Lecture 02 - The shell 🐚

ENSF461 - Applied Operating Systems

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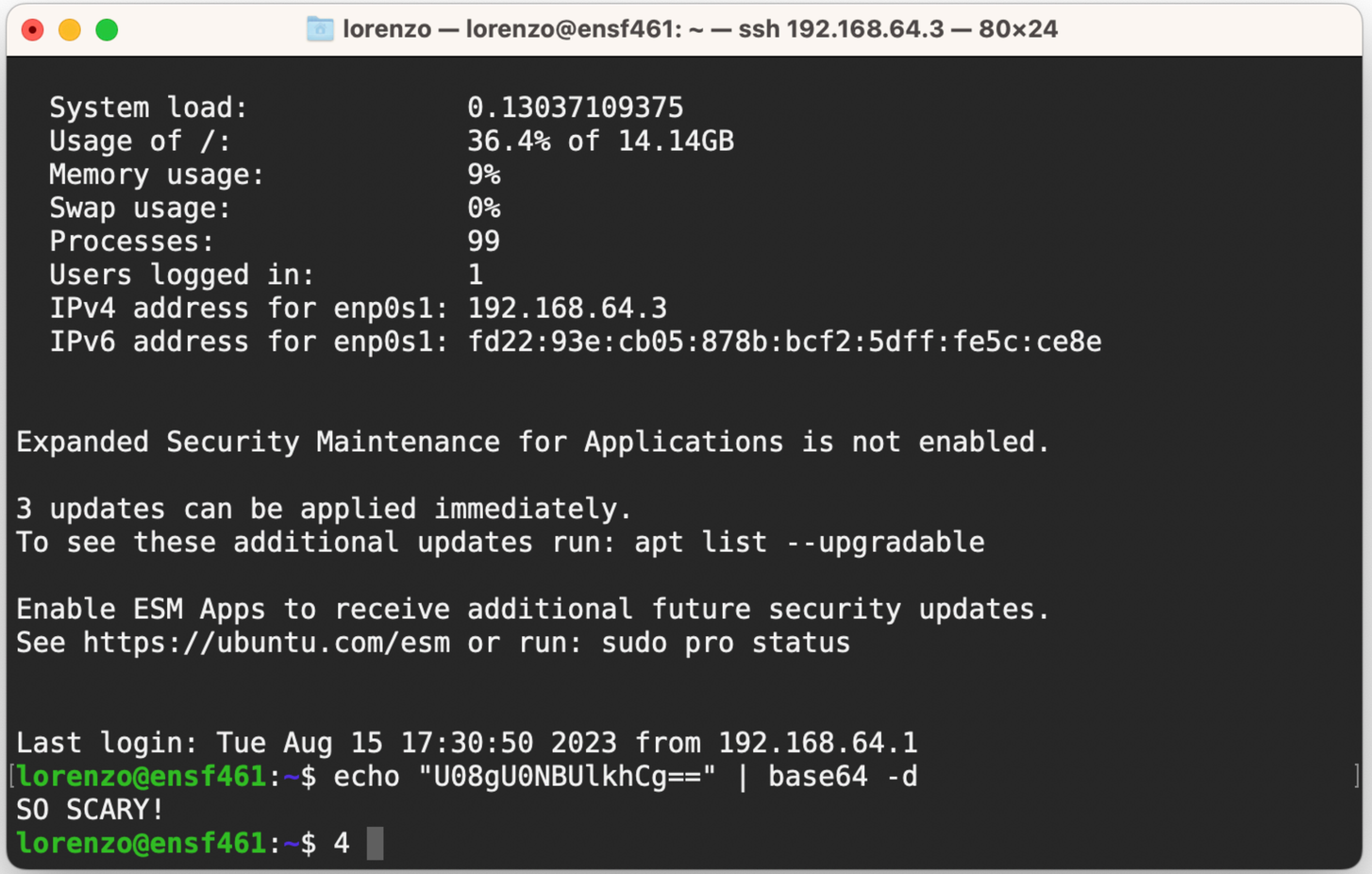
Slides by Lorenzo De Carli, partly based on material by Robert Walls (WPI)

What are we talking about today?

