The basics of file systems

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JETBRAINS

What a file system must do:

- store our data

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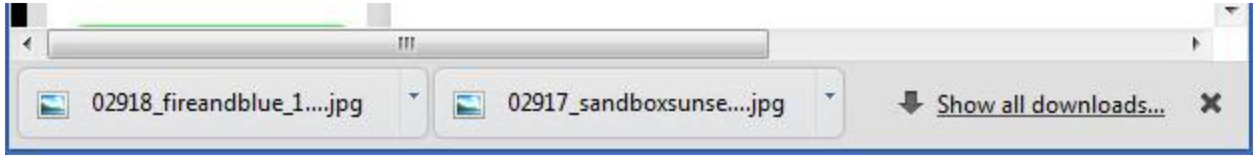
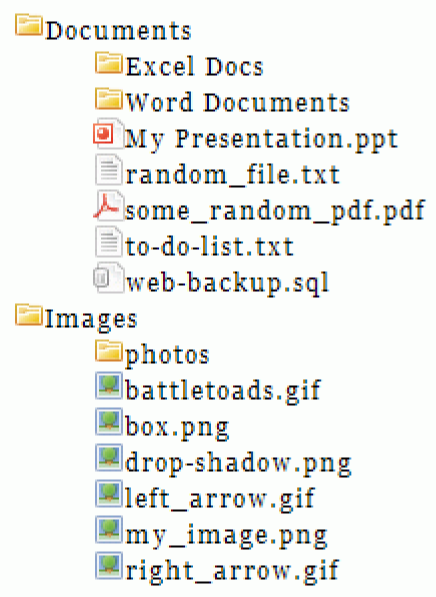


This organisation becomes inconvenient
if we have thousands of files.

What a file system must do:

- store our data,
- organise data into a hierarchy of files and directories



What a file system must do:

- store our data,
- organise data into a hierarchy of files and directories,
- provide and limit the access to stored files.

Today we will limit ourselves to file systems that store data in a single computer and provide access only to local users.

The desired interface to a file system:

```
f = open(“./pstorage-fes/src/fes.c");
read(f, buffer, size);
.....
write(f, buffer, size);
.....
close(f);
```

The desired interface to a file system:	The interface of a storage device:

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	* read a sector* nr. N,
	* write a sector nr. M.
	
	** a sector is a contiguous piece of a storage device that is 512 bytes or 4096 bytes long; the start of a sector is a multiple of the sector size*

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* r

*

This restriction is not always true. Chips are getting denser, and nowadays a single PCI-e card can host a computer with 16 ARM cores, 32G RAM, 4x400Gbit ethernet, and dedicated accelerators for NVMe-oF, compression and erasure coding. For example, see Mellanox (Nvidia) BlueField. Such devices can provide a much more sophisticated API.

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The task of a file system:

Atop of a block device provide an API that enables users to

- create files and directories,
- find files and directories by their name,
- write and read files at arbitrary offsets (not necessarily sector-aligned),
- do these operations fast and reliably.

A problem that a file system must solve: how does one store a list of files*?

An array with file names, unsorted:

file15, file1,
file2, file3,
file4, file9,
file6, file8,
file7, file5,
file12, file11,
file10, file13,
file14, file0

