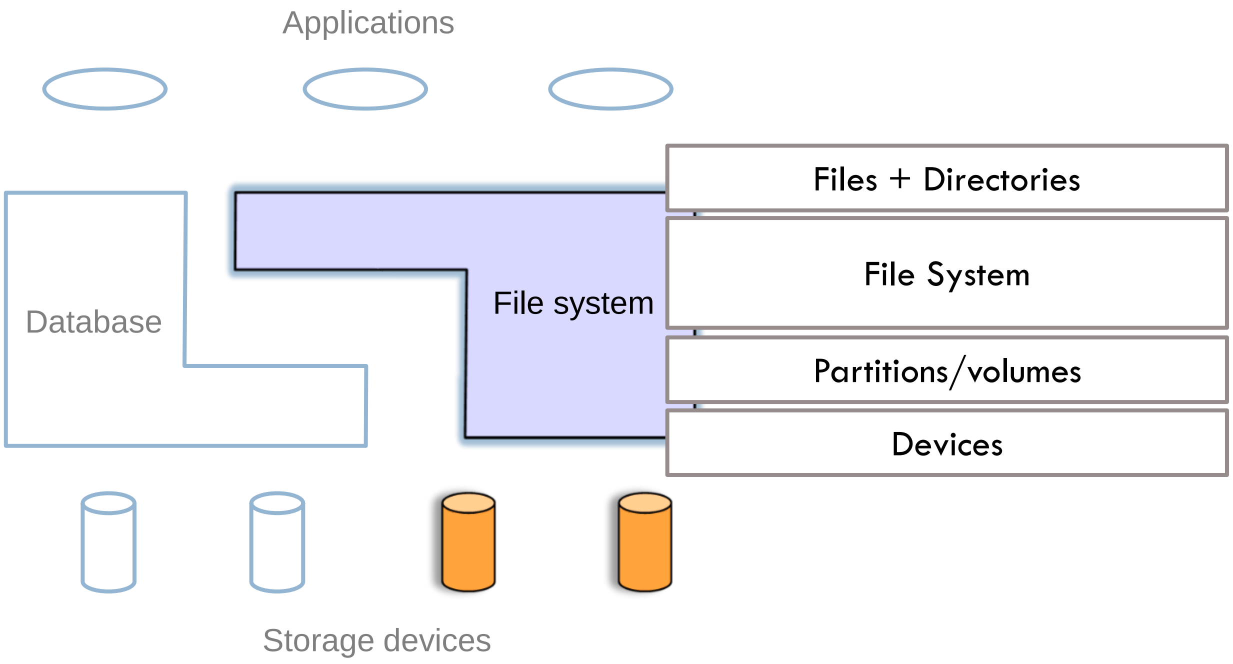
- In this topic we will focus on the management by the O.S. through the file system:
  - Organization
  - Storage
  - Retrieval
  - Name management
  - Implementation of co-utilization semantics
  - Protection

Summary: abstractions



- □ To be studied: $\underbrace{\text{files, directories, file systems, volumes}}_{\text{Logical view}}$ and $\underbrace{\text{devices}}_{\text{Physical vision}}$

Summary: abstractions



- □ Beware of the term "file system" which is used to name both the management software and the data structures on disk (context is important).

Introduction
summary

important

- File System:
  - It is the part of the OS in charge of distributing and organizing the S.M.
  - It provides an abstraction (based on files, directories, etc.) that hides the details of the M.S. organization.
    - Hides details about data storage/distribution on peripherals.
  - Main functions:
    - (1) Organization, (2) Names Management, (3) Storage, (4) Retrieval, (5) Implementation of co-utilization semantics, (6) Protection.
- File System also:
  - It is the software layer between devices and users.
  - Simplifies handling of peripherals by treating them as files
    - Establishes a correspondence between logical devices and files.
    - Facilitates protection and logical vision (as independent of physical details).

Introduction
summary

important

- File System from the user point of view:
  - Permanent storage of information:
    - It does not disappear even if the computer is turned off.
  - Logical abstraction to facilitate information handling:
    - A set of information logically structured according to application criteria.
    - Logical and structured names.
    - They are not tied to the life cycle of a particular application.
    - Abstracting physical storage devices.
  - Access to services offered through an API:
    - They are accessed through operating system calls or utility libraries.
  - It is possible to work with several file systems at the same time in an O.S.:
    - Example: Linux admits at the same time ext4, btfs, fat32, etc.