- The **command line**!
- A **mysterious interfaces** that **dark magicians** use to **control computers**
- Typically provided by a utility called a **shell**…
- Running in a **terminal**



No, seriously…

- Technically the way you interface to a OS is **irrelevant** to how it works
- In practice, however, a **low-level UI (command line)** is much more conducive to playing with **OS internals**
- Also, learning the command line is a **useful skill** in itself
  - Simplifies **system management**
  - Sometimes the **only UI available** (e.g., interfacing to remote server)

Important concepts

- The **structure** of the **command line**
- **Working directory**
- **Relative** vs. **absolute paths**.
  - The meaning of ./ or ../ in a path
- **Stdin** vs **Stdout** vs. **Stderr**

Yes, but what is a shell?

- A shell is a program that presents a **prompt** and waits for **text commands**
- **Commands** are typically the names of executable programs
- Most commonly, the shell finds the **program** indicated by the **command**, **executes it**, and **displays its output**
- **Note:** every time you see a line beginning with “**$**” in my slides, it means what follows is a shell command

More precisely…

- Users type **commands**, which correspond to files on the disk. Commands may include **arguments / parameters**
- These files are compiled programs (typically). They are often called **binaries**.
- Through a complicated set of actions, the OS loads the binary into memory and executes it.
- An executing program/binary is called **a process**.
- The OS stores metadata about each process, e.g., the **process ID (PID)**.
- **Command-line applications** often interact with each other and the user through files, e.g., file redirection, pipes, stdin, stdout, etc.
- Shells use **environment variables** to store configuration information, e.g., $PATH denotes where to look for binaries.

Common shells

- **sh:** Bourne Shell: the original UNIX shell, developed at Bell Labs in the 1970s
- **bash:** Bourne Again Shell: GNU project extension of sh (default in Linux)
- **zsh:** Z Shell: extended version of bash w/ different syntax (default in MacOS)

- In this course we are going to use **bash** (which is probably what you would use anyway in any situation where you need to interact with a shell)

Before we get to see these concepts in practice

Where to find examples used in class

- All **coding examples** seen in class will be uploaded at **`https://github.com/ldklab/ensf461F23`**
- You can clone the **git repository** by running the following command: **`git clone https://github.com/ldklab/ensf461F23.git`**
- If you are not sure what do, don’t worry just yet! In **lab 1** (September 7th) we will show you how to build **your own virtual machine** to build/execute code

Let’s see those concepts in action

Don’t worry if you don’t yet understand all the details!

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- Example 1: running a program (**`ex01_basicprogram.c`**)

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- Example 2: command line arguments (**`ex02_parameters.c`**)

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- Example 1: running a program (**`ex01_basicprogram.c`**)
- Example 2: command line arguments (**`ex02_parameters.c`**)
- Example 3: process id aka PID (**`ex03_pid.c`**)

This is a good time…

… to introduce the concept of **working directory**

- How does the shell knows **where to find programs**?
- Well, before we get to that we need to introduce the concept of **environment variable**

What is an environment variable?

- A shell maintain some **metadata** that **alter its functioning**, or that of the programs that are executed
- This metadata is stored as **key-value pairs**:

```
VAR1_NAME = VAR1_VALUE
VAR2_NAME = VAR2_VALUE
…
```

- Each key-value pair represents a **variable** and its **value**
- Variables can be **read and/or modified** by the shell, programs, or the user

An example: PATH

The most important variable of all! 👑

- PATH tells the shell in which folders it should look for programs
- We can check its content with the echo command:
  - Let's try `$ echo $PATH`

