MAD76 Academy: A. Linux

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1 Agenda

- What is Linux? Why Linux? (see Section 2)
- Computer Architecture (see Section 3)
- Linux Users (see Section 4)
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- Networking Basics (see Section 6)

Teaching Objectives

- Understand the basic concepts of Linux
- Understand computer architectures (Raspberry Pi as example)
- Learn about the role of an operating system and why Linux is a popular choice
- Gain knowledge about Linux users and permissions
- Familiarize with the Linux file system structure
- Understand Linux as a networking operating system
- Learn about common Linux commands and their usage

2 What is Linux

- Linux is a multi-user, multi-tasking *operating system (OS)* [1]
  - Other OS are: Windows, macOS, iOS, Android (which includes Linux)
- Linux is a Unix-like OS
- Other Unixes are: FreeBSD (basis of Darwin, macOS, iOS), AT&T Unix, IBM AIX, Sun/Oracle Solaris, QNX
- An OS is an intermediate layer between hardware (HW) and software applications (SW apps, programs)
  - Apps can be programmed once and run on many different HW platforms
- An OS in itself is SW
- Main features of an OS
  - HW drivers for computer graphics, network, sound, microphone, touch, cameras, radars, robots etc.
  - File system management for data storage
  - Process/thread management for running apps in parallel
  - User management for multi-user systems
  - Security management for protecting data and processes
  - Application programming interfaces (API) for apps to access OS features
  - User interfaces (UI) for user interaction: graphical (GUI), textual, audio, touch etc.

- Linux consists of
  - Linux Kernel (protected kernel land, main features)
  - GNU userland (utilities, libraries, C/C++ compilers)
  - additional software packages (GUI desktops, apps, libraries, programming languages, programming tools, server software)
- Linux is distributed in Linux Distributions (Distros)
  - Debian (strictly free software)
  - Raspberry Pi OS (Debian-based)
  - Ubuntu (Debian-based, user-friendly)
  - Red Hat Enterprise Linux (RHEL) (commercial, enterprise)
  - Fedora (Red Hat-based, cutting-edge)
  - SteamOS (Gaming platform)
  - Windows Subsystem for Linux (WSL)
  - Yocto (Embedded Linux)

2.1 Why Linux?

- Linux is free and open source software (FOSS)
- Linux is highly customizable
- Linux runs from tiny to huge computers
  - notebooks
  - cloud servers
  - all supercomputers in TOP500 (`https://www.top500.org/`)
  - robots: e.g., Mars Rover and Drone
  - Android
    - smartphones, TVs, watches
    - in cars: cockpit, infotainment, navigation
- Linux has a large community and extensive documentation
- Linux is known for its stability and performance
- Linux is supported by big players: e.g. Google, IBM, Microsoft, Amazon

- Linux apps can be programmed in many programming languages, e.g.
  - C, Rust, C++, Python, MATLAB/Simulink, Java
- and a wide range of Integrated Development Environments (IDEs) / text editors, e.g.
  - Visual Studio Code (VS Code) from Microsoft
  - Eclipse
  - Qt Creator
  - Emacs
  - Vim
  - MATLAB/Simulink from The Mathworks
- Linux has been invented by Linus Torvalds in 1991, who still is the main developer
- Linux is developed and maintained
  - by a large community of developers from different companies and organizations
  - in a successful, collaborative, well-defined SW engineering process
  - using the configuration management system Git

3 Computer Architecture

- System on a Chip (SoC) Broadcom BCM2712
  - Central Processing Unit (CPU): Quad-core ARM Cortex-A72, 2.4 GHz
  - Graphics Processing Unit (GPU)
- Random Access Memory (RAM) 16 GB
  - is lost when app stops or device is powered off
  - fast
- Persistent storage (SD card) 128ĠB
  - is kept when app stops or device is powered off
  - slow
- Network devices (Ethernet, WiFi, Bluetooth)
- Peripherals (USB devices, cameras, digital I/O)
- Cooling system (fans, heat sinks)
- Power Management Integrated Circuit (PMIC)

