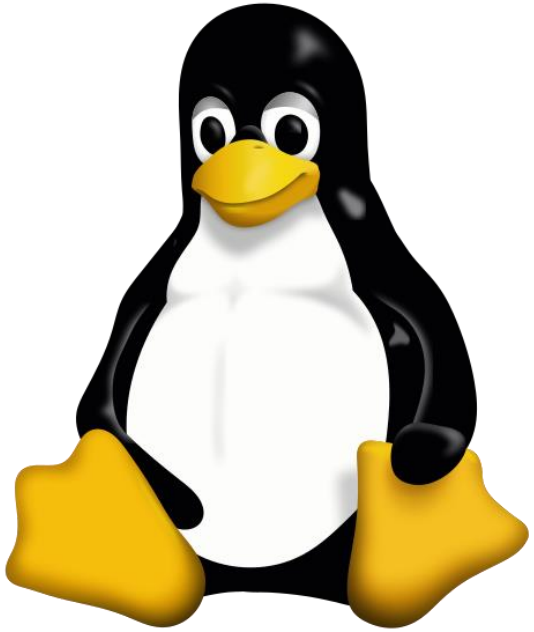
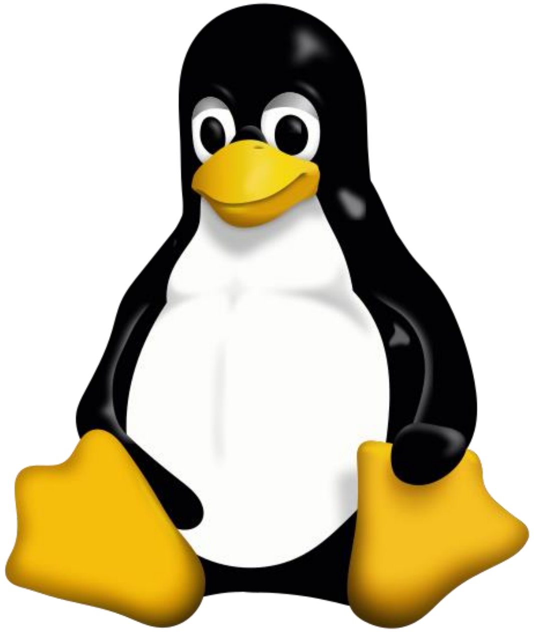
An Introduction to Unix



Types of Linux Installations



What (exactly) is Linux?

Linux™
UNIX®
00011110 00011110 00011110 00011110 00011110 00011110 00011110 00011110
FreeBSD
GNU Operating System
redhat®
ubuntu
CentOS

Linux comes in different distributions

- They vary in
  - Their choice of (non-core) software
  - Their support packages (the way software is installed for example)
  - How much non-core software they provide
  - Their frequency of update and length of support

Most Popular Distributions

- Ubuntu
  - Originally aimed at desktop users
  - Friendly and well supported
  - Regular updates (some with long term support)
  - Based on Debian

- CentOS / Alma / Rocky
  - Free versions of the RedHat commercial distro
  - Mostly aimed at servers
  - Stable software and long term support
  - Used in many large environments

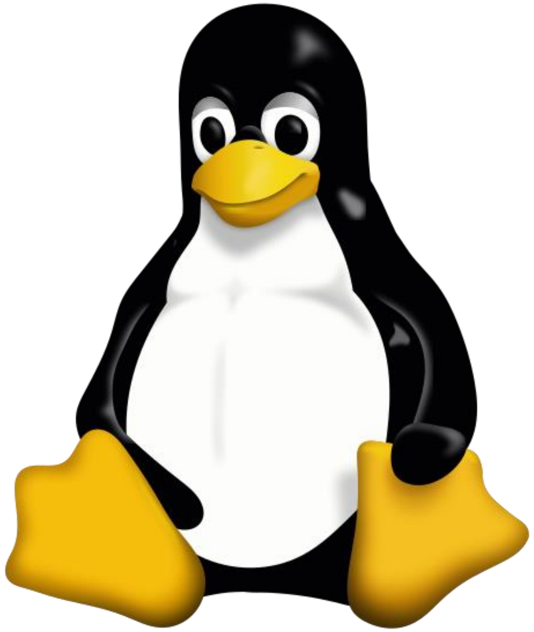
Types of Linux installation

- Bare metal
  - Physical hardware
  - CD / DVD / USB / Network installation
  - Can be physically accessible (desktop) or remote (server / cluster)

- Virtual Machine
  - Runs within another operating system
  - Portable / disposable
  - Install from ISO / Network

- Cloud
  - Virtual machine on someone else's hardware
  - Amazon / Google are the main providers
  - Range of available hardware and OS images available

Connecting to Linux Installations



Connecting to a Linux server

- Local
  - Physical keyboard / monitor connection to the machine
  - Interact with login prompt