** boxes in diagrams depict contiguous areas of a disk; different boxes are assumed not to be adjacent*

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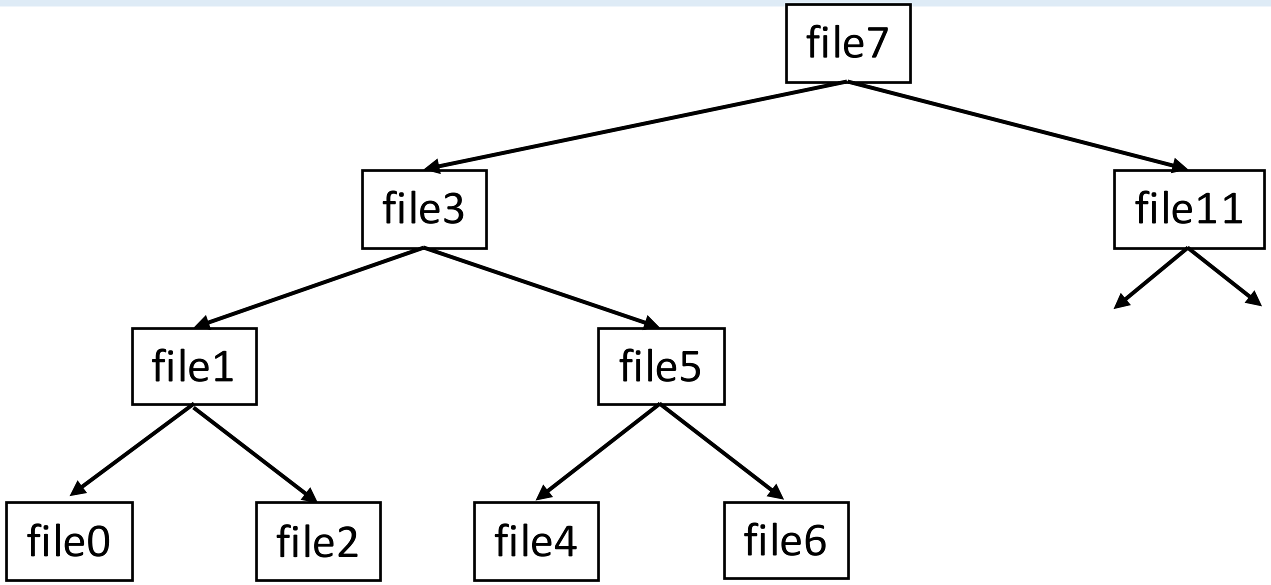
A balanced binary search tree:



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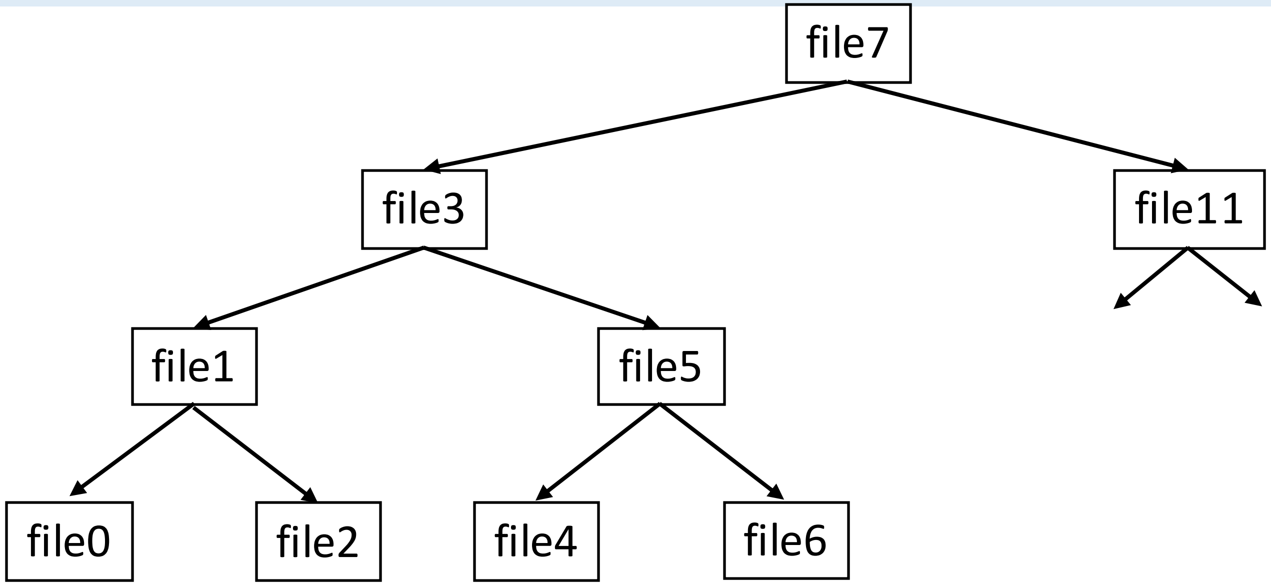

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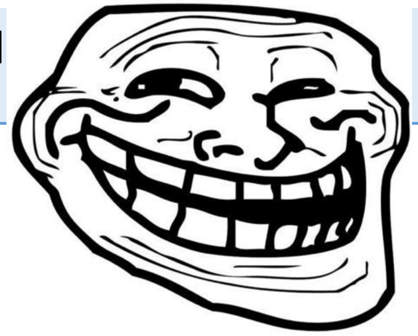