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  - Metadata
  - Interface
  - Access methods
  - Sharing semantics
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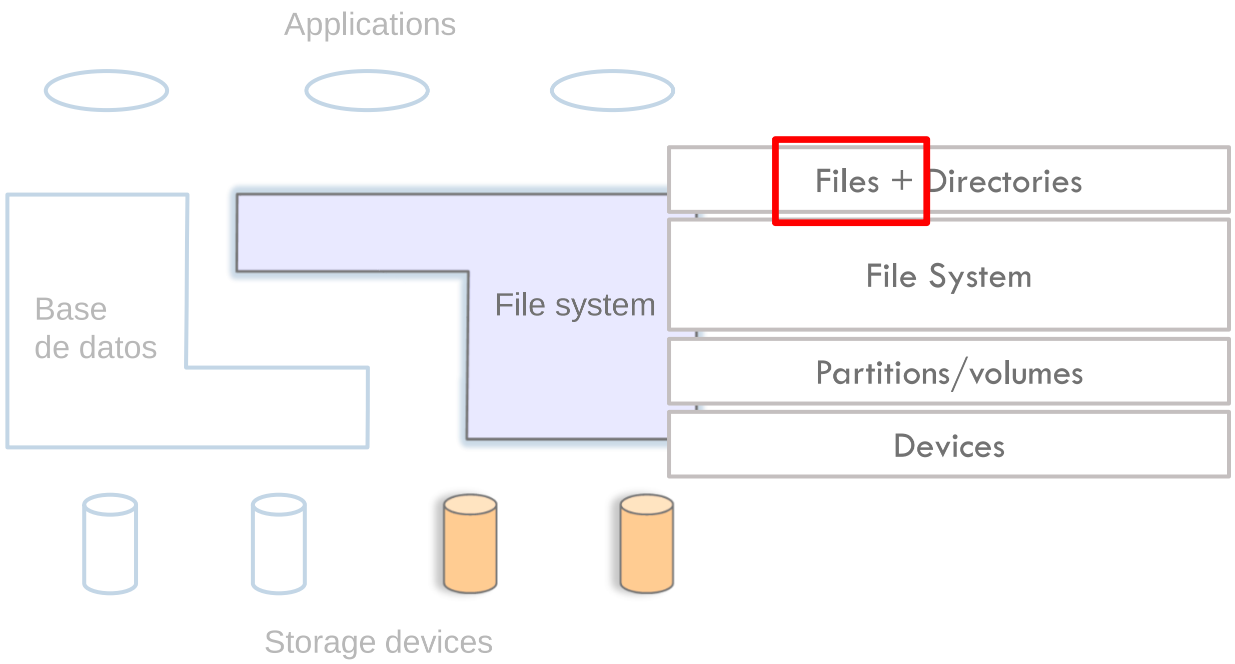
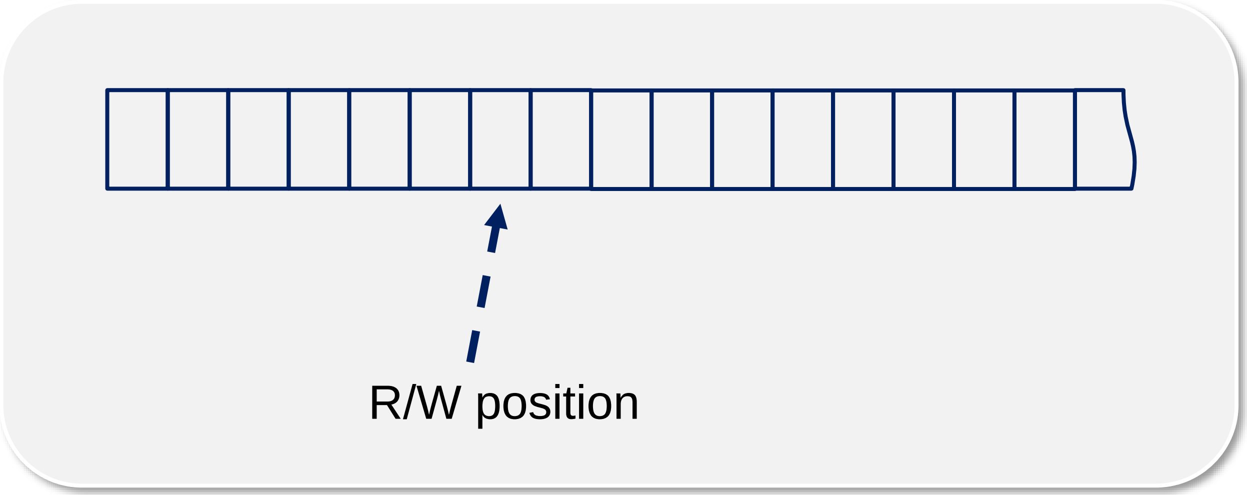
File