- Remote
  - Text only – SSH
  - Graphical – SSH + X11
  - Graphical – VNC

- Authentication
  - Username + Password
  - Username + SSH key

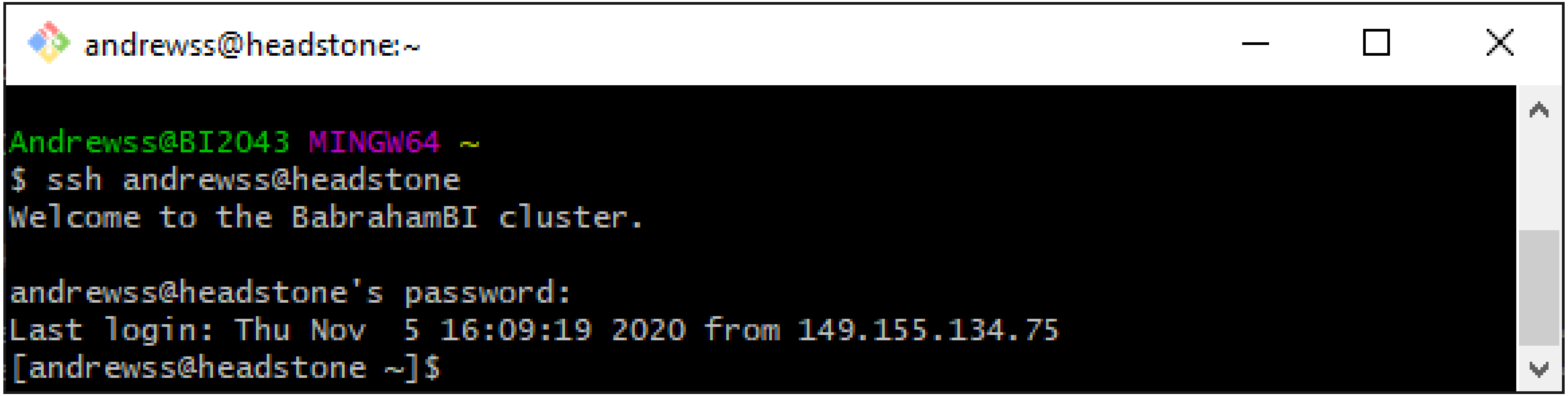
SSH Connection Software

- OSX or Linux
  - Use the terminal program which comes with the OS

- Windows
  - Git Bash (https://gitforwindows.org/) for a terminal
  - PuTTY (https://www.putty.org/) for a more graphical setup

SSH + Password connection

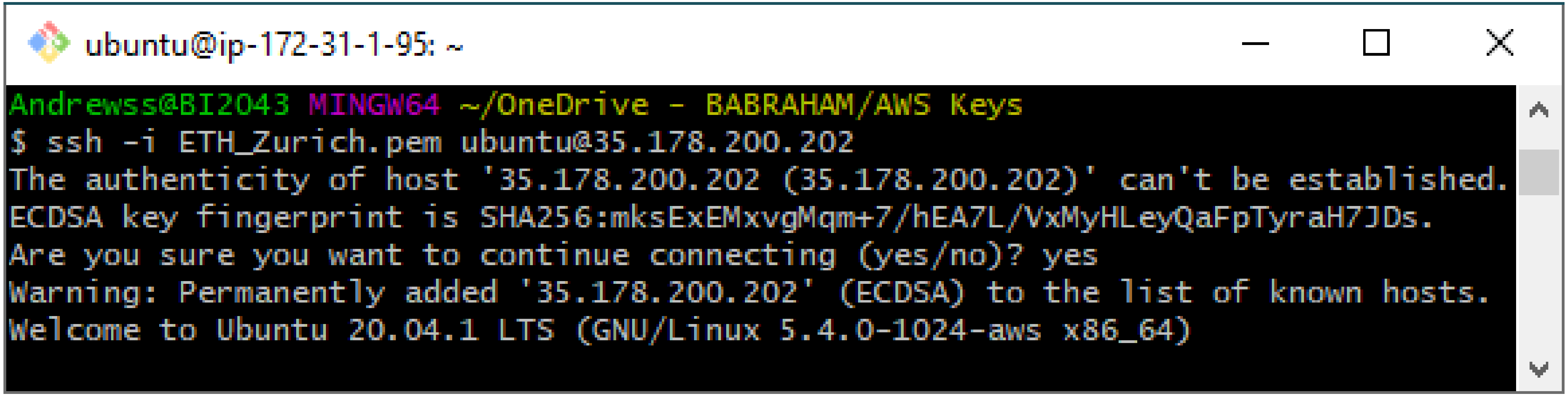
- `ssh username@server.address`
- `[Will be promoted for password]`



```
Andrewss@BI2043 MINGW64 ~
$ ssh andrewss@headstone
Welcome to the BabrahamBI cluster.

andrewss@headstone's password:
Last login: Thu Nov  5 16:09:19 2020 from 149.155.134.75
[andrewss@headstone ~]$
```

SSH + Key connection

- ssh -i [key_file.pem] username@server.address



```
Andrewss@BI2043 MINGW64 ~/OneDrive - BABRAHAM/AWS Keys
$ ssh -i ETH_Zurich.pem ubuntu@35.178.200.202
The authenticity of host '35.178.200.202 (35.178.200.202)' can't be established.
ECDSA key fingerprint is SHA256:mksExEMxvgMqm+7/hEA7L/VxMyHLeyQaFpTyraH7JDs.
Are you sure you want to continue connecting (yes/no)? yes
Warning: Permanently added '35.178.200.202' (ECDSA) to the list of known hosts.
Welcome to Ubuntu 20.04.1 LTS (GNU/Linux 5.4.0-1024-aws x86_64)
```

SSH + X11

- X11 is a system which allows a remote machine to draw windows on your local desktop
- To make it work you need:
  - To connect via SSH with an X11 tunnel enabled
  - To have a locally running X11 server program

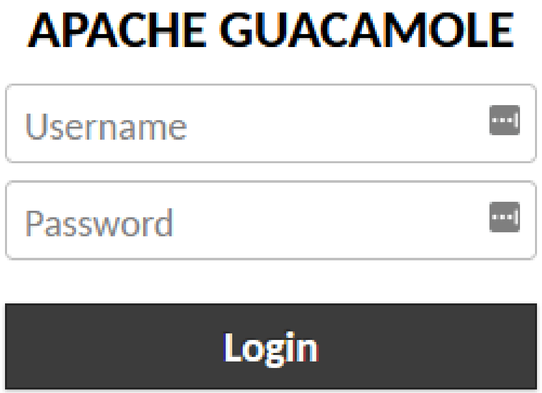
```
ssh -YC -i [key_file.pem] username@server.address
```

