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Computer Systems B

COMS20012

Introduction to Operating Systems and Security

File Systems

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I/O Devices

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Devices

- **Devices** is how computer receive inputs and outputs
  - **Keyboard** is an input device
  - **Printer** is an output device
  - **Touch Screen** is both input and output

- Sys161 have the following devices
  - Timer/clock
  - Disk
  - Serial Console
  - Text Screen
  - Network interface

Terminology

- **Bus**: communication pathway between devices in a computer
  - **Internal bus**: bus between the CPU and the RAM. Relatively fast!
  - **Peripheral**: or extension bus, allow devices within the computer to communicate
- **Bridge**: connects two different buses

Device Register

- Communication with devices carried through **device registers**

- Three primary types of registers:
  - **Status**: tells you about the state of a device
  - **Command**: issue a command to the device by writing a particular value
  - **Data**: used to transfer larger block of data

- Some device registers can be combination of primary types:
  - **Status and command**: read for device state, write for command

Device register: Sys161 example **clock**

Offset	Size	Type	Description
0	4	status	current time (seconds)
4	4	status	current time (nanoseconds)
8	4	command	restart-on-expiry
12	4	status and command	interrupt (reading clears)
16	4	status and command	countdown time (microseconds)
20	4	command	speaker (causes beeps)

Device register: Sys161 example **serial console**

Offset	Size	Type	Description
0	4	command and data	character buffer
4	4	status	Read IRQ
8	4	status	Write IRQ

Device driver

- Part of the kernel that interface with a device
- Example write a character to the serial console

wait(console_semaphore) # only one write at a time

write to character buffer

while(writeIRQ!=completed)

write writeIRQ to acknowledge completion

signal(console_semaphore)

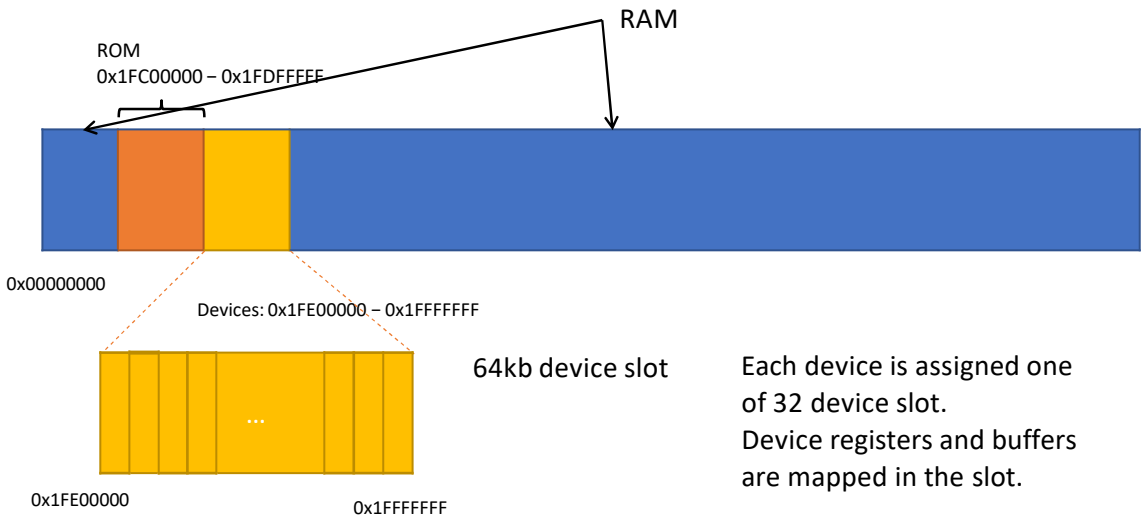
Device driver

- **Polling** approach
  - Check repeatedly the status of the device
  - Polling is bad (waste CPU cycles)
- Instead we should rely on **interrupts**
  - An interrupt is simply a signal that the hardware can send when it wants the processor's attention.

