A brief introduction to the bash shell

Presented for QLSC 612, Fundamentals of Neuro Data Science 2023 by Brent McPherson. Installation and exercise help with Alyssa Dai.

Based on the excellent previous versions of this lecture by Ross Markello, Sebastian Urchs, and Jacob Sanz-Robinson from as far back as 2020 as well as material from the Software Carpentries "Introduction to the Shell" course.

Before we get started...

The materials for this lecture live in the subdirectory `QLS-course-materials/Lectures/02-Terminal_and_Bash` inside the QLS-course-materials directory you previously cloned. In your home directory (e.g., `/home/user-name` or `/Users/user-name`), also create an extra copy of the specific dataset we'll be working with, called `shell-course`, by typing the following command into your **terminal**:

```
cp -R ~/QLS-course-materials/Lectures/02-Terminal_and_Bash/shell-course ~
```

This will be the directory you will play around with, located at `~/shell-course` on your computer.

(We'll learn more about what the above command means shortly!)

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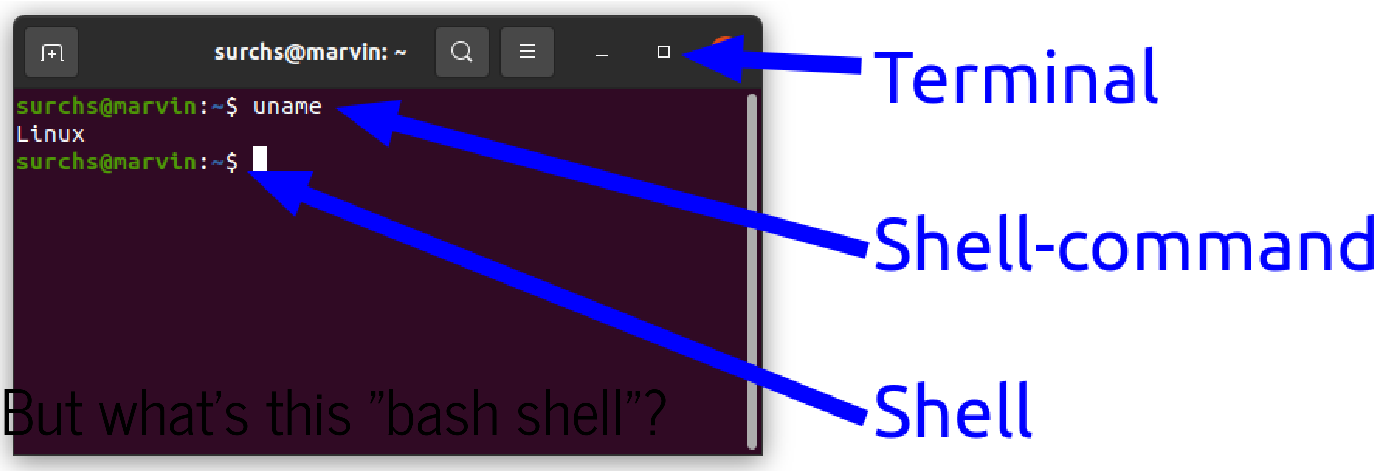
- A command-line shell runs inside a terminal that let's you type text
    - we call this a **command-line interface** (CLI), because you type commands in a line of text
    - this is in contrast to a **graphical user interface** (GUI) that you typically use
- command-line shell programs expect you to write **commands in a scripting language**



But what's this "bash shell"?

It's one of many available shells!

- `sh` - Bourne **SH**ell
- `ksh` - **K**orn **SH**ell
- `dash` - **D**ebian **A**lmquist **SH**ell
- `csh` - **C SH**ell
- `tcsh` - **T**ENEX **C SH**ell
- `zsh` - **Z SH**ell
- `bash` - **B**ourne **A**gain **SH**ell <-- We'll focus on this one!

WHY SO MANY?!

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- They all have different strengths / weaknesses
    - Some have more interactive support, others have more useful scripting features
- You will see many of them throughout much of neuroimaging software, too!
    - `sh` is most frequently used in FSL
    - `csh` / `tcsh` is very common in FreeSurfer and AFNI

So we're going to focus on the bash shell?