https://www.xquartz.org/

https://sourceforge.net/projects/vcxsrv/

VNC

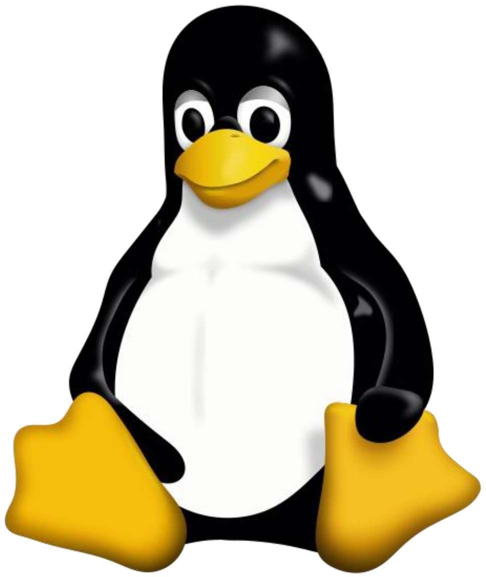
- Normally you would use a VNC client (eg TightVNC) to connect
- Simple username/password for VNC authentication
- Then provide the username/password for the account



- We are using Apache Guacamole which is a web client for VNC
- VNC authentication is handled internally
- Can just use username/password to access the desktop in a browser

Exercise 1

Running programs in the BASH shell



Launching programs in Linux

- Two major methods
  - Graphical
  - Command line

- Graphical launches only work for graphical programs accessed through a graphical environment

- Most data processing will be command line based, as will most remote access
  - Graphical programs can still be launched from the command line

Shells

- A shell is a command line interpreter, used to launch software in Linux
- There are many different shells available:
  - BASH
  - CSH
  - ZSH etc.
- Most software will work the same in all shells
- Some functions and automation are different between shells

- We will use the most popular shell, BASH

What does a shell provide

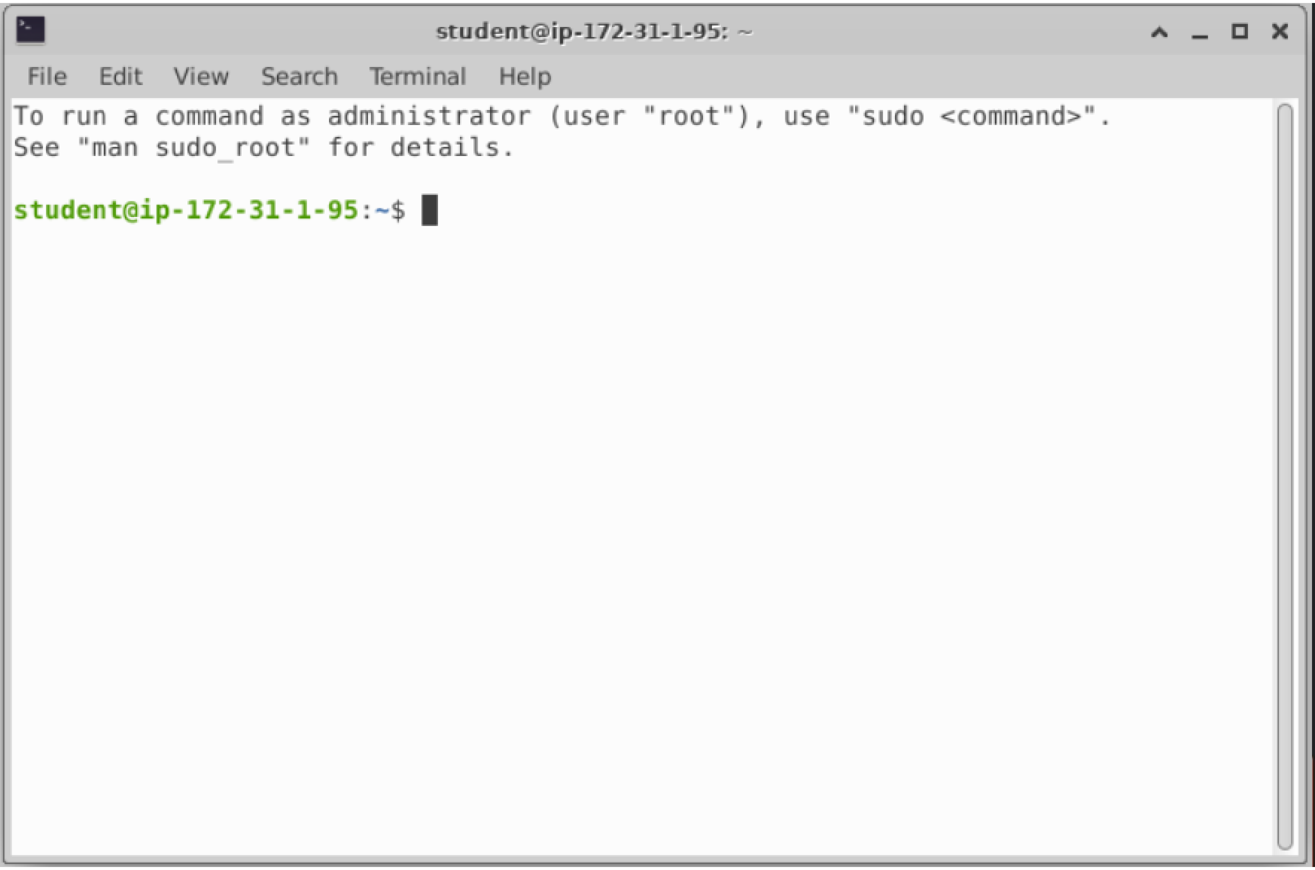
- Command line editing and construction tools (eg auto complete)
- History
- Job control
- Configuration management (startup scripts)
- Aliases

