Introduction to Linux

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Overview

DAY 1 – basics

- What is GNU/Linux?
  - available Linux-like environments
- The shell
  - what is the shell?
  - command-line basics
  - options & arguments
  - getting help
- The filesystem
  - navigating the filesystem
  - manipulating directories & files
  - using wildcard patterns
  - reading and editing text files
- Useful tools
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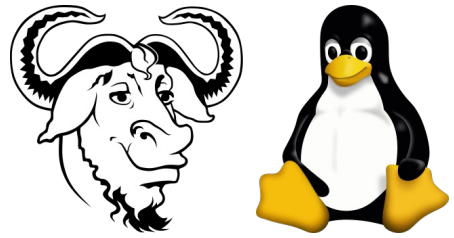
  - comparing files and directories
  - processing text-formatted structured data
- Streams & pipelines
  - input and output streams & redirection
  - command pipelines
  - overview of frequently used commands

What is GNU/Linux?



- Unix-like computer **operating system** (OS)
  - free and open-source, worldwide community, active development
- Under the hood: **Linux kernel**
  - abstraction between hardware and software
  - device drivers, system calls, process and memory management, ...
- Typically offers **GNU utilities and libraries**
  - basic tools to work with files, compile programs, ...
  - e.g.: coreutils, binutils, Bash shell, ...
- Comes in many flavours, called **distributions**
  - bundles desktop environments, applications, ...

Red Hat Enterprise Linux fedora Rocky Linux openSUSE debian Canonical Ubuntu

Available Linux-like environments

Microsoft Windows

- Microsoft Subsystem for Linux (**WSL**)
  - by default, the installed Linux distribution will be **Ubuntu**
- Installation instructions – *for recent versions of Windows*
  - search for PowerShell, right-click on the icon and select “Run as administrator”
  - type this in the PowerShell window to install WSL

    ```
    wsl --install
    ```

  - restart your machine
- Optional: use Windows Terminal
  - use Command Prompt, PowerShell and bash (via WSL) from one application
- Alternative: MobaXterm – *not recommended, some commands will behave differently*

Available Linux-like environments

Apple macOS

- Terminal app (built-in) or iTerm2
- note: macOS is based on BSD (Unix), thus offering BSD variants of commands
  - use **Homebrew** to install the GNU utilities – *first: run the one-line installation command*

    ```
    brew install coreutils findutils gnu-tar gnu-sed grep wget
    ```

  - the GNU variants of commands usually start with `g`
    - e.g., use (GNU) **`gsed`** instead of (BSD) `sed`
    - likewise for **`gls`**, **`ggrep`**, **`gtar`**, …
    - but not always, e.g., `wget`

Alternative options

- Use an **online terminal emulator** – e.g.: https://sandbox.bio/tutorials/playground

The shell — Part 1

Exploring the command line

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What is the shell?

bash

- A program that interprets commands and sends them to the OS
- Sometimes referred to as ”the terminal” or a “**Command-Line Interface**” (CLI)
  - waits for input and performs the requested tasks
  - the input language is a **scripting language** (variables, iterations, ...)
  - provides access to 100s of commands/programs
- Different shell programs exist
  - on most Linux systems, the default shell is called **bash** (Bourne Again SHell)
  - note: on macOS, the default shell is zsh, but bash is also available

Command-line basics

bash

- `$` and text preceding it is called the "**prompt**"
  - executing a command: type a command after the prompt and press the **Enter** key
  - autocompletion: type part of the command and press the **Tab** key (↹)

```
$ ls -l /etc/host↹
```

- **Linux systems are case and space sensitive**
  - files: `myfile` is not the same as `MyFile`
  - commands: spaces separate parts of commands

- Some keyboard shortcuts when using the Bash shell environment

Left ← and **Right** →	moving around the line	**Ctrl + a**	go to the beginning of the line
Up ↑ and **Down** ↓	browse the command history	**Ctrl + e**	go to the end of the line
Ctrl + r	backward history search	**Ctrl + l**	clear the screen

Hands-on

- Enter the following commands and try to interpret the output

```
$ echo Hello, world.
$ date
$ date --utc
$ whoami
$ hostname
$ uptime
$ clear
```

```
$ sleep 3
$ time sleep 3
$ who
$ echo $SHELL
$ echo -n Hello, world.
$ cal
$ history
```

Hands-on

- Note: some commands may not be available yet
  - more software can be added by installing extra *packages*
  - installation instructions depend on OS and/or distributions

- **Linux** and **Windows WSL** (Ubuntu)
  - advice: first update the package list

    ```
    $ sudo apt update
    ```

  - when a command is missing, a message is shown

    ```
    $ cal
    Command 'cal' not found, but can be installed with:
    sudo apt install ncal
    ```

  - install the `ncal` package to make the `cal` command available

    ```
    $ sudo apt install ncal
    ```

Hands-on

- Note: some commands may not be available yet
  - more software can be added by installing extra *packages*
  - installation instructions depend on OS and/or distributions

- **macOS** (Homebrew)
  - note: on Homebrew packages are reffered to as *formulae*
  - optional: install a helper command (first time only)

    ```
    $ brew tap homebrew/command-not-found
    ```

    - this allows you to search for a missing command

      ```
      $ brew which-formula tree
      ```

  - install the tree formula to make the tree command available

    ```
    $ brew install tree
    ```

Anatomy of a command

- Single command: program that does one thing

```
$ command
```

- **Arguments** (parameters): provide the input/output that the command interacts with

```
$ command argument1 argument2 [...]
```

- **Options**: modify a command's behavior (also called *flags*)

```
$ command -option
```
single dash + one letter (*short* form)

```
$ command --long-option
```
double dash + one word (*long* form)

- Generally, they compose as follows:

```
$ command [-o]... [--long-option]... [argument]...
```

Options & arguments

- Interpreted by the command itself → usage depends on the command
  - **convention: options first, non-option arguments last**
  - short options can be combined, the order often doesn't matter

    `$ date -R -u` = `$ date -Ru`
  - but for some commands, strict ordering rules apply

    `$ find -maxdepth 2 -type f`
  - non-option arguments often refer to a filename

    `$ less myfile`
  - but not always

    `$ echo "This is an example"`

    `$ date +"%A %e %B"`

Types of commands

type

- A command can be either:
  - any **program** (or script) on the system
    - use `which` to find out where the program is located/installed
  - a **built-in** shell command
    - get an overview with `man builtin`
  - an **alias** or (user-defined) shorthand for a more complex command
    - use `alias` to see the currently defined aliases
  - a (user-defined) shell **function**

Getting help

man

- Documentation for commands is available as online Linux man pages
  - *there is no shame in using Google or ChatGPT for help* – **the web is your friend!**

- Or directly from the command-line itself
  - ask a command about its use with the `--help` or `-h` options (if available)

```
$ ls --help
```

  - manual pages for commands – use **q** to quit

```
$ man ls
```

  - more elaborate info manuals – use **q** to quit

```
$ info ls
```

- Search man pages for keywords

```
$ man -k <keyword>
```

Getting help

man

- Efficiently reading man pages

↓ / ↑ or **j** / **k**	scrolling up or down
h	help for the man page viewer
q	quit reading the man page

- Searching through man pages

/ + "word" + Enter	search for the given word
n	find the *next* occurrence
N	find the *previous* occurrence

- Conventions for describing key combinations

^-<key> = **Ctrl + <key>**	press Ctrl and the given key together
C-<key> = **Ctrl + <key>**	
M-<key> = **Alt + <key>**	M stands for "Meta" key (*note: Option on Apple keyboards*)

Hands-on

- Get help for some of the commands from the previous hands-on
  - try browsing through the man page
  - what are the options and which arguments does it accept?
  - try searching for some words in the man page

- For those using macOS
  - install the GNU coreutils: `brew install coreutils`
  - look at the man page of the commands `ls` and `gls`
  - what is the difference between these commands?

