

FIT2014
Lab 0
Introductory Linux¹

Welcome to Lab 0 of FIT2014. This entire lab is designed to introduce you to the Linux operating system, some of its tools, and to help you become accustomed to the lab environment. You shall be using Linux for all practical work in FIT2014. Although this lab is not assessed, it is possibly the most crucial lab of the course as far as building your understanding of Linux is concerned. Please take it seriously: work carefully, and think critically about what you are doing at each step.

Linux may be unfamiliar territory for you. Even if you already have some Linux experience, you should come into the computer labs and familiarize yourself with the Linux environment **before** your scheduled lab session. In particular, you should treat the first section of this lab sheet as preparation work: **be sure to get through all of it before you arrive for class.**

This lab is only the beginning, however, as you will continue to learn about Linux and its tools over the semester. Here is some helpful, general advice:

1. Take the time to **experiment** with the work that you do. Ask yourself questions as you go along. Play with the commands and tools that you meet.
2. When you run into difficulties, try to work through them on your own or with a fellow student before seeking the help of your tutor. Any help that you eventually receive will be of greater value if you have already thoroughly thought about the problem you are tackling.

We hope you enjoy the lab and, more generally, the unit!

1 Preparation: The FIT2014 lab environment

This part of the lab will help you get started in your Linux work environment² and introduce you to the fundamental tasks that you'll need to be able to carry out while doing the unit. You should treat this section as preparation work: try to get through as much of it as possible before you arrive at your scheduled lab.

1.1 Orientation

For our work in Linux, we use the Bash shell via the desktop terminal program.³ *Bash* is an example of a *shell*, which is a program that acts as your text-based interface to the operating system. It takes your typed commands as input and displays text in response.

¹The introduction, and Section 1, are based in part on previous work by former FIT2014 tutor and Faculty of I.T. adjunct member Chris Monteith. Thanks to him, and to former FIT2014 tutor Michael Gill for some testing and updates.

²If you already have Linux installed on a laptop that you can bring to class, you're welcome to work within that environment. However, FIT2014 teaching staff are under no obligation to assist you with any problems that arise through the use of your own computer for classwork.

³Although the GUI interface would work just as well, treat this as an exercise in getting to know the basic commands and behaviour of Bash—an extremely powerful programming tool in its own right. Also, many programs are run from the terminal, including compilers, interpreters, and powerful data-processing tools. Learning to work in the terminal efficiently is **essential** to becoming a skilled Linux programmer.

Open up a terminal in your Linux desktop environment (look under “Accessories” in the “Applications” menu on the task panel). You should see the `$` prompt of the Bash shell as it awaits your command.

Spend a minute or so *experimenting*. Try pressing Return; what happens? What if you enter some spaces (then Return)? What if you enter some random text? Try the commands `pwd` and `ls`.

Files in Linux are organised into *directories*. These are arranged in a tree: every directory has one *parent directory*, and may have one or more *subdirectories*.⁴

At any given time, as you interact with Linux via Bash, you have a “current location” within this directory hierarchy. This is known as your *current directory* or *working directory*. You can find this out using the command `pwd`, for *print working directory*.

```
$ pwd
```

The output from this command is a *path*. Read from left to right, a path pinpoints a location in the filesystem by specifying the route to that location from a source reference point. In this case, the root directory `/` is used, which is the top-most location in the filesystem’s tree.

You have a special directory called your *home directory*, which is the default location of many things you do, and the usual starting point for your own subtree of directories containing your own files. It is also, by default, your initial working directory, when you first login. So, if you entered `pwd` as above, just after logging in, Linux should respond with the path to your home directory. In the current Linux system in labs, this should be

```
/srv/home/username
```

Whereas your working directory changes as you move around in Linux, your home directory is always the same.

You can find out what’s in your current directory using the *list directory* command:

```
$ ls
```

You will see a list of names of all the files and subdirectories that belong to the current directory. This list is usually in multicolumn format (i.e., several names per line). If you prefer one name per line, you can use the `-l` option:

```
$ ls -l
```

This list includes the **Documents** directory. You will need to store your FIT2014 work there, since files can be stored in this directory from week to week. To this end, we will shortly make an FIT2014 *subdirectory* here. Unfortunately, apart from the **Documents**, **Pictures** and **Desktop** directories, files elsewhere in your home directory will disappear after you logout. This is not typical of Linux systems, but we will have to work with this restriction.

You can move from one directory to another using the *change directory* command. For example, to go to the **Documents** directory, enter

```
$ cd Documents
```

You can go to the parent directory using

```
$ cd ..
```

You can go to the home directory using

```
$ cd ~
```

⁴Think about the logical implications of this statement. Is it entirely correct? If not, how would you correct it?