- Automation
  - Scripting language
  - Variables, functions etc

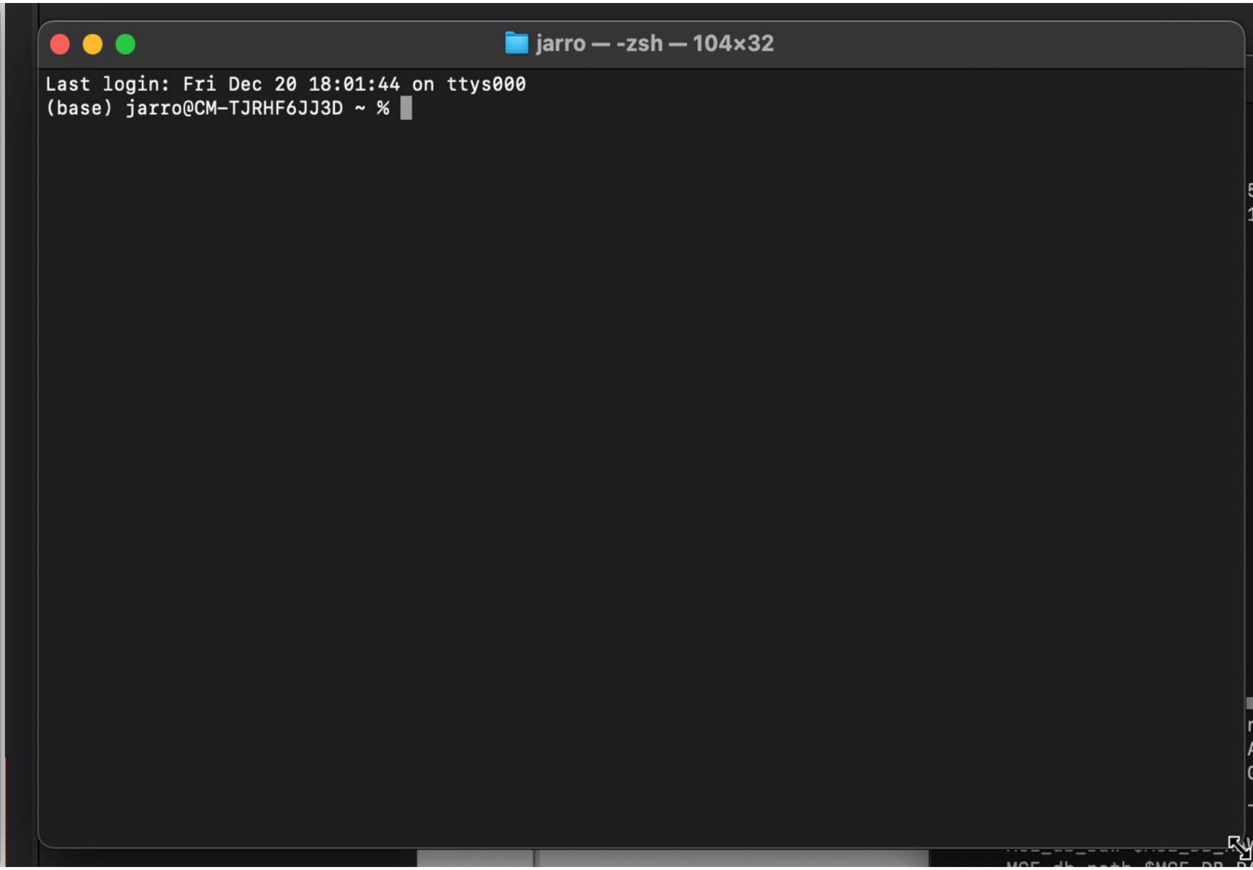
Running programs in BASH

- We will be using a graphical terminal running BASH

- Right click and select "Open terminal here“
  - ..or click the black square in the toolbar
  - ..or, from Applications menu find Terminal Emulator



```
To run a command as administrator (user "root"), use "sudo <command>".
See "man sudo_root" for details.

student@ip-172-31-1-95:~$ 
```



```
Last login: Fri Dec 20 18:01:44 on ttys000
(base) jarro@CM-TJRHF6JJ3D ~ % 
```

Running programs

- Type the name of the program you want to run
- Add on any options the program needs
- Press return - the program will run
- When the program ends control will return to the shell
- Run the next program!

Running programs

```
student@ip1-2-3-4:~$ ls
Desktop  Documents  Downloads  examples.desktop  Music
Pictures  Public  Templates  Videos

student@ip1-2-3-4:~$
```

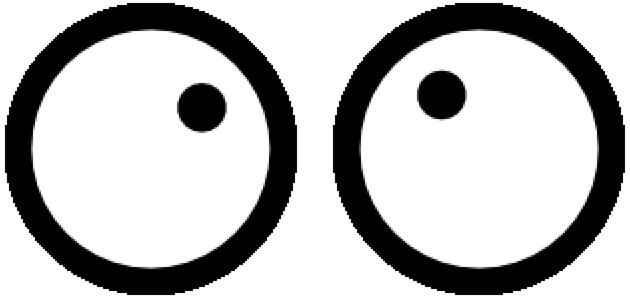
🟦 Command prompt - you can't enter a command unless you can see this

⬛ The command we're going to run (`ls` in this case, to list files)