The filesystem – Part 1

Navigating the filesystem

Manipulating files & directories

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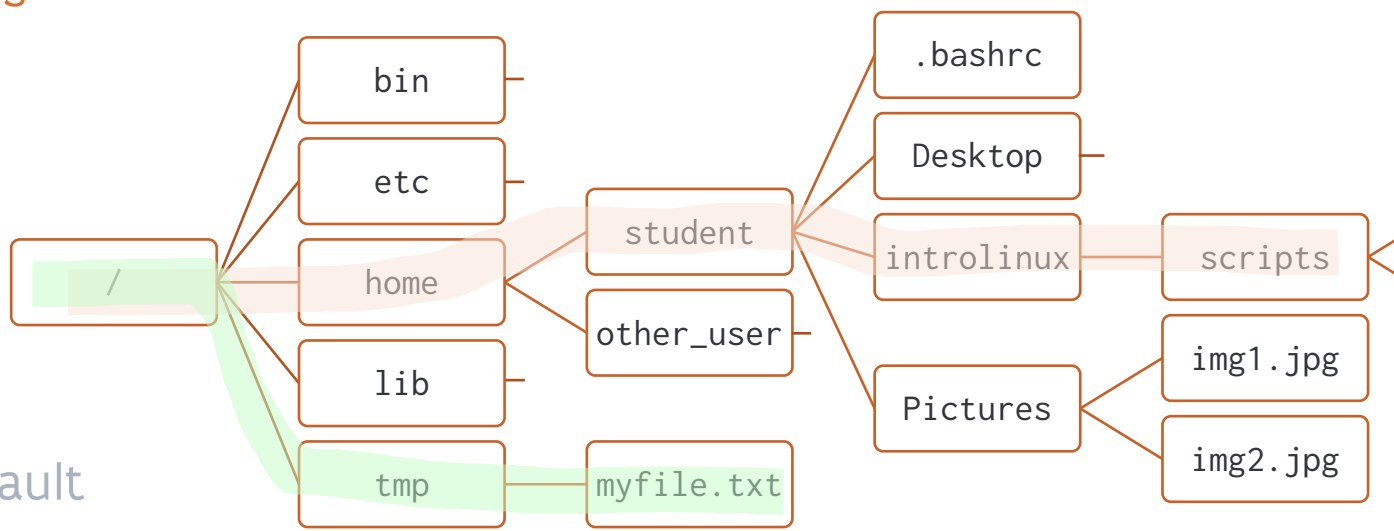
The filesystem – Directories and files

- Tree of **directories** and **files**
- **File name** describes the full location (also called *path*) in the file system
  - `/home/student/intro_linux/scripts`
  - `/tmp/myfile.txt`
  - **/** is called the *root* directory
- Directories are separated by `/`
- The filesystem is **case sensitive**
  - note: macOS is case insensitive by default

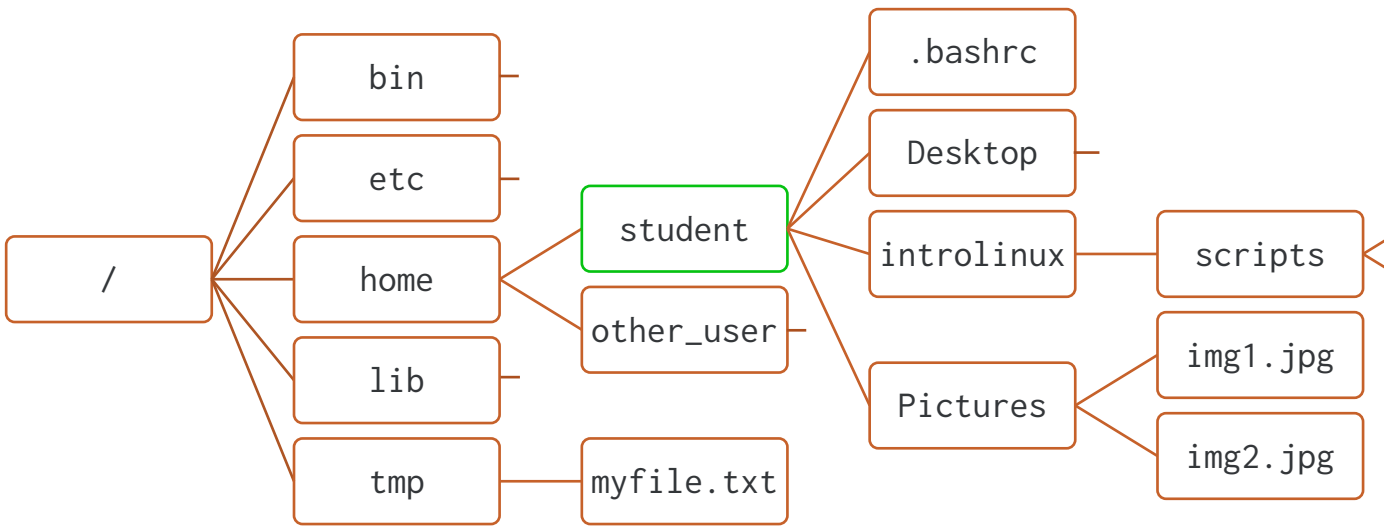


The filesystem – Absolute and relative path

pwd

- **Absolute** file name path starts from root `/`
- **Relative** file name starts from *current working directory*
- **pwd** prints the current working directory
  - at login, usually your home directory
- Use `..` to refer to a *parent directory*
- E.g., starting from `/home/student`

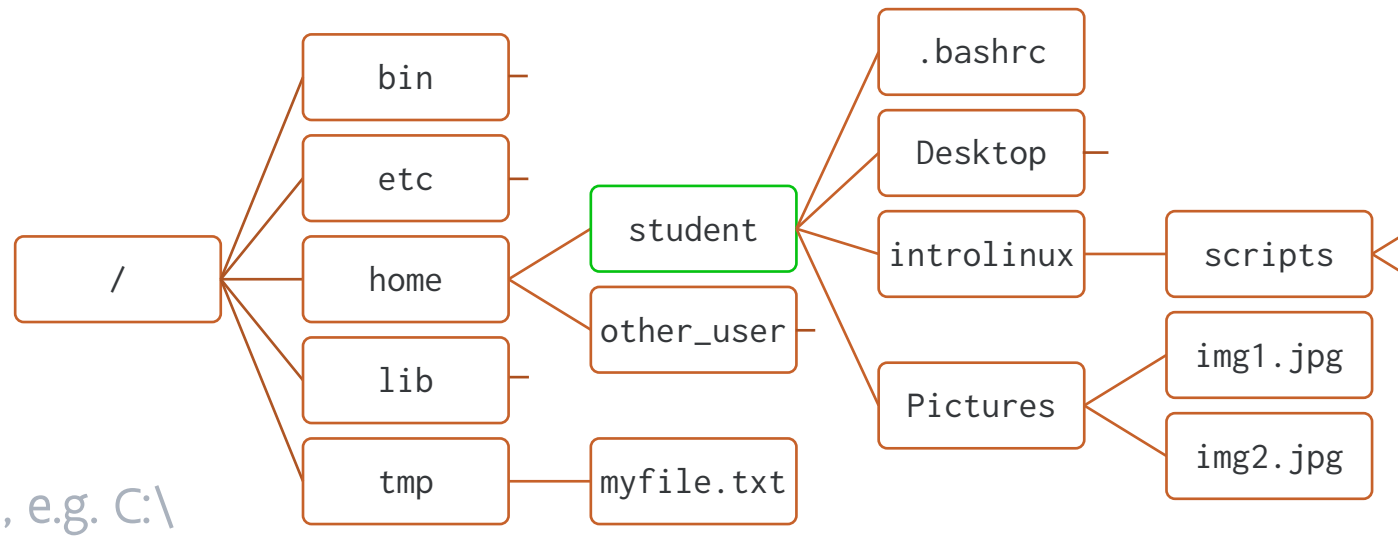
relative path	absolute path
`..`	`/home`
`../other_user`	`/home/other_user`
`../..`	`/`
`introlinux`	`/home/student/introlinux`



