Linux Fundamentals

Enrico RUSSO <enrico.russo@dibris.unige.it>

Preliminary remarks

- we take as a reference Linux **distribution** the Ubuntu 22.04 Long-term support (LTS), codename Jammy Jellyfish, **server version** (Ubuntu Server)
    - **distributions** are **customized versions** of Linux, and the most significant differences are
        - the **software package manager** (e.g., apt, dnf, pkg, …)
        - **tools for configuring services** and keeping persistent their configurations (e.g., the network configuration manager)
        - some **paths** on the filesystem of the **tools/applications configuration files**
    - **server distros** are tailored for networks and services
        - they **do not include** a Graphical User Interface (**GUI**) and their installation involves a **minimal number of software packages**
        - they are deployed in datacenters (where servers run headless)

Preliminary remarks

- we administer each Linux server using the **shell** and a (virtual) **terminal**
  - the **shell** is a program that takes **commands** from the **keyboard** and gives them to the operating system to perform
    - many shell implementations exist but we take **bash** (or **sh**) as our reference
  - a **terminal** lets you **interact** with the **shell**
    - a **console** is generally a terminal in the **physical** sense, i.e., the primary terminal directly connected to a machine
    - a **virtual terminal** uses specific **network protocols** (e.g., telnet, ssh, …) to connect to a remote machine and allow users to interact with its shell

man and tldr.sh

`man` command in Linux is used to display the user **manual** of any **command** that we can run on the terminal

- `man [command]` (e.g., `man sshd`)

tldr pages simplified and community-driven man pages.

- https://tldr.sh/

Users and accounts

Users and groups

Linux is a **multi-user** operating system and it can deal with several users simultaneously.

- each user needs an **account**, i.e., a login and (when required) a password
- users have a **personal environment** (e.g., a home directory, a shell, ...), which can be accessed only by them (and the system administrator and everyone knowing the password)
- inside the system the user is identified by the **user ID** (**UID**) and one or more **group ID**s (**GID**)

Accounts

There are three types of accounts on a Linux system:

- **root** account: is also called superuser and would have complete and unfettered control of the system (in recent distributions often does not have a password for interactive login)
- **system** accounts: are those needed for the operation of system-specific components
- **user** accounts: provide interactive access to the system for users and groups of users

User administration files

There are four main user administration files

- **/etc/passwd**: keeps the user account information
- **/etc/shadow**: holds the encrypted password of the corresponding account
- **/etc/group**: contains the group information for each account
- ~~**/etc/gshadow**: contains secure group account information~~

Becoming root

To become **root** user **from** an **unprivileged** (normal user account) account when no root password is set, we can use the *substitute user do* command

- **`sudo -s`** (enter the password of your Ubuntu user when requested)

According to its configuration file (`/etc/sudoers`), in Ubuntu distros users that are **members of the `sudo` group** can become root user.

```
# (%)user(/group) hostname=(runas-user:runas-group) command
# members of group sudo, logged in to any hostname, may run, as any user
# or group, any command
%sudo   ALL=(ALL:ALL) ALL
```

Manage accounts and groups

Command	Description
`useradd`	adds accounts to the system
`usermod`	modifies account attributes
`passwd`	changes user password
`userdel`	deletes accounts from system
`groupadd`	adds groups to the system
`groupmod`	modifies group attributes
`groupdel`	removes groups from the system
`id`	print user and group information of specified/current user

Filesystem

Filesystem Structure

Linux uses

- a **hierarchical** file system structure (much like an upside-down tree)
- with **`root`** (**`/`**) at the base of the file system and all other directories spreading from there
- **directories** have **specific purposes** and hold the same types of information following a hierarchy standard, namely **Filesystem Hierarchy Standard** (**FHS**)

File types

The following file-system objects can be found

- **normal** (text-)**files**
- **executable** files (binary files or shell scripts)
- **directories**
- **device** files: all physical devices (hard disks, DVD, USB, …) are denoted by specific files
- symbolic or hard **links**: references to files
- **sockets**: used for inter-process communication (similar to TCP/IP sockets)
- (named) **pipes** (see later)

Filesystem Hierarchy Standard (FHS)

Path	Description
`/etc`	configuration files (disk configuration, valid user lists, groups, network configuration, hosts…)
`/dev`	device files: special files that provide an interface to a device driver (e.g., disk partitions, printers, and serial ports)
`/bin`	executable files available to all users
`/sbin`	executable files (usually for system administration)
`/lib`	shared library files
`/usr`	additional commands and data files

Filesystem Hierarchy Standard (FHS)

Path	Description
`/var`	variable-length files (e.g., log files).
`/home`	home directories
`/boot`	files for booting the system.
`/tmp`	temporary files.
`/mnt`	used to mount other temporary file systems.
`/run`	run-time variable data (e.g., running daemons)

FHS: `/proc`

`/proc` (process information pseudo-file system) is a **virtual** filesystem.

