CS 241: Systems Programming
Lecture 3. More Shell

Spring 2025

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Friday Review - Intro to Unix/Shell

- Relative vs absolute paths
- Bash commands
- Man pages

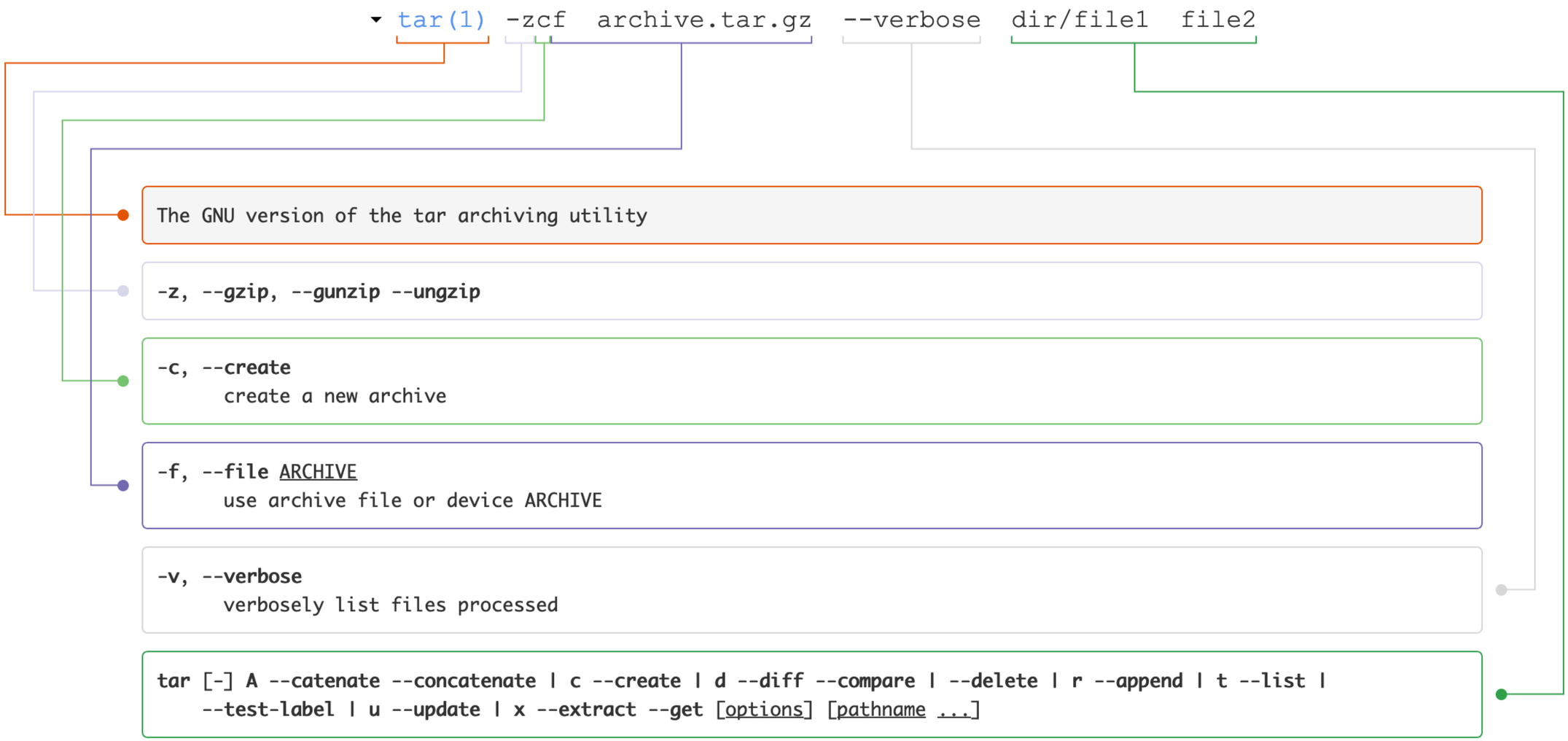
Anatomy of a single command

⟨command⟩ ⟨options⟩ ⟨arguments⟩

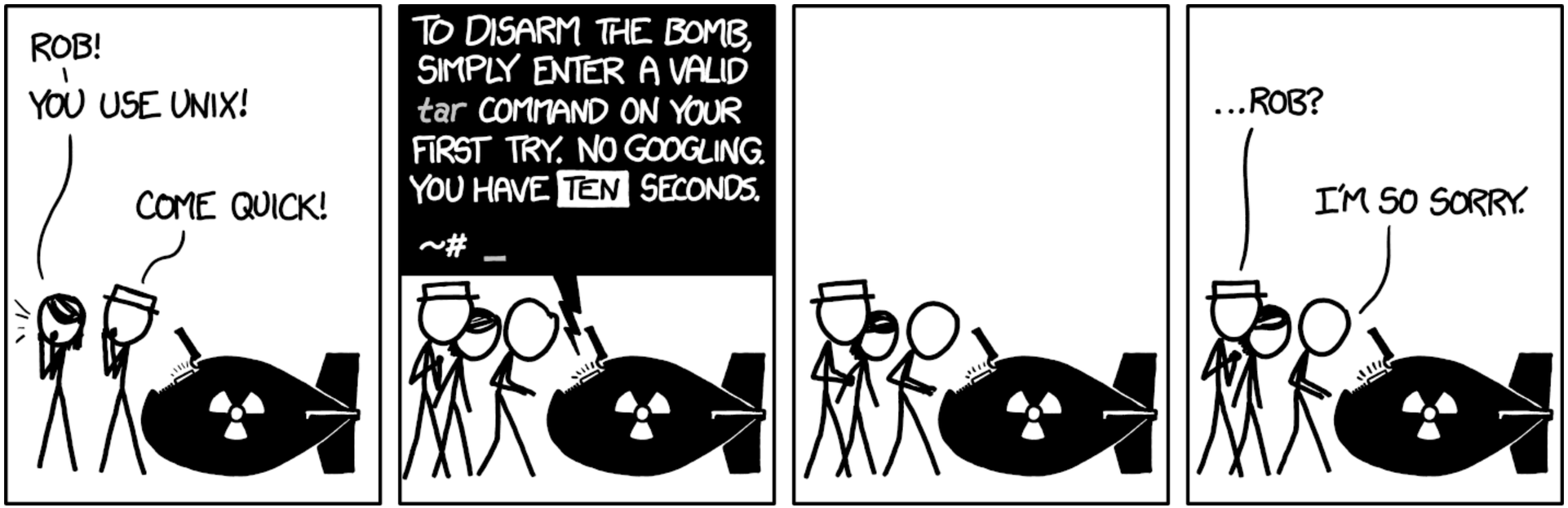
- ⟨command⟩ is the name of a command or a path to a program
- ⟨options⟩ are directives to the command to control its behavior
  - Short options are a hyphen and a letter: `-h`
  - Long options are (usually) two hyphens and multiple letters: `--help`
  - Multiple short options can be combined `-a -b -c` is the same as `-abc`
  - Options can take arguments: `-o file.txt` or `--output=file.txt`
- ⟨arguments⟩ are the things the command acts on
  - Often file paths or server names or URLs
  - When no arguments are given (or a single `-`), many commands read stdin

Example: `tar -zcf archive.tar.gz --verbose dir/file1 file2`

Example meaning



Click to go to explainshell.com



https://xkcd.com/1168

Shell commands

Shell builtins

- Functionality built into bash (all listed in the manual)
- E.g., `cd`, `alias`, `echo`, `pwd`

Shell functions

- User-defined functions (we'll get to these later)

Aliases

- E.g., `alias ls='ls --color=auto'`

Programs stored on the file system

- `/bin`, `/usr/bin`, `/usr/local/bin`, `/sbin`, `/usr/sbin`
- E.g., `ssh`, `cat`, `ls`, `rm`