Applications
Files + Directories
Base
de datos
File system
File System
Partitions/volumes
Devices
Storage devices

important

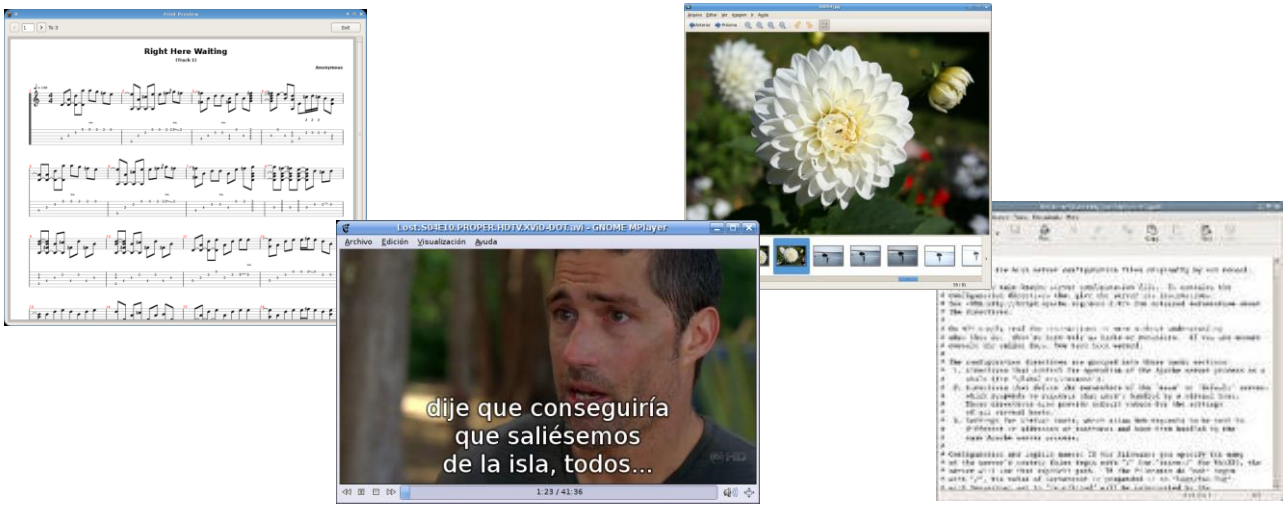
File (logical vision)

- □ Set of related information that has been defined by its creator.
- □ The content is usually represented by a sequence or row of bytes (UNIX, POSIX):