Accessing device registers

- How can our driver access device registers?
  - Option 1: **port-mapped I/O** with special instructions
    - Device are assigned port numbers which corresponds to an address in a separate smaller address space
    - Special instruction to read/write to this address space (in/out on x86)
  - Option 2: **memory-mapped I/O**
    - Each device registers associated to a physical memory address
    - This is not mapped to user space virtual addresses!
    - Read/write using normal load/store instructions (as reading/writing to normal memory)
  - An architecture can have both

Sys161 example

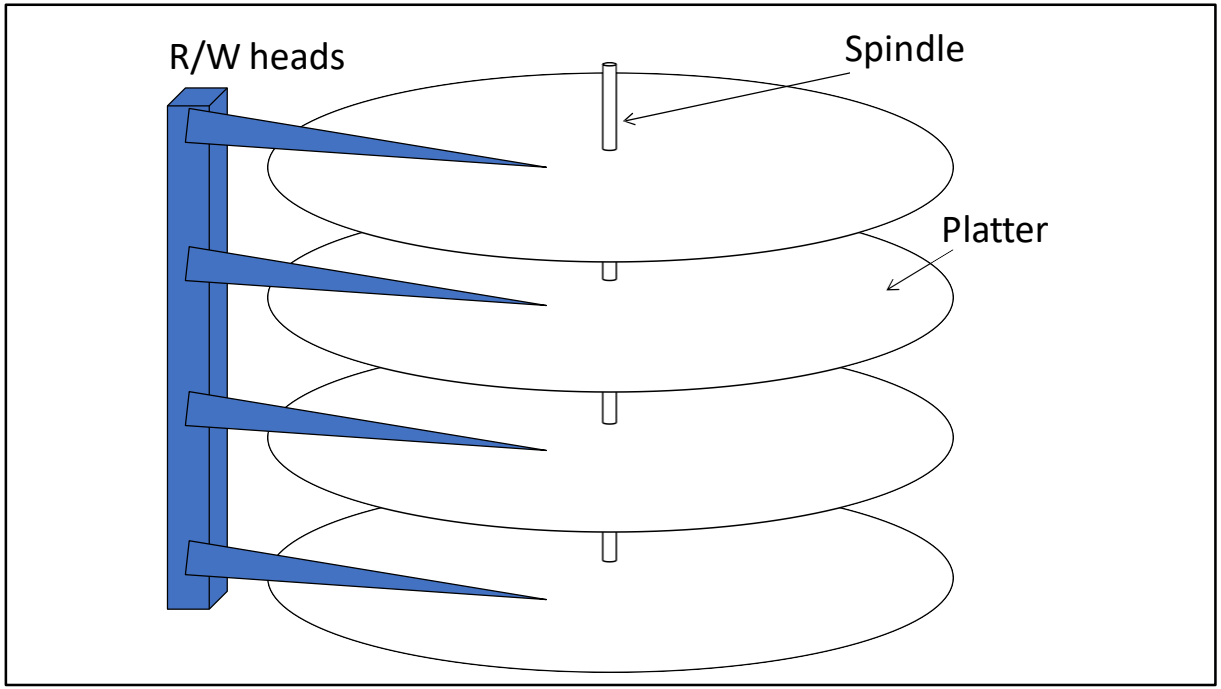


64kb device slot

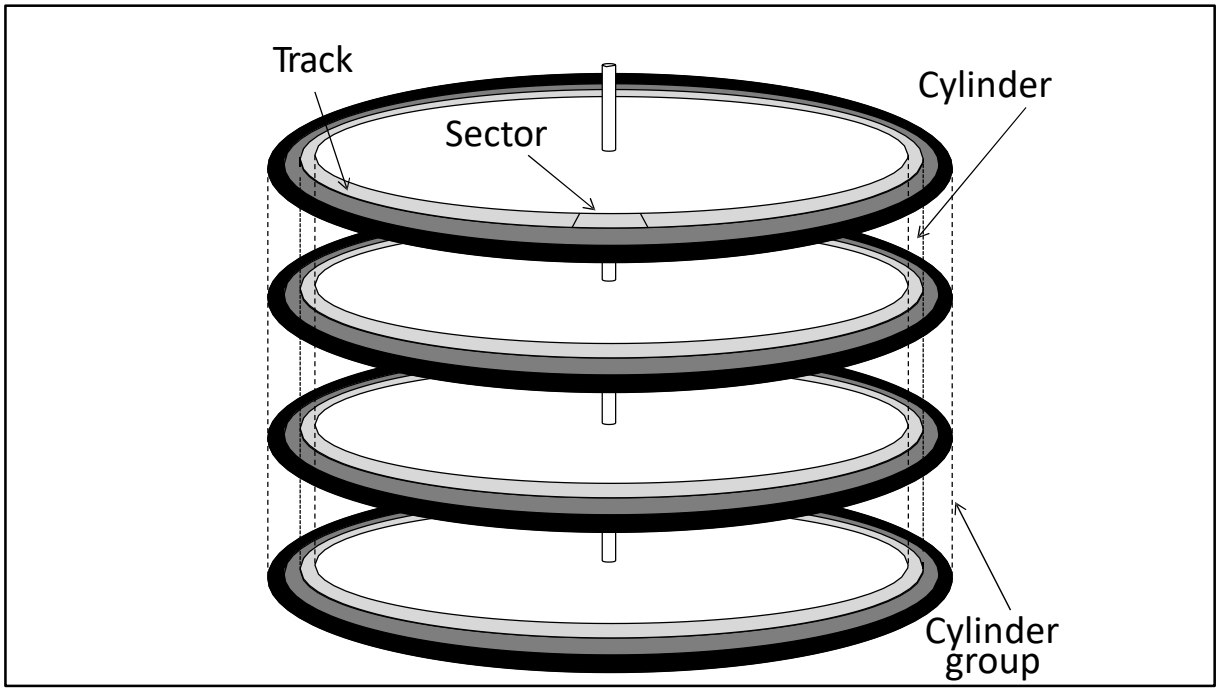
Each device is assigned one of 32 device slot.
Device registers and buffers are mapped in the slot.

