# 3150 - Operating Systems

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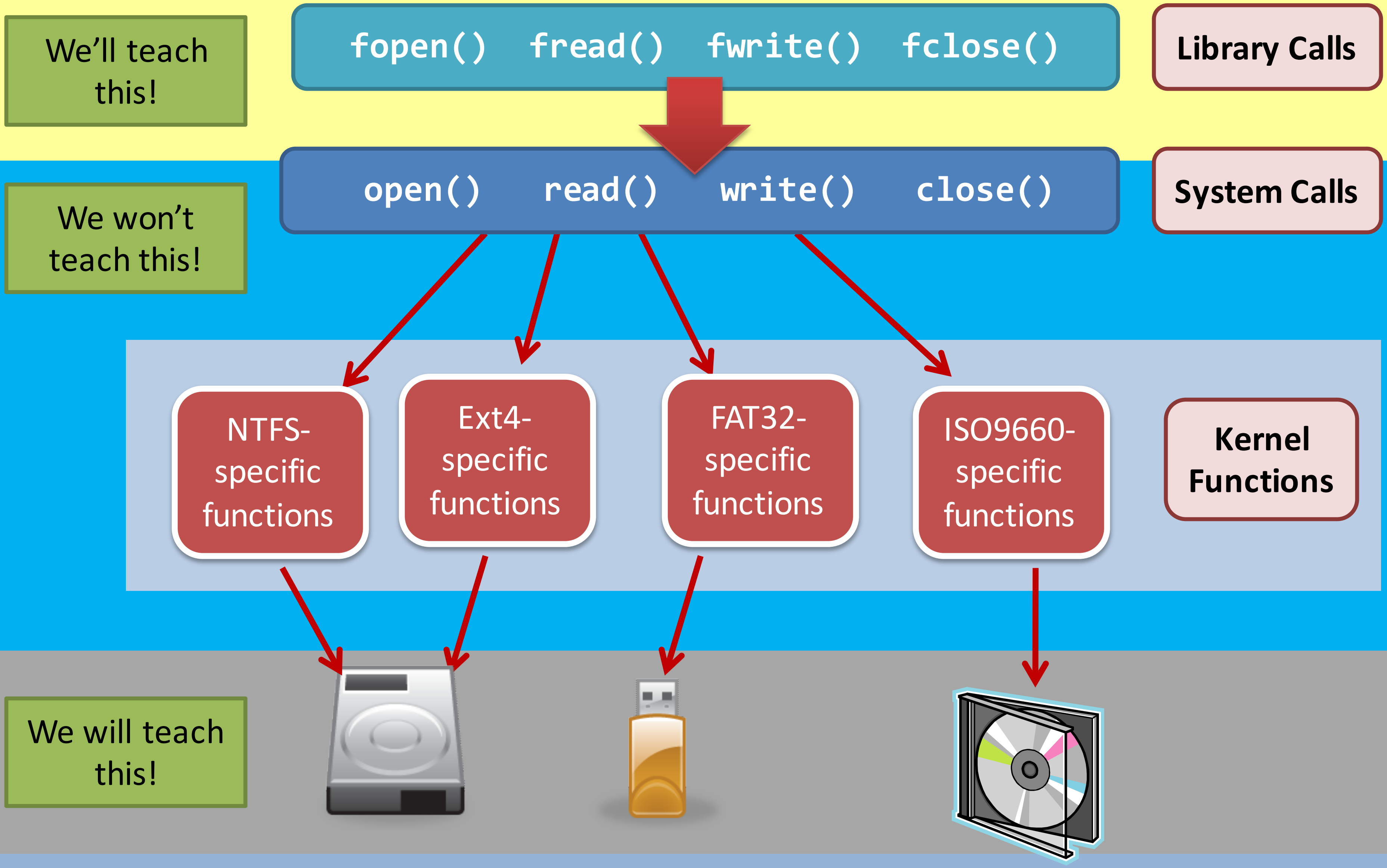
## Chapter 3, part 1
## File Systems – Programmer Perspectives.

*- Here comes the chapter that you can play with something solid,*
*e.g., to corrupt a disk …*

# Outline



We'll teach this!

fopen() fread() fwrite() fclose()

Library Calls

We won't teach this!

open() read() write() close()

System Calls

NTFS-specific functions

Ext4-specific functions

FAT32-specific functions

ISO9660-specific functions

Kernel Functions

We will teach this!

# Class Discussion: Question #1

OS == FS? Reasons?

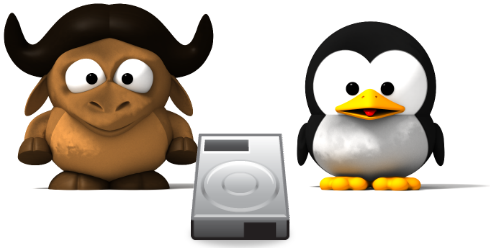
- An OS supports a FS.
- An OS supports more than one FS.
- A FS can be used by more than one OS.
- But, “FS != OS”.

# Class Discussion: Question #2

Storage Device == FS? Reasons?

- A FS needs a storage device.
  - But, a device can be either physical or virtual.
- A storage device is just a container.
  - Doesn’t need to know what FSes are stored.
  - Doesn’t need to know how many FSes are stored (on different partitions.
- So, “Storage Device != FS”!

# Looking at FS from the userspace
## - GNU C Library call VS System call?



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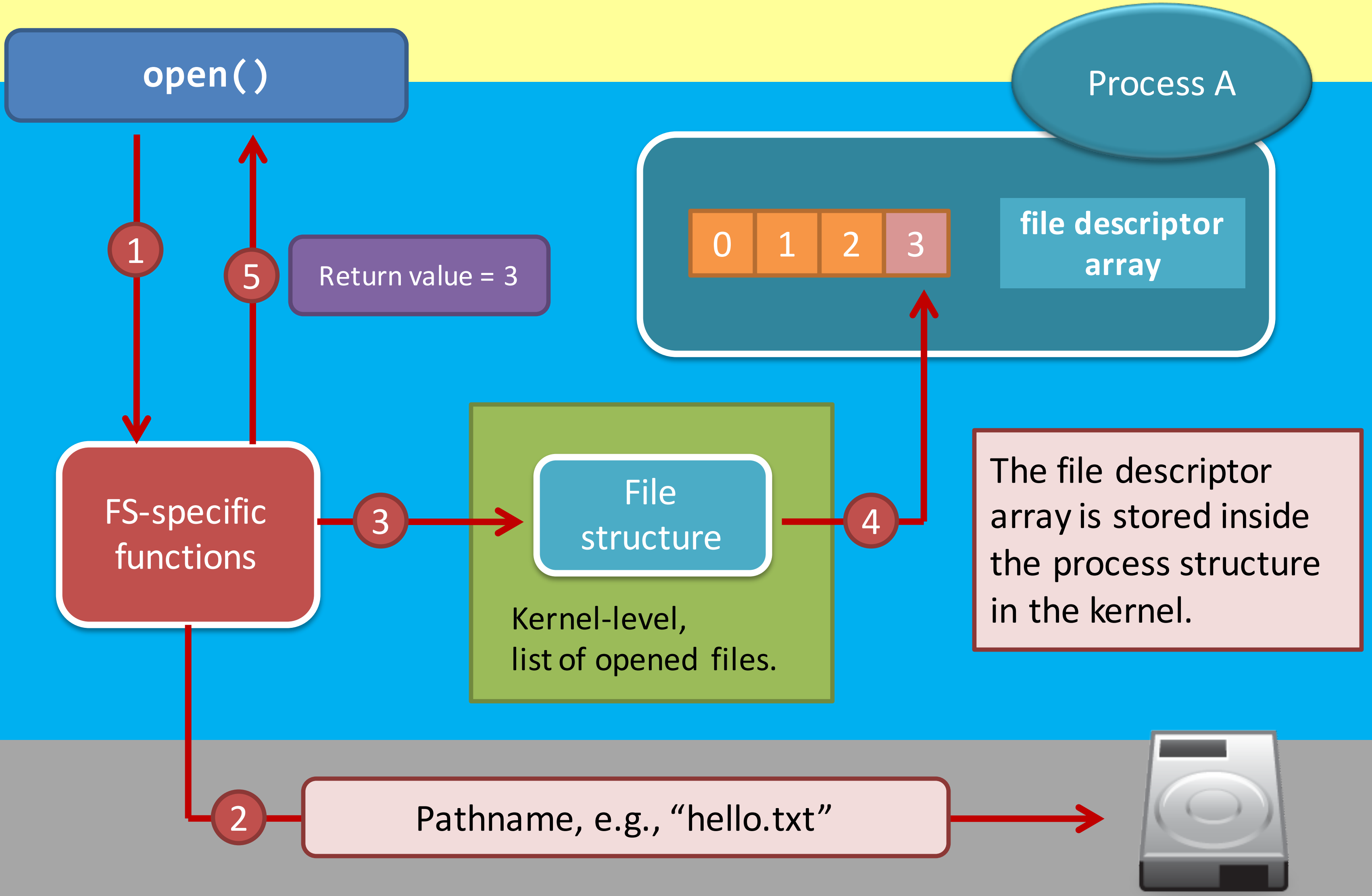
# What is a file descriptor?



open()

1

5

Return value = 3

Process A

0 1 2 3

**file descriptor array**

FS-specific functions

3

File structure

Kernel-level,
list of opened files.