Yes! It's perhaps **the most common** shell, available on almost every OS:

- It's **the default** shell on most Linux systems
- It's the default shell in the Windows Subsytem for Linux (WSL)
- It's the default shell since Mac <=10.14
    - `zsh` is the new default on Mac Catalina (for licensing reasons 🙄)
    - But `bash` is still available!!

Alright, but why use the shell at all?

Isn't the GUI good enough?

- The GUI is great, but the shell is **very powerful**
- Some tasks take many "clicks" in a GUI, the shell is often extremely good at automating these
    - these steps can be hard - or impossible - to reliably reproduce
- You can write sequences of shell commands to connect the outputs of programs to other programs (pipelines)
- You can store the shell commands you used in a script file and execute them again later
    - this is a great way to document what you have done
    - it makes your work reproducible in a way that describing the "clicks" could not
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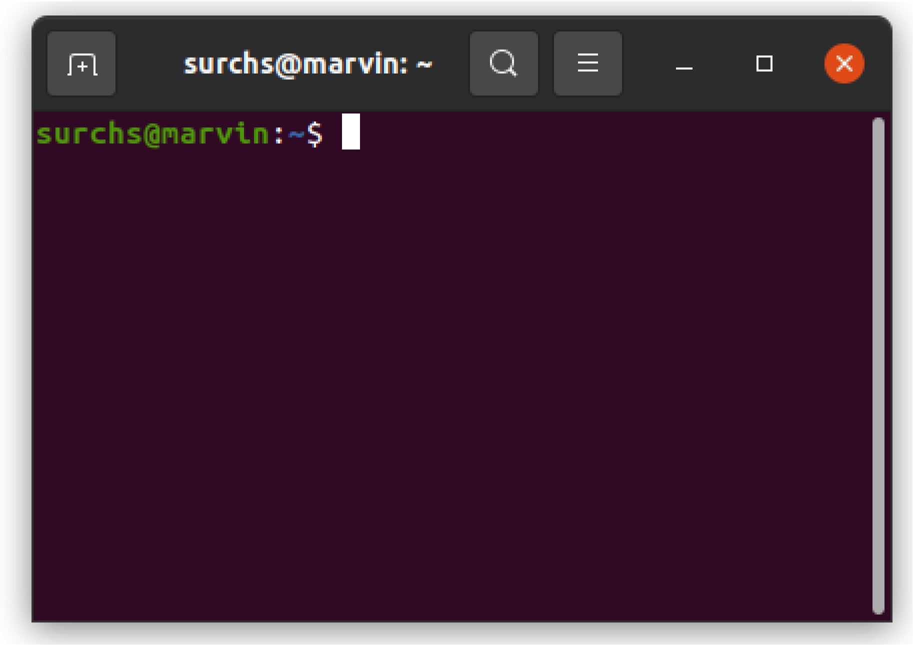
NOTE: We will not be able to cover all (or even most) aspects of the shell today.

But, we'll get through some *basics* that you can build on in the coming weeks.

The (bash) shell

Now, let's open up your terminal!

- **Windows**: Open the Ubuntu (WSL) application
- **Mac/Linux**: Open the Terminal application



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IMPORTANT: When typing commands, either in this lesson or from other sources, **do not type the prompt**, only the commands that follow it!

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Voila! You're now in the bash shell.

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Voila! You're now in the bash shell.

Note: We just ran our first shell command!

The `echo` command does exactly what its name implies: it simply echoes whatever we provide it to the screen!

(It's like `print` in Python / R or `disp` in MATLAB or `printf` in C or ...)

What’s with the `$SHELL`?

- Things prefixed with `$` in bash are (mostly) **environmental variables**
    - All programming languages have variables!
- We can assign variables in bash but when we want to reference them we need to add the `$` prefix
- We'll dig into this a bit more later, but by default our shell comes with some preset variables
    - `$SHELL` is one of them and it stores the path to the shell program that currently interprets our commands

Working within the Shell

- There is a *lot* of typing that happens when you're working in a Terminal
- The two most important time saving tips are:
    1. **Tab Completion**: Press the `Tab` button to fill in the available options.
    2. **Command History**: Press ↑ (up) to cycle through the previously entered commands.