Performing repetitive tasks

Setup: You have a project directory containing some source code, some data, and a README.

```
project
├── README.md
├── a.csv
├── b.csv
├── c.csv
├── d.csv
└── process.py
```

```
project
├── README.md
├── data
│   ├── a.csv
│   ├── b.csv
│   ├── c.csv
│   └── d.csv
└── process.py
```

You want to reorganize the project by moving all of the CSV files into a new data directory

A suboptimal approach

We can create the new data directory easily

```
$ cd project
$ mkdir data
```

Moving all of the files is really repetitive

```
$ mv a.csv data
$ mv b.csv data
$ mv c.csv data
$ mv d.csv data
```

Even this is repetitive: `$ mv a.csv b.csv c.csv d.csv data`

A better approach: globbing

```
$ mv *.csv data
```

The *.csv isn’t handled by the mv command, but by bash itself

*.csv will be replaced with a (space separated) list of files that in the directory that end with .csv

In other words, that command becomes the following before it is executed

```
$ mv a.csv b.csv c.csv d.csv data
```

Pathname expansion/globbing

Bash performs pathname expansion via pattern matching (a.k.a. globbing) on each unquoted word containing a wild card

Wild cards: `*`, `?`, `[`

- `*` matches zero or more characters
- `?` matches any one character
- `[…]` matches any single character between the brackets, e.g., `[atz]`
- `[!…]` or `[^…]` matches any character not between the brackets
- `[x-y]` matches any character in the range, e.g., `[a-f]`

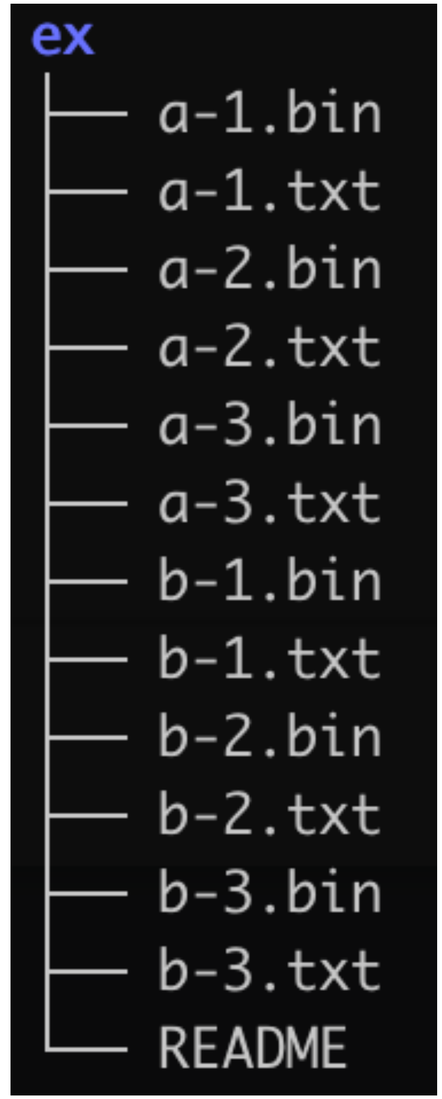
Example

```
$ ls ex/*.txt
ex/a-1.txt  ex/a-2.txt  ex/a-3.txt  ex/b-1.txt
ex/b-2.txt  ex/b-3.txt

$ ls ex/?-3.*
ex/a-3.bin  ex/a-3.txt  ex/b-3.bin  ex/b-3.txt

$ ls ex/[^acd]-[0-9].b*in
ex/b-1.bin  ex/b-2.bin  ex/b-3.bin

$ ls "ex/*"
ls: cannot access 'ex/*': No such file or
directory
```



```
CP(1)                          User Commands                          CP(1)

NAME
       cp - copy files and directories

SYNOPSIS
       cp [OPTION]... [-T] SOURCE DEST
       cp [OPTION]... SOURCE... DIRECTORY
       cp [OPTION]... -t DIRECTORY SOURCE...

DESCRIPTION
       Copy SOURCE to DEST, or multiple SOURCE(s) to DIRECTORY.
```

Which command copies all Rust source files (those whose names end in `.rs`) from the directory `a/b` to the directory `/tmp`?