The filesystem – Absolute and relative path

pwd

- **Absolute** file name path starts from root /
- **Relative** file name starts from *current working directory*
- **pwd** prints the current working directory
  - at login, usually your home directory
- Use `..` to refer to a *parent directory*
- note: on Windows
  - folders are separated by \
  - the filesystem is case insensitive
  - the root indicates a physical partition, e.g. C:\
  - there can be multiple (root) trees



Navigating the filesystem

cd
ls

- Use **cd** <directory> to change the current directory

```
$ cd Downloads
$ cd ../Documents
$ cd -          go back to the previous directory
$ cd            go to your home directory
```

- **ls** (without arguments) lists the current directory's contents

- **~** ("tilde") is a shorthand for the absolute path to your *home directory* (*)

```
$ cd ~ = $ cd /home/<username>
$ cd ~/Downloads = $ cd /home/<username>/Downloads
```

- A single **.** points to the *current directory*

```
$ cd ./Downloads = $ cd Downloads
```

(*) *note: on macOS, when using Belgian keyboard layout (AZERTY), use* **Option + n**

Hands-on

- Try out the following sequence of commands

```
$ cd
$ ls
$ cd Documents
$ pwd
$ cd ..
$ cd ./Documents
$ pwd
```

```
$ cd /bin
$ ls
$ pwd
$ cd ~
$ pwd
$ cd -
$ pwd
```

Manipulating directories and files

mkdir
rmdir

- **Warning: no “recycle bin” or undo!**
  - be *very* careful when moving/copying/removing files at the command-line!

- **`mkdir`** creates directories

```
$ mkdir dir1 dir2 dir3
```

  - create *nested* directories

```
$ mkdir -p topdir/subdir/subsubdir
```

- **`rmdir`** removes *empty* directories

```
$ rmdir dir1 dir2 dir3
```

- **`touch`** creates an empty file, or updates the timestamp of the file if it already exists
  - *note: commands to create real file content will follow later*

Move, copy and remove

mv
cp
rm

- `mv source target` *moves (renames)* files and directories
  - if `target` = existing file → overwrite
  - if `target` = existing directory → move inside it

```
$ mv source1 source2 ... target
```
move list of items into existing `target` directory

- `cp source target` *copies* files and directories
  - same rules as `mv`, except:

```
$ cp srcdir target
cp: -r not specified; omitting directory 'srcdir'
```

  - **recursively** copy directories and their content:

```
$ cp -r srcdir target
```

- `rm file1 file2 ...` *removes (deletes)* files – *remember: no "recycle bin" or undo!*

```
$ rm -r mydir
```
recursively deletes directories *with* their contents

Using wildcards

- Wildcards help generate lists of filenames, e.g.:

```
$ mv file*.txt target
```

  - Bash replaces `file*.txt` by the list of matching files – called "*wildcard expansion*"

- `*` matches everything → `file*.txt` matches any filename which
  - starts with `file` and ends with `.txt`

- *Remember: no "recycle bin" or undo!*
  - *typing mistake can be dangerous!*

- *Safety first* for `cp`, `mv` and `rm`
  - using **`-i`** or **`--interactive`** asks for **confirmation** before overwriting or deleting
  - alternatively, use `echo` in front of the command to see the wildcard expansion

Wildcard patterns

- `*` any sequence of (0 or more) characters

  `file*.txt` → `file.txt file_copy.txt file1.txt ...`

- `?` any single character

  `file?.txt` → `file1.txt file2.txt ... files.txt`

- `[set of characters]` any single character from the given set

  `[fF]ile.txt` → `file.txt File.txt`

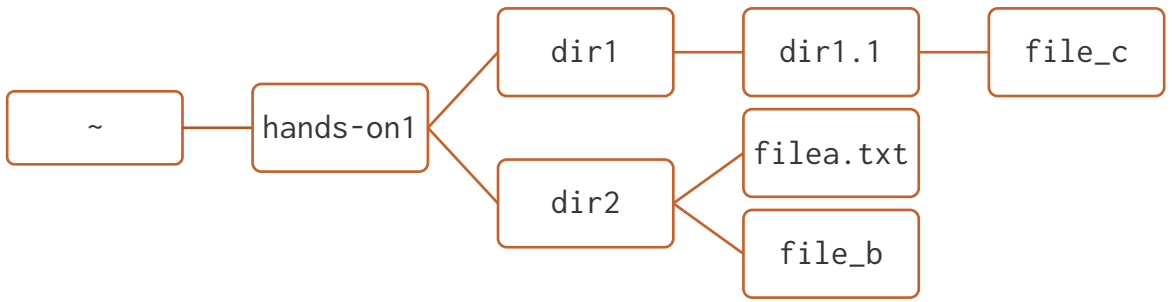
- `[!set of characters]` any single character *not* from the given set

  `file[!123].txt` → `file4.txt file5.txt ... files.txt`

- `[[:class:]]` use a predefined character class

Hands-on

- Create new directories and files in your home directory, according to the given diagram
  - use `touch file.txt` to create empty file
  - check your result with `tree ~/hands-on1`
  - *challenge yourself:* do this exercise from your home `~` without using `cd`



- Let's move things around
  - copy the files in `dir1.1` to its parent directory
  - rename `dir1` to `dir0`
  - copy `dir2` (including its contents) to `dir2_backup`
  - delete the files in `dir2` using wildcards
  - restore the backup directory

Hands-on

- Which names match the following patterns?

```
[abcdefghijk]*.pdf
backup.[0-9][0-9][123]
[Ff]ile?.*
file_[[:digit:]].txt
```

file_1.txt	A.pdf
cv.pdf	File_C.docx
backup-001	thesis.pdf
backup.182	Filea.txt
introLinux.pdf	backup.634

Reading and editing text files

- **Reading** (displaying) text files
  - `cat` → display the entire content of a text file
  - `less` → allows forward and backward navigation and searching
  - `head -n <x>` or `tail -n <x>` → print the first/last *x* lines of a file

- **Edit** text files using **text editors** that run inside the terminal
  - `nano` → simple and straightforward text editor
    - user-friendly, with an easy-to-use interface
  - `vi` → stands for visual interface, takes some practice
    - use "modes" for insert or commands
  - `emacs` → highly customizable, extensible text editor
    - powerful editing capabilities with, built-in support for multiple languages, with plugins
    - note: has a steep learning curve (e.g., lots of keybindings)