There are also a bunch of shortcuts while holding the control (CTRL) key. Like:

- `CTRL` + C - end current process
- `CTRL` + A / E - go to the beginning / end of the current line
- `CTRL` + L - clear the terminal
- `CTRL` + K - delete to end of line
- `CTRL` + R - search command history (this has other navigation keys to help)
- `CTRL` + D - exit the session

There are many tools, techniques, and shortcuts you can learn when working in a Terminal. Definitely explore and look on your own for solutions to problems or pain points you have - someone has probably already solved it!

Navigating Files and Directories

- The **file system** is the part of our operating system for managing files and directories
- There are a lot of shell commands to create/inspect/rename/delete files + directories
    - Indeed these are perhaps the most common commands you'll be using in the shell!

So where are we right now?

- When we open our terminal we are placed *somewhere* in the file system!
    - At any time while using the shell we are in exactly one place
- Commands mostly read / write / operate on files wherever we are, so it's important to know that!
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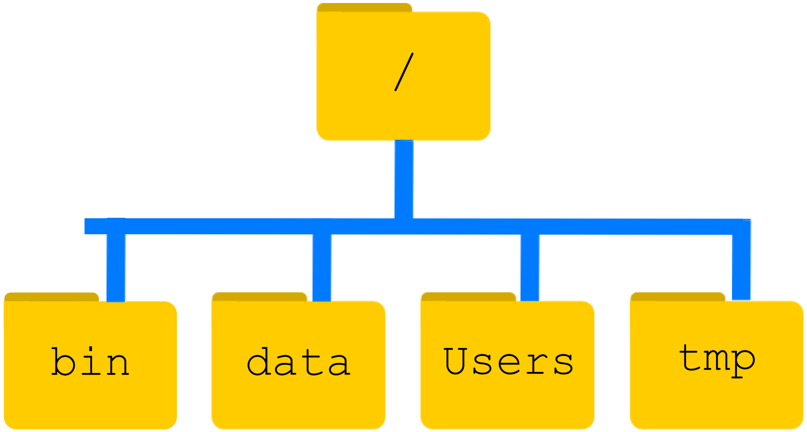
- Many bash commands are acronyms or abbreviations (to try and help you remember them).
    - The above command, `pwd`, is an acronym for "**p**rint **w**orking **d**irectory">

Let's look at the file system

Let's take a look at an example file-system (for a Macintosh):



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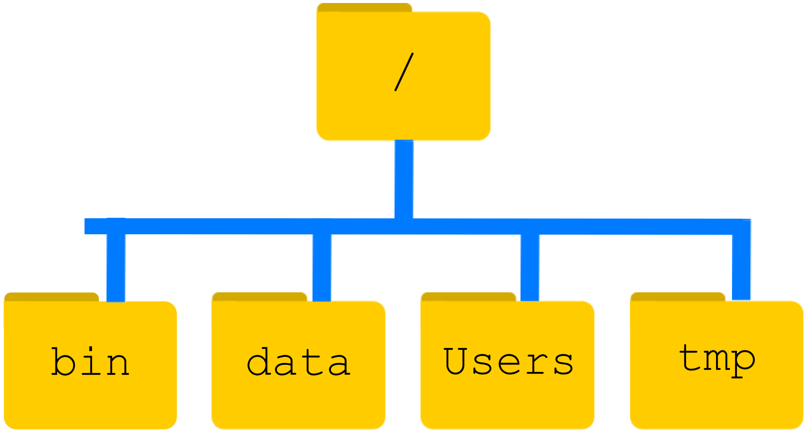