Large data transfer

- Write bytes one by one in register won't be very efficient
  - Think of a hard drive
- Buffer in memory
- Two strategy for transfer
  - Program-controlled I/O
    - The device driver move data between the CPU and I/O device
    - The CPU is Busy
  - Direct memory access DMA
    - The device itself copy the data from memory to itself
    - The CPU is not busy while this happen
    - The device will trigger an interrupt when done
- Sys161 disks use program-controlled I/O



Note that the platters are double-sided, i.e., they store data on both sides. Also note that all of the read/write heads move together, in unison.



For a long time, hard disks used a sector size of 512. However, modern disks now use a sector size of 4K.

Cylinder group to blocks

- Cylinder groups are divided into blocks
- Blocks can be addressed to read/write from disk
- You can check the textbook for discussion on optimization around reading/writing from hard drive
- – 6.1.2 (page 223)
  - –6.1.3 (page 226), first finish all videos
  - –Not mandatory, just if you are curious

Device register: Sys161 **disk controller**

Offset	Size	Type	Description
0	4	status	number of sectors
4	4	status and command	status
8	4	command	sector number
12	4	status	rotational speed
32768	512	data	transfer buffer

Writing to a Sys161 disk

- Device driver

wait(disk_semaphore)
copy data from memory to transfer buffer
write target sector to sector register
write "write" command to disk status register
wait(disk_completion) signal(disk_semaphore)

- Interrupt handler

write disk status register to acknowledge completion
signal(disk_completion)

Reading from a Sys161 disk

- Device driver

wait(disk_semaphore)

write target sector to sector register
write "read" command to disk status register
wait(disk_completion)
copy data from buffer to memory
signal(disk_semaphore)

- Interrupt handler

write disk status register to acknowledge completion
signal(disk_completion)

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Files on disk

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It is all about abstractions

- OS see storage as a large addressable array of bytes
- User space wants better abstraction
  - –Naming: /pics/meme.jpg instead of bytes between 24,048 to 28,156
  - –Performance optimization
    - Caching
    - Pre-fetching
  - –Transparent sector/block management
  - –Reliability in case of crash/power failure

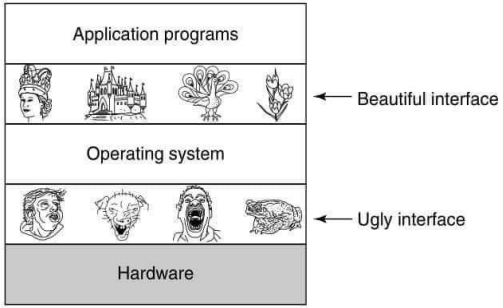


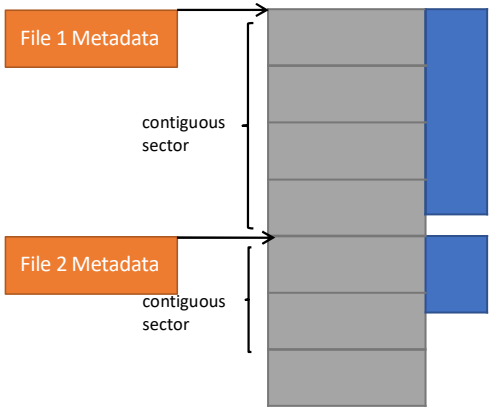
Figure 1-2. Operating systems turn ugly hardware into beautiful abstractions.