Useful tools – Part 1

Hands-on & examples

Hands-on

- Scenario: a colleague sends you a link to a dataset (here: zip-file) and you want to know how many inputs there are in the file `squeue.txt`
  - *note: step by step instructions and commands are given*
    - *it is up to you to look up the correct usage*
  - download the file https://calcua.uantwerpen.be/courses/intro-linux/input.zip – use **`wget`**
  - extract (or unzip) the files – use **`unzip`**
    - *can you look at the content of the zip file without unzipping it?*
  - locate the file named `squeue.txt` – use **`tree`** (*) and **`find`**
    - *which tool was better suited?*
  - count the number of lines in the file `squeue.txt`– use **`wc`**

(*) note: the `tree` command may not be installed yet

Hands-on

- Scenario: you download some scripts, and you quickly want to know the value of a parameter
  - *note: step by step instructions and commands are given*
    - *it is up to you to look up the correct usage*
  - download the files: https://calcua.uantwerpen.be/courses/intro-linux/pi_montecarlo.tar.gz
  - extract the files – use **`tar`**
    - *pay close attention to the options!*
  - you encounter two scripts with a similar name: `script01_new.py` and `script01_latest.py`
    - show the difference between these two files, but ignore white spaces – use **`diff`**
  - show the line where parameter `n_points` is assigned – use **`grep`**

Download & extract files

wget
unzip
tar

- Download files with **wget**

```
$ wget https://[...].zip
```

- **ZIP** file format

```
$ unzip file.zip
$ zip -r file.zip
```

- **TAR / TAR.GZ**

```
$ tar -czf file.tar.gz source_dir
$ tar -xzf file.tar.gz
```

  - TAR stands for Tape Archive – also called "*tarball*"
  - more common in Unix/Linux environments
  - preserves file permissions, ownership, and timestamps, making it more suitable for backups and archives

What I type:

```
$ tar czf data.tar.gz data
$ tar xzf data.tar.gz
```

What I say in my head:

"create ze file"

"extrakt ze file"

`diff` – Comparing files and directories

- Show differences between text files

`$ diff -i file1 file2`	ignore case
`$ diff -w file1 file2`	ignore all white space
`$ diff -y file1 file2`	output in two columns
`$ diff -r dir1 dir2`	recursively compare directories

Hands-on

- Scenario: you see that a colleague opens file `scores.csv` with *comma separated values* in Excel to sort the data by `Score`
  - *Not on your watch – you use Miller like a pro!*
  - *note: parts of the commands are given, complete them using the documentation*
- Start by reading Miller in 10 minutes
- Install the Miller command **mlr**
  - on Linux and Windows WSL (Ubuntu) : `sudo apt install miller`
  - on macOS (with Homebrew) : `brew install miller`
- Try to “pretty-print” the `scores.csv` file
  - also, try to sort it by the values of the field `Score`

Processing text-formatted structured data

mlr

- Why our sysadmin 😍 **Miller** (*obligatory slide!*)
  - easily query, shape and/or reformat CSV, TSV, JSON, … data files
  - pretty-print data files, convert between file formats
  - using compact verbs instead of a programming language

- Some examples

```
$ mlr --icsv --ojson cat scores.csv                convert scores.csv to JSON format
$ mlr --c2j cat scores.csv                         using a keystroke-saver flag
$ mlr --csv tail -n 4 scores.csv                   print header and last 4 lines
$ mlr --c2p cut -f Name,Gender scores.csv          pretty-print only fields Name and Gender
$ mlr --c2p filter '$Course=="History"'            for the course History
  then cut -f Name,Score                           show Name and Score
  then sort -r Score scores.csv                    sorted in descending order
```

Streams & pipelines

Input and output streams & redirection

Command pipelines

Input and output streams

- Output and input (**I/O**) of commands is managed using *streams* and *file descriptors*
  - **streams** provide an interface with powerful formatted input and output functions (high-level)
  - under the hood, streams use **file descriptors** (fd) to keep track of the I/O-resources (low-level)

stream	readable name	purpose	fd
stdout	standard output	for normal output	1
stderr	standard error	for printing warnings and errors	2
stdin	standard input	from which commands receive input	3

  - by default, “stdin” is read from the keyboard, while “stdout” and “stderr” are sent to the terminal

- We can **redirect** the output and input streams, to
  - write output to a file
  - send output from one command to input of another
  - read stdin from a file

Output redirection

- To redirect an output stream, use operator **i>** with its associated file descriptor (fd) **i**

- **Redirect standard output** (stdout)

```
$ ls > ls-output.txt = ls 1> ls-output.txt
```

  - the file `ls-output.txt` is created and contains the command's output
  - note: stderr is still shown in terminal

- **Redirect standard error** (stderr)

```
$ ls wrong-filename 2> ls-error.txt
```

- Redirect both stdout and stderr

```
$ ls *.txt *.jpg > ls-output.txt 2> ls-errors.txt        to different files
$ ls *.txt *.jpg > ls-output-and-errors.txt 2>&1         to the same file
= $ ls *.txt *.jpg &> ls-output-and-errors.txt           to the same file
```

Output redirection

- **Hiding** a program's output

```
$ ls > /dev/null
```

  - **/dev/null** is a special "file" that discards everything written to it

- Warning: redirecting (**>**) creates a **new file**
  - if a file exists with the same name, it will be overwritten!
  - if the command produces no output, the file will be empty

- **Append** (**>>**) stdout and/or stderr to the end of a file *without erasing previous content*

```
$ date >> diary.txt
$ echo "Dear diary, today ..." >> diary.txt
$ ls notfound 2>> ls-errors.txt
$ ls *.txt *.jpg >> ls-output-and-errors.txt 2>&1
= $ ls *.txt *.jpg &>> ls-output-and-errors.txt
```

Input redirection

- Standard input (stdin) is by default read from the keyboard
- The **input redirection** operator `< filename` opens a file, and the program processes it as input
  - example, using the command-line calculator **bc**

```
$ echo "2 * 17" > homework.txt
$ bc < homework.txt
34
```

  - useful for automating commands that normally require user input
  - or for reading from specific sources (devices) directly
- Redirecting both standard input and standard output

```
$ bc < homework.txt > answers.txt
```

Command pipelines

- **Combine several commands** by chaining them using the “pipe” operator **|** (*)

```
$ command1 | command2 | command3 [| ...]
```

  - a *pipeline* creates a flow of data between commands
  - stdout from `command1` is directly sent to stdin of `command2` (etc)
  - the commands run in parallel, each command processes input as it becomes available

- Example: scrolling through the list of all processes with **`ps`** and `less`

```
$ ps aux | less
```

- **Create complex commands from simple building blocks**

```
$ who | cut -d' ' -f1 | sort | uniq > users
```

- note: to pipe stderr from a command, redirect it to stdout

```
$ command1 2>&1 | command2
```

(*) *note: on macOS, when using Belgian keyboard layout (AZERTY), use* **`Shift + Option + l`**

Hands-on

- Given the file `chemistry.txt`, how many courses are taught by Wouter Herrebout in the first semester?
  - *note: use pipelines whenever possible!*
  - investigate the file – use `cat`
  - print only the lines belonging to the first semester – use `grep`
  - of those lines, select the lines containing Wouter Herrebout – use `grep`
  - count the resulting number of lines – use `wc`
  - *challenge yourself: use `mlr` instead*

Hands-on

- Which are, in alphabetical order, the last 5 course codes starting with **1001WET**? Write them to a new file.
  - alphabetically sorted by *course code*
  - sort the lines in alphabetical order – use **`sort`**
    - *pay close attention to the options*
  - Of those lines, select the last 5 – use a pipe and `tail`
  - write the output to a new file
  - edit your pipeline to instead sort alphabetically by *course name*

Hands-on

- Which course is **listed more than once** in the file chemistry.txt?
  - print each unique line of the file, with the number of times it occurred – use `uniq`
    - *carefully read the last line of DESCRIPTION in the man page*
  - print only the course(s) which are listed more than once, together with the number of times