- The top (`/`) is the **root directory**, which holds the ENTIRE FILE SYSTEM.
- Inside are several other directories:
    - `bin` contains some built-in programs
    - `data` is where we store miscellaneous data files
    - `Users` is where personal user directories are
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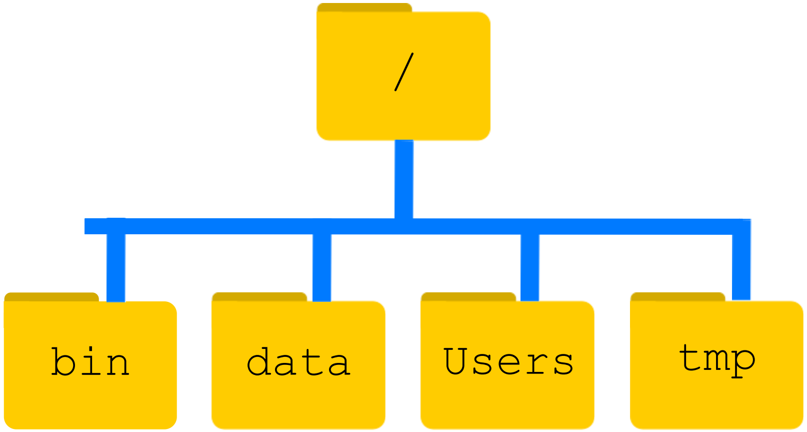

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Note: The filesystem on a Linux machine will have slightly different directory names (e.g. `/Users` is typically `/home`) but the same principles apply.

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We are inside the `home` directory (e.g. `User` on Mac) for the user `bcmcpher` (me) and in a sub-directory called `shell-course`.

Let's see what is in here

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`ls`, as we saw before, prints the contents of your **current working directory**.

We can make it tell us a bit more information about our directory by providing an **option** to the `ls` command

General syntax of a shell command

Consider this command (where we are looking inside the `interesting_files` directory) as a general example:

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We have:

1. A **command** (`ls`),
2. An **option** (`-F`), also called a **flag** or a **switch**, and
3. An **argument** (`interesting_files`)

Options (a.k.a. flags, switches)

- Options change the behavior of a command
- They generally start with either a `-` or `--`
- They are case sensitive!
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- These tell the command what to operate on!
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If we do not give `ls` an argument, it will list the contents of the current working directory.

So many options, where can I find help

Either `man ls` or `ls --help`!

This will vary depending on: (1) the command and (2) your operating system!

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We can do more than list directories

So many interesting things to see, let's change to a different working directory so we can do things there.

- The `cd` or "change directory" command will let us do that

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We are back in our home directory! This is *incredibly* useful if you've gotten lost.

- `cd` without arguments brings you to your home directory
- the `~` (tilde) character is a shorthand for your home directory. So `cd ~` also brings you there
- the `-` (dash) character is a shorthand for the previous directory you were in. So `cd -` brings you back to where you just were

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We can string together paths with the `/` separator instead of changing one directory at a time! Because the path we gave to `cd` did not start with the file system root directory (`/`), it was interpreted as a relative path, i.e. in reference to the home directory that we called `cd` from.

Relative versus absolute paths

So far, we have been using **relative** paths to change directories and list their contents.

- A **relative** path is **relative to the current working directory**. It does **not** begin with the file system root (`/`).
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Here, `..` refers to "the directory containing this one". This is also called the **parent** of the current directory.

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`ls` is supposed to list the contents of our directory, but we didn't see `..` anywhere in the listings from before, right?