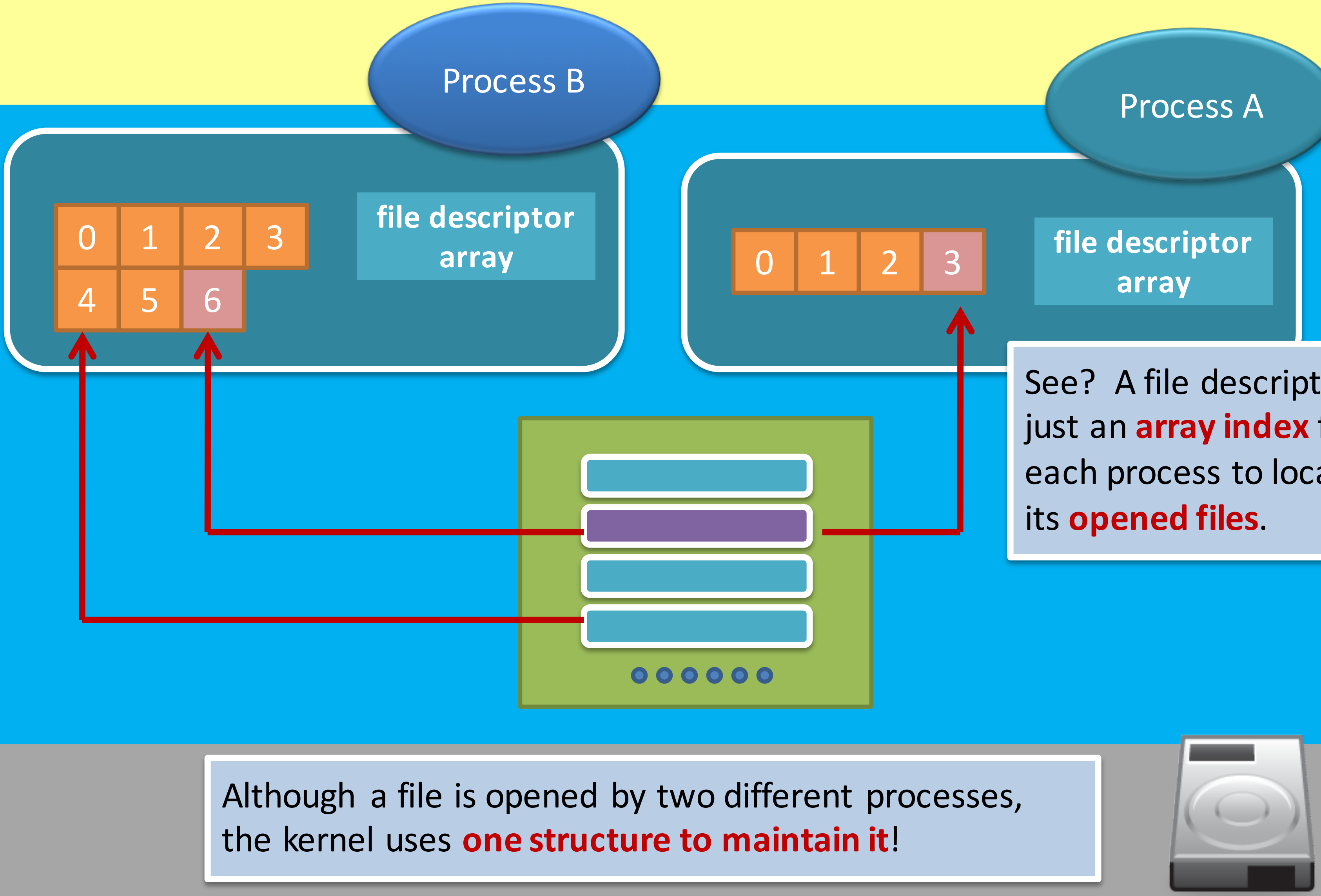
4

The file descriptor array is stored inside the process structure in the kernel.

2

Pathname, e.g., “hello.txt”

# What is a file descriptor?

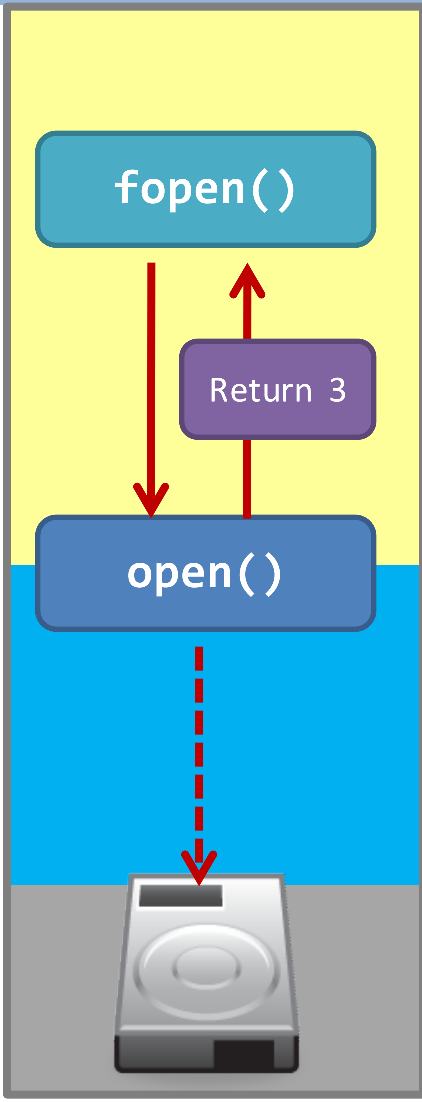


See? A file descriptor is just an **array index** for each process to locate its **opened files**.

Although a file is opened by two different processes, the kernel uses **one structure to maintain it**!

# Library call VS System call

- What is **fopen()**? What is the type “**FILE**”?
  - First thing first, **fopen()** calls **open()**.
  - “**FILE**” is just a structure in defined in “**stdio.h**”.
  - However, **fopen()** *creates memory* for the “**FILE**” structure.
    - Fact: occupying space in the area of dynamically allocated memory, i.e., `malloc()`



# What is inside the “**FILE**” structure?

- There is a lot of helpful data in **FILE**:
  - Two important things: the **file descriptor** and **a buffer**!

```
int main(void) {
    printf("fd of stdin  = %d\n", fileno(stdin)  );
    printf("fd of stdout = %d\n", fileno(stdout) );
    printf("fd of stderr = %d\n", fileno(stderr) );
}
```

**fileno()** returns the file descriptor of the FILE structure.

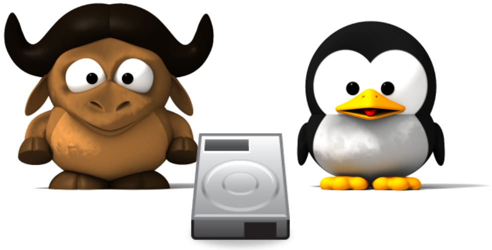
The type of **stdin**, **stdout**, and **stderr** is “**FILE ***”

```
$ ./fileno
fd of stdin  = 0
fd of stdout = 1
fd of stderr = 2
$ _
```

```
[examples@3150] cat fileno.c
```

# Looking at FS from the userspace

- GNU C Library call VS System call?
  - Buffered I/O and efficiency.



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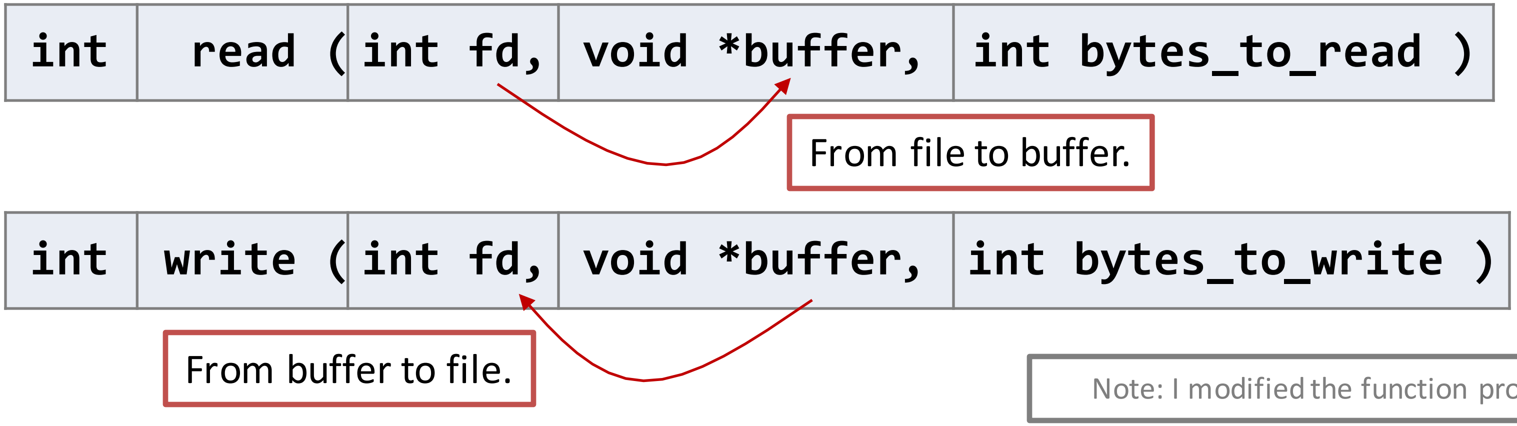
# `read()` & `write()`

- You know, I/O-related calls will invoke system calls.



```
int  read  ( int fd, void *buffer, int bytes_to_read )
```

From file to buffer.

```
int  write ( int fd, void *buffer, int bytes_to_write )
```

From buffer to file.