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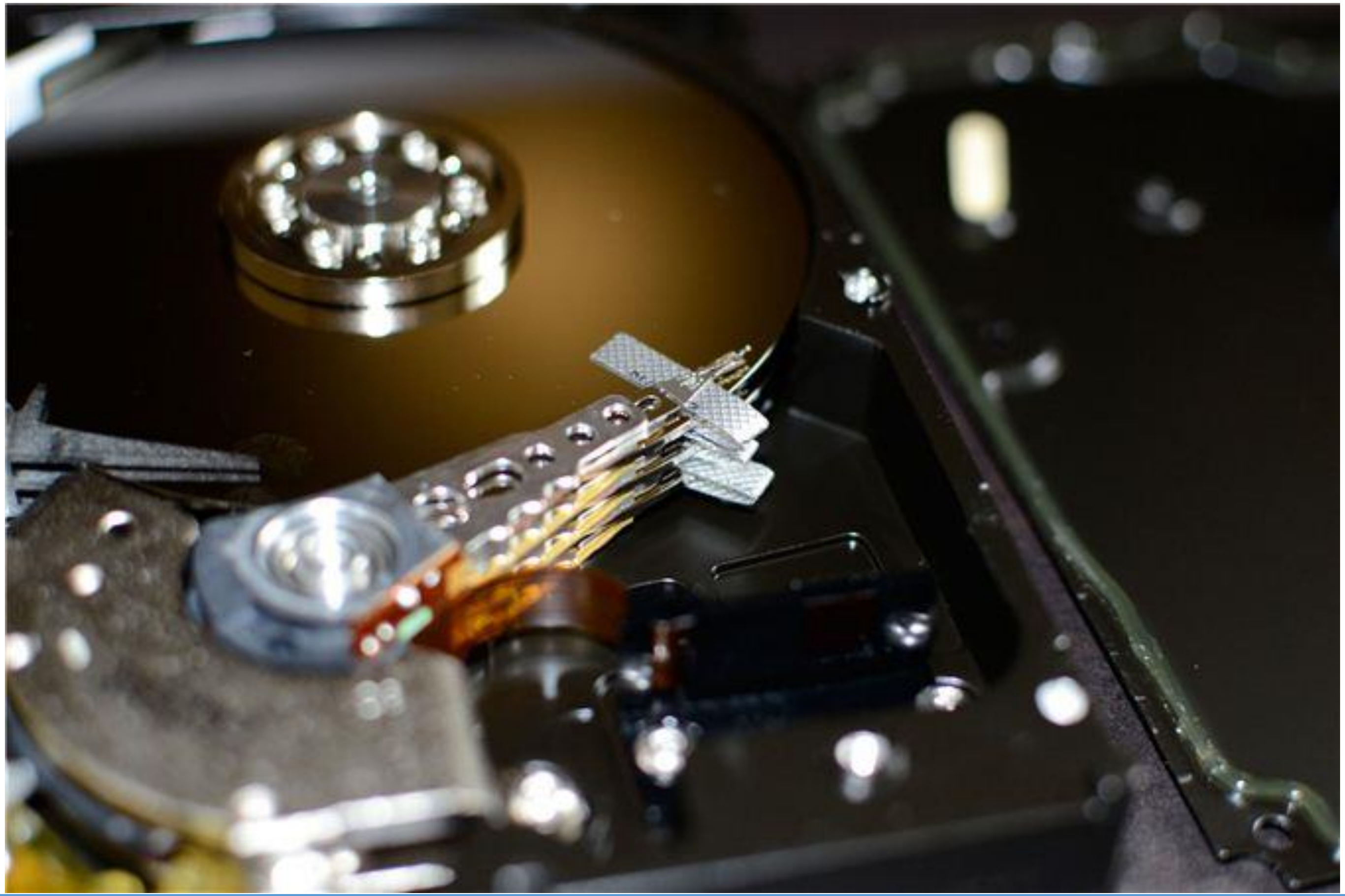
The reader head needs to be positioned very precisely. It takes much time to reposition it which makes random reads from HDD very slow. For reference:

- the speed of sequential reads from an HDD is ≈100 MB/sec, which is ≈10 ms per 1 MB,
- time to reposition the reader head is also ≈10 ms.



Modern HDDs are more performant. For example, Seagate Exos 16T does sequential reads at the rate of up to 250MB/sec and has a 6ms latency of random accesses.

The values of 100 MB/sec and 10ms are much handier for estimates.