Overview of frequently used commands

- Typical commands for pipelines

`cat`	concatenate files (useful to print out file content)
`grep`	filter lines which match a given search pattern
`head` / `tail`	print first/last lines of input
`sort`	sort input alphabetically
`uniq`	report or leave out repeated lines
`wc`	print the number of lines, words and bytes of input
`sed`	transform input (pattern replacement and more)

- Find more commands in the GNU core utilities manual

DAY 2 – Sneak preview – Shell scripts

bash

- **shell script** = text file containing a series of commands
- Example script "`myscript.sh`"

```
my_analysis input.data > my_results/science.txt
tar -cvzf my_results.tar.gz my_results
rm input.data
```

- Run (execute) the script

```
$ bash myscript.sh
```

- note:
  - commands are separated by newlines or by semicolons '**;**' (as in the terminal)
  - commands are executed one after the other, just as if you entered them manually

Introduction to Linux

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Version Spring 2025 – Day 2

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Overview

DAY 2 – diving deeper

- The environment
  - environment variables
  - aliases & environment startup
- The shell
  - variable and arithmetic expansions
  - command substitution
  - escaping special characters
- Useful tools
  - regular expressions
  - search and replace
- Bash scripting basics
  - writing and running shell scripts
  - using variables & command-line arguments
  - the `for` loop
- The filesystem
  - permissions & ownership
- Running programs
  - processes and threads
  - managing processes
- More bash scripting

The environment

Environment variables

Aliases & environment startup

Environment variables

export

- We can use variables in the shell

  `$ myvar=some_value` set the value for variable myvar

  `$ echo $myvar` get the current value of myvar – this is called "*variable expansion*"

  `$ set` display *all* (shell) variables (and functions)

  - no spaces around '='
  - no spaces in `some_value` unless using quotes
  - these are "plain" variables – they only exist in the running shell itself

- **Environment variables** are special

  `$ export myvar` make `myvar` an environment variable

  `$ printenv` display (exported) *environment* variables

  - they are passed on to processes started from the shell
  - they can influence the behaviour of programs (e.g. `OMP_NUM_THREADS`)

Environment variables

$PATH

- Some **standard** environment variables

PATH	a colon-separated list of directories that are searched when you enter the name of an executable program
HOME	the path name of your home directory (**~**)
USER	your user name
SHELL	the name of your shell program
PWD	the current working directory
TMPDIR	directory for temporary files (usually `/tmp`)

- Example: access an environment variable from within a Python script

```
$ python3 -c 'import os
> print("hi there,", os.getenv("USER"), "!")'
```

Aliases

alias

- Substitute a string for a simple command
- `$ alias <name>=<value>` means that `<name>` will be replaced by `<value>`
- Handy to set default options and simplify your commands

```
$ alias ls="ls -F --color=auto"          append filetype indicator, colorize output
$ alias lart="ls -Falrt --color=auto"    show hidden files, recently modified first
```

- Removing (deleting) aliases – *in the current shell only*

```
$ unalias <name>      removes the alias for <name>
$ unalias -a          removes all aliases
```

Environment startup

- User-defined aliases, variables and functions are reset when restarting the shell
- Store the settings in a **startup file** so they are persistent for your environment
  - applied every time you start an interactive shell

    `~/.bashrc` *you can define your own aliases and functions here*
  - other files are applied for a login shell and when exiting a shell
    - see Bash Startup Files for more information
- note: on macOS, the default shell nowadays is **zsh** (Z shell)
  - for zsh, the startup file used for an interactive shell is named `~/.zshrc`
  - see Z Shell Startup Files for more information

The shell — Part 2

Variable and arithmetic expansions

Command substitution

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Shell expansions

- When you type a command-line and press **Enter**
  - the shell performs several processes on the text before it carries out your command
  - the process that makes this happen is called *expansion*

Variable expansion

- `$variable` → variable's current value

```
$ echo $USER                print the current value
$ set                       display all variables
$ echo $SUER                what if variable doesn't exist?
$ echo ${USER}_home         use {} to disambiguate the variable name
$ echo $USER_home           doesn't work without {}
$ myvar='Hello, world!'     set a variable
$ echo $myvar
```

Shell expansions

Arithmetic expansion

- `$((expression))` → result of expression

```
$ echo $((10 + 5 + 3))
```

  - arithmetic expression – *integers only!*
  - operators: `+`, `-`, `*`, `/` , `%` (remainder), `**` (exponentiation)
  - single parentheses may be used to group multiple subexpressions:

```
$ echo $(( (5**2) * (3*4) ))
```

Command substitution

- `$(command)` → output of command

```
$ echo We are now $(date)
$ echo I see $(ls -A | wc -l) files and subdirs
```

Shell expansions

Escaping special characters & using quotes

```
$ echo The total is $100.00 # ?!
```

- Use the **escape character** **** for literal use of **special characters** (**$**, ****, **`**, **{**, **}**, **(**, **)**, ***, **␣**)

```
$ echo The total is \$100.00
```

- Inside single quotes **''** special characters lose their meaning → no expansion at all

```
$ echo text ~/*.txt {a,b} $(echo foo) $((2+2)) $USER
$ echo 'text ~/*.txt {a,b} $(echo foo) $((2+2)) $USER'
$ echo "text ~/*.txt {a,b} $(echo foo) $((2+2)) $USER"
```

- Inside double quotes **""** special characters lose their meaning *except* **$**, ****, **`**

```
$ echo "$USER $((2+2)) $(cal)"
$ echo "The total is \$100.00"
```

Shell expansions

Other

- Word splitting: words separated by space become separate arguments

```
$ touch "two words.txt"
$ ls -l two words.txt
$ ls -l "two words.txt"
$ ls -l two\ words.txt
$ ls -l two⇆
```

- Quote removal: after all expansions, quotes are removed unless you escape or quote the quotes

```
$ echo "hello world"
$ echo \"hello\" '"world"'
```

Useful tools – Part 2

Regular expressions

Find and replace

Regular expressions

- Also called "*regex*"
  - symbolic notation used to **match text patterns**
  - similar to wildcards (*, [], ?), but more powerful

- Many programs and programming languages support regular expressions
  - `grep`, `sed`, ...
  - Text editors, e.g. `emacs`
  - Python, Perl, Matlab...

- *Note: slight differences exist in notation and supported patterns*

Regular expressions

grep

- Example: counting animals in the Bible

```
$ grep -Eo ' (dragon|serpent|lion|eagle)s? ' bible.txt | sort | uniq -c
     10     dragon
      4     dragons
     10     eagle
      3     eagles
     43     lion
     13     lions
     14     serpent
      4     serpents
```

Regular expressions

grep -E
egrep

- Literal characters and digits

```
$ grep lion bible.txt
```

- "*Metacharacters*" are used for repetitions, grouping, alternatives, ...
  - Two notations for metacharacters
    - **basic regular expressions** (BRE)

      ```
      ^ $ . [ ] * \( \) \{ \} \? \+ \|
      ```

    - **extended regular expressions** (ERE)

      ```
      ^ $ . [ ] * ( ) { } ? + |
      ```

- *Note: on the slides, we use ERE for readability*
  - using `$ grep -E` = `$ egrep`

Regular expressions – Metacharacters

- `.` Match any single character

```
$ grep '.word' /usr/share/dict/words
```

  - *Note: remark the difference with using wildcards*

```
$ touch .zip 1.zip 1zip 22.zip 2zip
$ ls *zip
$ ls *.zip
$ ls | grep .zip
```