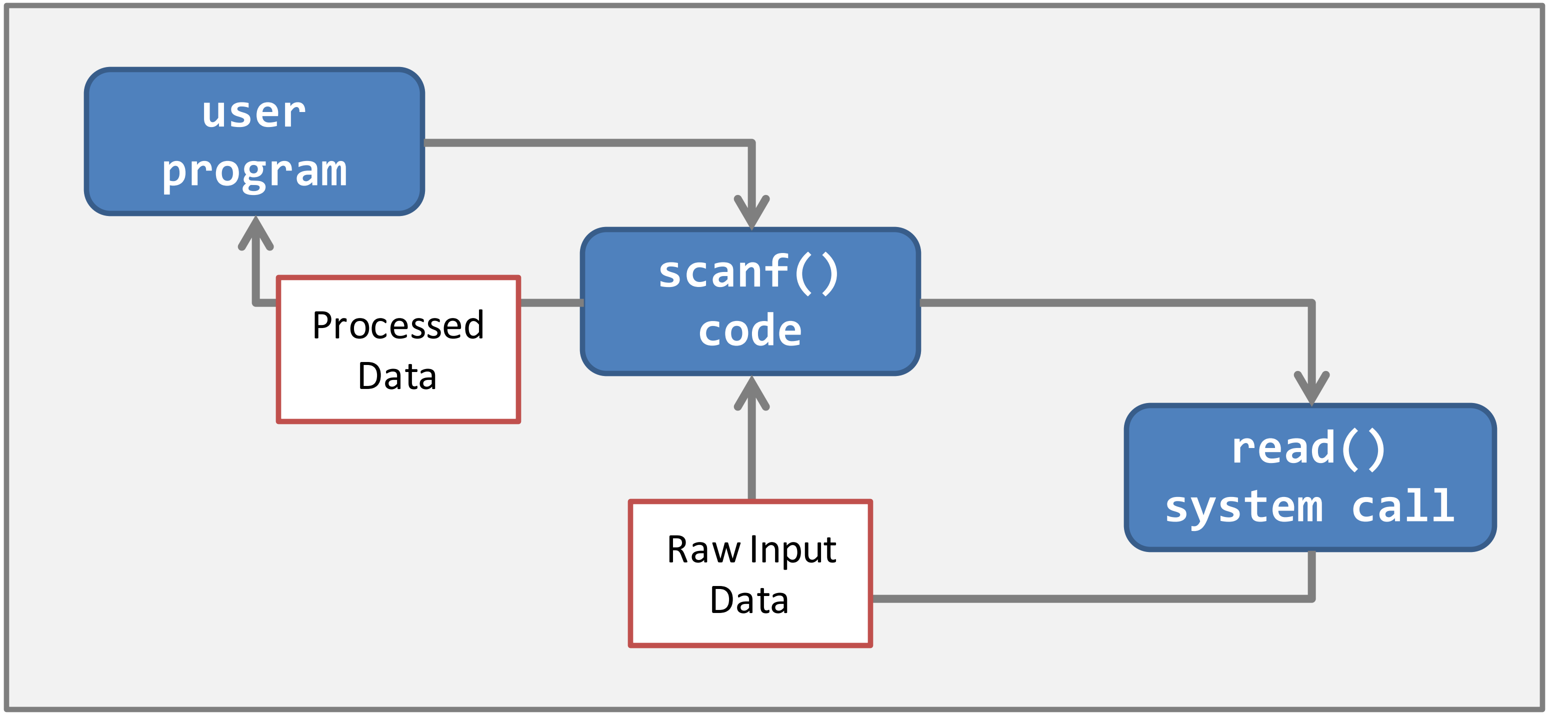
Note: I modified the function prototypes.

| Library calls that eventually invoke the `read()` system call | Library calls that eventually invoke the `write()` system call |
|---|---|
| `scanf(), fscanf()` | `printf(), fprintf()` |
| `getchar(), fgetc()` | `putchar(), fputc()` |
| `gets(), fgets()` | `puts(), fputs()` |
| `fread()` | `fwrite()` |

# read() & write()

- **scanf()** as an example!

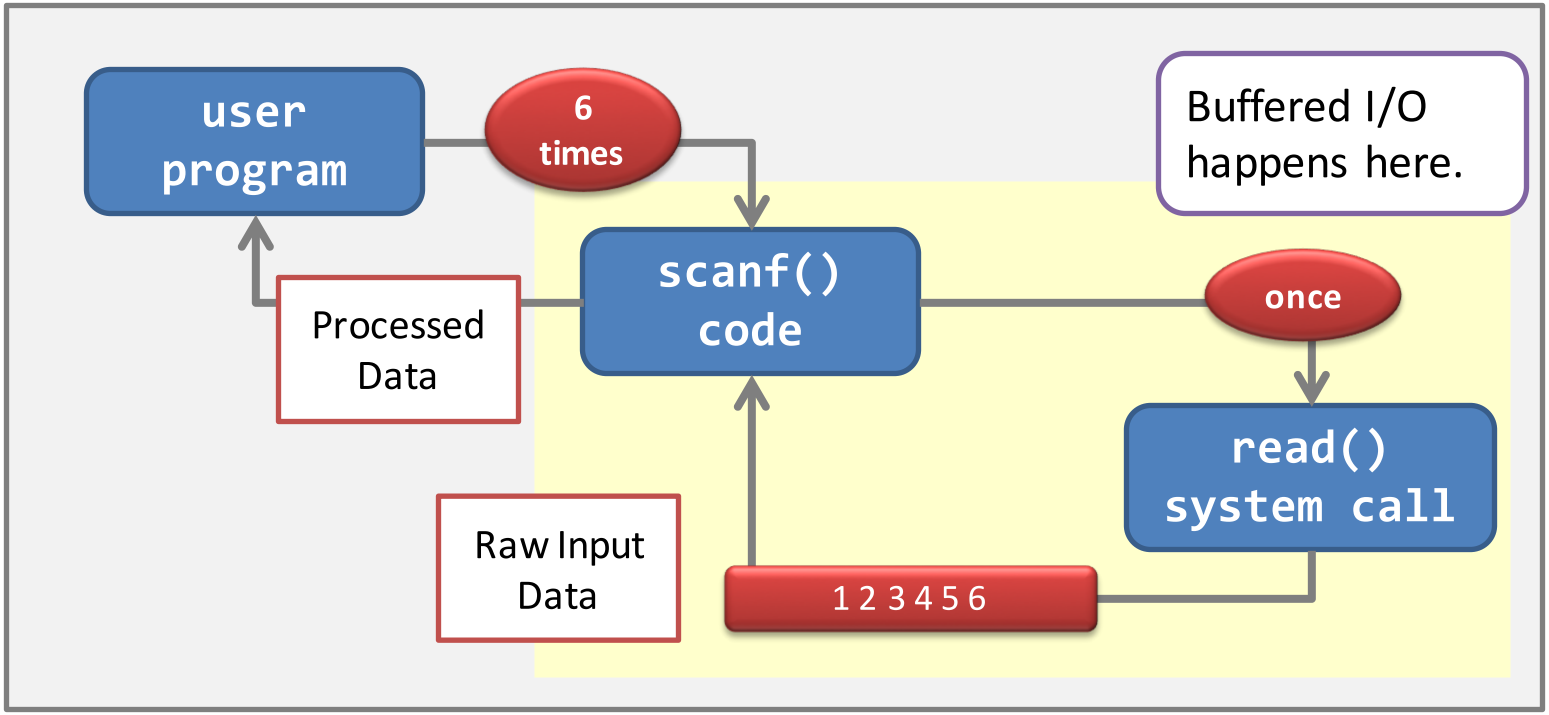
```
int main(void) {
    int input;
    while(1) {
        scanf("%d", &input);
        printf("%d\n", input);
    }
}
```



# What is buffered I/O?

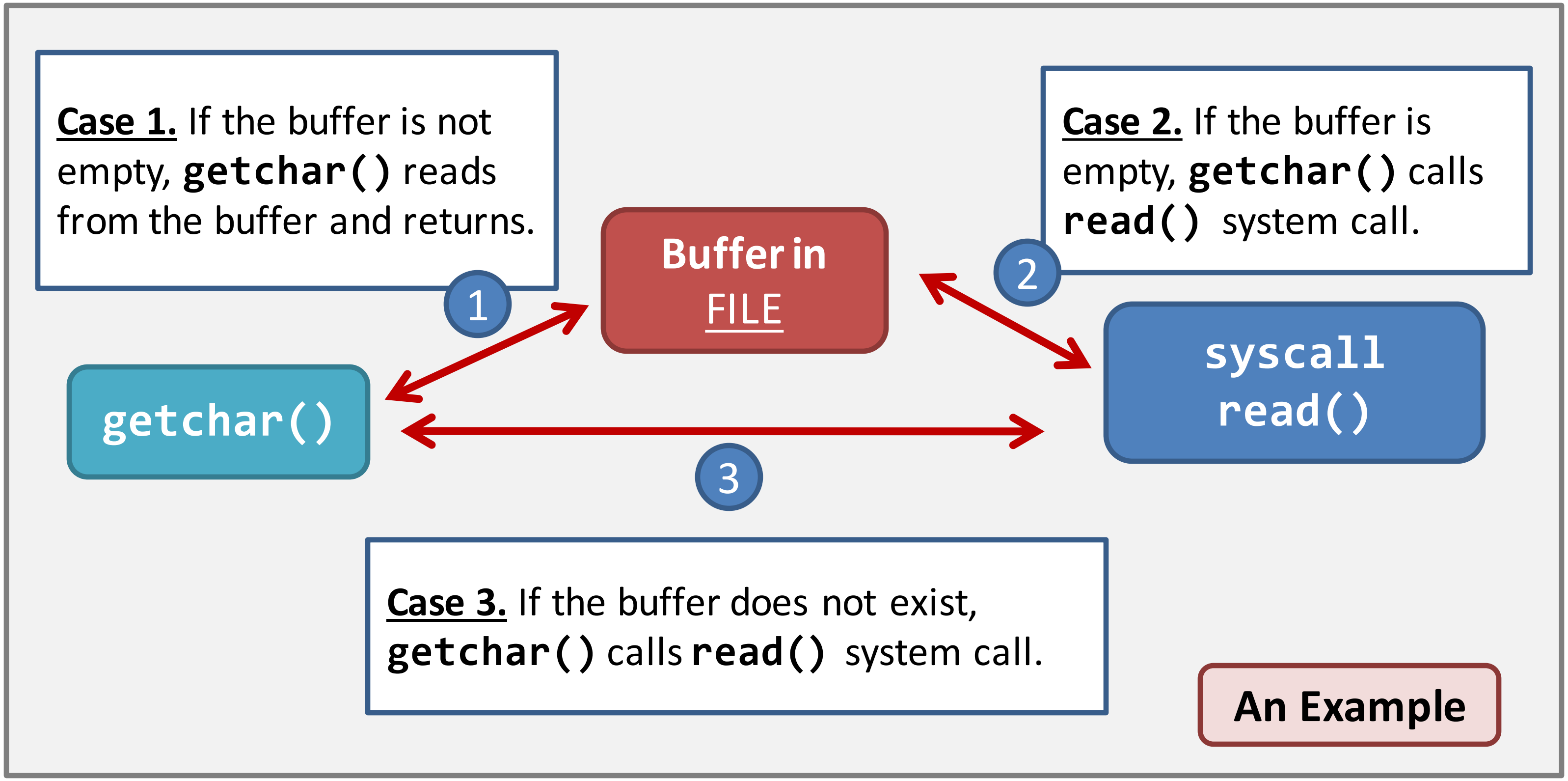
- If I input "**1 2 3 4 5 6**", you will find 6 outputs, right?
  - But, are there 6 `read()` calls?

```
int main(void) {
    int input;
    while(1) {
        scanf("%d", &input);
        printf("%d\n", input);
    }
}
```



# Buffered I/O  and the “`FILE`” structure?

- There is a **memory buffer** in the **`FILE`** structure and **this cache (or buffer) to reduce the number of system calls**!