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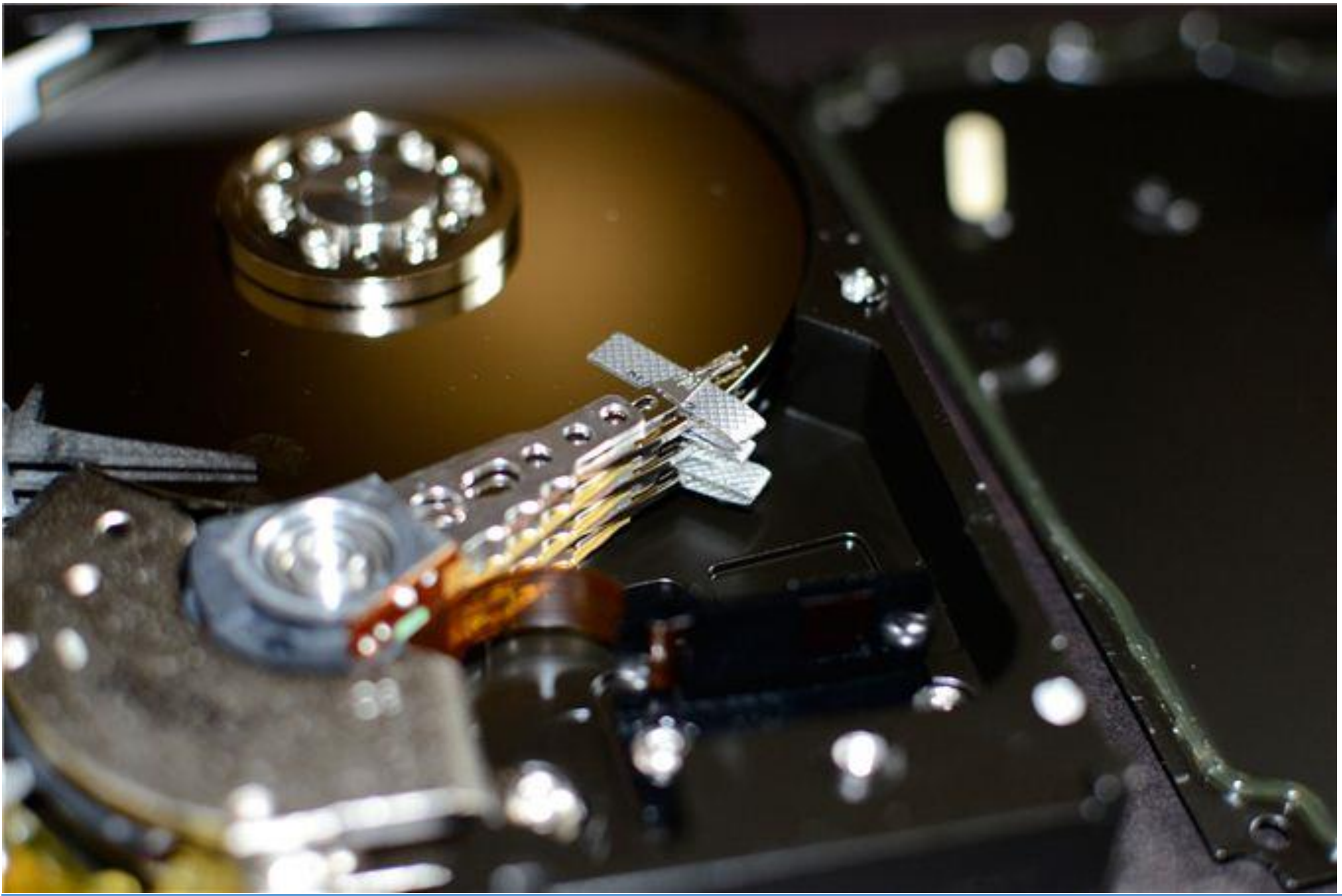

Let us change the scale and have durations that we see in the everyday life:
1ns ---> 1s

L1 latency (Zen 4, 5.7Ghz)	**0.7s**
L2 latency	**2.5s**
L3 latency	**10s**
RAM latency	**≈84s**