- it does not contain real files but **runtime system information** (e.g., system memory, devices mounted, hardware configuration, …)
- a lot of system utilities are simply calls to files in this directory (e.g., lsmod prints `/proc/modules`)
- by altering files located in this directory (**`/proc/sys`** or **`/sys`**) you can even read/change kernel parameters (see also **`sysctl`** command) while the system is running (see **`/etc/sysctl.conf`**).

File information

While using **`ls -lai`** command, it displays various information related to file

inode	type	permissions	# links/dir	user	group	size	date	name
1984883	d	rwxrwxr-x	3	enrico	enrico	4096	set 25 13:59	.
1969658	d	rwxr-x---	24	enrico	enrico	4096	set 25 13:10	..
1984888	b	rw-rw-rw-	1	root	root	247,0	set 25 13:05	block_device
1984887	c	rw-rw-rw-	1	root	video	246,0	set 25 13:05	char_device
1984885	d	rwxrwxr-x	2	enrico	enrico	4096	set 25 13:53	dir
1984884	-	rw-rw-r--	2	enrico	enrico	10	set 25 13:53	file
1984884	-	rw-rw-r--	2	enrico	enrico	10	set 25 13:51	hard_link
1966437	-	rw-rw-r--	1	enrico	enrico	0	set 25 13:10	.hidden_file
1984886	l	rwxrwxrwx	1	enrico	enrico	4	set 25 13:03	link -> file
1984889	p	rw-rw-r--	1	enrico	users	0	set 25 13:06	pipe
1581	s	rw-rw-rw-	1	root	root	0	set 30 16:38	snapd.socket

File ownership/permissions

- Every file/directory **belongs** to a specific **user** or a **group** of users
- Every user/group may have **permissions** to **read**, **write**, and/or **execute**

user	**group**	**others**
`rwx`	`rwx`	`rwx`

	File	**Directory**
`r`	the file can be read	the directory's contents can be shown.
`w`	the file can be modified	the directory's contents can be modified (requires the execute permission to be also set)
`x`	the file can be executed	the directory can be accessed with `cd`

File ownership/permissions: commands

- `chown [user.group] [file]`: **changes ownership** of a file or a directory
- `chmod` **changes** the `rwx` **mode** bits of a file or directory
  - **+/-**: **adds** or **removes** the mode bits
  - **u**: sets the permissions for the **owner**
  - **g**: sets the permissions for the **group** that of the owner belongs to
  - **o**: sets the permissions for the **other** users
  - **a**: sets the permissions for **all**

For example, `chmod g+w file` (add the write permission to the group owner of `file`)

u g o

type	permissions	# links/dir	user	group	size	date	name
d	rwxrwxr-x	2	enrico	enrico	4096	set 25 13:53	dir
-	rw-rw-r-- a	2	enrico	enrico	10	set 25 13:53	file

Special permissions

Run programs with **temporarily elevated privileges** in order to perform a specific task:

- user `+s` (or **SUID**): a file with SUID always **executes** as the **user who owns the file**, regardless of the user passing the command

- group `+s` (or **SGID**):
    - If set on a **file**, it allows the file to be **executed** as the **group that owns the file** (similar to SUID)
    - If set on a **directory**, any **files** created in the directory will have their **group ownership** set to that of the **directory owner**

Sticky bit:

- other `+t`: at the **directory level**, it **restricts** file **deletion**, i.e., Only the **owner** (and **root**) of a file can remove it within that directory

Filesystem commands and links

- create/remove file/dir: `touch`, `rm`, `rmdir`, `mkdir`, …
- edit files: `nano`, `vi` (to exit: press *`<Esc>`*, Press *:* and use *`q!`* or *`wq`*)
- view files: `cat`, `less`, `more`, `head`, `tail` (use `tail -f` with logs), `grep`...
- find files: `find <options> <starting/path> <expression>`
  - `find / -name passwd`: find all files with name passwd starting from /
  - `find /etc -name passwd -exec wc -l {} \;`: find files with name passwd starting from `/etc` and for each found file count lines; use `{}` within the command to access the filename
  - `locate <filename>` (`apt install mlocate` and update the db with `updatedb`)
- `ln -s <path> <linkname>`: create a symbolic link

Mounting a file system

A file system must be **mounted** in order to be usable by the system.