**Case 1.** If the buffer is not empty, **`getchar()`** reads from the buffer and returns.

**Case 2.** If the buffer is empty, **`getchar()`** calls **`read()`** system call.

**Case 3.** If the buffer does not exist, **`getchar()`** calls **`read()`** system call.

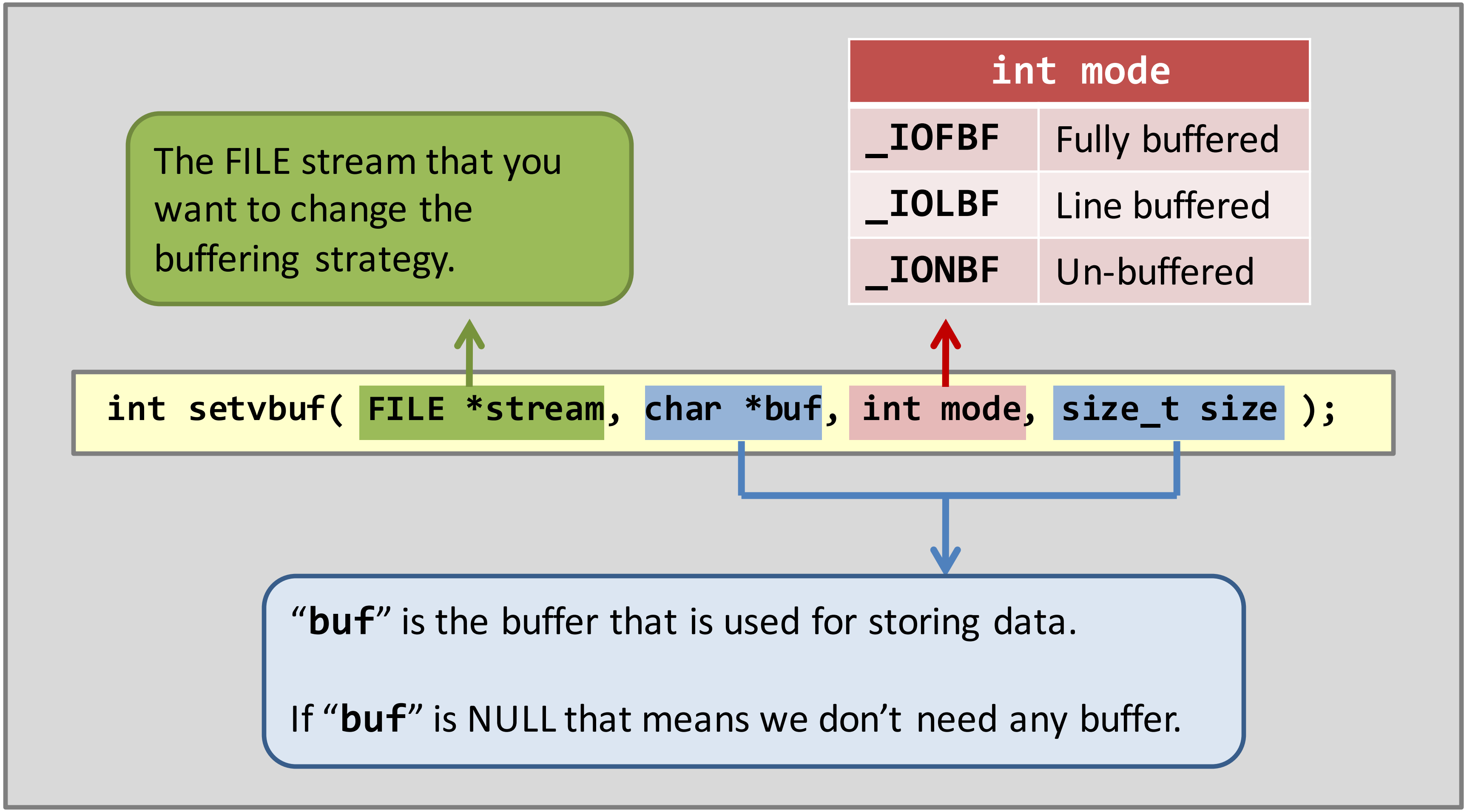
# Buffered I/O – different modes

- 3 modes:

| Modes | Read-related call<br>e.g., getchar() | Write-related call<br>e.g., putchar() |
|---|---|---|
| **Fully-buffered** | Data is **read in one bulk** and is stored in the buffer.<br>Invoke the **`read()`** system call when the buffer becomes empty. | Data is written to the buffer.<br>Invoke the **`write()`** system call when the buffer becomes full, or before the process terminates. |
| **Line-buffered** | Data is read into the buffer until the **newline character** is encountered. | Data is written to the buffer. When a **newline character** is encounter, **`write()`** system call is invoked. |
| **Un-buffered** | Directly translate every library call into a **`read()`** system call. | Directly translate every library call into a **`write()`** system call. |

# Buffered I/O – change the buffer

- There is a convenient call that controls **everything**!



The FILE stream that you want to change the buffering strategy.

| int mode | |
|---|---|
| `_IOFBF` | Fully buffered |
| `_IOLBF` | Line buffered |
| `_IONBF` | Un-buffered |

```
int setvbuf( FILE *stream, char *buf, int mode, size_t size );
```

“**buf**” is the buffer that is used for storing data.

If “**buf**” is NULL that means we don’t need any buffer.

# Buffered I/O – change the buffer

- “**stdin**” and “**stdout**” are **line-buffered** by default.
- “**stderr**” is **un-buffered** by default.

```
char buf[1024];
int main(void) {
    ......
    printf("H");     sleep(1);
    printf("E");     sleep(1);
    printf("L");     sleep(1);
    printf("L");     sleep(1);
    printf("O");     sleep(1);
    printf("\n");    sleep(1);
}
```

```
setvbuf(stdout, NULL, _IONBF, 0);
```

```
setvbuf(stdout, buf, _IOLBF, sizeof(buf));
```

```
setvbuf(stdout, buf, _IOFBF, sizeof(buf));
```

```
[examples@3150] cat no_buf.c line_buf.c full_buf.c
```

# Buffered I/O – summary

VERY IMPORTANT

- Now, you know the buffer is just a piece of memory.
  - So, you need to be careful when you are playing with **`fork()`** and **`pthread_create()`**.

- **Challenge.** What will be the output?

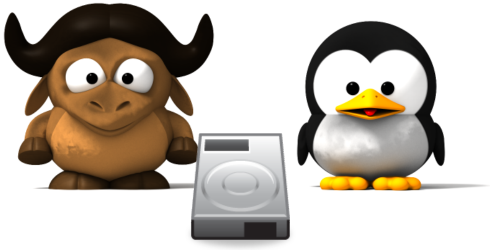
```
int main(void) {
    printf("Hello");
    fork();
    printf("\n");
    return 0;
}
```

printf係stdout，default係line-buffered，所以printf完如果冇“\n”都會繼續儲係buffer裡面，咁再fork()就會fork左兩個buffer出黎，所以會print兩個“Hello\n”。

```
[examples@3150] cat fork.c
```

## Looking at FS from the userspace

- GNU C Library call VS System call?
  - Buffered I/O and efficiency.
  - What is the true meaning of EOF?



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# Library call VS System call – what is EOF?

- Well, the following is just one of the common usage of EOF:

```
int main(void) {
    char c;
    unsigned long long count = 0;
    while(1) {
        c = getchar();
        if(c == EOF)
            break;
        else
            count++;
    }
    printf("EOF! Read %lld bytes.\n", count);
}
```

Do you know what EOF really is?

```
[examples@3150] cat getchar_eof.c
```

# Library call VS System call – what is EOF?

- First of all, **you can't find any "*EOF character*"** when using system calls.

```
int main(void) {
    int ret;
    char c;
    unsigned long long count = 0;
    while(1) {
        ret = read(fileno(stdin), &c, 1);
        if(ret == 0)
            break;
        else {
            count += ret;
            if(c == EOF)
                printf("WoW!\n");
        }
    }
    printf("Read %lld bytes.\n", count);
}
```

No more bytes to read.

Any "**WoW!**"?

no

```
[examples@3150] cat read_eof.c
```

# Library call  VS  System call – what is EOF?

- Somewhere inside “**/usr/include/stdio.h**”:

```
#ifndef EOF
# define EOF (-1)
#endif
```

- That means: all those “**f*()**” functions *memorize* whether the end of file is reached or not!
  - If yes, it just returns -1 (EOF)!
  - If no, it either reads data from the buffer or system calls.

- **Main point: No EOF character in any files!**

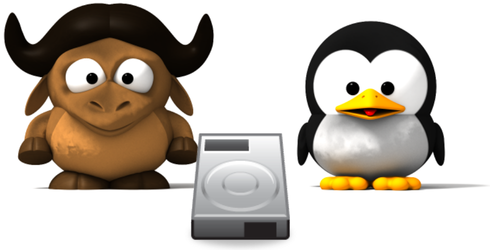
# Summary

- The GNU I/O library functions give you a lot of convenience:
  - Great functions: **`fscanf()`**, **`fprintf()`**

- Yet, this abstracts away many truths and introduces (not on purpose) mis-conceptions!
  - From now on, you should never said: "***An empty file has an EOF character at the end of the file!***"
  - Also, use ***`feof()`*** with great care!

## Looking at FS from the userspace

- GNU C Library call VS System call?
  - Buffered I/O and efficiency.
  - What is the true meaning of EOF?
- File and directory.
  - basics;



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# Attributes

- First, both files and directories are very similar:
  - They **both** have two kinds of data: **attributes** and **data**.
  - Attributes are as important as data:
    - Can you read the data correctly *without the size attribute*?