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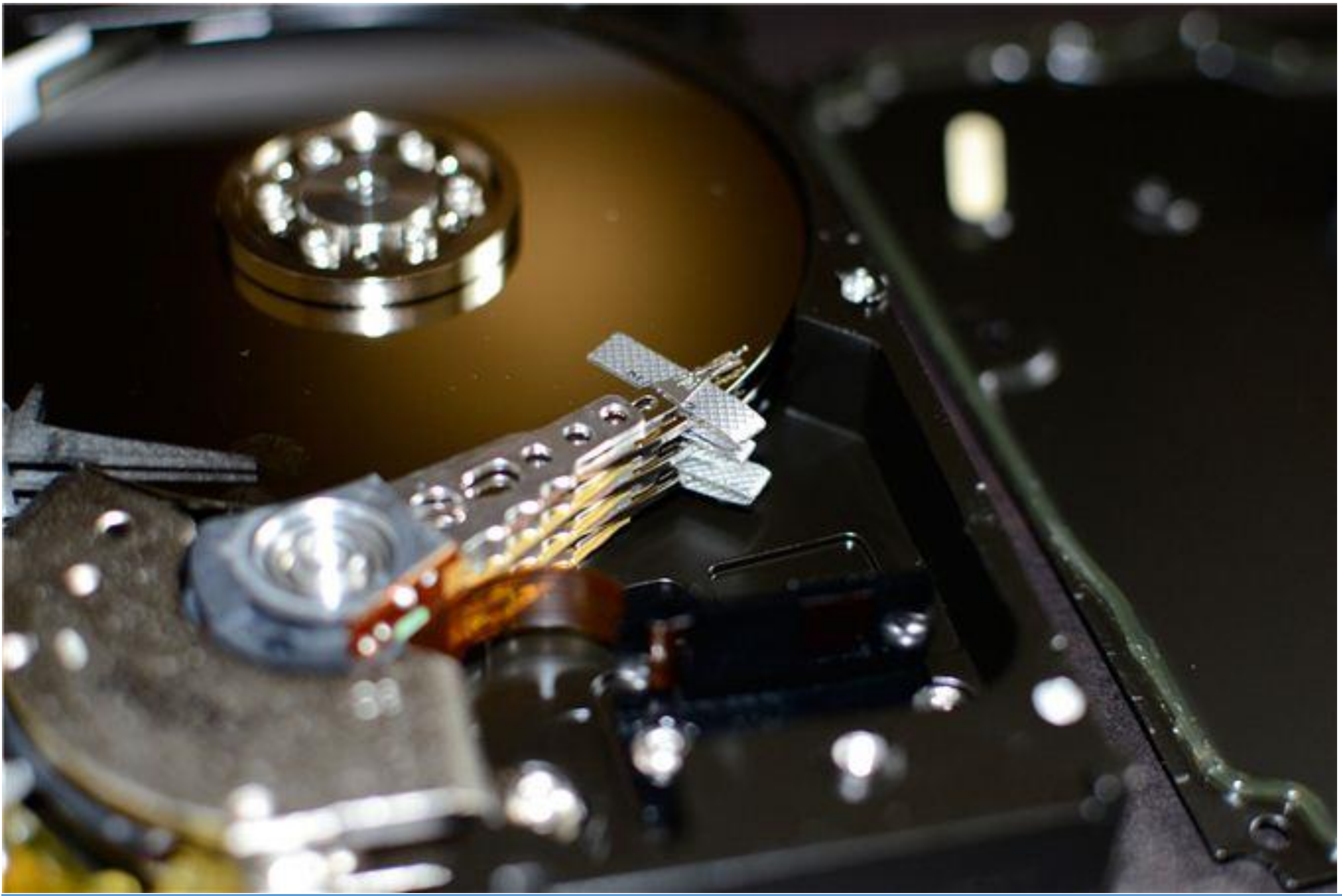

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A read from an HDD	**116 days only to position the reader head**