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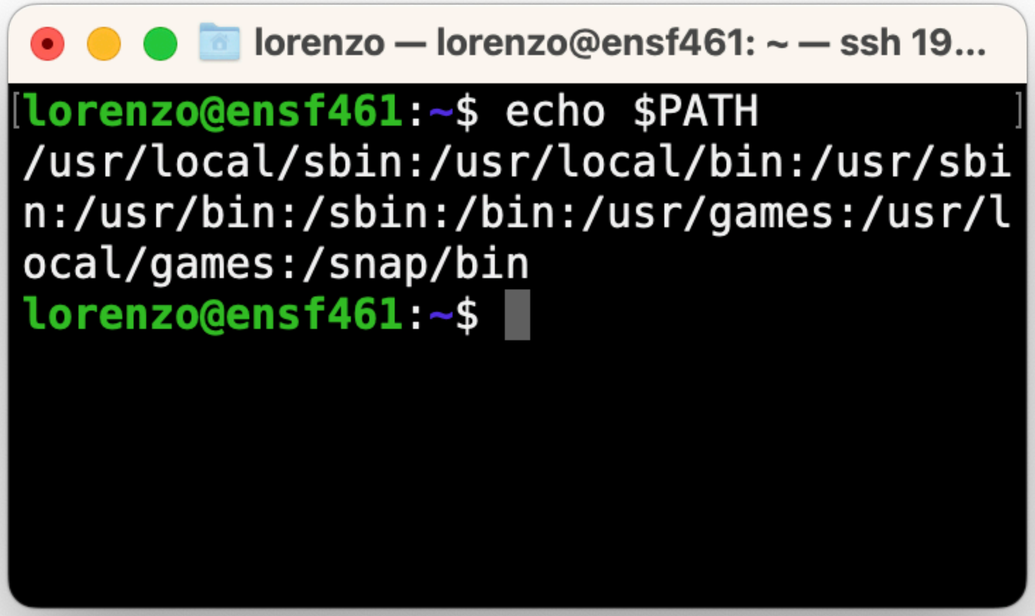

What if…

my program is not in one of the folders in PATH?

- Well, one option would be to add your folder to PATH:
  `$ PATH=$PATH:/path/to/my/folder`
- This is **very bad** and **thou shall never do it**! 😱☠️
- Why?
  - **Confusing:** you end up not knowing from where you are executing
  - **Bad for security**: you are not executing the program you think you are

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Incidentally, this is how you **set** an environmental variable

Well, what do I do then?

- The shell provides a **syntax** to express **“run a program from the current working directory”**
- But what does the above mean?

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- The shell provides a **syntax** to express **“run a program from the current working directory”**
- But what does the above mean?
- **Any idea?**

Working directory

- The **command line** is different from the typical graphical UI
- Actions depend on the **context** where they are run…
- …where context mostly means a **location (directory)** in the **file system**

Working directory/2

- Bash (and other shells) offer a **shorthand** for “run a command from the current working directory”
- Simply **prepend** the name of the command with “**`./`**“
- E.g. “**`$ ./mycmd`**” will look for a program called **`mycmd`** in the current directory and run it
- Print current working directory: **`$ pwd`**
- Change working directory: **`$ cd path/to/new/working/directory`**

Working directory/3

- **Physical analogy:** image that you are the **shell** and I hand you a list of **instructions** to execute.
- **One of those instructions says:** turn around and grab the book labeled “Algorithm Design” from the bookshelf.
- If you are executing those instructions **in my office**, then you will have no problems. But if you execute **in a classroom** then **there is no book to grab**.

```
1 #!/bin/bash
2
3 echo "Currently in: `pwd`"
4 cat meow.txt
```

Working directory/3

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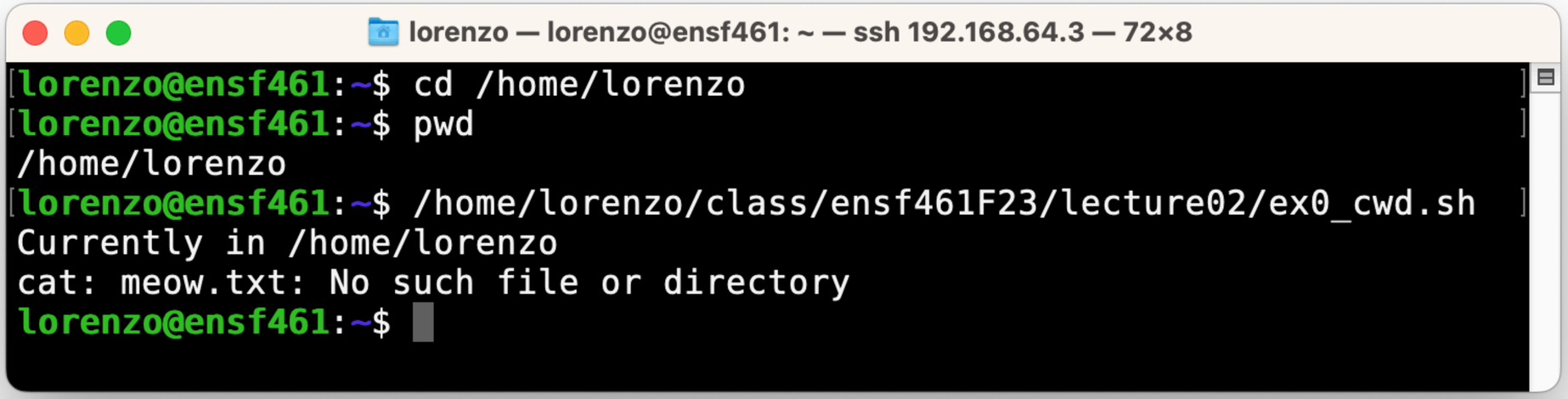
Incidentally, this is a **shell script** (more on this later)