🟩 The output of the command - just text in this case

Running graphical programs

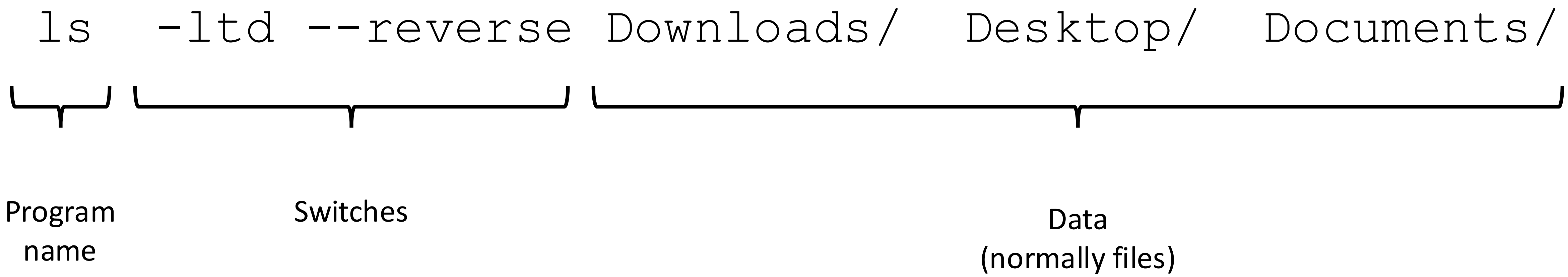
```
student@ip1-2-3-4:~$ xeyes
```



```
student@ip1-2-3-4:~$
```

Note that you can't enter another command
until you close the program you launched

The structure of a unix command



```
ls  -ltd --reverse Downloads/  Desktop/  Documents/
```

Program name

Switches

Data (normally files)

Each option or section is separated by spaces. Options or files with spaces in must be put in quotes.

Command line switches

- Change the behaviour of the program
- Come in two flavours (each option usually has both types available)
  - Minus plus single letter (eg `-x -c -z`)
    - Can be combined (eg `-xcz`)

  - Two minuses plus a word (eg `--extract --gzip`)
    - Can't be combined
- Some take an additional value, this can be an additional option, or use an = to separate (it's up to the program)
  - `-f somfile.txt` (specify a filename)
  - `--width=30` (specify a value)

Manual pages

- All core programs will have a manual page to document the options for the command

- Manual pages are accessible using the man program followed by the program name you want to look up.

- All manual pages have a common structure

Manual Pages (`man cat`)

```
CAT(1)                             User Commands                            CAT(1)

NAME
       cat - concatenate files and print on the standard output

SYNOPSIS
       cat [OPTION]... [FILE]...

DESCRIPTION
       Concatenate FILE(s) to standard output.

       With no FILE, or when FILE is -, read standard input.

       -A, --show-all
              equivalent to -vET

       -n, --number
              number all output lines

       -T, --show-tabs
              display TAB characters as ^I

       --help display this help and exit

EXAMPLES
       cat f - g
              Output f's contents, then standard input, then g's contents.

       cat    Copy standard input to standard output.
```

Help Files

- Non-core programs (including most analysis tools) won't have a manual page

- They will often have their own internal help which looks very similar

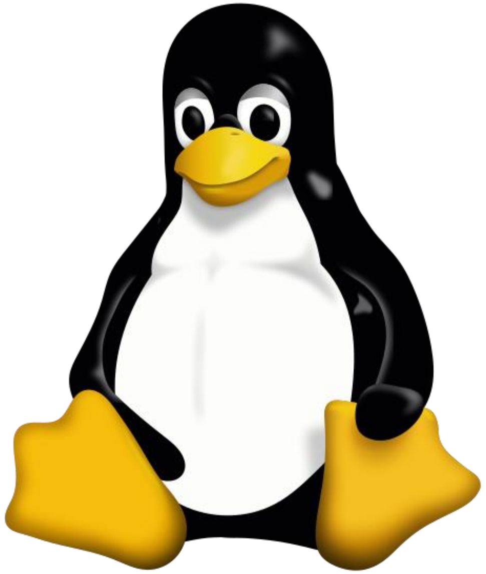
- You can usually access this using the `--help` (or `-h`) switch

Help Files (`fastqc --help`)

```
 FastQC - A high throughput sequence QC analysis tool

SYNOPSIS

        fastqc seqfile1 seqfile2 .. seqfileN

    fastqc [-o output dir] [--(no)extract] [-f fastq|bam|sam]
           [-c contaminant file] seqfile1 .. seqfileN

DESCRIPTION

    FastQC reads a set of sequence files and produces from each one a quality
    control report consisting of a number of different modules, each one of
    which will help to identify a different potential type of problem in your
    data.

 The options for the program as as follows:

    -h --help       Print this help file and exit

    -v --version    Print the version of the program and exit

    -o --outdir     Create all output files in the specified output directory.
                    Please note that this directory must exist as the program
                    will not create it.  If this option is not set then the
                    output file for each sequence file is created in the same
                    directory as the sequence file which was processed.
```

Exercise 2

Understanding Unix
File Systems



Unix File Systems

- Consists of a hierarchical set of directories (folders)
- Each directory can contain files

- No drive letters (drives can appear at arbitrary points in the file system)

- No file extensions (you can add them, but they're not required)

A simple unix filesystem

```
/   (Always the top of the file system)
  home/   (Directory containing all home directories)
    anne/
    simon/
      Documents/   (All names are case sensitive)
        test.txt   (A file we want to work with) /home/simon/Documents/test.txt
  media/
    myusb/   (A USB stick added to the system)
```

Creating and moving into directories

- Every Unix session has a ‘working directory’ which is a folder where the shell looks for file paths
- You can see your current working directory with `pwd`
- Your initial working directory will be your home directory (`/home/user`)
- You can change your working directory with `cd [new working directory]`
- Running `cd` on its own takes you back home
- You can create a new directory with `mkdir [new directory name]`

Specifying file paths

- Some shortcuts
  - ~ (tilde, just left of the return key) - the current user's home directory
  - . (single dot) - the current directory
  - .. (double dot) - the directory immediately above the current directory

Specifying file paths

- Absolute paths from the top of the file system
    - `/home/user/Documents/Course/some_file.txt`

- Relative paths from whichever directory you are currently in
    - If I'm in `/home/user/Course/`
    - `Data/big_data.csv`
        - is the same as `/home/simon/Course/Data/big_data.csv`

- Paths using the home shortcut
    - `~/Documents/Course/some_file.txt` will work for user anywhere on the system