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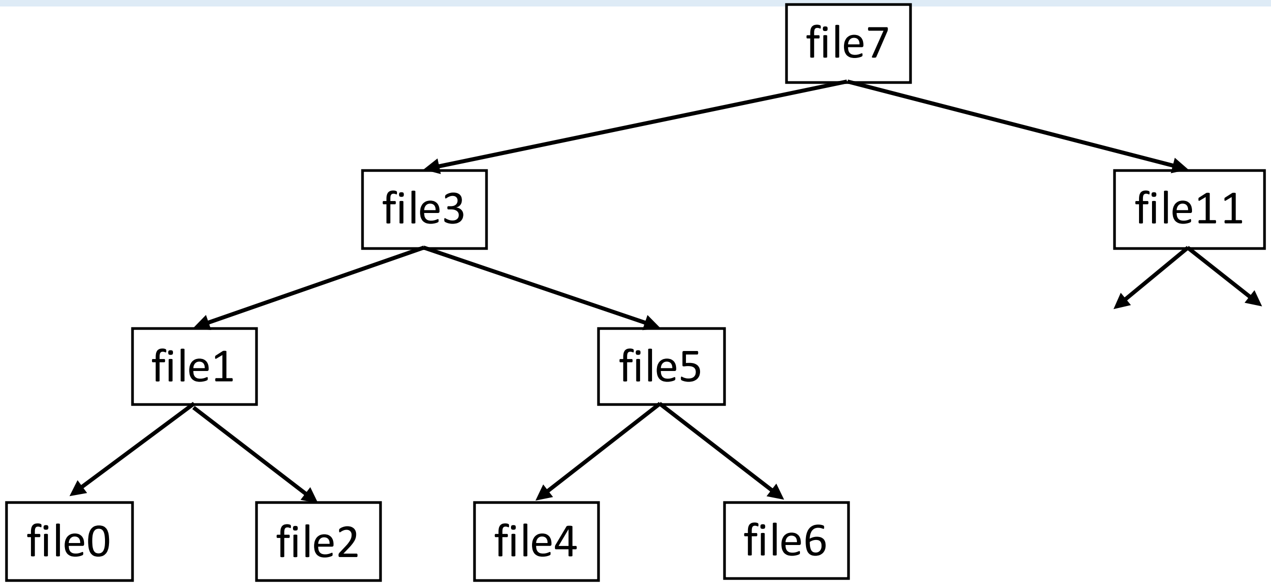

Jump to the start of the list:	≈10msec
Read the whole list:	<1msec (<100K)
Scan the array in RAM:	<1msec

Most files need 4 or 3 random accesses which translates to latencies above 30 msec.

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Kinds of storage devices:

HDD (Hard Disk Drive, a.k.a. Rotating drive, a.k.a. Spinning rust)	+ sequential access is reasonably fast (≈250 MB/sec) - random access is very slow (≈100 IOPS*)

** IOPS stands for "Input/output Operations Per Second".*

** As per the spec of Intel SSD DC S3700 u D7-P5600.*

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Storage-class memory (3D cross-point memory, etc.)	Byte-addressable non-volatile random-access memory that connects to PCI-e or DRAM busses. “Non-volatile” means “does not lose data when powered off”. + the bandwidth and latency is comparable to DRAM, + the size is up to single-digit terabytes.

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APIs for working with file systems:

An operating system must hide hardware details from applications and provide a single API that can be used with different underlying storages.

- POSIX (Portable Operating System Interface),
- Windows API.

POSIX file system API

A file system is a tree of directories and files:

```
/
├── bin
├── boot
├── dev
├── etc
├── home
│   └── artem
├── lib
├── lib32
├── lib64
├── libx32
├── lost+found
├── media
├── mnt
├── opt
├── proc
```

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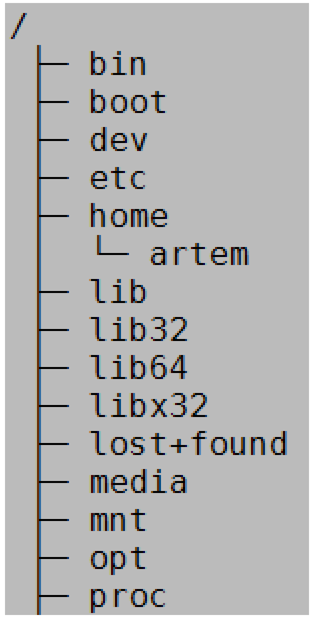
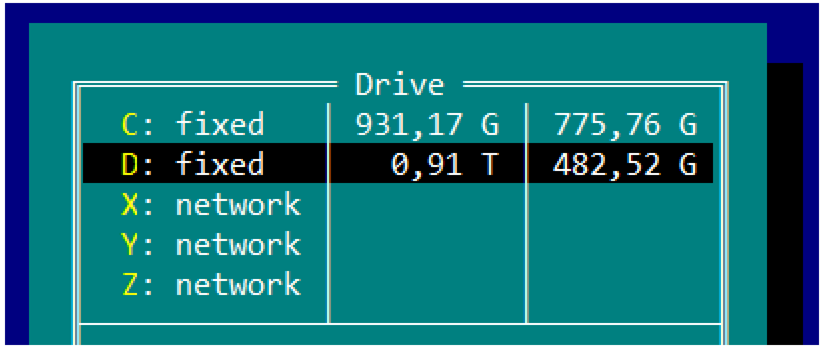
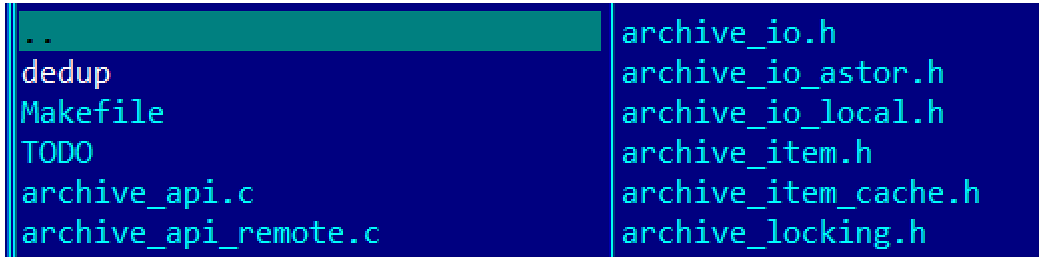