Let’s try to execute this script in different folders

Working directory/4

- You can run a command in **any directory** by specifying the **full path**
- Keep in mind, however, that the working directory is going to be **the one active at the moment** (i.e., the one returned by **pwd**)



Working directory/5

A final note

- Directories are (as you know) hierarchical
- You can use "**../**" to refer to the parent directory of the one you are currently in
- Examples:
  - **`$ cd ../`** → change the current working directory to the parent
  - **`$ ../myprog`** → executes **`myprog`** in the parent directory

And that’s the end of the detour!

…now you know what is a working directory

Let’s take a break and take a quiz

Navigate to D2L->Quizzes->Quiz 2

More examples

Interaction between programs

- **Example:** the **`/dev`** folder contains a number of files. Count how many file names contain the string “tty”
- **Solution:** **`$ ls -1 /dev | grep tty | wc -l`**
- What’s happening here?
  - **`ls -1 /dev`** lists all files in /dev in a single column of text
  - **`grep tty`** lists all the lines that contain the string “tty”
  - **`wc -l`** counts the number of lines in the output

What's this "|" business?

- The "**|**" symbol represents a pipe operand
- An expression of the form "**`cmd1 | cmd2`**" means:
  - Execute the **`cmd1`** program
  - Take its output
  - Feed it as input to the **`cmd2`** program
  - **Let's get to the bottom of this**

Standard what?

A primer on UNIX file access

- In a UNIX-like system (like Linux), programs can **open**, **read**, and **write** files
  - **Duh!**
- They can also open **things that look like files**, but are not files
- The most common examples of this concept are:
  - Standard input (**stdin**)
  - Standard output (**stdout**)
  - Standard error (**stderr**)

Say what?

- In a UNIX-like system, whenever a program starts it automatically opens **three file-like object**
- **Standard output:** an output stream which by is printed on the terminal
  - By convention, used for **regular output**
- **Standard error:** like standard input, but used for error messages
- **Standard input:** an input stream which receives input from the terminal

What does this mean in practice

- Suppose you write a C program. When you run it, **you already have three “files” opened** that you can use to **receive input** and **emit output**
  - Those are not really files though - the **inputs** and **outputs** happen through **the terminal**

Who remembers how to write to a file in C?

Who remembers how to write to a file in C?

lorenzo — lorenzo@ensf461: ~/class/ensf461F23/lecture02 — ssh 192.168.64.3 — 19

```
WRITE(2)                                                    Linux Programmer's Manual

NAME
       write - write to a file descriptor

SYNOPSIS
       #include <unistd.h>

       ssize_t write(int fd, const void *buf, size_t count);

DESCRIPTION
       write() writes up to count bytes from the buffer starting at buf to the file referred to by the file descriptor fd.
```

Let’s see an example

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```c
int main() {
    // Preparing the messages
    const char* out = "Hello, ENSF461!\n";
    const ssize_t out_l = strlen(out);
    const char* err = "Error, ENSF461!\n";
    const ssize_t err_l = strlen(err);

    // Let's write to the standard output
    write(1, out, out_l);

    // Let's write to the standard error
    write(2, err, err_l);

    return 0;
}
```

Let’s talk about what just happened

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Initialize strings,
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Initialize strings, compute their length

Write to file descriptor 1

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}
```

Initialize strings, compute their length

Write to file descriptor 1

Write to file descriptor 2

A few considerations

- The file descriptors 1 and 2 are **already defined at program startup**
  - No need to **open them**!
- There is **nothing special** about “output” or “error”
  - **By convention**, we send **regular output** to **stdout** and **errors** to **stderr**

What about standard input?

What do you think I should do to access it?