- `mount`: see what is currently mounted (available for use) on the system.
- `mount -t <file_system_type> <device_to_mount> <directory_to_mount_to>`: mount a file system contained in the `<device_to_mount>` to the directory `<directory_to_mount_to>`
    - e.g., `mount -t iso9660 /dev/cdrom /mnt/cdrom` (mounting a cdrom).
- `umount <device/directory_mounted>`: unmount a filesystem
    - e.g., `umount /dev/cdrom`

Compress and extract files: tar (gzip/bzip)

- `tar -cvzf name-of-archive.tar.gz /path/to/directory-or-file1 .. /path/to/directory-or-fileN`: compress one (or multiple) entire directory or one (or multiple) file on Linux (`c`: create, `v`: display progress, `z`: compress with gzip, `f`: specify archive file name)
    - use `j` for compressing with bzip
    - `--exclude=/path/to/directory-or-file1`: exclude directory or file
- `tar -xvfz name-of-archive.tar.gz`: extract archive
    - `--strip 1`: strip off the first directory and extract the rest (`tar -xvz --strip 1 -f <archive>.tar.gz`)

Filesystem-related commands

Command	Description
`pwd`	prints current working directory
`ls`	lists the contents of a directory
`cd`	change the current path to the destination directory
`mkdir`	makes a new directory
`rmdir`	removes an empty directory
`cp`	copy file or directory
`mv`	move/rename file or directory

Filesystem-related commands

Command	Description
`wc`	word, line, character, and byte count
`more`	paging through text one screenful at a time
`less`	improved version of more allows backward/forward movement
`head`	display first lines of a file
`tail`	display last lines of a file
`grep`	print lines in a file matching a pattern

Processes

Processes

“On a UNIX system, everything is a file; if something is not a file, it is a process.”

— Machtelt Garrels, *Introduction To Linux: A Hands On Guide*

- Whenever you execute a program (a command), Linux starts a new **process**
- The operating system tracks processes through a unique five-digit ID number known as the **pid** (or the process ID)
- show processes:
  - `ps -f`: processes of current user
  - `ps -ef`: all processes, `ps -aux`: all processes, BSD style
  - `top`: realtime

Processes [2]

- **foreground** processes: by default, every process that you start runs in the foreground. It gets its **input** from the **keyboard** and sends its **output** to the **screen**

- **background** processes[1]: a background process runs **without being connected to the terminal** (if it requires an input, it waits). Adding an ampersand & at the end of the command starts it as a background process
  - `jobs` (list background processes executed from the current shell)
  - `fg <jobid>`: put the job in foreground
  - `bg` or `CTRL-z`: put the job in background
  - `kill %<jobid>` or `CTRL-c`: kill the job

- `kill <pid>`: kill a process (If a process ignores a regular `kill` command, add `-9`)

[1] **daemons**: processes that run in the background and are not interactive (they have no controlling terminal)