Modern Operating Systems, by Andrew Tanenbaum, Herbert Bos, Pearson

Files and Directories

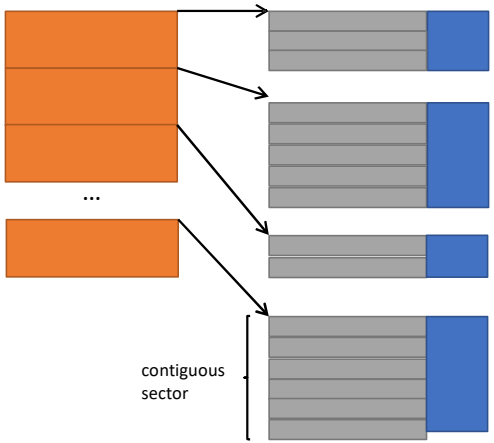
- File: linear region of bytes that can grow and shrink
  - Associated with metadata
    - A name (e.g., meme.jpg)
    - Size in bytes
    - Access permissions (read/write/execute)
    - Statistics (e.g., creation and access dates)
  - OS is agnostic to the content of the file (userspace is to interpret it)
- Directory: container for files and other directories
  - Associate with a name + metadata
  - Nested directories can create a hierarchy (e.g., /home/bob/pictures/meme.jpg)

File as a single extent (1960's file systems)



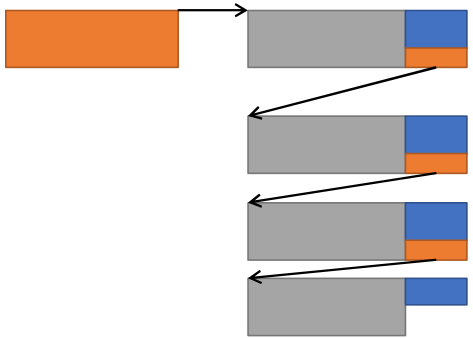
- File metadata
  - Starting sector
  - Length in byte (last sector may not be fully used)
- Advantages
  - Simple
  - Small metadata
  - Good sequential and random I/O
- Problems
  - How much space to allocate to new files
  - What to do if a file grow beyond its allocation? Or Shrink?
  - External fragmentation

File as a collection of extents (IBM 360, ext4)



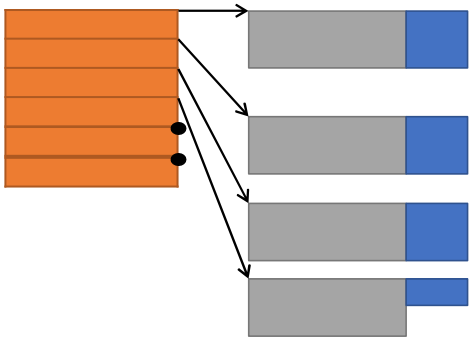
- Advantage
  - Metadata remain relatively small
  - Almost as good sequential I/O
    - Sequential offset calculation a bit tricky
  - Almost as good random I/O
- Challenges
  - How large the initial extent should be?
  - What to do if a file grows or shrink?
  - Improve on fragmentation!

Files as linked list: (FAT)



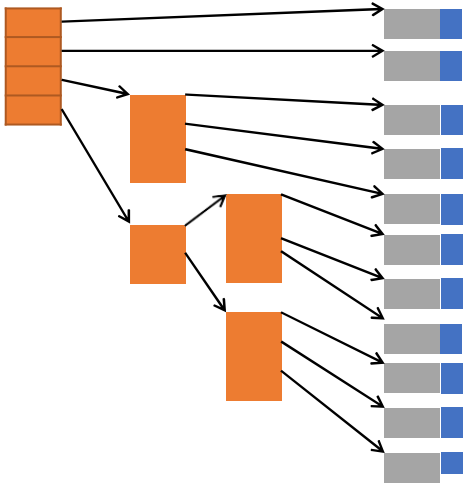
- Advantages
  - Easy to shrink and grow
  - Low internal and external fragmentation
  - Sequential offset calculation is easy
- Disadvantages
  - Need to go through the list to find the part ones need
  - Some metadata at the end of each data block
  - Sequential I/O requires lots of seeks (on hard drive mechanical movement)