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```c
#include <unistd.h>
#include <string.h>

int main() {
    char inputbuf[1024];
    ssize_t bytesread;

    bytesread = read(0, inputbuf, sizeof(inputbuf));
    if ( bytesread < 1 )
        return -1;

    write(1, inputbuf, strlen(inputbuf)-1);
    return 0;
}
```

What about standard input?

What do you think I should do to access it?

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#include <unistd.h>
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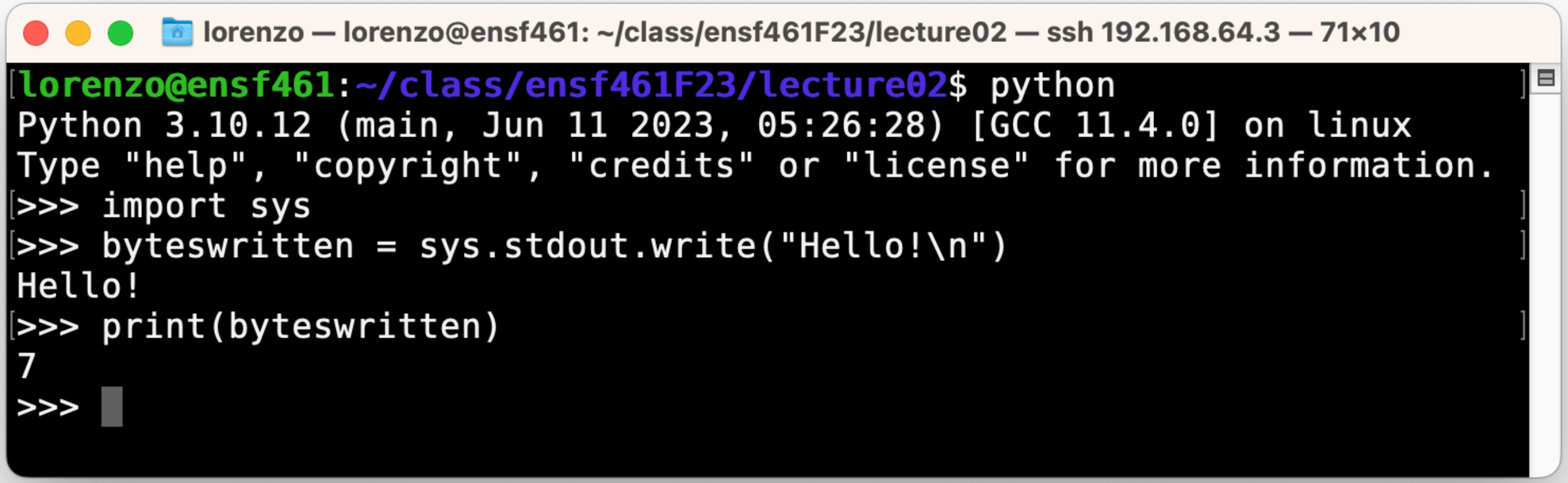
```

Reads at most `sizeof(inputbuf)` bytes

Aside: works in Python too!

…you just need to know the syntax



Piping, again

- UNIX-like operating systems (Linux, MacOS) come with a large number of standard **command-line utilities** preinstalled
- We have already seen some examples:
  - **`grep`**: search for a string in each line of input
  - **`wc`**: counts the number of characters/words/lines in the input
- Unless specified, these **read from standard input** and **output to standard output**