In fact, `~` is a standard Linux shorthand for the home directory. So, if you are elsewhere in the filesystem and want to go to your home directory, you can do `cd ~` which is easier than typing out the whole path to the home directory, as in `cd /srv/home/username`. Similarly, `.` (a single full stop) is an abbreviation for the path to the current directory, and `..` is an abbreviation for the path to the parent directory of the current directory.

You can find out what's in the root directory by going there. Try

```
$ cd /
$ pwd
$ ls
```

Now go back to your **Documents** directory. (How can you do this with as few keystrokes as possible?)

Some handy tips

With the system awaiting your next command, try pressing the up-arrow key, `↑`. This will bring back your previous command, and it's now sitting at the prompt. It won't execute until you press Return. Try pressing `↑` a few times, to run through your recent actions. Then try using `↓`, and see if the effect is what you expect. If you find a command you want to execute, hit Return.

The command `history` lists, in order, the commands you have entered recently.

Another shortcut is to press Tab *before* you have finished typing a command. If there is only one way to complete the command, then the system provides it for you without you having to type it all. Try this with `history`. How can you do this command with the fewest keystrokes?

Sometimes, a command generates so much output that it won't fit within the terminal window, and you miss it all except the last part. You can gain control over viewing the output by following the command with `| less`. For example, if `ls` generates an excessively long directory listing, try `ls | less`. (The vertical bar here is a *pipe*; we look at pipes in more detail later.) This shows you one window-full of output at a time. Press Space to go forwards, `b` to go backwards, and `q` when you have finished viewing and want to quit.

1.2 Your FIT2014 directory, and Lab 0 files

In your **Documents** directory, enter the following sequence of commands:

```
$ mkdir FIT2014
$ cd FIT2014
```

The first (*make directory*) makes a new directory for your FIT2014 work; please use it, and get into good habits of organizing your FIT2014 work properly. Then `cd` moves you into that new directory. Both commands take a path as their argument, but because we haven't specified a point of reference, the current directory is taken as the default. This is often much easier than specifying a path in terms of the root directory!

Now download the file `lab0.tar.gz` from Moodle. It should go into the **Downloads** subdirectory of your home directory. *Move* it into your FIT2014 directory:

```
$ mv ~/Downloads/lab0.tar.gz ~/Documents/FIT2014/
```

Enter the command

```
$ ls
lab0.tar.gz
```

to check that the file is in place. Now enter

```
$ tar -xvf lab0.tar.gz
lab0/
lab0/example/
lab0/example/Gadsby-para1.pl
lab0/Makefile
$ rm lab0.tar.gz
```

to unpack the lab files. The `tar` command removes the gzip compression from the file and unpacks the resulting tar archive, and `rm` tidies up by deleting the archive (with the *remove* command). As you can see, unpacking the tar file created directories and some files within them.

1.3 Using make to build submissions

The compressed archive you just downloaded and unpacked is an example of an FIT2014 assignment-workbench. One will accompany each assignment, providing you with directories for the problems, and each directory will contain files for you to complete or replace. Think of it as a template for guiding your work. Not only does this help marking by standardizing the names and locations of all solution files, it also allows us to provide you with an automated means of building your assignment submission file. You may have already noticed the mysterious file `Makefile` show up in the output of the commands that you just entered. This is a script used by the *make* command, a powerful utility for organizing and automating programming projects in Linux. Feel free to have a snoop around the workbench file-tree using some of the shell commands⁵ you used earlier.

Now that you know what the workbench contains, let's build a submission file. Head to the `lab0` directory. Load the script `Makefile` into a good text editor of your preference. If you happen to not have any particular preference, try `gedit`—a good basic editor for programming work. I'll assume from here onwards that you have decided to use it. Enter the command⁶

```
$ gedit Makefile &
```

and have a look at the script. You will notice that there are some comments to guide your use of it. Enter your ID number and surname into the file, as indicated, and be careful not to insert trailing spaces into the two fields by mistake. You should never modify any FIT2014 makefile beyond this point: you may lose work.

Your makefile is now fully configured for building submissions. Save the file and exit the text editor. Enter the command

```
$ make submission
```

You should see output indicating that the process succeeded. If you do a quick `ls`, you'll notice that the `lab0` directory has changed. Most importantly, there is a new gzipped tar archive containing a snapshot of the previous state of the workbench directory tree. This snapshot can be found in the newly-created directory that the archive derives its name from. If you want to check the files that were packaged for submission, this is the place to look. However, **do not modify this directory, or its contents, in any way**: you could end up breaking the build system, or even losing changes you make to the snapshot.