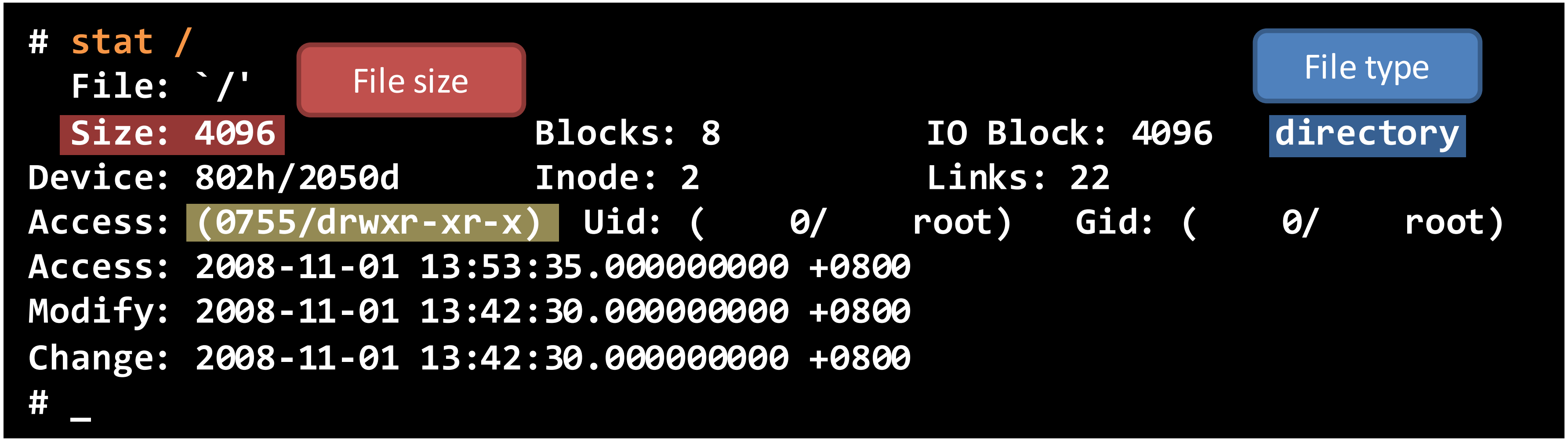
The design of FAT32 does not include any security ingredients.

| Common Attributes | FAT32 | NTFS | Ext2/3/4 |
|---|---|---|---|
| Name | ✓ | ✓ | ✓ |
| Size | ✓ | ✓ | ✓ |
| Permission | | ✓ | ✓ |
| Owner | | ✓ | ✓ |
| Access, creation, modification time | ✓ | ✓ | ✓ |

# Reading attributes

- The command is **stat**. You can find:
  - type, size, permission, etc.

- The system call counterpart includes:
  - **stat()**, **fstat()**, and **lstat()**.



```
# stat /
  File: `/'
  Size: 4096            Blocks: 8          IO Block: 4096   directory
Device: 802h/2050d      Inode: 2           Links: 22
Access: (0755/drwxr-xr-x)  Uid: (    0/    root)   Gid: (    0/    root)
Access: 2008-11-01 13:53:35.000000000 +0800
Modify: 2008-11-01 13:42:30.000000000 +0800
Change: 2008-11-01 13:42:30.000000000 +0800
# _
```

# Writing attributes?

- Can you change those attributes directly?

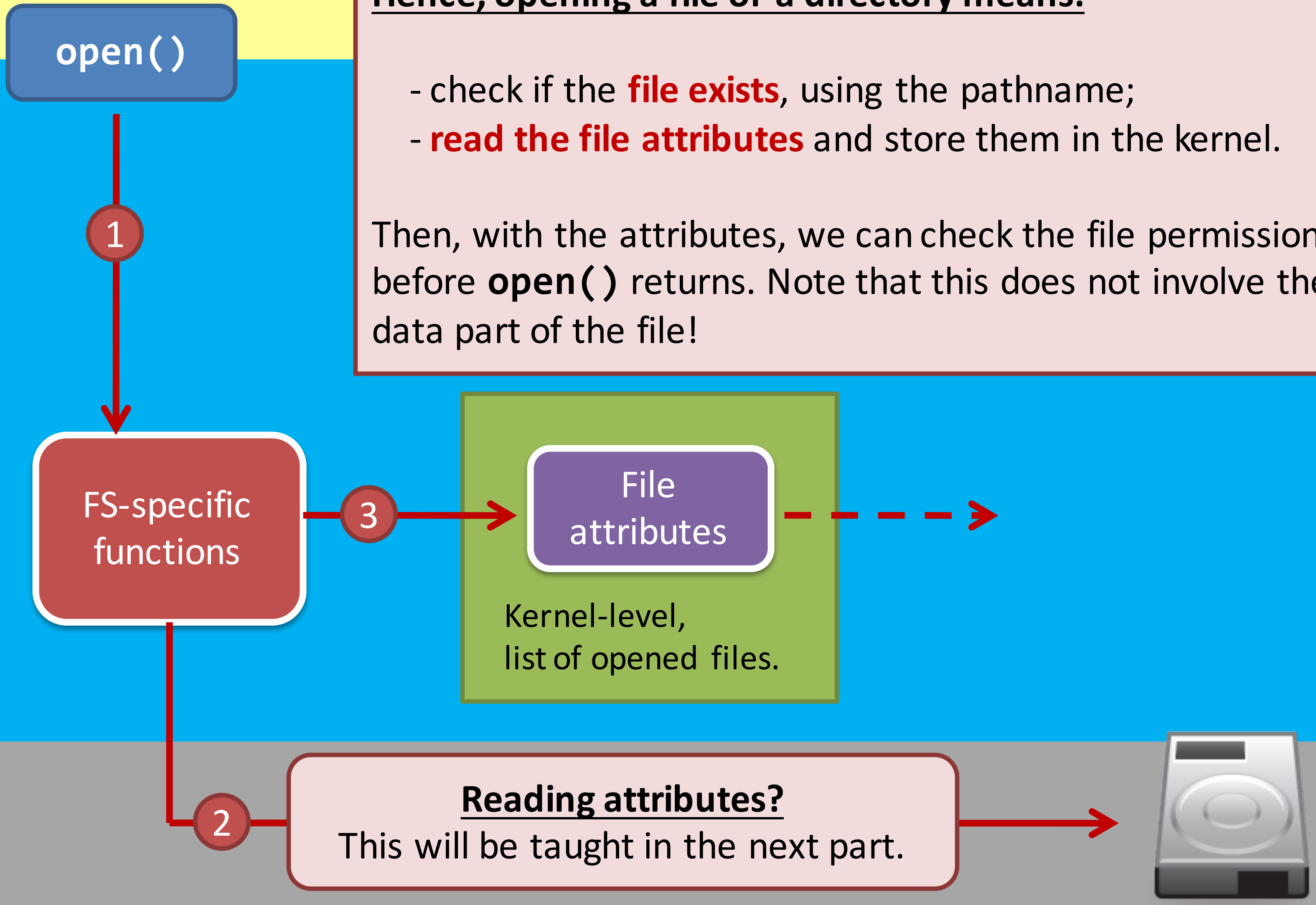
| Common Attributes | Way to change them? | |
|---|---|---|
| | Command? | Syscall? |
| **Name** | `mv` | `rename()` |
| **Size** | `Too many tools to update files’ contents` | `write(), truncate(), etc.` |
| **Permission** | `chmod` | `chmod()` |
| **Owner** | `chown` | `chown()` |
| **Access, creation, modification time** | `touch` | `utime()` |

# Still remember the flow of **open( )**?

**Hence, opening a file or a directory means:**

- check if the **file exists**, using the pathname;
- **read the file attributes** and store them in the kernel.

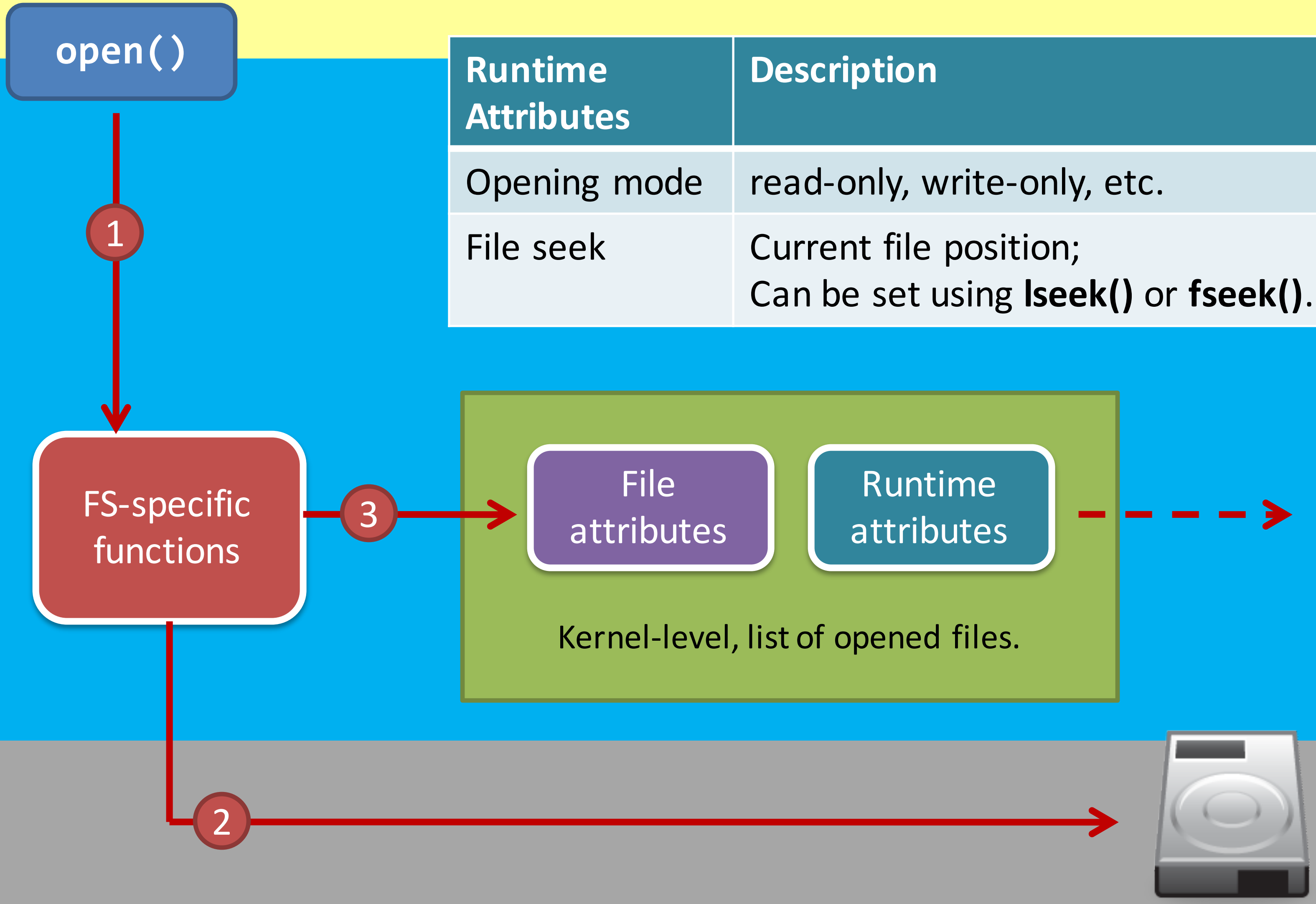
Then, with the attributes, we can check the file permission before **open( )** returns. Note that this does not involve the data part of the file!