- `^ $` Called "*anchors*", matches the beginning (`^`) or end (`$`) of a line

```
$ grep '^word' /usr/share/dict/words
$ grep 'word$' /usr/share/dict/words
$ grep '^word$' /usr/share/dict/words
```

Regular expressions – Character classes

- `[]` Character class

`[lw]ord`	matches `lord` and `word`
`[l-w]ord`	matches `lord`, `mord`, `nord`, …, `word`
`[^lw]ord`	matches any `ord` not preceded by `l` or `w`
`[^l-w]ord`	matches any `ord` not preceded by `l`, …, `w`
`^[A-Z]`	matches any uppercase letter at the beginning of a line
`^[-AZ]`	matches any line beginning with `-`, `A` or `Z`
	correction: matches only the character -, A or Z if at the beginning of a line

Regular expressions – Repetitions

- `?` Match preceding element zero or one time
- `*` Match preceding element zero or more times
- `+` Match preceding element one or more times
- `{}` Match preceding element a specific number of times
  - `{n}` exactly *n* times
  - `{n,m}` at least *n* times and/or at most *m* times – for or, drop *n* or *m*

- Some examples:

`A*`	matches <empty string>, A, AA, …
`.*`	matches any sequence of characters
`\$[1-9][0-9]{2,}`	match any amount of $100 or more

Regular expressions – Sub-expressions, alternatives

- `()` sub-expression

  `(tick)+` matches 1 or more repetitions of (the word) `tick`

- `|` alternatives

  `word|lord` matches `word` and `lord`

  `(w|l)ord` matches `word` and `lord`, using grouping

  `(w|l|sw)ord` matches `word`, `lord` and `sword`

- `\n` reference to the *n*-th subexpression (used in find and replace)

Regular expressions – Cheat sheet

`.`	Match any	(BRE)
`^ $`	anchor beginning or end of line	
`[ ]`	character classes	
`?`	0 or 1 times	`\?`
`*`	0 or more times	
`+`	1 or more times	`\+`
`{`*n*`}`	*n* times	`\{`*n*`\}`
`{`*n*`,`*m*`}`	more than *n*, less than *m* times	`\{`*n*`,`*m*`\}`
`( )`	subexpression	`\( \)`
`|`	alternative	`|`
`\`*n*	reference to the *n*-th subexpression	

- For a comprehensive overview, check this RegEX cheat sheet

Hands-on

- Use `grep -E` on the file **`words.txt`**
  - which words start with **`chemi`**?
  - which words contain both **`are`** and **`be`**? (answer using 1 regular expression)
  - which words start with a capital letter and contain two consecutive letters **`a`**?
  - how many five letter words do you find? (use a pipeline)

sed – Search and replace

- **sed** = **s**tream **ed**itor
  - works on standard input or a set of input files
  - perform text manipulations using regular expressions – *non-interactively*, using 'commands'
  - powerful, but somewhat complex

- Typical usage: **search and replace**

```
$ sed 's/regexp/replacement/'
```

  - processes input line by line, prints the modified text to standard output
  - by default, replaces only the first occurrence on each line
  - by default, matching is done case sensitive
  - by default, uses BRE

- *For larger tasks, you might choose awk, Perl, Python, …*

sed – Search and replace

sed

- **sed** [options] <script> <file>

`-n`	suppress automatic printing
`-i`	edit file in-place (instead of printing to standard output)
`-E`	use extended regex (ERE)

  - <script> = [line selection]<command>

n[,*m*]	line number *n* (until *m*)
$	refers to the last line
/`regex`**/**	lines that match `regex`

    - <command> performs an action on the (matched) text

s/`regex`**/**`repl`**/**	replace matches for `regex` by `repl`
d	delete the matched line(s)
*<command>***I**	use case insensitive matching
*<command>***g**	act on all matches on this line (global replacement)

sed – Search and replace

sed

- Some examples:

`$ sed -n '3,5p' distros.txt`	print only lines 3 to 5
`$ sed -i '1d' distros.txt`	delete the first line in the file
`$ sed '/Fedora/d' distros.txt`	equivalent of `grep -v Fedora`
`$ sed '/Fedora/a from Red Hat' distros.txt`	append the given text on a new line after the matched pattern
`$ sed 's/Fedora/& from Red Hat/' distros.txt`	use **&** to reference the whole matched pattern in the replacement string
`$ sed 's+/+-+g' distros.txt`	use another *delimiter* (**+** instead of **/**)

- Check the sed manual or this sed cheat sheet

Hands-on

- Find and replace all instances “`chemie`” by “`scheikunde`” in the file `chemistry.txt` and write the output to a new file.
  - make sure the replacement is case insensitive
  - do the replacement directly in the file
- In distros/distrostab.txt, rewrite `MM/DD/YYYY` as `YYYY-MM-DD`.
  - match the pattern `MM/DD/YYYY` using 3 subexpressions
  - construct the replacement by referring to the subexpressions

Bash scripting basics

Writing and running shell scripts

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Shell scripts – Writing shell scripts

bash

- **shell script** = text file containing a series of commands
- Example script "`myscript.sh`"

```
my_analysis input.data > my_results/science.txt
tar -cvzf my_results.tar.gz my_results
rm input.data
```

`$ bash myscripts.sh` run (execute) the script

- Note that
  - commands are separated by newlines or by semicolons ';' – just as in the terminal
  - commands are executed one after the other – just as if you entered them manually
- Example scripts in https://calcua.uantwerpen.be/courses/intro-linux/scripts.zip

Shell scripts – Note about line endings

`file`
`dos2unix`

- Note about **line endings**
  - line endings are encoded differently under Windows and Unix/Linux
    - Windows style: carriage return + line feed (CRLF, **\r\n**)
    - Unix/Linux style: newline (**\n**)
  - this can introduce problems when running bash scripts

- Check which encoding is used:

```
$ file filename
```

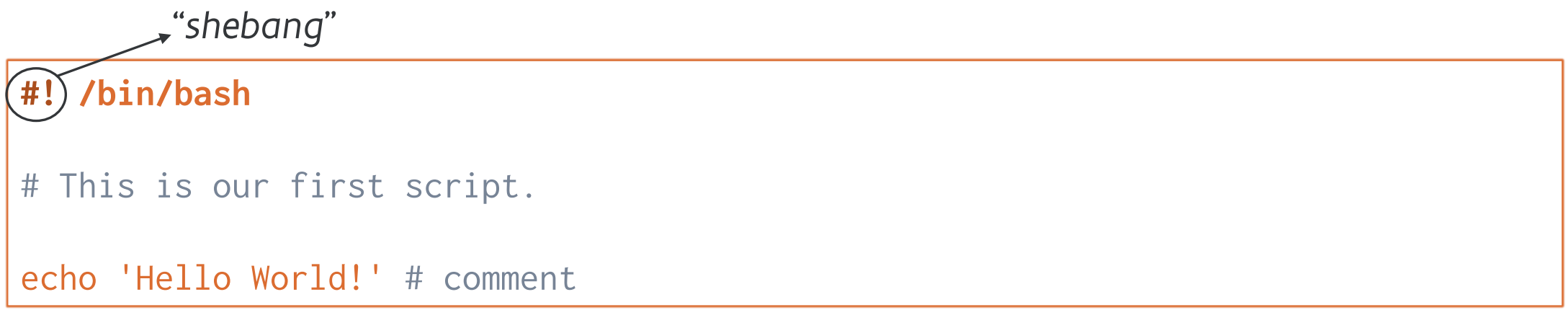
- If needed, convert your “Windows style” file into a “Unix/Linux” style:

```
$ dos2unix -n inputfile outputfile
```