Background processes: example

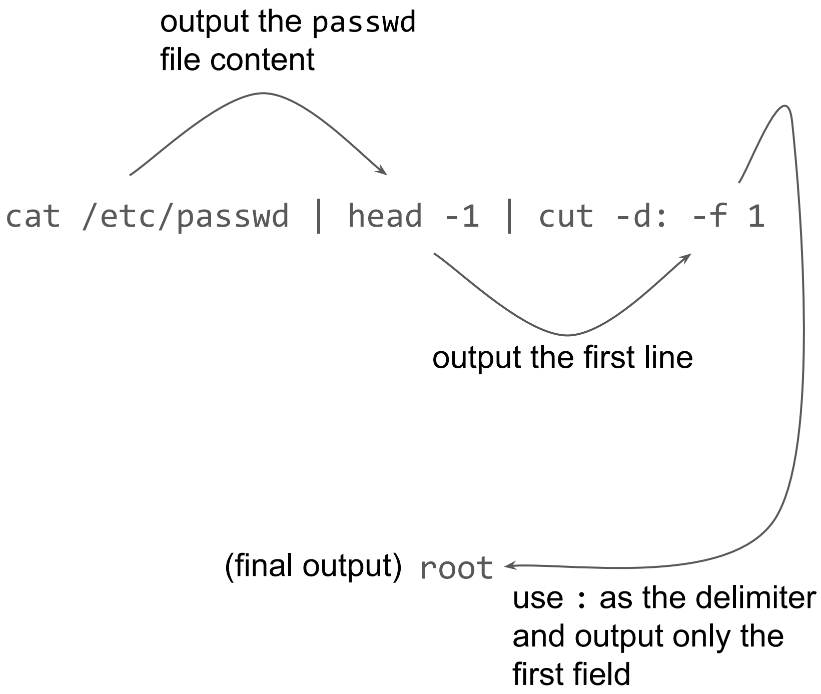
- `./loop.sh` (start in foreground and sends its output to the screen)
- `CTRL-z`: put the job in background (but stopped)
```
[1]+  Stopped                 ./loop.sh
```
- `bg`: run the process in background (it sends its output to the screen)
```
[1]+ ./loop.sh &
```
- `jobs`: list jobs
```
[1]+  Running                 ./loop.sh &
```
- `kill %1`: kill the job `[1]`
```
[1]+  Terminated              ./loop.sh
```

```
#!/bin/sh

# loop.sh
while true
do
 echo "hello"
 sleep 4
done
```

Pipes and Filters

- You can connect two commands together so that the output from one program becomes the input of the next program. Two or more commands connected in this way form a **pipe**
- To make a pipe, put a vertical bar **|** on the command line between two commands
- When a program takes its input from another program, it performs some operation on that input, and writes the result to the standard output. It is referred to as a **filter**
- **named pipes** provide such communication to processes using a special file (it is subjected to permission checks)



output the `passwd` file content

```
cat /etc/passwd | head -1 | cut -d: -f 1
```

output the first line

(final output) `root`

use `:` as the delimiter and output only the first field

Packages and services

Advanced Package Tool (APT)

A packaging system is a way to provide programs and applications for installation (without building a program from source). Debian derivatives use the `dpkg` format and `apt` for interacting with the packaging system.

- `apt update`: updates the database of available packages
- `apt install <package-name>`: install `<package-name>`
- `apt search <str>`: search a package having `<str>` in the name or description
- `apt remove <package-name>`: remove `<package-name>`

Find the package providing a specific file: `dpkg -S <file>`, list packages: `dpkg -l`

systemd

`systemd`[1] is a Linux **initialization system** and **service manager**

- `systemctl`: show services status
- `systemctl start/stop/status <unit_name>`: start/stop/view a service

`journalctl` is a utility for **querying** and **displaying logs** from `journald`, the logging service of systemd.

- `journalctl -u <unit_name>`: message from specific unit (`journalctl --field _SYSTEMD_UNIT` list availables units)
- `journalctl path/to/executable`: message from specific executable
- `journalctl -f`: follow new messages (like `tail -f`)

[1] https://freedesktop.org/wiki/Software/systemd/

Networking

Networking

`ip` command[1]: show/manipulate routing, devices, policy routing and tunnels

- `ip a`: show addresses
- `ip r`: show routes
- `ip route add default via 192.168.53.2`: add default gw
- `ip addr add 192.168.53.100/24 dev ens33`: add new address
- `ip addr del 192.168.53.100/24 dev ens33`: delete address

Configurations with the `ip` command are not persistent!

[1] https://access.redhat.com/sites/default/files/attachments/rh_ip_command_cheatsheet_1214_jcs_print.pdf

Netplan

netplan is a utility for easily configuring networking on a linux system (https://netplan.io/). It reads network configuration from /etc/netplan/*.yaml (see https://netplan.io/examples/ for examples).