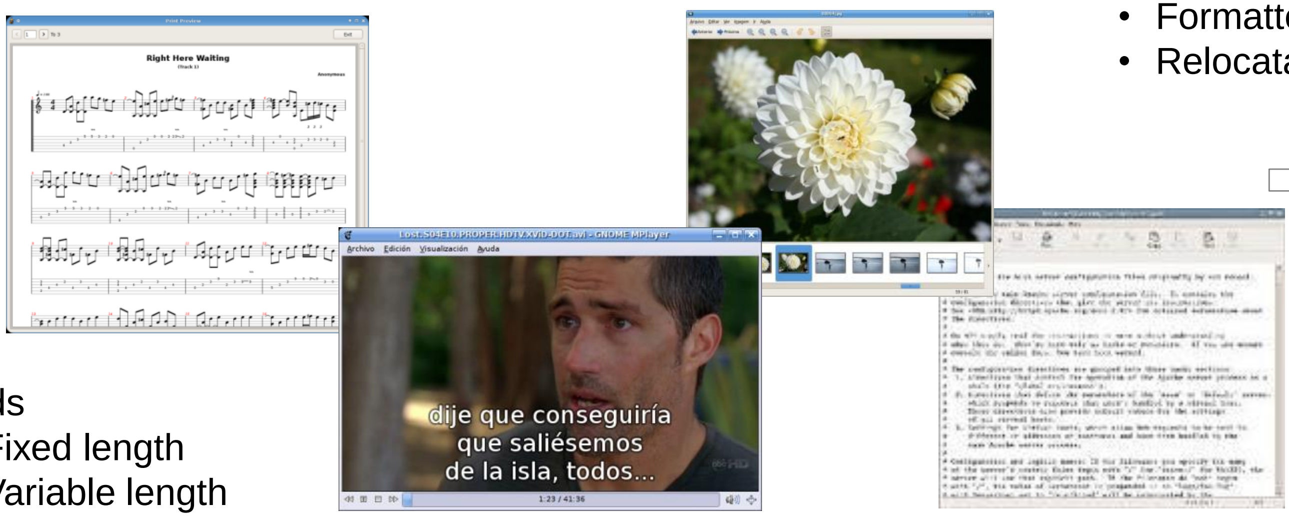
File

- □ Different types of information:

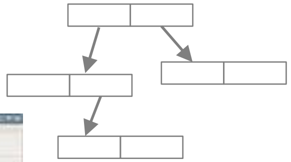


File (structure)

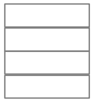
- Different types of information structures :

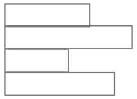

Right Here Waiting
Lost.S04E10.PROPER.HDTV.XViD-DOT.avi - GNOME MPlayer
Archivo Edición Visualización Ayuda
dije que conseguiría
que saliésemos
de la isla, todos...
1:23 / 41:36

- Complex
  - Formatted (XML, etc.)
  - Relocatable



- Records
  - Fixed length
  - Variable length

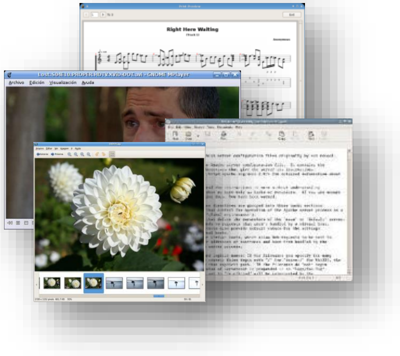


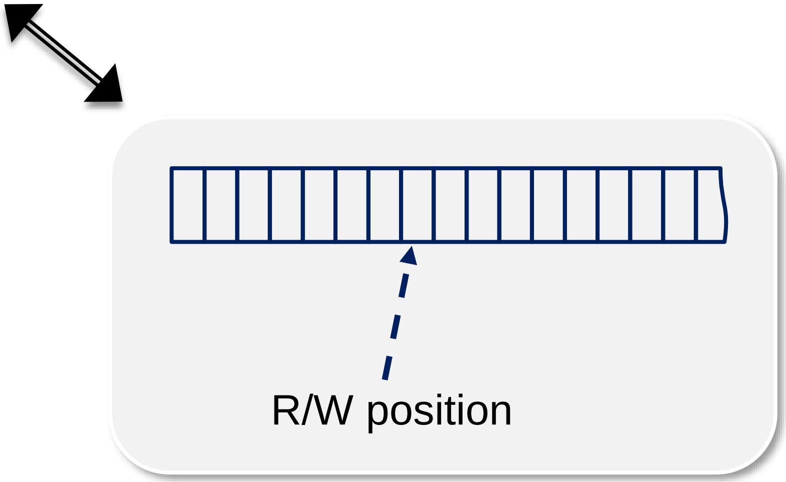


- Sequence of words

File

- Applications convert and store as a sequence or row of bytes.





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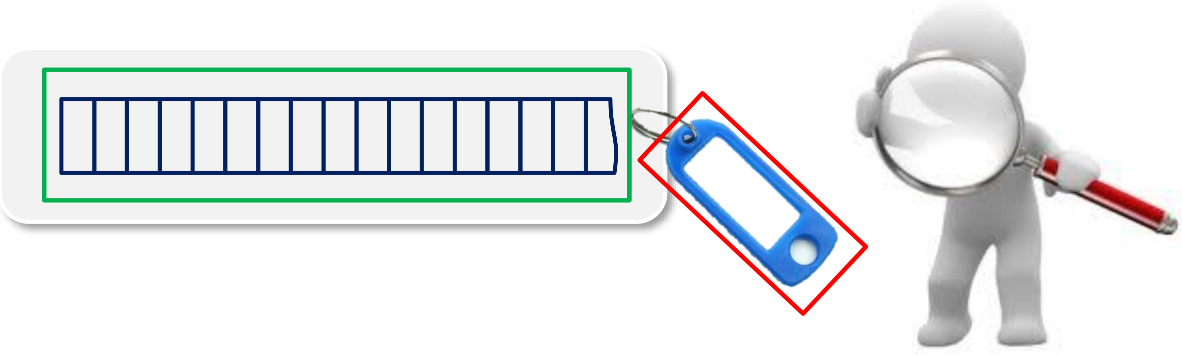
File