In an assignment situation, you'd now submit the archive file to Moodle. If you decide, for whatever reason, that you're not ready to submit the work, you can revert the workbench back to its pre-submission state using the command

⁵Use the path `..` to refer to the parent directory of your current location. Changing directory to this path moves you up the directory tree. You can use the `ls` command with it, too!

⁶The ampersand `&` ensures that the editor process will run in the background, which means that your Bash session won't seize up and wait for `gedit` to finish running; this trick will work with any command that you wish to run from the terminal.

```
$ make clean
```

without doing any harm to your work. Once you’ve made the required modifications, you can rebuild your submission using the earlier invocation of **make**.

If you want to find out further information on any Linux command, you can consult the manual pages (known as *manpages*), from the terminal, by simply using the **man** command. For example, to know more about listing directories, enter

```
$ man ls
```

You can navigate the document with the arrow keys; hit “q” to escape back to the shell.

2 Some useful commands and tools

Try out, and play with, each of the following commands.

The **echo** command just repeats any strings you give it, followed by a newline. For example:

```
$ echo Panini
Panini
$ echo Alan Turing
Alan Turing
$ echo "Alan Turing"
Alan Turing
```

Although this command doesn’t do much, it can be useful when playing with other commands.

You can *copy* a file using the **cp** command:

```
$ cp filename1 filename2
```

creates a new file which is an exact copy of the first file. Try this, and then use **ls** to see that the new file does indeed now exist. If you don’t want the copy after all, you can *remove* it with **rm**.

If you want to rename a file, you can *move* it:

```
$ mv filename1 filename2
```

You can cause the entire contents of a file to be output for the user to see:

```
$ cat filename
```

This is useful for displaying small files. But for longer files, the contents may pass in front of you too quickly. If the file is too large to fit in one terminal window, try **more**, which displays one screenfull at a time (press the space bar to move forwards to the next screenfull), or **less**, which is like **more** except that it also allows you to move backwards by pressing “b”.

You can also use **cat** to *concatenate* several files and display them all:

```
$ cat filename1 filename2 filename3 ...
```

The *wordcount* command gives a one-line output containing the numbers of lines, words, and characters (including newline characters) in the file. For the purposes of this command, *words* are delimited by spaces, tabs, or newlines.

```
$ wc filename
```

Now, try `wc` without any filename:

```
$ wc
```

It seems nothing happens, and you don't get a `$` prompt. In fact, the system is waiting for your input, from the keyboard. Such input is known as *standard input*. Type a few words, then Return, then a few more words, and so on. The system accepts your input but does nothing with it; you see no output. After a few lines, type Control-D. This terminates the standard input to this program. Now, `wc` gives output to the screen, giving counts of the lines, words and characters you typed in standard input.

You can *sort* the lines of a file:

```
$ sort filename
```

Note that this will not change the original file. A sorted version is shown to the user, but then disappears (in the sense that it is not stored in any file). Fortunately, we will shortly see how to retain it.

The command `uniq` removes repeated lines. So, if you have two or more identical lines in a row, all but one is removed. Lines that are identical but have other, different lines in between them are kept; neither is removed, as they are not repeats. Again, the output (with repeated lines removed) goes to the screen; the original file is unchanged. The option `-c` causes each line of the output file to have, at its start, the number of repeats of that line that there were in the input file.

3 Input, output, redirection, pipes

By default, the output from a Linux command is to the screen where it is displayed in the terminal window (*standard output*). But you can change this.

Some commands will have a specific way of nominating an output file. Examples:

- `sort` can take the name of an output file given as part of the `-o` option. So

```
$ sort inputFile -o outputFile
```

places the sorted output into file *outputFile*.

- `uniq` can take the name of an output file as a second argument. So

```
$ uniq inputFile outputFile
```

places the output in *outputFile*. Here, there is no `-o` option.

In each case, any existing file of the same name is overwritten — so take care.

To determine how output files are specified for a particular command, you need to look up its documentation (e.g., its manpage). It is instructive to try to use `sort` as above but without the `-o`, and explain what happens.

If a command or program in Linux gives output to the screen (standard output), then you can *redirect* this output to a file, say *outputFile*, by using `> outputFile`.

Whenever output goes to a file, the output is not seen by the user at that time. To see the output, the user must inspect the contents of that output file (for example, by `cat outputFile`, or by opening it with an editor).

For example,

```
$ ls > directoryList
```

places a directory listing in the file `directoryList`, rather than showing it on the screen.