- *Note: any suitable text editor can do this as well*

Shell scripts – Running shell scripts


```
$ cat scripts/script01.sh
```




```
$ bash script01.sh
```
call the interpreter (bash) ourselves

```
$ chmod +x script01.sh
```

```
$ script01.sh
```
doesn't work because work dir is not in PATH!

```
$ ./script01.sh
```
the interpreter from the "shebang" is used

Shell scripts – Running shell scripts

- `#!` is called "**shebang**" – it tells the system which **interpreter** should execute the script
  - for a bash script:

    `#!/bin/bash`
  - spaces (between parts) are optional:

    `#!/bin/bash` = `#! /bin/bash` = `#!  /bin/bash`

- Any scripting language interpreter can be used (not just bash)
  - example for Python:

    `#!/usr/bin/python3` uses that specific Python executable
  - or preferably:

    `#!/usr/bin/env python3` uses the first `python3` found in **PATH**

Shell scripts – Using variables

```
#!/bin/bash                                                    # script02.sh

currenttime=$(date +"%x %r %Z")
myname=$USER

echo "id: $myname, current time: $currenttime"
```

- Remember:
  - Setting a variable: without **$**, no spaces around **=** e.g., myname=**some_value**
  - Using a variable (variable expansion): with **$** e.g., echo **$**myname
- User variables can not start with a digit: $**1**, $**2**, …
  - these are special variables, a.k.a. “command-line arguments”

Shell scripts – Command-line arguments

```
#!/bin/bash                                                    # script07.sh

echo "Number of arguments: $#
\$0 = $0
\$1 = $1
\$2 = $2
...
\$9 = $9"
```

```
$ ./script07.sh these are four arguments
$ ./script07.sh "this is a single argument"
```

- Using command-line arguments in your script:
  - more than 9 args? → **`${10}`**, **`${11}`**, … or use **`shift`** (see next slide)
  - last arg → **`${!#}`** or **`${@: -1}`** (space is required) or **`$BASH_ARGV`** (bash only)
  - list of all command-line arguments: **`$@`**

Bash scripting – The **for** loop

```
for variable in list; do commands; done
```

```
#!/bin/bash                                                    # script09.sh
for i in A B C D; do
  echo $i
done
```

- `list` can be any bash expression resulting in a list, e.g.

  `for file in *.txt; do ... done` loop over each `txt` file

- if "`in list`" is omitted, **for** loops over the command-line arguments

Bash scripting – The **for** loop

```
#!/bin/bash                                                    # script09b.sh


for i in $(seq 1 10); do
  echo $i
done


for i in $(seq 11 0.75 20); do
  echo $i
done


for i in {21..30}; do
  echo $i
done
```

Hands-on

- Write a script that adds up all command-line arguments
  - loop over all command-line arguments
  - add each argument to the total – use arithmetic expansion `$(( ))`
  - test your script with different inputs – make sure your script is executable
- What do you expect to happen when instead of integers you input:
  - text?
  - decimals?
  - *test your expectations!*

Hands-on

- Write a script that loops over each command-line argument and that
  - creates a directory `dir_<argument>` in the current location
  - copies a template file `input_<argument>.txt` into this directory
  - replaces "`<param>`" in this file by the value of the argument
- *Challenge yourself!*
  - we want the name of the template file as the first command line argument
  - run previous script without changes, with this new argument – what happens?
  - try to fix what went wrong – look into the **`shift`** command

Hands-on

- Here is an example of a script with some more logic structures
  - **if**
  - **while**
  - ~~case~~
  - **break / continue**
  - ~~functions~~
  - ...
- *Try to figure out what it does*

```
#!/bin/bash                                    # script12.sh
while echo -n "enter number: "; read NUM
do
  if [ $NUM -eq $NUM ] 2>/dev/null; then
    :
  else
    echo " $NUM is not a number"
    continue
  fi
  if [[ $(( $NUM % 2 )) -eq 0 ]]; then
    echo " $NUM is an even number"
    continue
  fi
  echo " $NUM is an odd number"
  break
done
```

The filesystem – Part 2

Permissions & ownership

Permissions & ownership

`id`

- Every user has a unique **id** and (user)**name** and belongs to one or more **groups**

- To see your id, name and groups, run `id`

uid	your user id
gid	primary group id
groups	list of all groups you are a member of

- Every file or directory belongs to a user *and* a group with different **access permissions** for
  - **u**ser
  - **g**roup
  - **o**thers = all other users who are not a member of the file's group

Permissions & ownership

- Use `ls -l` to see **permissions** and **ownership**:

```
$ ls -l scripts
total 512
-rwxr-xr-x 1 vsc20xxx antwerpenall   76 Feb  8 12:43 script01.sh
...
permissions     user     group     size modif.time   filename
```

- `-rwxrwxrwx` = three kinds of permissions for “user,” “group” and “others”

permission	file access	directory access
read	read file’s contents	list directory contents
write	modify file’s contents	create, remove & rename files *(also needs x)*
e**x**ecute	run file as a program	enter directory & access contents

Setting permissions

chmod

- **chmod** can change the permissions for files or directories

- Add/remove permissions using `chmod +` or `chmod -`

```
$ chmod +w file.txt          add write permission for all users
$ chmod g-w file.txt         remove write permission for the group the file belongs to
$ chmod ug+x,o-r file.txt
```

- Or using numbers instead, where 0=none, 1=x, 2=w, 3=wx, 4=r, 5=rx, 6=rw, 7=rwx

```
$ chmod 640 file.txt
```

- **-R** = Recursive, change permissions on a directory and all its contents

```
$ chmod -R go-xr my_private_dir
```

Changing ownership

chown

- **chown** can change the owner and/or group of files and directories

```
$ chown owner file.txt
$ chown owner:group file.txt
$ chown :group file.txt
```

  - `-R` = Recursive

```
$ chown -R owner:group my_dir
```

Running programs

Processes and threads

Managing processes

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Processes and threads

- A **process** = running instance of a program
  - has a unique identifier or **PID** (Process ID)
  - can start other processes, its **child** processes
  - consists of one or more **threads**

- Threads **share** access to the process' memory
  - but processes cannot access other processes' memory!

- *Parallelization* on **multiple CPU cores**
  - multiple processes -> "*distributed memory parallelism*"
  - multiple threads in one process -> "*shared memory*"

Processes and threads – Looking at processes

ps
top
htop

- **ps** prints information on running processes.

```
$ ps
  PID TTY          TIME CMD
 8627 pts/12   00:00:00 bash
19621 pts/12   00:00:00 ps
```

show processes *in the current shell*

`$ ps x`	show **all** processes of current user
`$ ps ax`	show all processes of **all users**
`$ ps u`	show username, CPU and memory usage (can be combined with previous, e.g. `$ ps axu`)
`$ ps -u <user>`	show processes of the given user

- **top** or **htop** show processes together with CPU and memory usage *in real time*

Processes and threads – Managing processes

bg
fg

Foreground processes

- Example: run `xclock` with `$ xclock -update 1`
  - once the process is started, it is executing and occupying the terminal
  - you no longer have access to the prompt; it prevents you to run other commands

- To **terminate** the foreground process, press **`Ctrl + c`**
  - `xclock` disappears, the prompt returns

- To **stop** (pause) the foreground process, press **`Ctrl + z`**
  - the process is stopped, the prompt returns
  - the process can be restarted again using

    `$ fg` process resumes “in the foreground”

    `$ bg` process continues ”in the background”