- Information of a file:
  - Data
    - **Information that the file stores.**
  - Metadata
    - **Information about the file.**
    - Different **attributes** of the file (+ information used by the O.S.)
    - File system-dependent.



File

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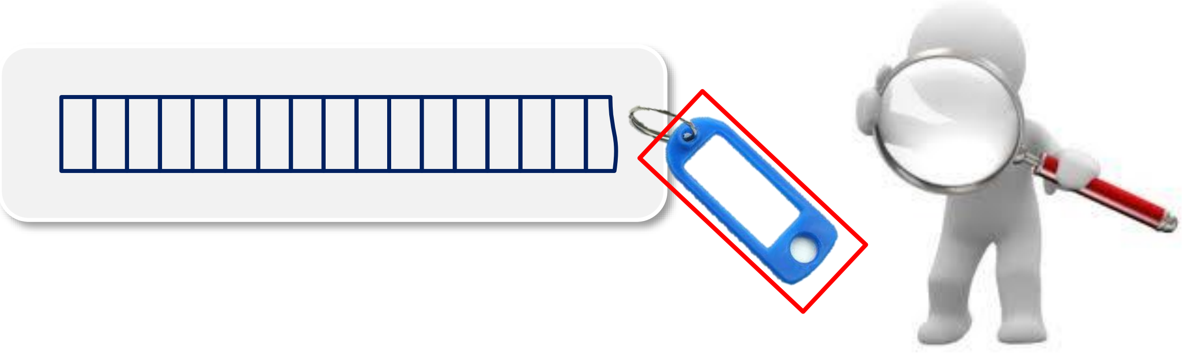

important

File: attributes

- Typical attributes of a file:
  - Name: identifier for users of the file.
  - Identifier: unique file label (numeric) used by the O.S.
  - Type: file type (for systems that require it)
    - E.g.: extension (.exe, .pdf, etc.)
  - Location: identifier that aids in locating the device blocks that belong to the file.
  - Size: current file size (in bytes or disk blocks).
  - Protection: access control and operations which user can do.
  - Temporary information: time of last access, creation, etc. that allows monitoring of file usage.
  - User identification: identifier of the creator, owner of the file, etc.

File name (and extension)

- Strings are used:
  - Allows users to better organize themselves.
  - Users do not remember names such as 00112233.
  - Directories associate name with their internal identifier.
- It is characteristic of each file system:
  - Length of name: fixed (MS-DOS) or variable (UNIX)
  - Case sensitive (Unix) or not (MS-DOS)
    - INMA vs inma
  - Extension required: yes, fixed (MS-DOS) or not (UNIX)

remain.zip

    - .zip -> identifies the file type (and the application to be used)

/bin/ls

    - file name -> identifies by content (magic number)

Access control

- Access control lists (ACL):
  - ACL is a list associated with a file that is made up of ACE entries in the form of (user/group, permission).
  - E.g.: NTFS, Solaris UFS, HP-UX HFS, etc.
  - In Linux: `setfacl -d -m g:development:rw /home/devs`
- Permissions:
  - Condensed version used in traditional UNIX.
  - 3 categories: user, group, other.
  - 3 types of access per category: read, write, execute.