A. `$ cp a/b/[a-z].rs  /tmp`

B. `$ cp a/*/*.rs  /tmp`

C. `$ cp a/b/*.rs  /tmp`

D. `$ cp a/b/?.rs  /tmp`

E. `$ cp a/b  /tmp  *.rs`

Typical Unix tool behavior

```
$ program
```

- reads from stdin, writes to stdout

```
$ program file1 file2 file3
```

- runs ‘program’ on the 3 files, write to stdout

```
$ program -
```

- For programs that require filenames, might read from stdin

Standard input/output/error

Every running program has (by default) 3 open "files" referred to by their file descriptor number

Input comes from stdin (file descriptor 0)

- `input()` # Python: Read a line
- `System.in.read(var)` // Java: Read bytes and store in `var` array
- `$ IFS= read -r var` # Read a line and store in `var` variable

Standard input/output/error

Normal output goes to stdout (file descriptor 1)

- `print(var)` # Python
- `System.out.println(var)` // Java
- `$ echo "${var}"` # Bash

Error messages traditionally go to stderr (file descriptor 2)

- `print(var, file=sys.stderr)` # Python
- `System.err.println(var)` // Java
- `$ echo "${var}" >&2` # Bash

Standard input/output/error redirection

By default, text written to stdout and stderr both appears on the console

We can control this behavior by **redirecting** one or both of stdout and stderr

Input to a program is read from stdin

By default stdin is connected to the console and characters we type are the input

We can control this behavior by **redirecting** stdin

Redirection

`>file` — redirect standard output (stdout) to `file` with truncation

`>>file` — redirect stdout to `file`, but append

`<file` — redirect input (stdin) to come from `file`

`|` — connect stdout from left to stdin on right

- `$ ls | wc`

`2>file` — redirect standard error (stderr) to `file` with truncation

`2>&1` — redirect stderr to stdout

Redirection examples

```
$ echo 'Hi!' >output.txt
$ cat <input.txt
$ sort <input.txt >output.txt
$ ps -ax | grep bash
$ grep hello file | sort | uniq -c
$ echo Hello | cut -c 1-4 >>result.txt
$ ./process <input | tail -n 4 >output
```

(Almost) everything is a file

Files on the file system

Network sockets (for communicating with remote computers, e.g., web browsers, ssh, mail clients etc.)

Terminal I/O

A bunch of special files

- `/dev/null` — Writes are ignored, reads return end-of-file (EOF)
- `/dev/zero` — Writes are ignored, reads return arbitrarily many 0 bytes
- `/dev/urandom` — Reads return arbitrarily many (pseudo) random bytes

Given that `/dev/null` ignores all data written to it, how can we run the program `foo` and redirect stderr so no error messages appear in our terminal but we continue to see normal output on stdout?

A. `$ foo >/dev/null`

B. `$ foo 1>/dev/null`

C. `$ foo 2>/dev/null`

D. `$ foo | /dev/null`

E. `$ foo &2>/dev/null`

Some programs read all of their input on stdin before terminating. If `foo` is such a program, how can we run `foo` such that it has no input at all? (`foo` is just an example, not a real program.)

A. `$ foo </dev/null`

B. `$ foo </dev/zero`

C. `$ foo </dev/urandom`

D. `$ foo </dev/eof`

E. `$ echo | foo`

Grep

Allows you to recursively search a directory

```
$ grep -r {pattern} {directory}
```

Really useful when working with large codebases

- Find all instances of when a function is used
- Find the definition of a function
- Find the source of error messages