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```
ls -a
```

The `-a` argument (show **a**ll contents) will list ALL the contents of our current directory, including special and hidden files/directories, like:

- `..`, which refers to the parent directory
- `.`, which refers to the current working directory

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The last command also revealed a `.i_am_hidden` file:

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The `.` prefix is usually reserved for configuration files, and prevents them from cluttering the terminal when you use `ls`.

Summary

- The file system is responsible for managing information on the disk
- Information is stored in files, which are stored in directories (folders)
- Directories can also store other (sub-)directories, which forms a directory tree
- `cd path` changes the current working directory
- `ls path` prints a listing of a specific file or directory; `ls` on its own lists the current working directory.
- `pwd` prints the user’s current working directory
- `/` on its own is the root directory of the whole file system
- A relative path specifies a location starting from the current location
- An absolute path specifies a location from the root of the file system
- `..` means "the directory above the current one"; `.` on its own means "the current directory"

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```

Creating a directory

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Since we provided a relative path, we can expect that to have been creating in our current working directory:

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```

(You could have also opened up the file explorer and made a new directory that way, too!)

Good naming conventions

1. Don't use spaces
2. Don't begin the name with `-`
3. Stick with letters, numbers, `.`, `-`, and `_`
    - That is, avoid other special characters like `~!@#$%^&*()`

Creating a text file

Let's

- navigate into our (empty) `notes` directory (with `cd`)
- confirm that it is in fact empty (with `ls`)
- and create a new file. For this we can use `nano`

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In [ ]:
```
cd notes
```

In [ ]:
```
# nano my_note.txt
```

`nano` is a useful command-line **text editor**. It only works with plain text (i.e., no graphs, figures, tables, or images!)

(You may be familiar with graphical editors like Gedit, Notepad, or TextEdit, or other command line editors like Emacs or Vim.)

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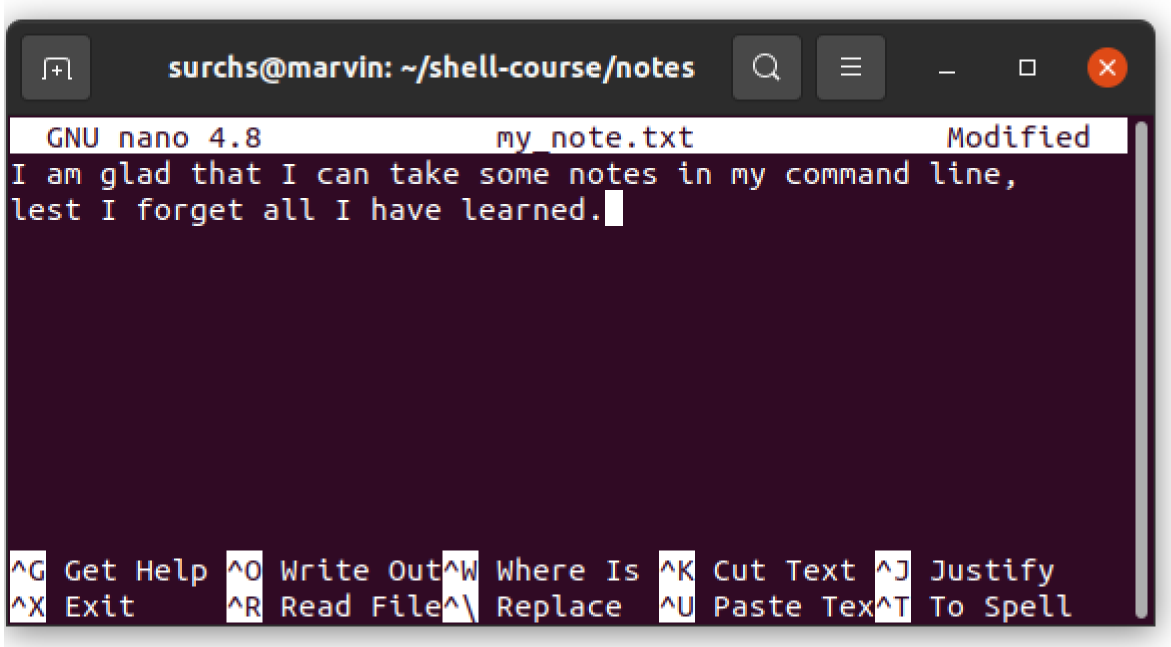

`nano` uses the Control (CTRL) and ALT key to make changes. The command help along the bottom of the editor window refers to these keys with abbreviations:

- `^` for CTRL: `^G` means "press and hold CTRL together with the `G` key"
- `M` for ALT: `M-U` means "press and hold ALT together with the `U` key"

Let's save our note with `^O`, i.e. `CTRL+O` (the letter o)

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You can also use `touch` to create an empty text file or update the access time on an existing one

Moving files and directories

Let's first go back up to our `shell-course` directory

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In [ ]:
```
cd /home/bcmcpher/qlsc612/qls612-git/Lectures/02-Terminal_and_Bash/shell-cour
```

Moving files and directories

Let's first go back up to our `shell-course` directory

In [ ]:
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cd /home/bcmcpher/qlsc612/qls612-git/Lectures/02-Terminal_and_Bash/shell-cour
```

In [ ]:
```
ls
```

Moving files and directories

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Let's look into this `dir_of_doom`.

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In [ ]:
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ls -F the_wrong_dir
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```

In [ ]:
```
ls -F
```

In [ ]:
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All of these files are in the wrong directory.