Windows file system API

In Windows, a file system is a collection of trees that Windows calls “drives”:





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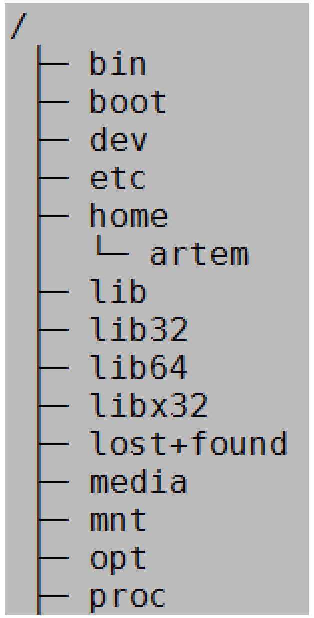

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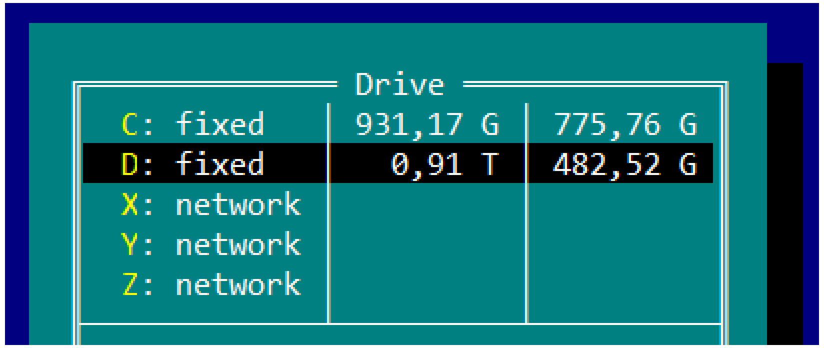

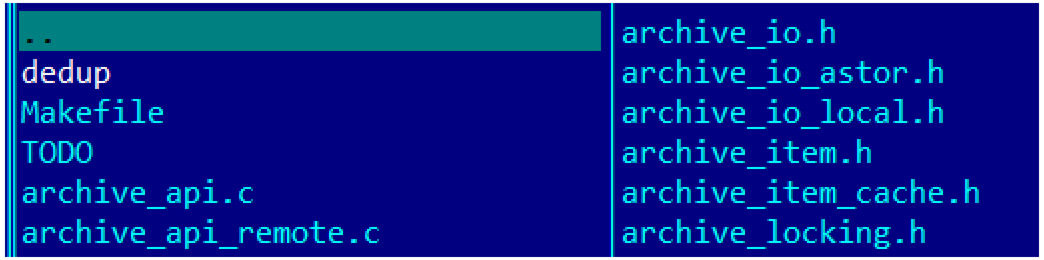

Filesystem Hierarchy Standard:
Linux:
http://refspecs.linuxfoundation.org/FHS_2.3/fhs-2.3.pdf
FreeBSD:
https://www.freebsd.org/doc/handbook/dirstructure.html

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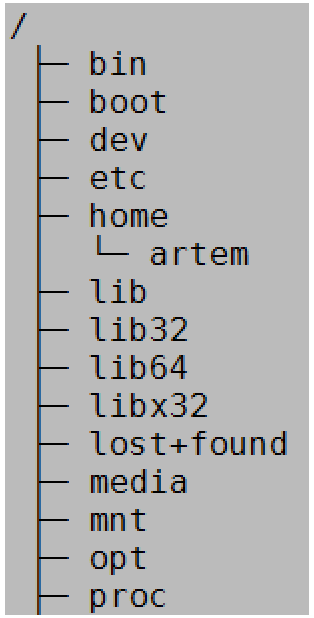