You can *append* output to a file using `>> outputFile`. This means that the original contents of *outputFile* are still there, but the file is now enlarged by having the new output at the end as well. For example,

```
$ echo "The End" >> outputFile
```

puts the string “The End” (without quotation marks) at the end of *outputFile*.

Exercise: Suggest two ways to concatenate two files, placing the combination into a single new file.

You can also do *input redirection*. Some commands may wait for you to type some input to them (*standard input*). We have not seen much of this yet; all our commands so far either take no user input at all, or take input from a nominated file (although we did briefly try `wc` with standard input). If a command uses standard input, you can use `< inputFile`, after a command, to specify that the input is taken from the file *inputFile*. The command will then execute without expecting anything further to be typed by the user.

Sometimes, you want the output from one program to be used as the input to the next. You can make this happen using *pipes*, represented by a vertical bar, `|`, as follows.

```
$ command1 | command2
```

Here, *command1* is executed first, and the standard output from it (which would normally be displayed to the user) instead becomes the standard input for *command2*, which is executed second. For example,

```
$ ls | wc
```

can be used to give information on the number of files. You can have a whole series of commands, linked by pipes in this way.

4 The character translator `tr`

The command `tr` is useful when you want to *translate* characters according to a mapping you specify.

```
$ tr string1 string2
```

The meaning is that, for each position in *string1*, the character there is mapped to the character at the corresponding position in *string2*. It's like specifying a function, in mathematics, with *string1* listing the characters in the domain, and *string2* specifying what the function does to each of those characters.

If *string2* is omitted, then `tr` simply removes all characters appearing in *string1*, without replacing them by anything.

The command does not specify an input or output file. Input is from standard input, and output is to standard output.

```
$ tr abc 123  
abracadabra  
12r131d12r1
```

```
open sesame
open ses1me
Control-D
$
```

One typical application is to convert all letters to lower case.

A handy option is `-s`, for *squeeze*, which removes consecutive repeats of nominated characters. There are also special ways of defining ranges of characters and special names for commonly used character sets. Check out the manpage for details of these and other features.

You can use redirection if you want to use files for your input and/or output.

Exercise: How would you use `tr` to concatenate all the lines of a file so that the file just contains one single long line (with all line breaks removed)?

5 The stream editor `sed`

The stream *editor* `sed` enables you to transform a file, line by line, according to rules you specify. A rule specifies a *pattern* to be replaced, and what the pattern is to be replaced with. `sed` is very powerful; for a full description, see its manpage, or one of the many introductions to it such as <https://www.gnu.org/software/sed/manual/sed.html> and <http://www.grymoire.com/Unix/Sed.html>.

The most basic way to use `sed` is as follows.

```
$ sed 's/pattern/replacement/' filename
```

The text between single-quotes is called the *script*, and this gives the rule to be used on the input file, *filename*. A *pattern* can be a simple string of characters, and the *replacement* could be the string that you want it replaced by. In that case, running `sed` as above causes the first occurrence of the pattern string in each line (if such exists) to be replaced by the replacement string. Lines without the pattern string are not changed. The output goes to the screen, as usual. If you want *all* occurrences of the pattern in every line to be replaced, you can append “g” to the script:

```
$ sed 's/pattern/replacement/g' filename
```

For example, the following command replaces every occurrence of *A Lady* by *Jane Austen*:⁷

```
$ sed 's/A Lady/Jane Austen/g' filename
```

You can include special characters in these pattern strings. For example, the tab, newline and forward-slash character are represented by `\t`, `\n` and `\/`, respectively. (The latter is necessary if you want to include a forward-slash character in your pattern, since that character is also used in the script to delimit the pattern.)⁸

Patterns can be more general than just one specific string. To match any one of a set of characters, use a list within square brackets (with no commas, or other separators, between the items in the list). For example, `[aeiou]` matches any lower-case vowel. So the pattern `b[aeiou]t` matches any of the words *bat*, *bet*, *bit*, *bot*, *but*. To match a range of characters, use `[α_1 - α_2]`, where α_1 and α_2 are the first and last characters in the range. The order of characters in the range is alphabetic — or, more precisely, in order of ASCII values. So the range `[a-z]` matches any lower-case letter; `[N-Z]` matches any upper-case letter in the second half of the alphabet; and `[-&]` matches any of

⁷Jane Austen (1775–1817) is one of the most popular authors in English. 2017 was the 200th anniversary of her death. Her first novel was published under the pseudonym, “A Lady”.

⁸An apostrophe in the pattern is trickier. To match it, instead of just using a single apostrophe `'`, use `'\''`.