Piping, again /2

Let’s break down the example we saw earlier

```
$ ls -1 /dev | grep tty | wc -l
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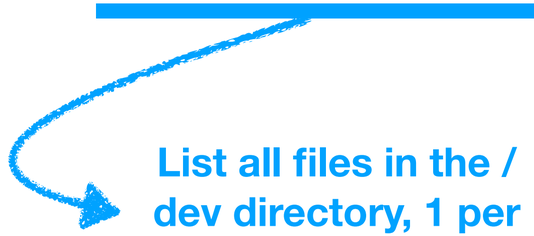

List all files in the /dev directory, 1 per line ("-1" command line parameter)

Piping, again /2

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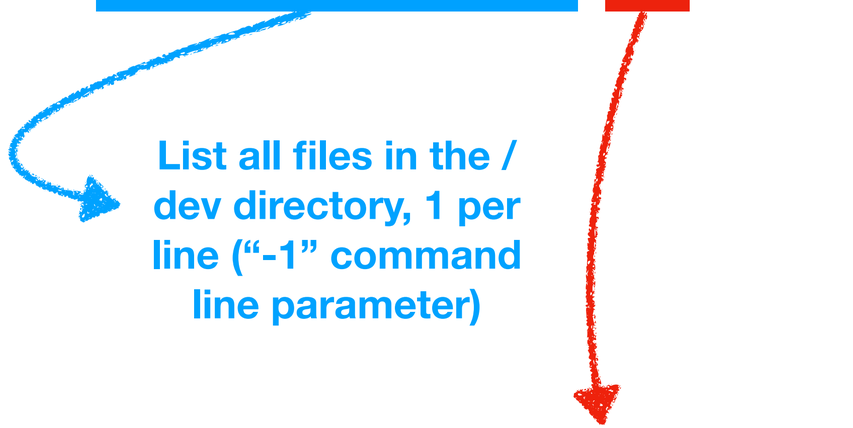

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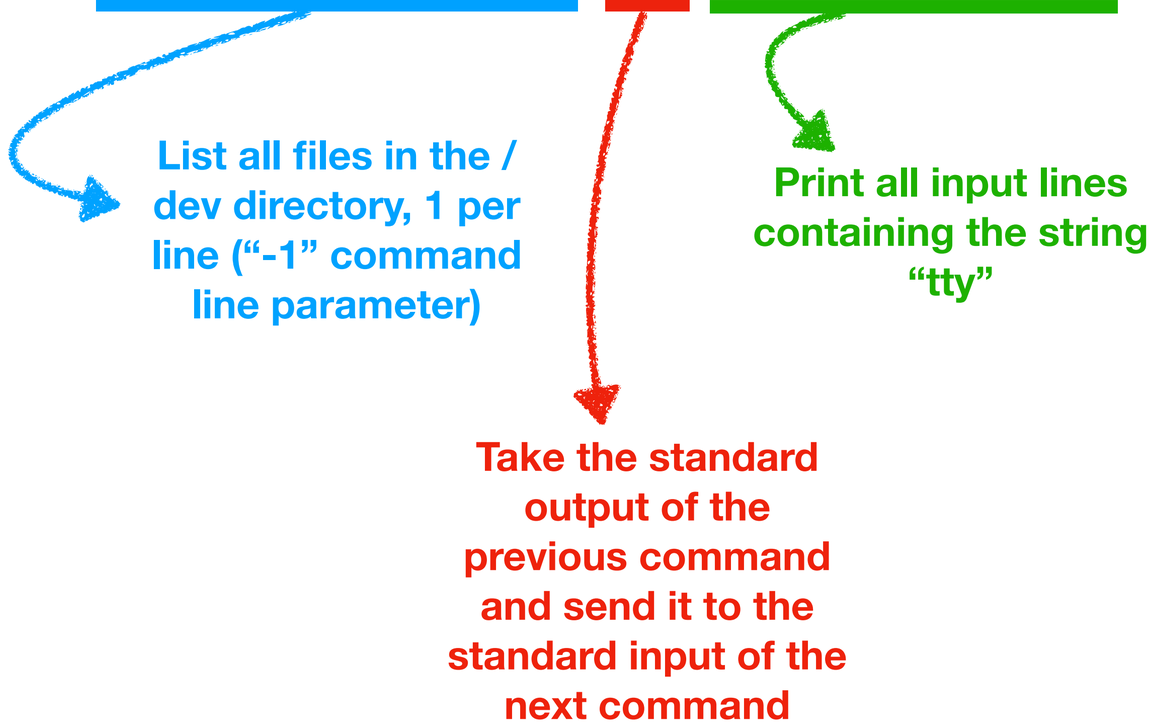

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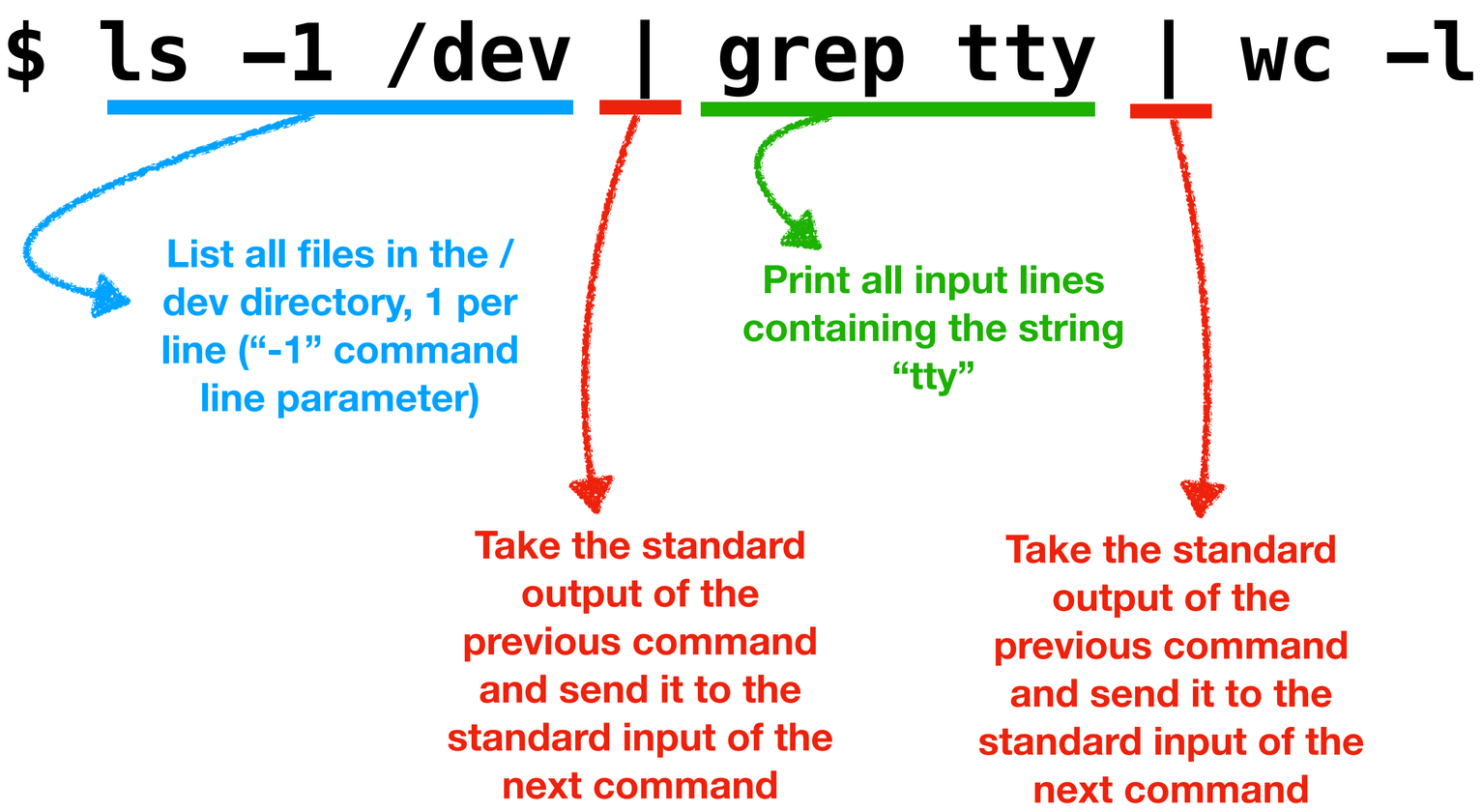

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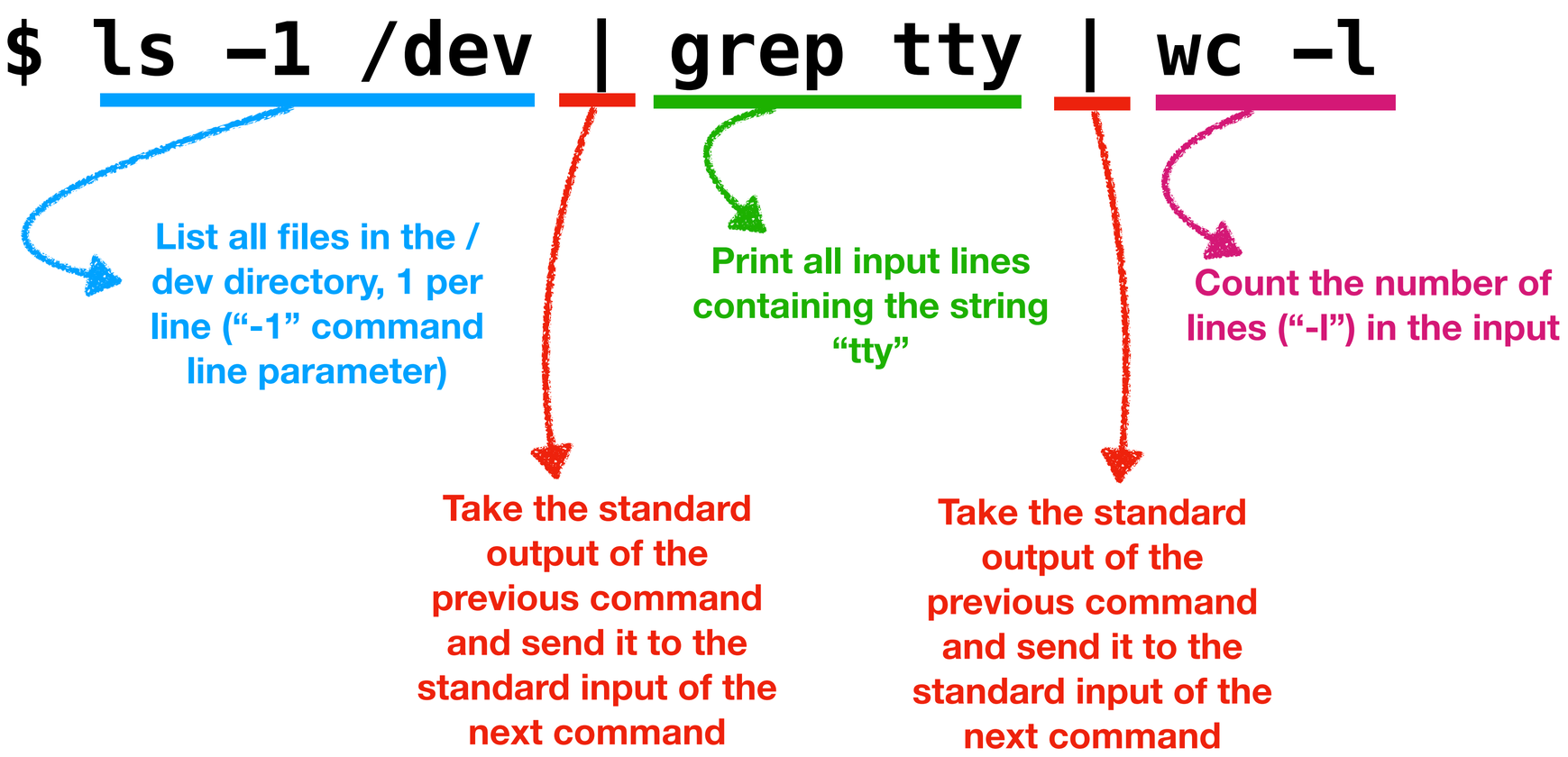

Redirecting standard input/error

- The shell can also **redirect** the **standard output/error** of a command to **file**
- …or even **redirect the standard output to error** (and **vice versa)**