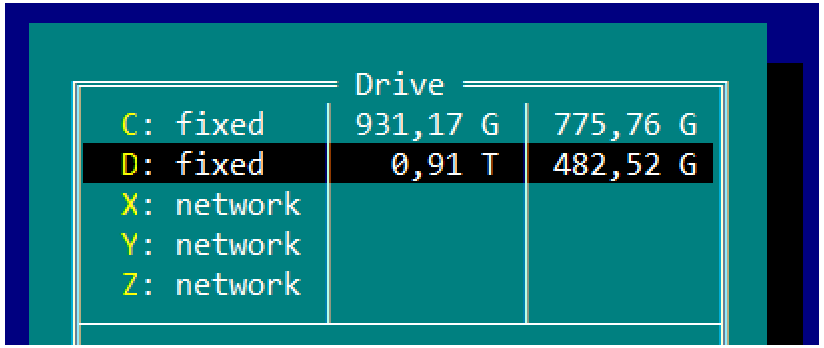

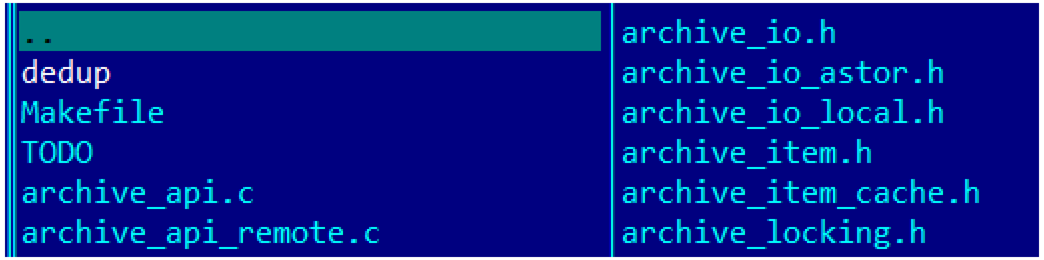

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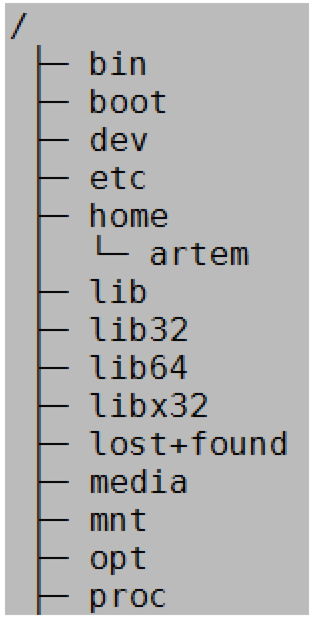
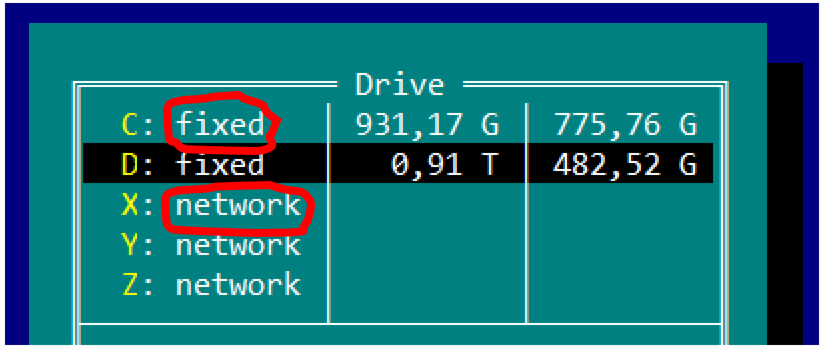
\Global??\C:\foo\bar.txt

An ambiguity in the terminology

A file system is a hierarchy of directories and files presented to a user

A file system is a mechanism of storing files and directories on a storage device.





A refresher on the POSIX Filesystem API

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- O_CREAT,
- O_EXCL,
- O_NOATIME,
- O_CLOEXEC.

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dirfd replaces the “current working directory” for openat(). This gives multiple improvements:

- ???

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dirfd replaces the “current working directory” for openat(). This gives multiple improvements:

- no races with chdir(),
- per-thread working directories instead of a process-global one,
- fewer steps to traverse the file system.

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- files with no names.

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open(O_TMPFILE) creates a file that has no name from the outset.

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7. Special files:

- directory,
- character devices,
- block devices,
- pipes,
- unix domain sockets.

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