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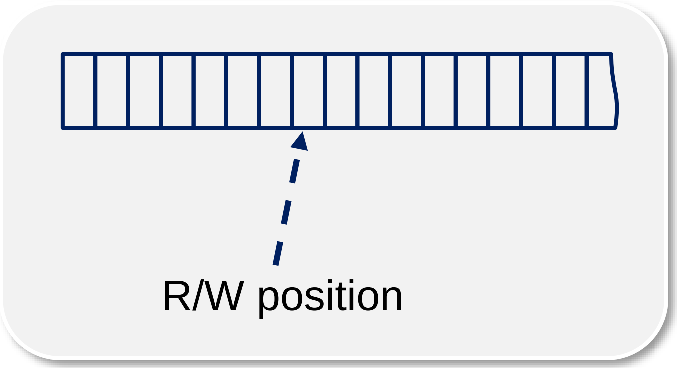
important

File: interface

- Generic interface to access information:
  - descriptor ← open (name, flags, mode)
  - close (descriptor)
  - read (descriptor, pointer, size)
  - write (descriptor, pointer, size)
  - lseek (descriptor, offset, whence)
  - ioctl (descriptor, command, pointer_to_command_arguments)



OPEN – Opening a file

Service	`#include <sys/types.h>`
	`#include <sys/stat.h>`
	`#include <fcntl.h>`
	
	`int` **`open`**`(char *pathname, int flags[, mode_t mode]);`

Arguments	□ `pathname` file name (pointer to the first character). □ `flags` opening options: ■ `O_RDONLY` Read-only ■ `O_WRONLY` Writing-only ■ `O_RDWR` Reading and writing ■ `O_APPEND` Place the access pointer at the end of the open file ■ `O_CREAT` If it exists it has no effect. If it does not exist, it creates it ■ `O_TRUNC` Truncated if opened for writing □ permissions `mode`: ■ `S_I{RWX}{USR|GRP,OTH}` Read, Write, Execute x user, group, others
Return	A file descriptor or -1 in case of error.
Description	File opening (or creation if O_CREAT is used)

CLOSE – Closing a file

Service	`#include <unistd.h>`
	`int close(int fd);`

Arguments	`fd` file descriptor.
Return	Return 0 or -1 if error.
Description	The process closes the work session with the file, and the descriptor becomes free.

READ – Reading from file

Service	`#include <sys/types.h>`
	`ssize_t read(int fd, void *buf, size_t n_bytes);`

Arguments	`fd` file descriptor `buf` data storage area `n_bytes` number of bytes to read
Return	Number of bytes actually read, 0 if end-of-file (EOF) and -1 if error
Description	Attempts to read `n_bytes`. May read less data than requested (e.g., if the end of file is exceeded or interrupted by a signal). After reading, the file position pointer is updated with the number of bytes actually read.

WRITE – Writing to a file

Service	`#include <sys/types.h>`
	ssize_t **write**(int fd, void *buf, size_t n_bytes);

Arguments	`fd` file descriptor `buf` data area to be written `n_bytes` number of bytes to write
Return	Number of bytes actually written or -1 if error.
Description	Attempts to write `n_bytes`. May write less data than requested (e.g., if the maximum size of a file is exceeded or is interrupted by a signal). After writing, the file position pointer is updated with the number of bytes actually written. If the end of file is exceeded, the file increases in size.

LSEEK – Pointer position movement

Service	`#include <sys/types.h>`
	`#include <unistd.h>`
	
	`off_t` **`lseek`**`(int fd, off_t offset, int whence);`

Arguments	□ `fd` file descriptor □ `offset` offset (in bytes, positive or negative) □ `whence` base of the offset
Return	□ The new position of the pointer or -1 if error. □ Example: lseek(fd, 55, SEEK_SET) would return 55 if there is no error.
Description	□ Modifies the read/write pointer associated to `fd` □ The new position is calculated as follows: ■ `SEEK_SET` -> position = offset ■ `SEEK_CUR` -> position = current position + offset ■ `SEEK_END` -> position = file size + offset □ Jumping beyond the end is only consolidated if you write.

LINK – Link creation

Service	`#include <unistd.h>`
	
	`int` **`link`** `( const char* oldpath,`
	`                 const char* newpath );`

Arguments	□ `oldpath` name of the existing file to link to. □ `newpath` name of link to be created.
Return	Return 0 or -1 if error.
Description	□ Creates a hard link from an existing entry (file or directory) in the same partition as the linked entry. □ Increases the link counter of the file.

UNLINK – Deletion of file

Service	`#include <unistd.h>`
	`int` **`unlink`** `( const char* path );`

Arguments	`path` name of the file
Return	Return 0 if all correct or -1 if error.
Description	□ Decrements the link counter of the file. □ Si el contador es 0 entonces: □ If it is not open, then delete the file and free its resources. □ If it is open, closing it will delete it and free its resources.