**Reading attributes?**
This will be taught in the next part.

# Still remember the flow of **open( )**?

| **Runtime Attributes** | **Description** |
|---|---|
| Opening mode | read-only, write-only, etc. |
| File seek | Current file position;<br>Can be set using **lseek()** or **fseek()**. |



open( )

1

FS-specific functions

2

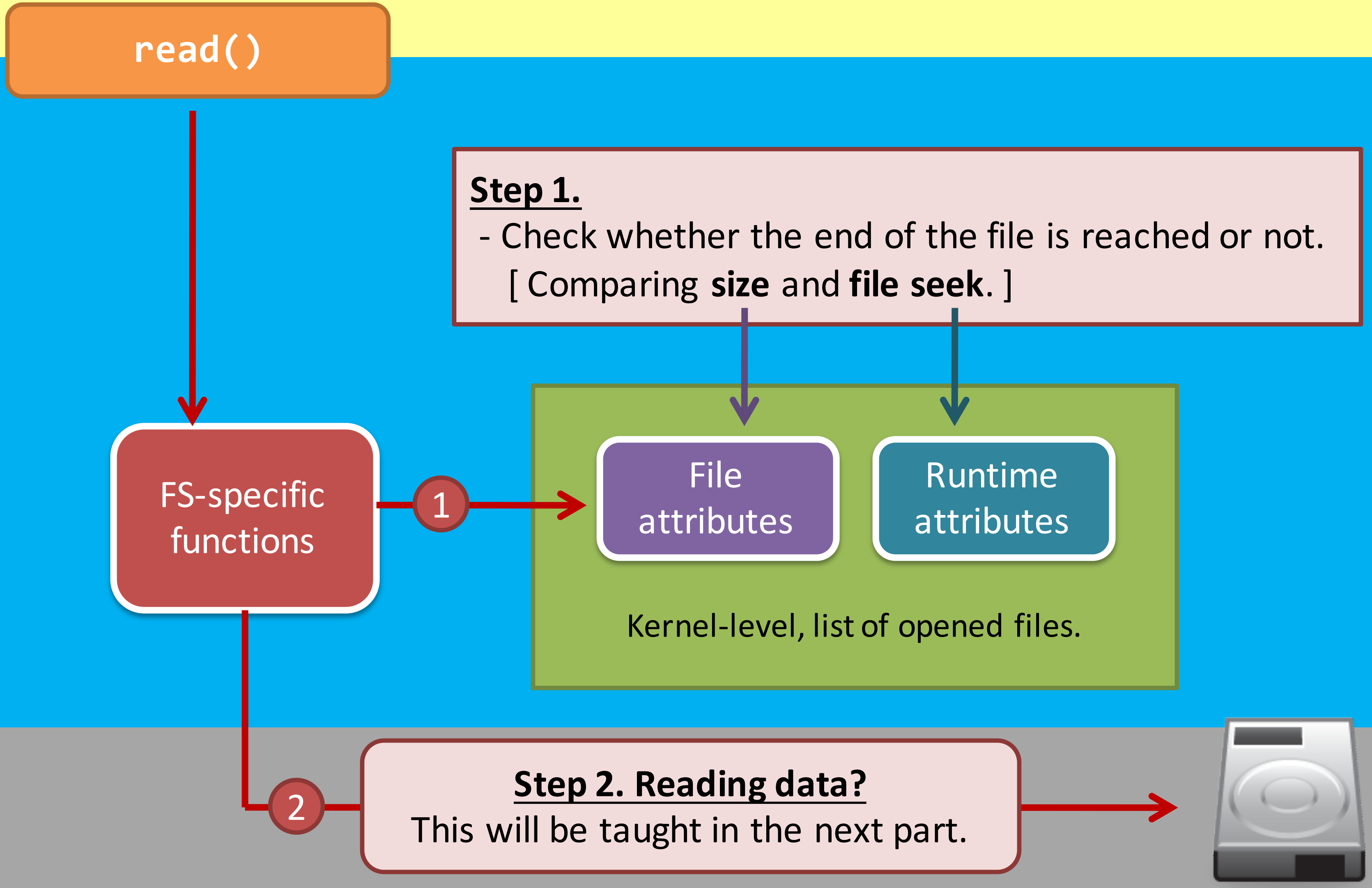
3

File attributes

Runtime attributes

Kernel-level, list of opened files.

# How about the **read()** system call?



**read()**

FS-specific functions

1

2

File attributes

Runtime attributes

Kernel-level, list of opened files.

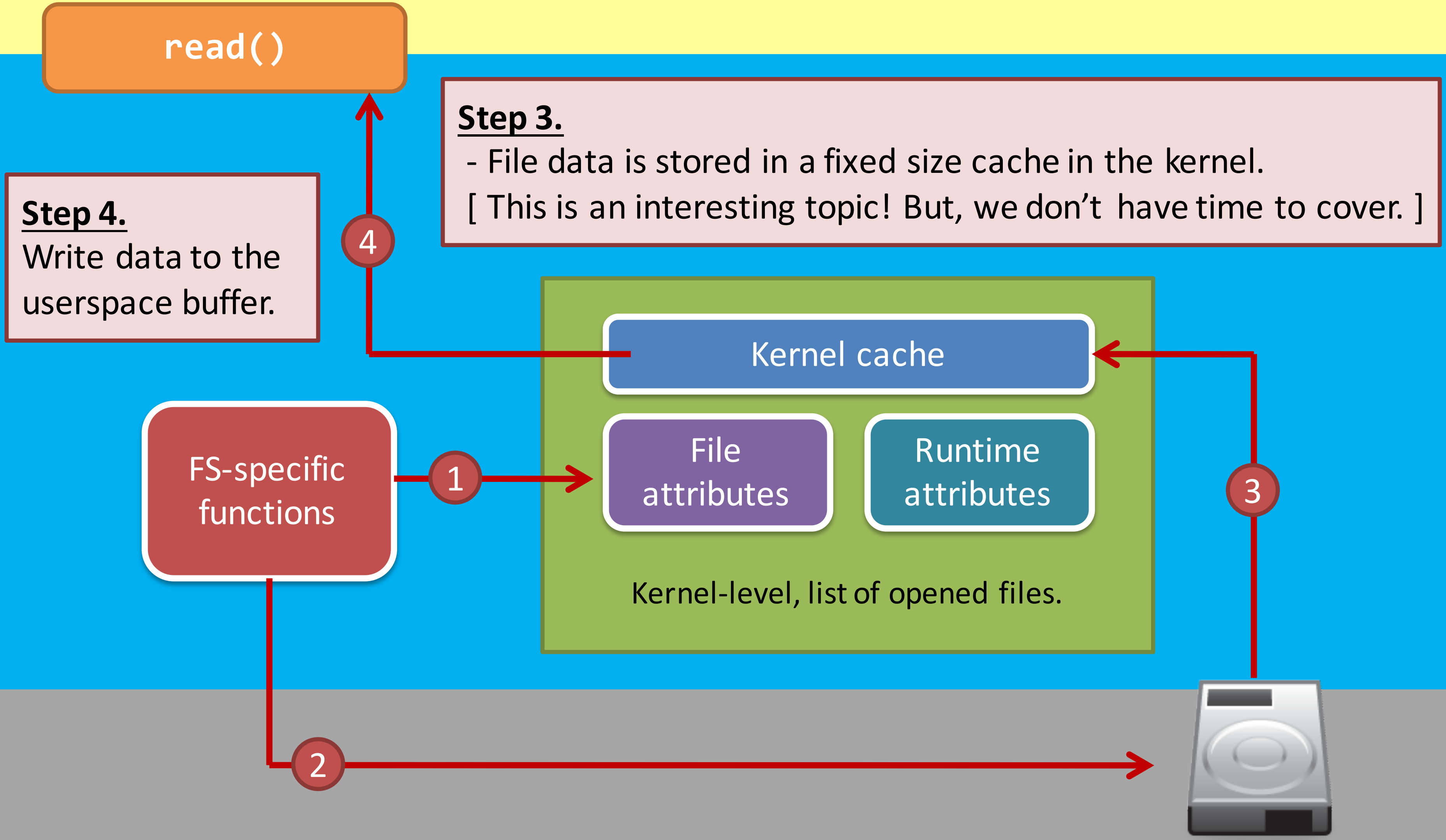
**Step 1.**

- Check whether the end of the file is reached or not.
  [ Comparing **size** and **file seek**. ]

**Step 2. Reading data?**

This will be taught in the next part.