Processes and threads – Managing processes

& jobs

Background processes

- To start a process in the background, terminate the command by **&**

```
$ xclock -update 1 &
```

bash prints the job number and PID, e.g. `[1] 9582`

- When having multiple background processes, use `$ jobs` to see a list

```
$ xclock -update 1 &
[1] 9582
$ xclock -update 1 &
[2] 9588
$ jobs
[1]- Running xclock -update 1 &
[2]+ Running xclock -update 1 &
```

- Use the jobs' number to control the different processes, e.g.

```
$ fg %2
```

run job 2 in the foreground

Processes and threads – Managing processes

kill

Terminating processes

- *Reminder*: **`Ctrl + c`** terminates the **foreground** process

- Use the command **`kill`** `<PID>` to terminate any process (owned by you)

  `$ kill 12345` terminate process with PID 12345
  note: the process may belong to another shell

- `kill %<jobnum>` terminates a **background** process

  `$ kill %2` terminate job 2, with time for cleanup
  `$ kill -KILL %2` terminate job 2 *immediately*

- Use `$ kill -STOP` and `$ kill -CONT` to pause/resume processes

More bash scripting

Conditional and looping constructs

Functions & debugging

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Bash Scripting – `if` conditional construct

- **Generic form**

```
if test1; then commands1
elif test2; then commands2
elif ...
else commandsn
fi
```

```
#!/bin/bash                                    # script04.sh

x=5
if [ $x -eq 5 ] ; then
  echo "x equals 5."
else
  echo "x does not equal 5."
fi
```

- Test syntax – different forms possible

```
if test expression
```

```
if [ expression ]
```
equivalent form

```
if [[ expression ]]
```
enhanced version – easier to use, e.g. in combination with variables

```
if (( expression ))
```
for arithmetic expressions only

Bash Scripting – Test expressions

Tests with files

`file1 -nt file2`	file1 is newer than file2
`file1 -ot file2`	file1 is older than file2
`-d file`	file exists and is a directory
`-f file`	file exists and is a regular file
`-s file`	file exists and has size > 0
`-L file`	file exists and is a symbolic link
`-r file`	file exists and is readable
`-w file`	file exists and is writable
`-x file`	file exists and is executable

- Search for “bash file test operators” (or `man test`) to see more exotic ones…

Bash Scripting – Test expressions

Tests with strings

`-n string`	the length of the string > 0
`-z string`	the length of the string = 0
`string1 = string2`	strings are equal
`string1 != string2`	strings are not equal
`string1 > string2`	string1 sorts after string2
`string1 < string2`	string1 sorts before string2

Bash Scripting – Test expressions

Tests with integers

`int1 -eq int2`	int1 = int2
`int1 -ne int2`	int1 ≠ int2
`int1 -le int2`	int1 ≤ int2
`int1 -lt int2`	int1 < int2
`int1 -ge int2`	int1 ≥ int2
`int1 -gt int2`	int1 > int2

Bash Scripting – Test expressions

Combining test expressions

	[ ]	[[ ]]
AND	-a	&&
OR	-o	||
NOT	!	!

- Example:

```
if [[ $((x % 5)) -eq 0 && $((x % 2 )) -eq 0 ]]
then
        echo "$x is a multiple of 10"
fi
```

Bash Scripting – The **while** loop

- **while** test; **do** commands; **done**

```
#!/bin/bash                                                    # script06.sh

count=1
while [ $count -le 5 ]; do
  echo $count
  count=$((count + 1))
done
echo "value of count: $count"

echo "Finished."
```

Bash Scripting – The **while** loop

```
#!/bin/bash                                                    # script06b.sh

while read jobid partition jobname user state rest; do
  echo $jobid $state
done < squeue.txt
```

- Alternatively, use this one-liner at the prompt:

```
$ cat squeue.txt | while read line; do ... done
```

- Combining `while` and `read` gives an easy (quick & dirty) way to process lines of output
  - no worries about how many spaces separate fields).
- Note: `squeue.txt` can be found in the `input.zip` file

Bash Scripting – read input values

- Create variables and read their values from standard input

```
#!/bin/bash                                                    # script05.sh

echo -n "Please enter an integer -> "
read int

echo -n "Enter one or more values > "
read var1 var2 var3 var4 var5

echo "int = ${int}, var1 = ${var1}, ..."
```

- Remarks:
  - `-n` prevents `echo` from printing a new line
  - extended version: see `script05a.sh`

Bash Scripting – case conditional construct

```
case word in
  pattern1) commands1 ;;
  pattern2) commands2 ;;
  ...
esac
```

```
#!/bin/bash                                                    # script11.sh

read -p "enter word > "
case $REPLY in
  [[:alpha:]])        echo "single alphabetic character." ;;
  [ABC][0-9])         echo "A, B, or C followed by digit." ;;
  ???)                echo "is three characters long." ;;
  *.txt)              echo "is a word ending in '.txt'" ;;
  *)                  echo "is something else." ;;
esac
```

Bash Scripting – break and continue

```
#!/bin/bash                                                    # script12.sh
while echo -n "enter number: "; read NUM
do
  if [ $NUM -eq $NUM ] 2>/dev/null; then
    :
  else
    echo " $NUM is not a number"
    continue
  fi
  if [[ $(( $NUM % 2 )) -eq 0 ]]; then
    echo " $NUM is an even number"
    continue
  fi
  echo " $NUM is an odd number"
  break
done
```

Bash scripting – Functions

```
#!/bin/bash                                                    # script03.sh
function func {                 # shell function
  echo "use func for $1"
  return
}

echo "step 1"
func "step 2"
echo "step 3"
```

- Useful for sequence of commands that is often repeated
- Functions can also take arguments
- Example using functions defined in another file: `script03a.sh` and `script03b.sh`

Bash scripting – Debugging

- How to detect and handle errors in a script?

- Each finished command has an **exit status** – by convention:
  - success → exit status **0**
  - error → exit status **non-zero** – *the status values can differ for each command*

- The special variable **$?** holds the last process' exit status:

```
$ ls existing_file
existing_file
$ echo $?
0
$ ls missing
ls: cannot access missing: No such file or directory
$ echo $?
2
```

Bash scripting – Debugging

- Debugging a script = inspecting the commands that it executes

- Put `set -x` at the beginning of your script
  - will print out all steps as they are executed
  - it's a way to follow what's going on if your script behaves unexpectedly

- Alternatively, use `set -e -u`
  - will stop the script if any command fails
  - or when an empty variable is used

- For more info info on debugging, check Debugging Bash scripts
- For other options to use with the `set` command, see Bash options

The end

Course feedback

- Please fill in our short questionnaire before Mar 13
- Let us know what you liked and how we can improve our courses
- *Thank you for your participation!*

Some links

- The Linux Command Line (downloadable book by William Shotts, 6th edition, 2024)
- Introduction to the GNU/Linux and UNIX command line (legacy)
- The (GNU) Bash Reference Manual
- Greycat's Wiki Bash Guide and FAQ and Reference Sheet
  - Bash Pitfalls – common mistakes made by bash users
- The Linux Documentation Project (TLDP)
  - Advanced Bash-Scripting Guide (by Mendel Cooper)
- Covering various Linux topics: Let's talk Linux @ How-To Geek, OMG! Ubuntu, …
- Cheat sheets via cheatsheets.zip or devhints.io

More training

- HPC core facility CalcUA
  - HPC@UAntwerp introduction
  - More Linux commands
- VSC Trainings
  - trainings organized by other VSC sites and abroad (including LUMI, PRACE, EUROCC)