Files as flat indices



- Array mapping ranges to a block
- Advantages
  - Offset is easy to calculate
  - Low fragmentation
- Disadvantages
  - Maximum file size is fixed by number of entries in an index
  - Sequential I/O requires lots of seeks (on hard drive mechanical movement)

Files as hybrid indices (FFS, ext2, ext3)



- Top level index contains: direct pointers, indirect pointers, doubly indirect pointers etc.
- Advantages
  - Efficient for small files (do not materialize unused indirect list)
  - Big maximum file size (function of depth and index size)
  - Low fragmentation
- Disadvantages
  - Sometimes multiple disk access for a single read/write (need to fetch indirections)
  - Still require a large number of seek

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Naming

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Naïve naming

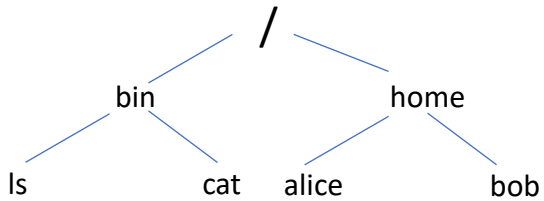
- One directory for the entire disk
- Small maximum name size
- Maximum number of files at creation
- Implementation
  - Allocate space for the directory
  - Directory structure is a big map
    - key: char file_name[MAX_SIZE]
    - value: file representation (see video 2) or an ID that easily map to it

- Pros:
  - Simple to implement
- Cons:
  - Hard to organize data
  - No two objects with the same name
  - Collision likely in multi-users systems
  - Names are limited

Hierarchical structure

- Tree structure
- Directories are normal files with a specific format
- Bit indicate if file or directory
- Contains directory entries
  - –Map name to some ID
  - –User can read
  - –Only kernel can write

- Pros
  - –Much better organization
  - –Reuse file implementation
- Cons
  - –File look up is a bit more complicated
    - ➢Need to traverse directories



Directory Implementation

- Directory are implemented like files
- Content of directory entries:
  - Name
  - inode number (the name come from the original UNIX)
  - Type
- Root directory has a designated inode (so we know where to start!)

Root directory “/”

Name	inumber
home	6
etc	2254
net	3
sbin	4512
var	25615
tmp	14525
…	…

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Files and System Calls

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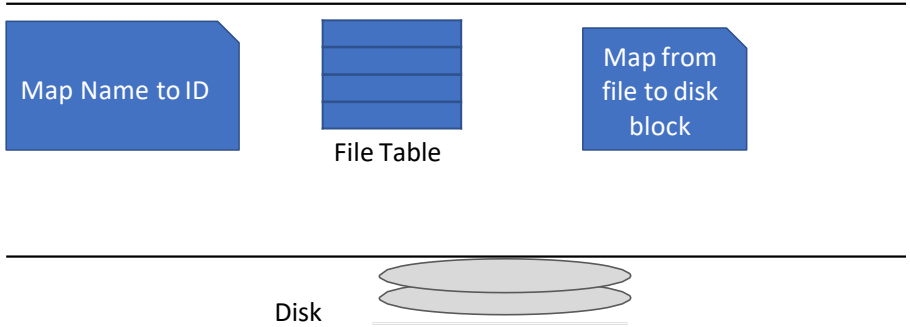
From System Call API to disk



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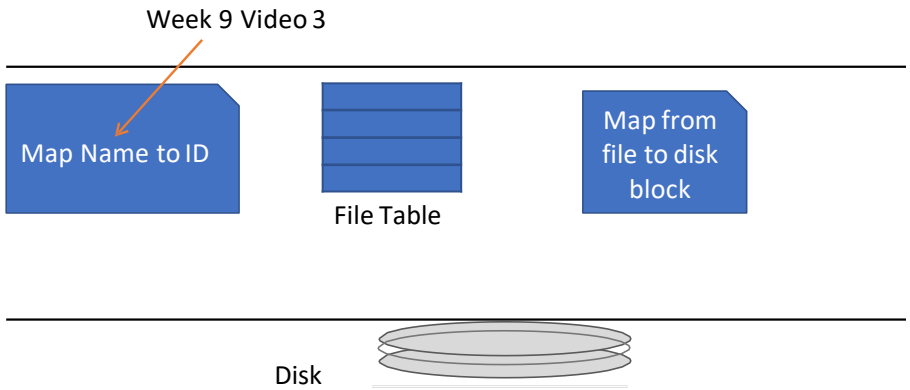