Command line completion

- Most errors in commands are typing errors in either program names or file paths

- Shells (ie BASH) can help with this by offering to complete path names for you

- Command line completion is achieved by typing a partial path and then pressing the TAB key (to the left of Q)

Command line completion

Actual files in a folder:

```
Desktop
Documents
Downloads
examples.desktop
Music
Pictures
Public
Templates
Videos
```

If I type the following and press tab:

`De` [TAB] will complete to `Desktop` as it is the only option

`T` [TAB] will complete to `Templates` as it is the only option

`Do` [TAB] will no nothing (just beep) as it is ambiguous

`Do` [TAB] [TAB] will show `Documents` and `Downloads` since those are the only options

`Do` [TAB] [TAB] `c` [TAB] will complete to `Documents`

You should ALWAYS use TAB completion to fill in paths for locations which exist so you can't make typing mistakes

(it obviously won't work for output files though)

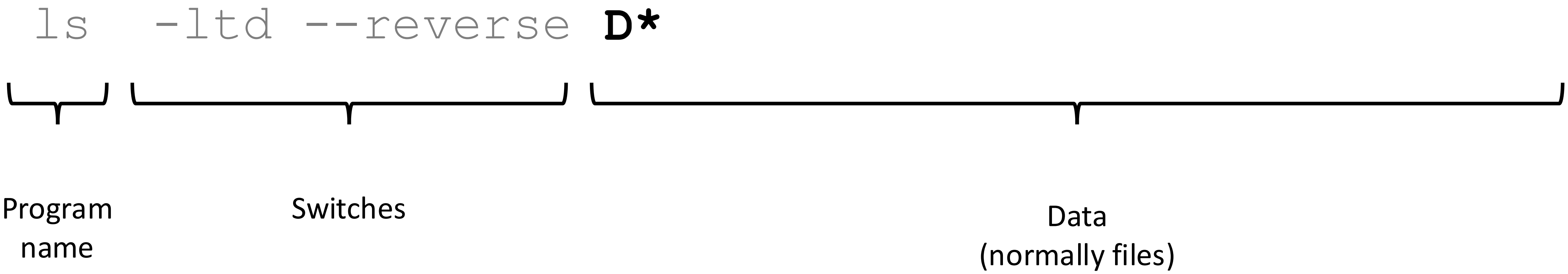
Wildcards

- Another function provided by your shell (not your application)
- A quick way to be able to specify multiple related file paths in a single operation
- There are two main wildcards
  - **`*`** = Any number of any characters
  - **`?`** = One of any character
- You can include them at any point in a file path and the shell will expand them before passing them on to the program
- Multiple wildcards can be in the same path.
- Command line completion won't work after the first wildcard

Wildcard examples

```
$ ls Monday/*txt
Monday/mon_1.txt  Monday/mon_2.txt  Monday/mon_3.txt  Monday/mon_500.txt

$ ls Monday/mon_?.txt
Monday/mon_1.txt  Monday/mon_2.txt  Monday/mon_3.txt

$ ls */*txt
Friday/fri_1.txt  Monday/mon_1.txt  Monday/mon_3.txt    Tuesday/tue_1.txt
Friday/fri_2.txt  Monday/mon_2.txt  Monday/mon_500.txt  Tuesday/tue_2.txt

$ ls */*1.txt
Friday/fri_1.txt  Monday/mon_1.txt  Tuesday/tue_1.txt
```

The structure of a Unix command



```
ls  -ltd --reverse D*
```

Program name

Switches

Data (normally files)

Each option or section is separated by spaces. Options or files with spaces in must be put in quotes.

Manipulating files

- You will spend a lot of time managing files on a Linux system.
  - Viewing files (normally text files)
  - Editing text files
  - Moving or renaming files
  - Copying files
  - Deleting files
  - Finding files

Viewing Files

- Simplest solution
  - `cat [file]` Sends the entire contents of a file (or multiple files) to the screen.

- Quick look
  - `head` or `tail` will look at the start/end of a file
    - `head -10 [file]`
    - `tail -20 [file]`

- More scalable solution
  - `less` is a 'pager' program, sends output to the screen one page at a time

Return / j	=	move down one line
k	=	move up one line
Space	=	move down one page
b	=	go back one page
/[term]	=	search for [term] in the file
q	=	quit back to the command prompt