<table>
<tr><th>DHCP</th><th>Static</th></tr>
<tr><td><pre>
network:
  version: 2
  ethernets:
    enp3s0:
      dhcp4: true
</pre></td><td><pre>
network:
  version: 2
  ethernets:
    enp3s0:
      addresses:
        - 10.10.10.2/24
      routes:
         - to: default
           via: 10.10.10.1
      nameservers:
          search: [mydomain, otherdomain]
          addresses: [10.10.10.1, 1.1.1.1]
</pre></td></tr>
</table>

Test network configuration

- apply netconf configuration
    - `netplan apply`
- check connectivity

```
ping [address]
```

- check nameservers

```
host [name]
```

Register names (locally)

The `/etc/hosts` is a plan text file that maps hostname to ip addresses.

```
127.0.0.1 localhost
127.0.1.1 vcc
192.168.58.2 gw gw.my.net
```

```
enrico@vcc:~$ ping gw.my.net
PING gw (192.168.58.2) 56(84) bytes of data.
64 bytes from gw (192.168.58.2): icmp_seq=1 ttl=128 time=0.179 ms
64 bytes from gw (192.168.58.2): icmp_seq=2 ttl=128 time=0.360 ms
64 bytes from gw (192.168.58.2): icmp_seq=3 ttl=128 time=0.397 ms
```

* Windows: `C:\Windows\System32\drivers\etc\hosts`

Remote terminal

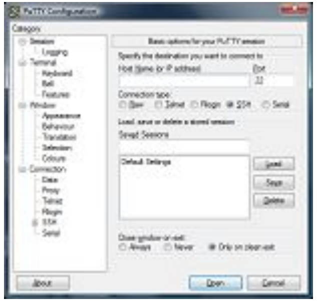
SSH client

Windows

- openssh client
  - from **powershell** (as administrator): `Get-WindowsCapability -Online | ? Name -like 'OpenSSH*'` (check) and `Add-WindowsCapability -Online -Name OpenSSH.Client~~~~0.0.1.0` (install)

  connect with `ssh user@[address]`

- putty
  - https://www.putty.org/



PuTTY Configuration

Basic options for your PuTTY session

Specify the destination you want to connect to

Host Name (or IP address) Port
22

Connection type:
○ Raw ○ Telnet ○ Rlogin ● SSH ○ Serial

Load, save or delete a stored session

Saved Sessions

Default Settings

Close window on exit:
○ Always ○ Never ● Only on clean exit

SSH pubkey authentication

Public key authentication is a way of logging into a remote account using a cryptographic key rather than a password.

Client side (WINDOWS)

- generate a keypair: `ssh-keygen`
- copy the pub key to the server (using secure-copy from ssh): `scp id_rsa.pub enrico@192.168.58.100:.`

Server side (LINUX)

- create a `.ssh` directory (`mkdir ~/.ssh`)
- move `id_rsa.pub` in a new `~/.ssh/authorized_keys` file (`mv id_rsa.pub ~/.ssh/authorized_keys`)

Shell scripting

Shell scripting

A shell script is a program designed to be run by the Linux shell.

```
1.  #!/bin/bash
2.  # print current dir
3.  pwd
4.  # list files
5.  ls
6.  echo “end”
```

Line 1: **shebang** construct, specify the interpreter (sh shell)
Line 2,4: comments
Line 3,5: commands (listed in the order of execution)
Line 6: print the “end” string

Variables

The name of a variable can contain only letters (a to z or A to Z), numbers (0 to 9) or the underscore character (_).

```
#!/bin/bash

NAME=”Enrico” # assign value
echo $NAME # print value (use $)
A=10
OP=$(expr $A ‘*’ 2) # assign the output (man expr) to OP
TMP=`ls -1` # you can also use `` (backtick) instead of $()
```

Environment variables

- Every shell has a set of attached variables
  - **system-defined** (e.g., `$PATH` contains an ordered list of paths that Linux will search for executables when running a command)
  - **user-defined**: `export` command **promotes** a shell **variable** to an **environment variable**
- They are defined for the **d** and are inherited by any child shells or processes

Special variables

Name	Description
`$0`	The filename of the current script
`$n`	These variables correspond to the arguments with which a script was invoked. Here n is a positive decimal number corresponding to the position of an argument (the first argument is $1, the second argument is $2, and so on)
`$#`	The number of arguments supplied to a script
`$*`	All the arguments are double quoted. If a script receives two arguments, $* is equivalent to “$1 $2”
`$@`	All the arguments are *individually* double quoted. If a script receives two arguments, $@ is equivalent to “$1” “$2”
`$?`	The exit status of the last command executed
`$$`	The process number of the current shell. For shell scripts, this is the process ID under which they are executing
`$!`	The process number of the last background command

Operations

We can use external programs to perform basic (arithmetic, boolean, string, file test) operations.