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The first argument of `mv` is the file we're moving, and the last argument is where we want it to go!

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In [ ]:
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We can provide more than two arguments to `mv`, as long as the final argument is a directory! That would mean "move all these things into this directory".

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In [ ]:
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mv the_wrong_dir/my_file2.txt the_wrong_dir/my_file3.txt the_right_dir
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We can make our life easier by using wildcards! Wildcards are simple patterns that can match any character in a file name:

- `*` (the asterisk) will match any character 0 or more times. i.e. `*.txt` will match both `a.txt` and `any.txt` (any file ending in `.txt`)
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```
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We can use wildcards to move any file that fits our pattern so we don't have to type each individual file name.

In [ ]:
```
ls the_right_dir/my_file?.txt
```

Note: `mv` is **quite dangerous**, because it will silently overwrite files if the destination already exists! Refer to the `-i` flag for "interactive" moving (with warnings!).

Copying files and directories

The `cp` (**c**o**p**y) command is like `mv`, but copies instead of moving! Let's use it to make a backup of the files in `the_right_dir`

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In [ ]:
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```

In [ ]:
```
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```

Let's confirm we have copied the file into `backup` and it is also still in `the_right_dir`. We could run two `ls` commands, but we can also just use a wildcard to look inside all directories!

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Let's confirm we have copied the file into `backup` and it is also still in `the_right_dir`. We could run two `ls` commands, but we can also just use a wildcard to look inside all directories!

In [ ]:

```
ls */my_file1.txt
```

Let's copy the complete `the_right_dir` to `backup`

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In [ ]:
```
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In [ ]:
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ls backup
```

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```
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The `rm` command deletes files. Let's check that the file is gone:

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The `rm` command deletes files. Let's check that the file is gone:

In [ ]:
```
ls
```

Deleting is **FOREVER** 💀💀

- The shell DOES NOT HAVE A TRASH BIN.
- You CANNOT recover files that have been deleted with `rm`
- But, you can use the `-i` flag to do things a bit more safely!
    - This will prompt you to type `Y` or `N` before every file that is going to be deleted.

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Let's try and remove the `the_wrong_dir`:

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```

Because **deleting is forever** 💀💀, the `rm -r` command should be used with GREAT CAUTION.

You can also use `rmdir` to remove an empty directory. This will remove a folder only if it's empty.

Summary

- `cp <orig> <new>` copies a file
- `mkdir <path>` creates a new directory
- `mv <old> <new>` moves (renames) a file or directory
- `rm <path>` removes (deletes) a file
- `touch <file>` creates an empty text file or updates the access time of an exising file
- `*` matches zero or more characters in a filename, so `*.txt` matches all files ending in `.txt`
- `?` matches any single character in a filename, so `?.txt` matches `a.txt` but not `any.txt`
- The shell does not have a trash bin: once something is deleted, it’s really gone

Finding things with the shell

Oftentimes, our file system can be quite complex, with sub-directories inside sub-directories inside sub-directories.

What happens in we want to find one (or several) files, without having to type `ls` hundreds or thousands of times?

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ls
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Unfortunately, this doesn't list any of the files in the directories. But we know from our previous exploration that there there are files and sub-directories. We can display the full sub-directory tree with the `tree` command:

Note - `tree` *may not be installed by default. We will cover installing it in the exercises.*

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In [ ]:
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```

`tree` has options to display additional information, only show a certain depth of the tree and even filter certain file names. But if we are searching for a certain file name pattern, there is a better tool for us:

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In [ ]:

```
find . -name 'my_*'
```

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In [ ]:
```
find . -name 'my_*'
```

Remember, `.` means "the current working directory".

Here, `find` begins the search in the current working directory and then traverses the entire directory structure. With the `-name` option, we specify a pattern that includes a wildcard to specify the names we are looking for.

One of the results here is a directory. We can filter the results further by specifying that we only want to see **f**ile matches.

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One of the results here is a directory. We can filter the results further by specifying that we only want to see **f**ile matches.

In [ ]:
```
find . -name 'my_*' -type f
```

Finding things inside of files

Searching for files and directories based on their names and meta-data is helpful, but often it is interesting to search inside a file as well.

For this, we can use `grep`. This is an abbreviation for "**g**lobally search for a **r**egular **e**xpression and **p**rint matching lines". If you can't remember this, just ask `whatis grep`.

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Let's take a look in `hello_world.txt` and then use `grep` search for what we find inside.

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In [ ]:

```
cat helloworld.txt
```

In [ ]:

```
grep "Bash" helloworld.txt
```

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```
grep "rabbit" -i --count --no-messages flying_circus/*
```

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OK, only one of these files seems to have any mention of rabbits in it. We can use `man` to understand the options used here.