`#`, `$`, `%`, `&`. If you want to match any character that is *not* in some list, or range, of characters, you can put `^` just after `[`. For example, `[^aeiou]` matches any character that is not a lower-case vowel, and `[^a-zA-Z&]` matches any character that is not a letter or an ampersand.

Exercise: How would you use `sed` to remove all characters that are not letters?

Replacement strings can also be used to specify a variety of ways of replacing a string that matches the pattern. If you put `\(...\)` around some part of the pattern, then the corresponding portion of the matching string can be used, using `\1`, in the replacement string. For example, suppose you have a file of postcodes (which are four-digit numbers in Australia), one per line, whose first digits have been erroneously recorded as 2 (for NSW) when they should be 3 (for Victoria), but are otherwise correct. Then you could correct your file by

```
$ sed 's/2\([0-9][0-9][0-9]\)/3\1/' filename
```

Here, the pattern matches every erroneous postcode, and the *subpattern* in `\(...\)` matches the last three digits of the postcode. The matched string (the entire erroneous postcode) will be replaced by 3 followed by the portion of the original matched string that matches the subpattern, i.e., by the last three digits of the original postcode.

Exercise: Suppose you have a file of prices in dollars and cents, all under \$100. Use `sed` to remove all cents from the prices. Then consider how, instead, to round all prices to the nearest dollar. (This is considerably harder.)

The “1” in `\1` indicates the string that matches the *first* subpattern (counting from left to right in the pattern). You can have up to nine subpatterns, referred to in the replacement string by `\1`, `\2`, ..., `\9`. For example,

```
$ sed 's/ \([0-9]\)\/\([0-9]\) / \2\/\1 /' filename
```

takes a fraction, with single-digit numerator and denominator and a space on each side, and swaps the numerator and denominator.

Exercise: Use `sed` to insert a space between every pair of adjacent letters in a file.

6 Frequency count

Let us now combine some of the tools and skills we have learned, in order to determine frequencies of words and letters in English text. This is a common task in studying the statistical properties of human language, and is useful in data compression, machine learning and cryptography.

First, find a good source of reasonably long English text files that have little or no formatting or mark-up. For example, look at one of Project Gutenberg’s lists, <https://www.gutenberg.org/browse/scores/top>, choose a book, then choose Plain Text, and download it.

Exercises:

1. From your input file, derive one with the same words, in the same order, but with each word on a separate line.
2. From this file, find one in which each word appears only once, and is accompanied by its frequency (i.e., the number of times it occurs in the file).

- Sort the file of word frequencies in order of decreasing frequency.
- Now do a frequency count of *letters* in the file. You should give the frequency count in two separate files: one with the letters in alphabetical order, the other with the letters ranked by frequency.
- A *digraph* is a pair of consecutive letters. Do a frequency count of all *digraphs* in a file. (Overlapping digraphs are still counted separately. For example, if the file just consists of the single word `dodo`, then we have three digraphs, namely `do`, `od`, and `do`, so the frequency count should show that `do` has frequency 2 and `od` has frequency 1.)

To test your solutions, you can use small input files you write yourself, and/or the file provided in the `lab0/examples` directory. Once your method works on these small examples, try it on the large textfile you downloaded earlier.

7 Challenges

- Suppose you represent each word of a file by its position in the list of words ranked by frequency. So the most frequent word (which might be “`the`”, say) is represented by the number 1, and for all i , the i -th most frequent word is represented by the number i . If each word in your file is replaced by its corresponding number (with spaces, newlines and punctuation unchanged), how much compression of the file is achieved? It is possible to do a good estimate of this without actually implementing this compression.
- How could you convert your frequency count files to ones where the frequencies are given as percentages rather than raw counts? Do not use a spreadsheet or write a program to do this. Read more about the capabilities of some of the Linux tools we have met, and other tools such as `awk`.
- Suppose we do `ls | wc` as above, followed by a sequence of further applications of `| wc`.

```
$ ls | wc
```

```
...
```

```
$ ls | wc | wc
```

```
...
```

```
$ ls | wc | wc | wc
```

```
...
```

```
:
```

Before trying it out, can you predict how many pipes are required before the output ceases to change, and what that output will be? Having made your prediction, try it out.

What if we had started out with some other command, instead of `ls`? How would you *prove* that, for *every* Linux command, continued application of `| wc` eventually produces this same fixed output?

- Read about how *Simple Substitution* cyphers work, and show how to implement Simple Substitution using `tr`.

8 List of Linux commands for this lab

| | | | |
|---------|-------|-------|------|
| cat | ls | pwd | tr |
| cd | make | rm | uniq |
| cp | man | rmdir | wc |
| cpdir | mkdir | sed | |
| echo | mv | sort | |
| history | mvdir | tar | |