- `expr` (`man expr`)
  - `expr 10 '/' 3`
- `test` (`man test`)
  - `test -f /etc/passwd; echo $?`: test if `/etc/passwd` is a file; the exit status is `0` for `true`
  - `test -d /tmp/testdir || mkdir /tmp/testdir`: create `/tmp/testdir` if it does not exist
  - `test -d /tmp/testdir && rmdir /tmp/testdir`: remove `/tmp/testdir` if it exists
  - `test 10 -gt 50; echo $?`: test if `10` is greater than `50`

Redirect Input/Output

- `cat /etc/passwd > /tmp/users`: **redirects the output** of the command in the `/tmp/users` file
- `echo “test” >> /tmp/users`: **appends the output** in an existing file
- `wc -l < /tmp/users`: count the number of lines in the file by **redirecting the standard input** of the wc command from the file `/tmp/users`
- `command > /dev/null`: **discard** the **output**
- `command > /dev/null 2>&1`: **discard** both **output** of a command and its **error output** (`2` represents STDERR and `1` represents STDOUT)
- `echo message 1>&2`: display a message on STDERR by **redirecting** STDOUT into STDERR

if..then..else

The base for the '**if**' constructions is:

```
if [ expression ]; then
 code if 'expression' is true.
else
 code if 'expression' is false.
fi
```

```
#!/bin/bash
a=100
if [ $a -gt 50 ]; then
echo "yes"
fi

b="enrico"
if [ $b == "Enrico" ]; then
 echo "equal"
fi

ls /tmp/nonexistent
if [ $? == 0 ]; then
 echo "yes"
else
 echo "no"
fi
```

while

The base for the '**while**' constructions is:

while [expression];
do
 code if 'expression' is true.
done

```
#!/bin/bash
i=0
while [ $i -lt 10 ];
do
 echo "i: $i"
 i=$(expr $i '+' 1)
done
```

```
#!/bin/bash

a=0
while true # infinite loop
do
 echo "now: $a"
 sleep 1
 if [ -f /tmp/exit ]; then
  echo "bye."
  exit
 fi
 a=$(expr $a '+' 1)
done
```

for

The base for the '**for**' constructions is:

for variable in [expression]
do
code using $variable
done

Some examples of [expression]:

- *1 2 3 4 5..N* (a numeric range)
- *string1 string2..stringN* (strings)
- *$(a_cmd_here)* (the output of a command)
- *{0..10..2}* (a range with a step)

```
#!/bin/bash
for i in {0..10..2}
 do
  echo "Welcome $i times"
 done

for e in $(ls -1 /etc)
do
 if [ -d "/etc/$e" ]; then
  echo "$e is a directory"
 fi
done
```

for (example)

```
if [ $# -lt 1 ]; then
     echo "This command count the entries of a list of directories."
     echo
     echo "$0 [listofdir]"
     echo
     echo "Please specify a list of directories."
     exit
fi

for e in “$@”
do
 tmp=$(ls -1 $e | wc -l)
 echo "$e has $tmp entries."
done
```

Useful commands

sed	stream editor for filtering and transforming text
cut	cut out fields from `stdin` or files
tr	translate characters
sort	sort lines of text files
wc	count lines, words, or bytes
uniq	output the unique lines from the given input or (sorted) file
xargs	execute a command with piped arguments coming from another command
egrep	return lines that contain a pattern matching a given regular expression
logger	log a message to syslog

Exercises

1. create a script that accepts a filename *f*, a color *c* (red, blue, yellow, white or green) and an integer *i* as args and return *true* iff *c* appears *i* times in *f* (check if args are valid!).

   A sample file follows:

   ```
   red
   blue
   yellow
   red
   green
   green
   red
   ```

2. create a script that accepts an optional arg *a*. if *a* is the string ‘empty’ shows all the Linux accounts without password or show others otherwise.

3. create a script that accepts a program name *n* and a message *m* as args. It loops checking if *n* is running. If *n* is not running, logs for 3 times the message *m*.

Further Readings

- Ubuntu Server Guide (https://ubuntu.com/server/docs)
- The Linux Command Line (http://linuxcommand.org/tlcl.php)
- GNU Bash Manual (https://www.gnu.org/software/bash/manual/)
- Advanced Bash-Scripting Guide (https://tldp.org/LDP/abs/html/)
- 25 Free Books To Learn Linux For Free (https://itsfoss.com/learn-linux-for-free/)