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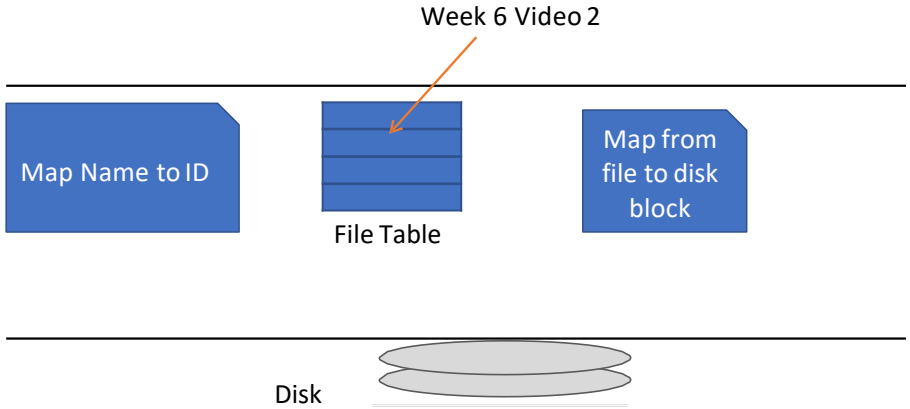

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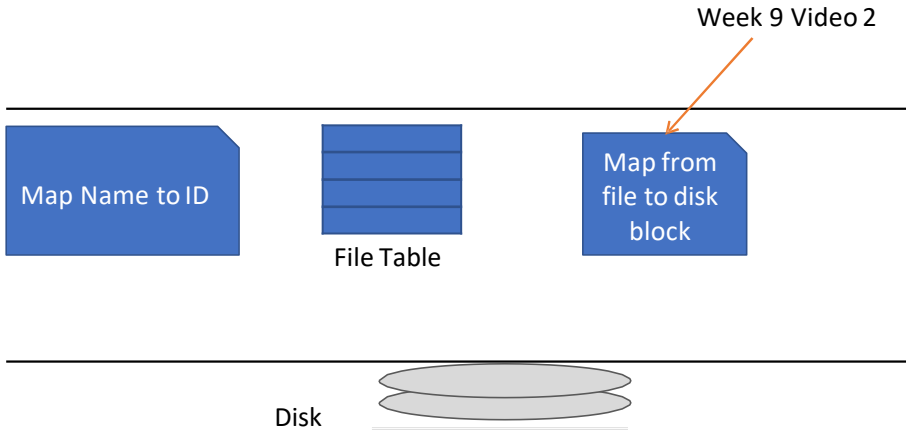

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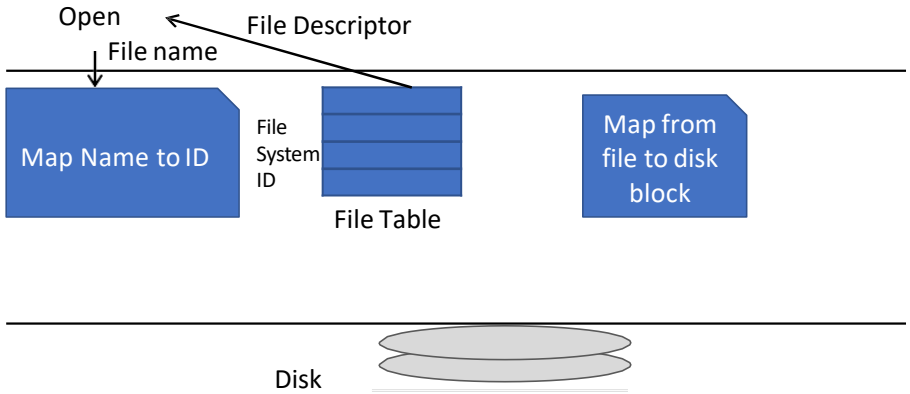