Note that the file `dangerous_rabbits.txt` was not a match, even though the file name contains "rabbit"

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In [ ]:
```
man grep
```

Context: passing information with pipes

A strength of using the shell is that you can connect the output of one command to the input of another command. To do so, you can use the `|` (pipe) character. When you connect commands together with the pipe (`|`) operator, we can the entire statement a **pipeline**.

Pipelines take the general form of:

`command1 -flags arguments | command2 -flags arguments`.

Let's say we want to use grep to search for the occurence of a word that we think could be quite common, like "Ni". We could just print all of the matches. But maybe we want to see the 10 last occurences. A pipe allows us to take the output of `grep`, and give it to another command, `tail`, that does just that.

Let's say we want to use grep to search for the occurence of a word that we think could be quite common, like "Ni". We could just print all of the matches. But maybe we want to see the 10 last occurences. A pipe allows us to take the output of `grep`, and give it to another command, `tail`, that does just that.

In [ ]:
```
whatis tail
```

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In [ ]:
```
whatis tail
```

In [ ]:
```
grep "Ni" --no-messages flying_circus/the_holy_grail.txt -nH | tail -n 10
```

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In [ ]:

```
whatis tail
```

In [ ]:

```
grep "Ni" --no-messages flying_circus/the_holy_grail.txt -nH | tail -n 10
```

`grep` and `tail` are two commands that each do a very specific thing. This is generally the case for shell commands on Unix systems, i.e. they follow the "Unix philosophy" of doing a single thing well. Pipes are a great way to combine the functionality of several commands to do what you want.

Note: in this example, we could have also used additional options for `grep` to achieve the same result without using a pipe.

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Very interesting.

Summary

- we can print the structure of any given directory with `tree`
- `find` is a great tool to search for files and directories based on their name and other meta-data like size, age, and so on
- `grep` is a great tool to search within (text)files for occurences of a given string or even complex regular expressions
- pipes (`|`) allow us to combine the output of one command with the input of another command

Scripts and variables

One of the most powerful functions of using the shell is that you can write your commands into a text file called a shell script, and then ask the shell to execute each command in the script in sequence.

This is very helpful if you want to

- run the same set of commands repeatedly (e.g. every time you log into your computer)
- keep a detailed record of what commands you used to create an output
- share a set of commands with someone, or run their commands

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cd interesting_files
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ls -F
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Anatomy of a shell script

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A shell script needs to contain two things:

- the `#!/bin/bash` statement in the line 1 is called a hash-bang (shebang) and declares what shell program shall be used to execute this script. Here we use the bash shell
- the `echo "Thank you, very kind!"` statement in line 4 is the shell command - this is what gets executed.

Lastly there is

- The statement `#` in line 3 is a comment. The `#` (hash) will prevent the remaining text in this line from being executed. This is a good way to explain in human readable form what your script does
- our text file also uses the file ending `.sh` to show that it is a shell script

Anatomy of a shell script (contd.)

However, in order to run (i.e. "execute") the script, the right content is not enough. Our script file must also have the right permission.

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Where does the shell it look for these programs?

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These are the directories our current shell is looking inside.

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So which of these directories is e.g. `ls` inside of? Lucky for us, there is a shell command to tell us. It is called `which`:

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`which` is a great helper tool to see which command you are currently calling. This can be immensely helpful when you have multiple versions of a tool with the same name in different locations (e.g. different python versions).

We can also call `ls` by using its absolute path. The shell just normally resolves this for us.

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In [ ]:

```
/usr/bin/ls
```

You can change the `$PATH` variable

When you start a new shell, the `$PATH` variable gets set by a number of startup files on your system. The system wide startup files are protected and you should (in most cases) not try to change them as this will affect the way your system behaves. There are also user-level startup files in your home directory where you can make changes to the `$PATH` variable (and other variables) that will just affect your shells.