# How about the **read()** system call?

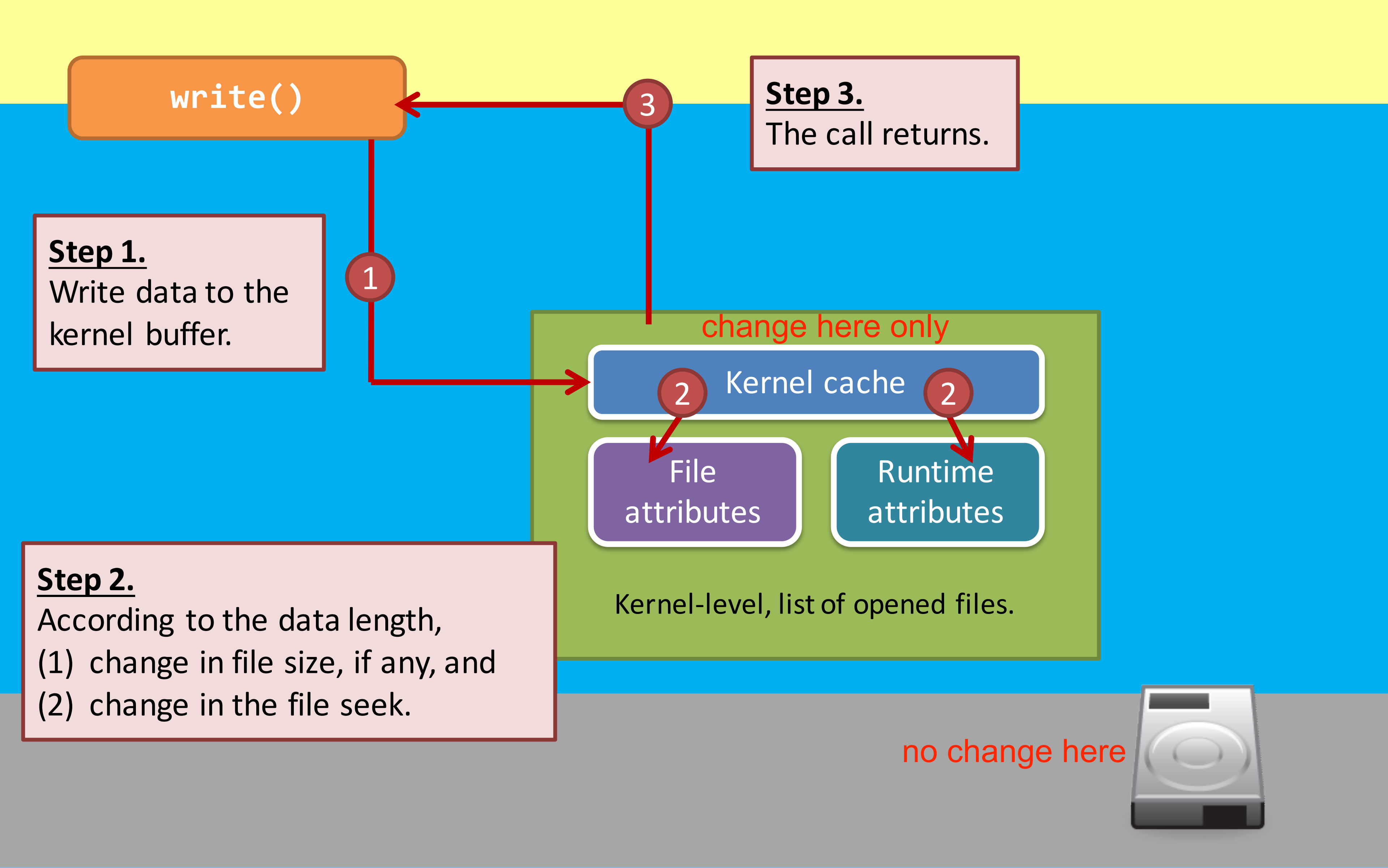


**Step 3.**
- File data is stored in a fixed size cache in the kernel.

[ This is an interesting topic! But, we don’t have time to cover. ]

**Step 4.**
Write data to the userspace buffer.

# How about the **write()** system call?

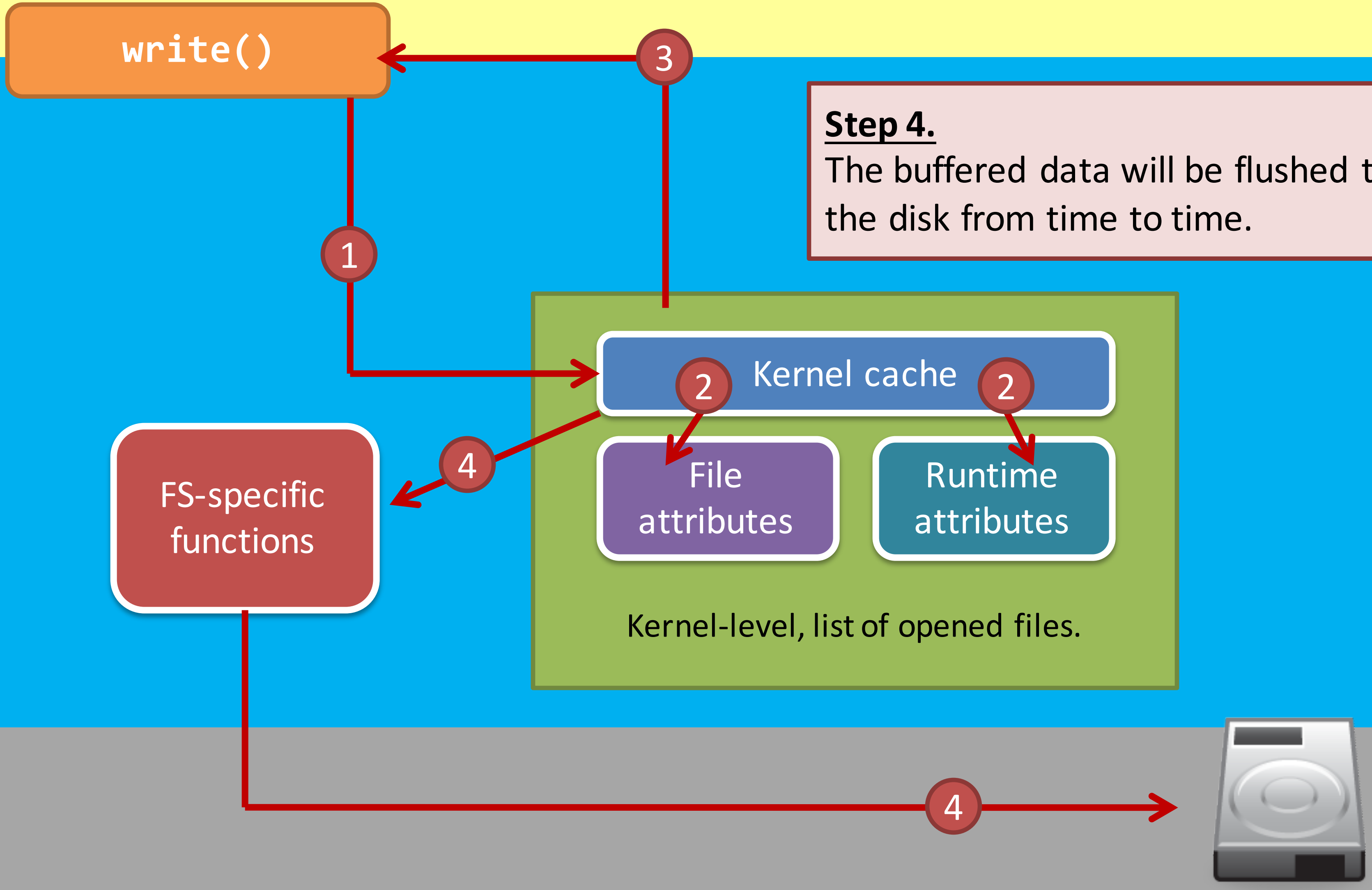


**Step 1.**
Write data to the kernel buffer.

**Step 2.**
According to the data length,
(1) change in file size, if any, and
(2) change in the file seek.

**Step 3.**
The call returns.

# How about the **`write()`** system call?



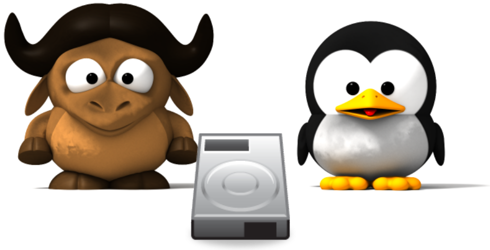
**Step 4.**
The buffered data will be flushed to the disk from time to time.

# The kernel buffer cache implies…

- Class Discussion!
  - Increase reading performance?
  - Increase writing performance?
  - Can you answer me why **you cannot press the reset button**?
  - Can you answer me **why you need to press the “eject” button before removing USB drives?**

## Looking at FS from the userspace

- GNU C Library call VS System call?
  - Buffered I/O and efficiency.
  - What is the true meaning of EOF?
- File and directory.
  - basics;
  - playing with directories.