- Useful to **save the output** of a chain of commands to a **file**
- **Let’s see how to do it**

Redirecting to file

- **`command > filename`**: save standard output to a new file **`filename`**
- **`command 2> filename`**: save standard error to a new file **`filename`**
  - If **`filename`** already exists, the commands above delete its entire content
- To avoid, use “**`>>`**” and “**`2>>`**” (append)
  - Example: **`command >> filename 2>> filename`**

Be careful!

- Something like **`command > outfile 2> outfile`** most likely **does not do what you want**

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- **Can you tell me what is the issue?**

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- Something like **`command > outfile 2> outfile`** most likely **does not do what you want**
- **Can you tell me what is the issue?**
- If command generates both standard output and error, the first to be generated will **erase the other one**

More redirection

- You can **redirect** the **standard error** to the **standard output** with “**2>&1**”
- You can **redirect** the **standard output** to the **standard error** with “**1>&2**”
- Remember, **stdout** is **file descriptor 1**, and **stderr** is **file descriptor 2**

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- **Who can tell me what this does?**

```
command 2>&1 > output.txt
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- Remember, **stdout** is **file descriptor 1**, and **stderr** is **file descriptor 2**
- **Who can tell me what this does?**
  ```
  command 2>&1 > output.txt
  ```
- (Redirects the **standard error** to the **standard output**, then redirects the **standard output** to a **file** named “output.txt”)

That’s all for today!