File: POSIX interface

important

write

```
#include <unistd.h>
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include <fcntl.h>

int main ( int argc, char *argv[] )
{
 int fd1 ;
 char str1[10] ;
 int nb ;

 fd1 = open ("/tmp/txt1",
             O_CREAT|O_RDWR, S_IRWXU);
 if (-1 == fd1) {
    perror("open:");
    exit(-1);
 }

 strcpy(str1,"hola");
 nb = write (fd1,str1,strlen(str1));
 printf("written bytes = %d\n",nb);

 close (fd1);
 return (0) ;
}
```

read

```
#include <unistd.h>
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include <fcntl.h>

int main ( int argc, char *argv[] )
{
 int fd1 ;
 char str1[10] ;
 int nb, i ;

 fd1 = open ("/tmp/txt1",O_RDONLY);
 if (-1 == fd1) {
     perror("open:");
     exit(-1);
 }

 i=0;
 do {
      nb = read (fd1,&(str1[i]),1); i++;
 } while (nb != 0) ;
 str1[i] = '\0';
 printf("%s\n",str1);

 close (fd1);
 return (0);
}
```

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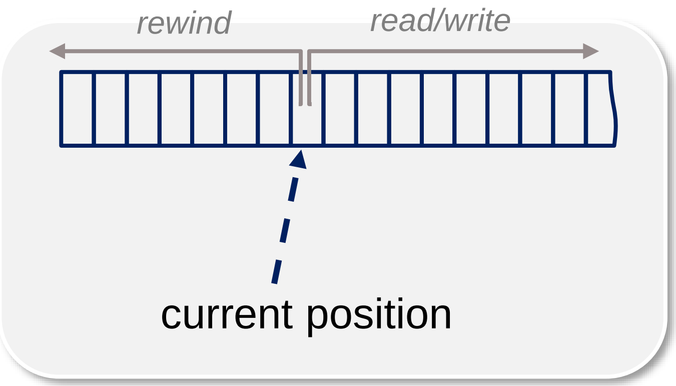
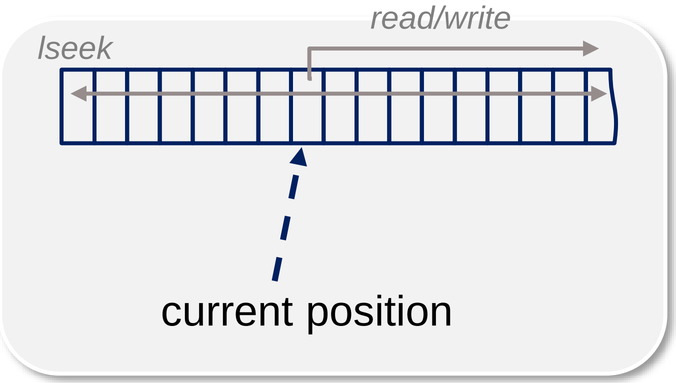
important

File: access methods

- **Sequential access:**
  - Sequential access devices: magnetic tapes.
  - It is only possible to rewind to the beginning of the file.



- **Direct access:**
  - Random access devices: hard disks.
  - It is possible to position (lseek) at any position in the file.
    - It allows other access methods to be built on top of it (e.g., indexing, etc.)



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File: Sharing semantics

- Several processes can simultaneously access a file.
- It is required to define a coherence semantics:
  - When are the changes to a file observable by other processes?
- Options:
  - UNIX semantics.
  - Session semantics.
  - Version semantics.
  - Immutable file semantics.

File: Sharing semantics

important

Unix Semantics	Session semantics	Version semantics	Immutable semantics
Writes to a file are immediately visible to all processes (and the new R/W pointer).	Writes to a file are not visible to other processes: when closing it is made visible.	Scripts are made on version numbered copies: they are visible when consolidating versions.	If a file is declared shared, it cannot be modified.
Once opened (*open*), the created process family (*fork*) shares its image.	Once the file is closed, the following processes that open the file see the modifications.	Use explicit synchronization for immediate updates.	Until the lock is released, neither name nor content can be modified.
Contention by exclusive access to the single image of the file.	A file can be associated with several images. No contention.	It will have several images and cost to consolidate.	No concurrence.
Ext3, ufs, etc.	AFS (*Andrew File System*)	CODA	HDFS

OPERATING SYSTEMS: FILE SYSTEMS

Files, directories and file system