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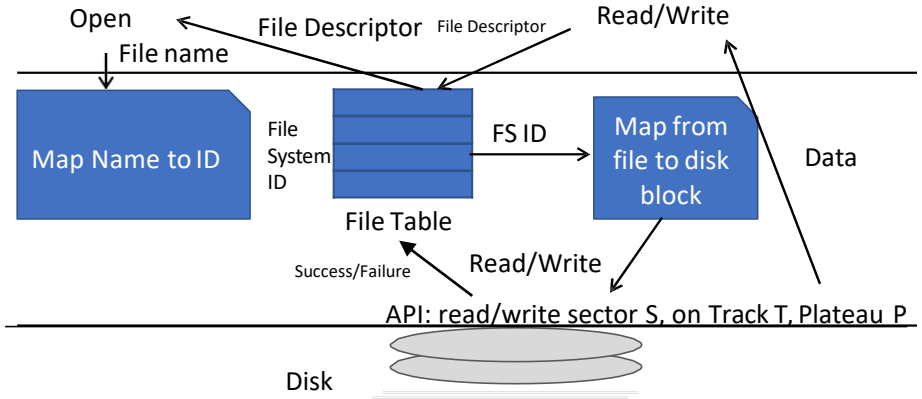

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Problem?

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Problem?
Disk are very slow!

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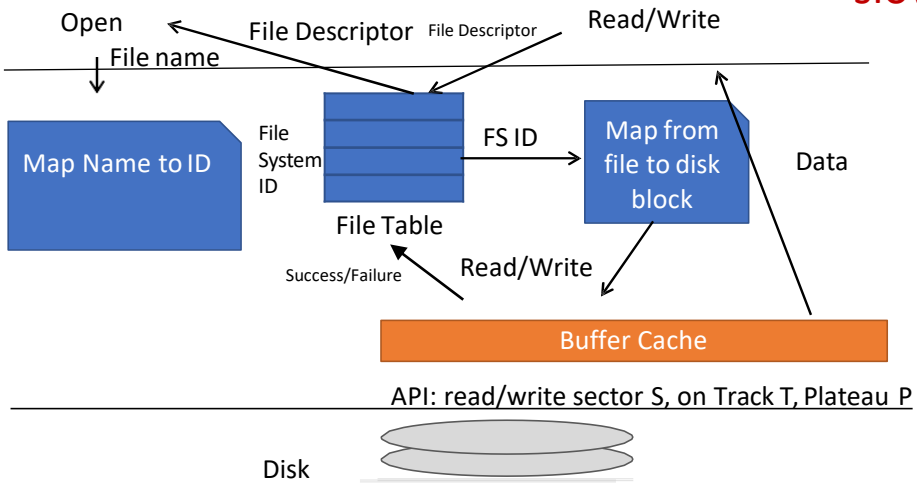
From System Call API to disk

Typical CS solution to fix
"slow" add some cache!



From System Call API to disk

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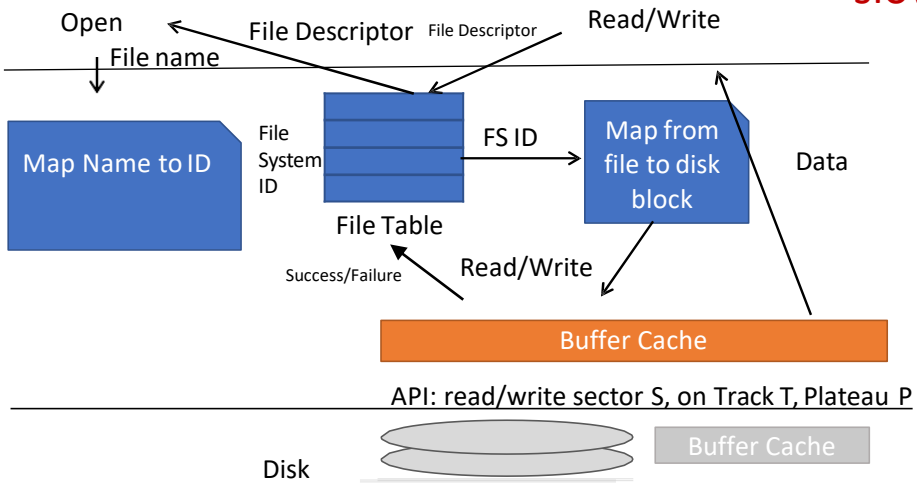

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Thank you

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