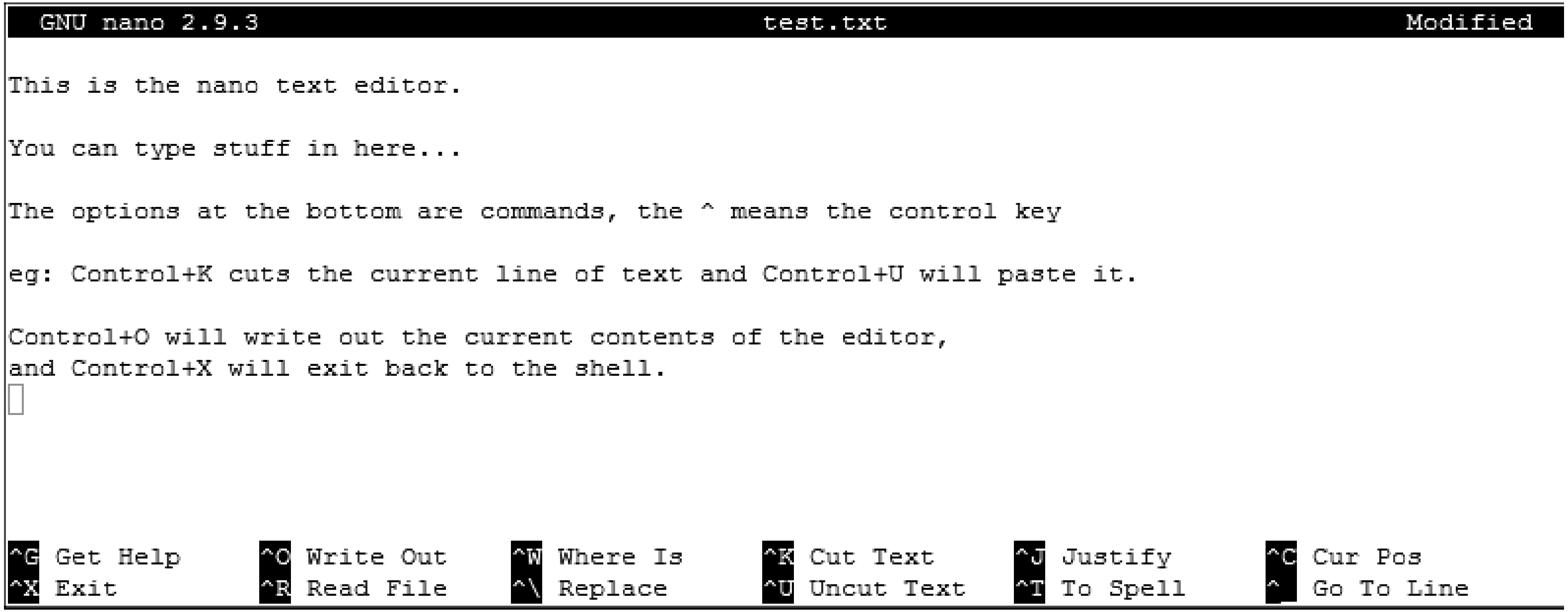
`less -S` (no wrapping)

Editing files

- Lots of text editors exist, both graphical and command line
- Many have special functionality for specific content (C, HTML etc)
- `nano` is a simple command line editor which is always present

Using nano to edit text files

- `nano [filename]` (edits if file exists, creates if it doesn't)



```
  GNU nano 2.9.3                          test.txt                              Modified

This is the nano text editor.

You can type stuff in here...

The options at the bottom are commands, the ^ means the control key

eg: Control+K cuts the current line of text and Control+U will paste it.

Control+O will write out the current contents of the editor,
and Control+X will exit back to the shell.




^G Get Help      ^O Write Out     ^W Where Is      ^K Cut Text      ^J Justify       ^C Cur Pos
^X Exit          ^R Read File     ^\ Replace       ^U Uncut Text    ^T To Spell      ^_ Go To Line
```

Moving / Renaming files

- Uses the `mv` command for both (renaming is just moving from one name to another)
- `mv [file or directory] [new name/location]`
- If new name is a directory then the file is moved there with its existing name
- Moving a directory moves all of its contents as well
- Examples
  - `mv old.txt new.txt`
  - `mv old.txt ../Saved/`
  - `mv old.txt ../Saved/new.txt`
  - `mv ../Saved/old.txt .`

Copying files

- Uses the `cp` command
- `cp [file] [new file]`
- Operates on a single file
- Can copy directories using recursive copy (`cp –r`)

- Examples
  - `cp old.txt new.txt`
  - `cp old.txt ../Saved/`
  - `cp old.txt ../Saved/new.txt`
  - `cp ../Saved/old.txt .`
  - `cp -r ../Saved ./NewDir`
  - `cp -r ../Saved ./ExistingDir/` (only if ExistingDir exists)

Linking rather than copying

- Copy duplicates the data in a file
  - Can be a problem with big data files

- Links are a way to do 'virtual' copies. You can make the same file appear in more than one place.

- Two types of link, hard links and soft (or symbolic) links
- We will always use soft links as they're more flexible.

Creating symbolic links

- Use the `ln` command with the `–s` modifier
- Usage `ln –s [from] [to]`
- Exactly the same structure as `mv`

- When you list a link you can see where it points, but you can use it like a file

```
$ cat test.txt
This is a test file

$ ln -s test.txt test2.txt
$ ls -l test2.txt
lrwxrwxrwx 1 babraham babraham 8 Sep 11 16:27 test2.txt -> test.txt

$ cat test2.txt
This is a test file
```

Deleting files

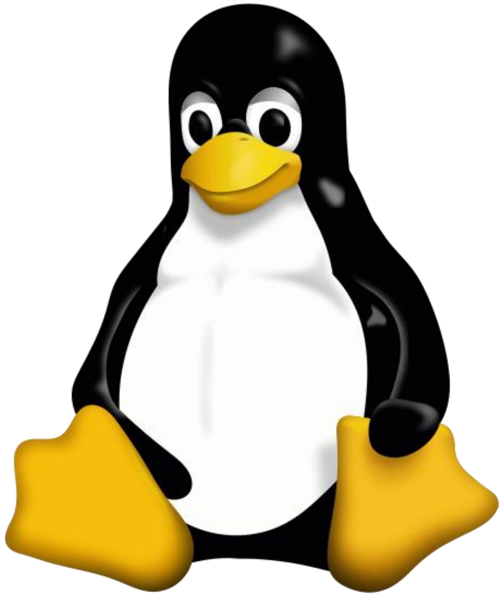
- Linux has no undo.
- Deleting files has no recycle bin.
- Linux will not ask you "are you sure"

- Files can be deleted with the `rm` command
- Directories (and all of their contents) can be deleted with `rm –r`

- Examples
  - `rm test_file.txt test_file2.txt`
  - `rm *.txt` (be VERY careful using wildcards. Always run `ls` first to see what will go)
  - `rm -r Old_directory/`

Exercise 3

More advanced BASH usage



What we know already

- How to run programs
- How to modify the options for a program using switches
- How to supply data to programs using file paths and wildcards