For example, `/home/bcmcpher/.bashrc` is a config file where I can make changes to my `$PATH` variable to have my shell search additional directories for programs.

To take a look, we can use the tool `cat`. Again, let's check what it does.

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In [ ]:

```
whatis cat
```

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cat /home/bcmcpher/.bashrc -n | tail
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```

The statement `export PATH="$PATH:$HOME/bin"` in line 120 adds a directory `bin` in my home directory to the shell $PATH. Notice again the `:` character to separate the new from the old value.

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In [ ]:

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In [ ]:
```
echo MY_VAR
```

In [ ]:
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echo ${my_var}
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```
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```

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echo ${my_var}
```

In [ ]:
```
echo ${MY_VAR}iscool
```

A variable can be removed from your shell with `unset`.

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In [ ]:

```
unset ${my_var}
echo ${MY_VAR}
echo ${my_var}
```

You can also create your own commands

- As you work on the command line, you will find yourself reusing commands with the same set of flags.
- `alias`es are a way for you to create your own shortcut call of a command.

For example:

- `alias ll='ls -l'`
- `alias la='ls -a'`

Aliases are a useful way to customize your file interactions in the terminal. Add them to your `~/.bashrc` file to have them every time you work in `bash` on a system.

They can also help you document options of commands you don't need very often.

Two kinds of shell variables

There are two different kinds of variables in a shell:

- `shell variables` only exist inside your current shell instance. They are not shared with any programs you execute from this shell. By convention we use all lower case letters for shell variables.
- `environment variables` by contrast are shared with programs you execute in the shell. By convention we use ALL CAPS for environment variables (like `$PATH`).

Any new variable you declare (or set) starts out as a `shell variable`. To "promote" it to an environment variable, you have to `export` it. You can also "demote" an environment variable with `export -n`. You can see all of the environment variables in your shell with `printenv`.

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In [ ]:

```
printenv | tail
```

Environment variables get passed to programs

The script `i_can_see_variables.sh` is printing the value of two variables:

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Because environment variables are passed to child processes (e.g. programs) they can change the behaviour of your system. Some tools and installation procedures will ask you to modify environment variables, e.g. by editing the `.bashrc` file in your home directory.

Summary

- the shell will look for programs in your command in directories defined in the `$PATH` variable
- `$PATH` and other environment variables are set by startup files at the sytem and user level
- you can edit the startup files for your user in your home directory (e.g. `~/.bashrc`)
- more generally, you edit any variable and also create new variables
- to retrieve the value of a variable, we need the `$` character (e.g. `$VAR` vs VAR)
- there are two types of variables: "shell variables" and "environment variables"
  - only environment variables get passed to programs you call from the shell
  - you can turn a "shell variable" into an "environment variable" with `export`
- shell scripts are text files that contain shell commands to be executed in sequence
  - the first line of your script typically declares what shell should run it
  - this statement (e.g. `#!/bin/bash`) is called the shebang
- shell scripts need to have execution permission to be run. You change file permission with `chmod`
- to run a shell script or any command not in the `$PATH` you need to specify the path to the command

Overall Summary

- The `bash` shell is very powerful!
- It offers a command-line interface to your computer and file system
- It makes it easy to operate on files quickly and efficiently (copying, renaming, etc.)
- Sequences of shell commands can be strung together to quickly and reproducibly make powerful pipelines

Also consider:

- `bash` and other shells are great for many tasks, particularly when they involve changes to your files and directories
- But `bash` is not the right tool to create complex pipelines and programs like the ones needed for research analyses
- For these tasks, modern programming languages like `python` offer better error handling, control flow, debugging and other features

References

There are lots of excellent resources online for learning more about bash:

- The GNU Manual is *the* reference for all bash commands: http://www.gnu.org/manual/manual.html
- "Learning the Bash Shell" book: http://shop.oreilly.com/product/9780596009656.do
- An interactive on-line bash shell course: https://www.learnshell.org/
- The reference page of the software carpentry course: https://swcarpentry.github.io/shell-novice/reference.html