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# Reading a directory

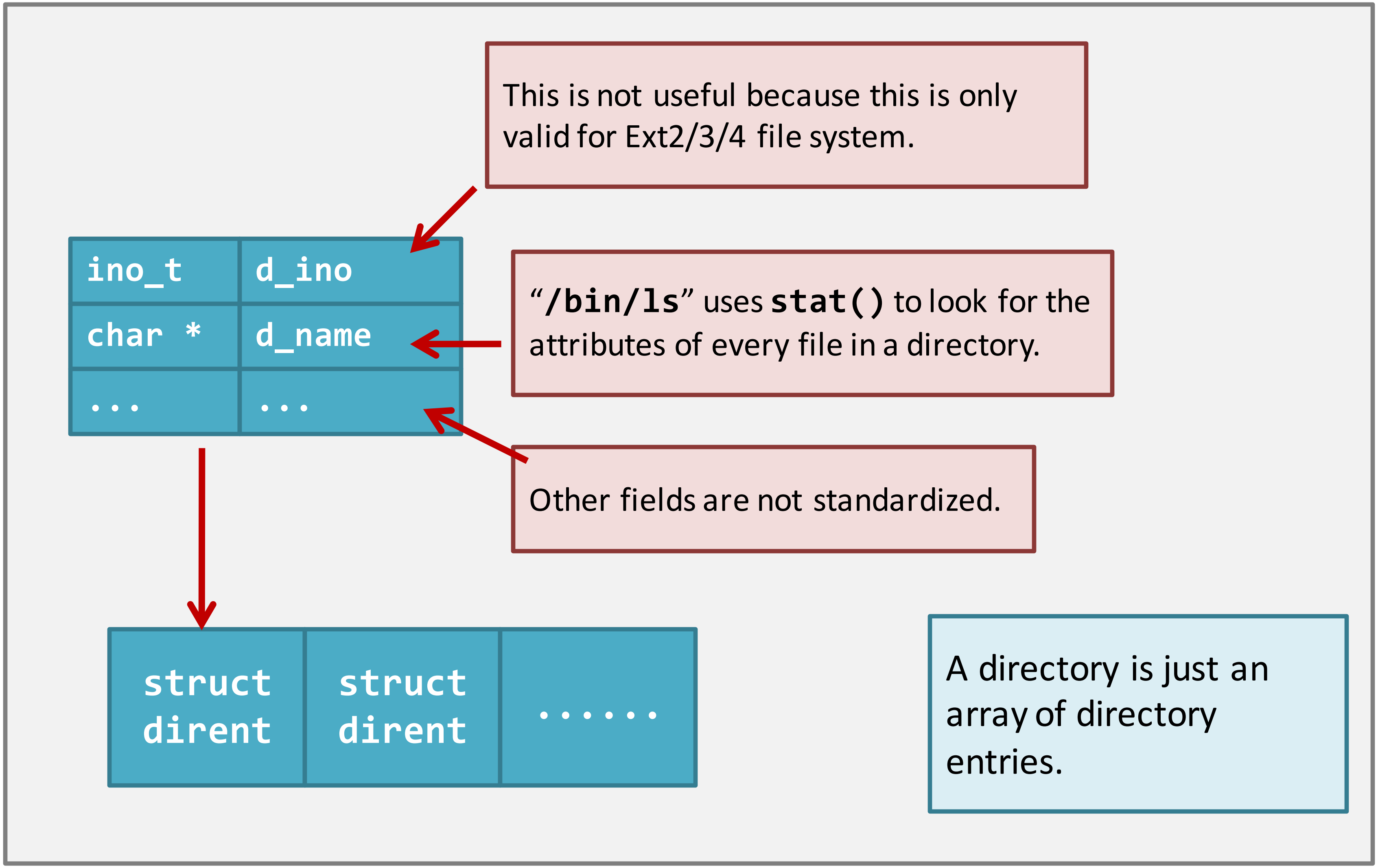
- Similarly, reading a directory also involves attributes and data.
  - – Yet, you don’t know how to play with in the userspace.

```
int main(int argc, char **argv) {
    DIR *dir;
    char *input = "/";
    struct dirent *entry;

    dir = opendir(input);                               // open
    while( (entry = readdir(dir)) != NULL ) {   // read
        printf("%ld\t\t%s\n",
                (long) entry->d_ino,   // unique ID
                entry->d_name);        // name, max char: 255
    }
    closedir(dir);                                      // close
}
```

```
[examples@3150] cat simple_ls.c
```

# Directory entries – read



| | |
|---|---|
| `ino_t` | `d_ino` |
| `char *` | `d_name` |
| `...` | `...` |

This is not useful because this is only valid for Ext2/3/4 file system.

"**`/bin/ls`**" uses **`stat()`** to look for the attributes of every file in a directory.

Other fields are not standardized.

| | | |
|---|---|---|
| `struct dirent` | `struct dirent` | `......` |

A directory is just an array of directory entries.

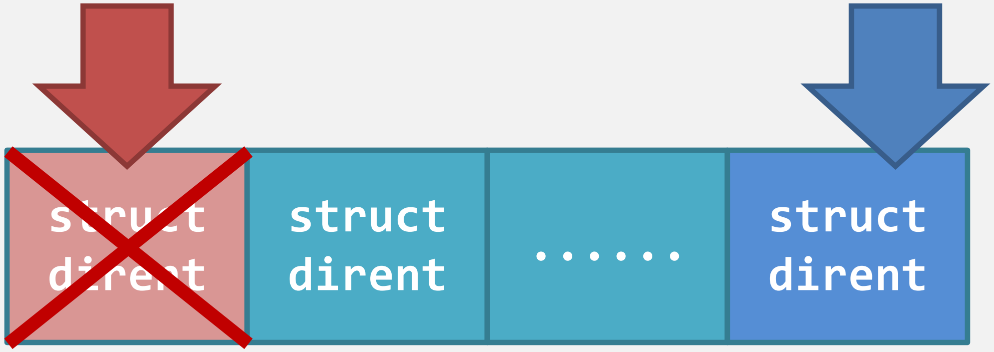
# Directory entries – write

Removing an existing file also means writing to a directory. But, the write operation is to erase something…

**The truth of file deletion**: the system **will not** remove the corresponding directory entry in hosting directory completely.

[What evil things can you think of?]

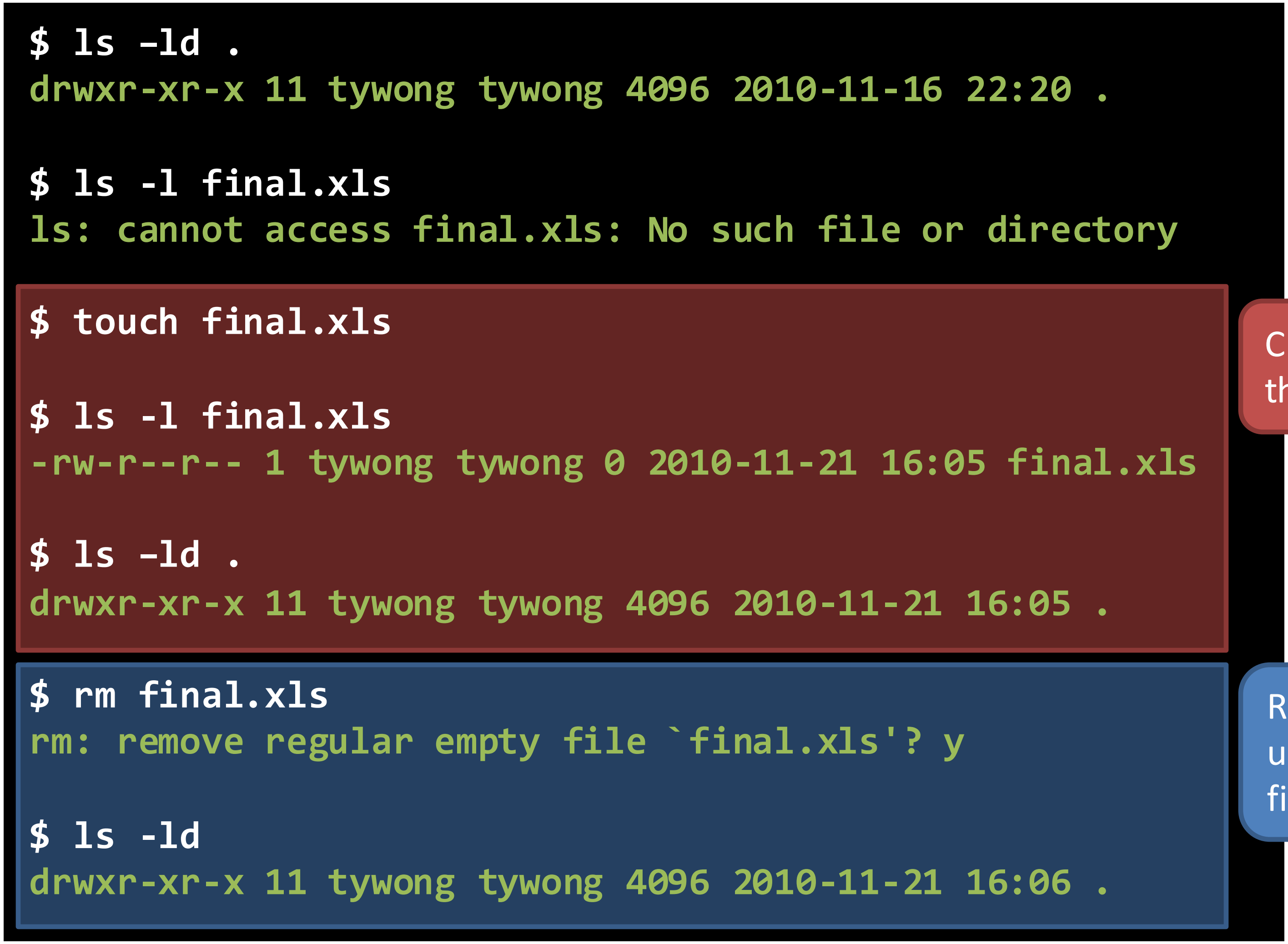
Add a new file to a directory means appending data to the directory file.



**This is a directory file**: it contains an array of directory entries.

# Directory entries – write

- Example screenshot.



```
$ ls -ld .
drwxr-xr-x 11 tywong tywong 4096 2010-11-16 22:20 .

$ ls -l final.xls
ls: cannot access final.xls: No such file or directory

$ touch final.xls

$ ls -l final.xls
-rw-r--r-- 1 tywong tywong 0 2010-11-21 16:05 final.xls

$ ls -ld .
drwxr-xr-x 11 tywong tywong 4096 2010-11-21 16:05 .

$ rm final.xls
rm: remove regular empty file `final.xls'? y

$ ls -ld
drwxr-xr-x 11 tywong tywong 4096 2010-11-21 16:06 .
```

Create a file updates the directory file.

Remove a file also updates the directory file.

# Summary

- Through this part, we learn:
  - the truth about the calls that we usually use,
  - the content of a file is not the only entity, but also the file attributes.

- In the next part, we will go into the disk:
  - How and where to store the file attributes?
  - How and where to store the data?
  - How to manage a disk?