What else can we do

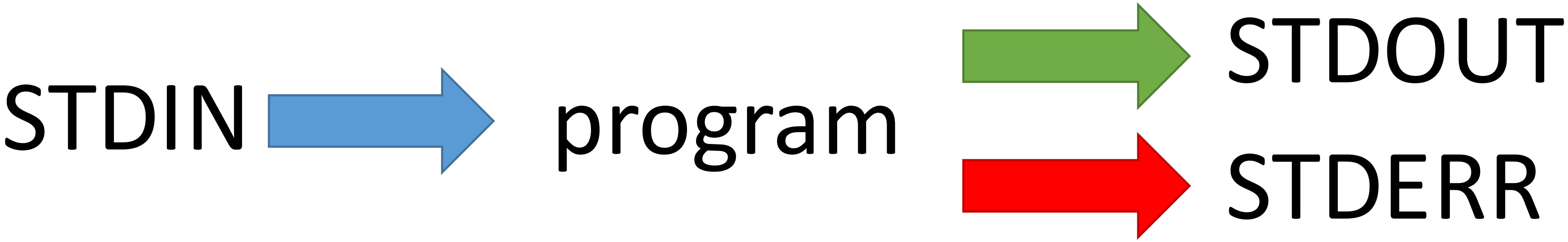
- Record the output of programs
- Check for errors in programs which are running
- Link programs together into small pipelines
- Automate the running of programs over batches of files

- All of these are possible with some simple BASH scripting

Recording the output of programs

- One of the aspects of POSIX is a standard system for sending data to and from programs.
- Three data streams exist for all Linux programs (though they don't have to use them all)
  - STDIN (Standard Input - a way to send data into the program)
  - STDOUT (Standard Output - a way to send expected data out of the program)
  - STDERR (Standard Error - a way to send errors or warnings out of the program)
- By default STDOUT and STDERR are connected to your shell, so when you see text coming from a program, it's coming from these streams.

Recording the output of programs



STDIN

program

STDOUT

STDERR

- Rather than leaving these streams connected to the screen, you can link them to either files, or other programs to either create logs, or to build small pipelines

Redirecting standard streams

- You can redirect using arrows at the end of your command
  - `> [file]` Redirects STDOUT
  - `< [file]` Redirects STDIN
  - `2> [file]` Redirects STDERR
  - `2>&1` Sends STDERR to STDOUT so you only have one output stream

```
$ find . -print > file_list.txt 2> errors.txt
```

```
$ ls
Data  Desktop  Documents  Downloads  errors.txt  examples.desktop  file_list.txt  Music  Pictures  Public  Templates  Videos

$ head file_list.txt
.
./Downloads
./Pictures
./Public
./Music
./.bash_logout
./.local
./.local/share
./.local/share/icc
./.local/share/icc/edid-33d524c378824a7b78c6c679234da6b1.icc
```

Throwing stuff away

- Sometimes you want to be able to hide output
  - STDOUT - I just want to test whether something worked
  - STDERR - I want to hide progress / error messages

- Linux defines a special file /dev/null which you can write to but just discards all data sent to it
  - `might_fail > /dev/null`
  - `chatty_app 2> /dev/null`

Linking programs together with pipes

- Part of the original UNIX design was to have lots of small programs doing specific jobs, and then to link them together to perform more advanced tasks.

- Pipes are designed to do this by connecting STDOUT from one program to STDIN on another

Linking programs together using pipes

- Pipes are a mechanism to connect the STDOUT of one program to the STDIN of another. You can use them to build small pipelines
- To create a pipe just use a pipe character | between programs

```
$ ls | head -2
Data
Desktop
```

Useful programs for pipes

- Whilst you can theoretically use pipes to link any programs, there are some which are particularly useful, these are things like:

    - `wc` - to do word and line counting
    - `grep` - to do pattern searching
    - `sort` - to sort things
    - `uniq` - to deduplicate things
    - `less` - to read large amounts of output
    - `zcat/gunzip/gzip` - to do decompression or compression

Small example pipeline

- Take a compressed fastq sequence file, extract from it all of the entries containing the telomere repeat sequence (TTAGGG) and count them

- `zcat file.fq.gz | grep TTAGGGTTAGGG | wc -l`

```
$ zcat file.fq.gz | wc -l
179536960

$ zcat file.fq.gz | grep TTAGGGTTAGGG | wc -l
3925
```

Iterating over files

- When processing data it is common to need to re-run the same command multiple times for different input/output files.

- Some programs will support being provided with multiple input files, but many will not.

- You can use the automation features of the BASH shell to automate the running of these types of programs

The BASH `for` loop

- Simple looping construct
  - Loop over a set of files
  - Loop over a set of values

- Creates a temporary environment variable which you can use when creating commands

Examples of `for` loops

```
for value in {5,10,20,50}
  do
  run_simulation --iterations=$value > ${value}_iterations.log 2>&1
done
```

```
for value in {10..100}
  do
  run_simulation --iterations=$value > ${value}_iterations.log 2>&1
done
```

```
for file in *txt
  do
  echo $file
  grep .sam $file | wc -l
done
```

Job Control

- By default you run one job at a time in a shell
  - Shells support multiple running jobs

- States of job
  - Running - foreground (shell has the attention of the job)
  - Running - background (output goes to the shell but other jobs can run)
  - Suspended - background (job exists but is paused, consumes no CPU)
  - Running - disconnected (output is no longer attached to the shell)

Job Control

- `prog_to_run` (starts in foreground)
- `prog_to_run &` (starts in background)

- Control of running jobs
  - `jobs` (lists the jobs in this shell)
  - Control + Z (suspends the current job)
  - `bg` (puts the current suspended job into the background
  - `fg [number]` (puts the selected job back in the foreground)

Job Control - nohup

- `nohup prog_to_run &`
  - Merges STDOUT and STDERR
  - Disconnects from the terminal
  - Can't be killed when the terminal exits
  - Output appended to `nohup.out`
  - Can redirect with `> logfile.txt`

Exercise 4