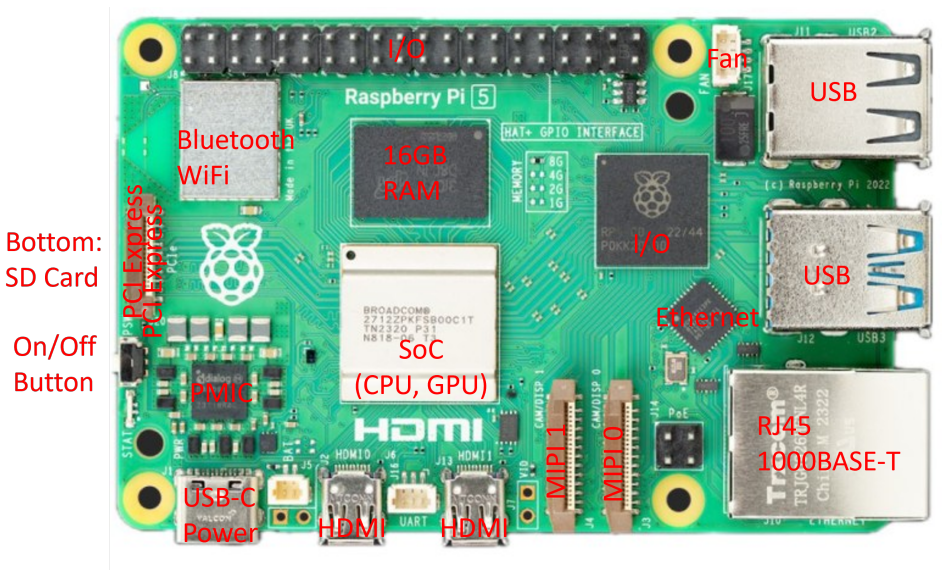


Figure 1: Raspberry Pi 5 board with components

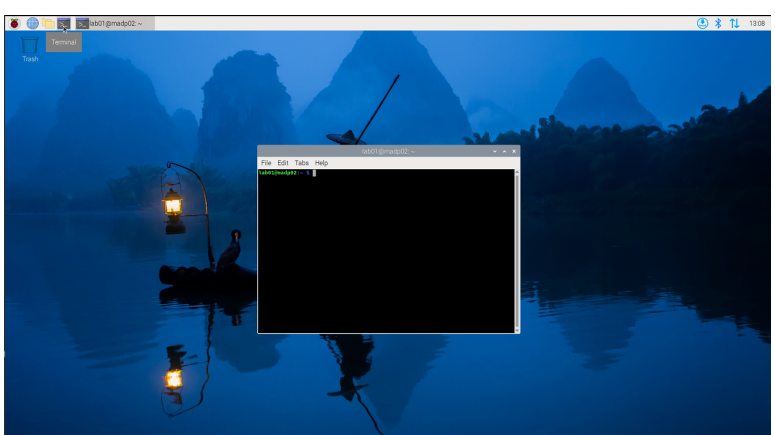
4 Linux Users

- Linux is a multi-user OS
- Each user has to login to the system
- Each user has a unique username and password
- Users can login at the console or via remote access (SSH, VNC)
- Each user lives in a protected userland
  - Each user has his own data files located in his home directory
  - Each user has his own set of running apps (processes)
  - Read and write access to files is restricted by user and group permissions
- Ideally, users do not interfere with each other
  - But: limited resources (CPU, memory, disk space, network) can lead to contention
- Users are grouped in groups

4.1 First Steps

1. At the console, enter your username and password
   - username: `lab01`
   - password: ask your teacher
2. You are now logged in as user `lab01` and see the lightweight GUI desktop `LXDE`
3. You can now run apps, e.g., the Web browser `chromium`
4. Or you can open a terminal window to enter commands (shortcut: `Ctrl+Alt+T`)
5. Try out some commands, e.g.,

`whoami`	show current user
`passwd`	change password
`ls`	list files and directories
`htop`	show running processes, CPU and memory usage (hit `q` or `Ctrl+C` to exit)



4.2 Bash

- The terminal uses the `bash` shell (Bourne Again SHell)
- Which is an enhanced version of the original Bourne shell
- Bash is an interpreter similar to Python, but for shell commands
- Bash provides a command line interface (CLI) for user interaction
- Bash interprets commands and executes them right-away
- Bash supports command history and tab completion

`history`	show command history
`TAB` key	autocomplete commands, arguments and filenames
`Ctrl+R`	search and select previous commands in history

- Bash can run commands, scripts, and apps (programs)
- Bash can be programmed with shell scripts
- Bash can be customized by configuration files, e.g., `.bashrc` in the home directory
- The prompt `lab01@madp02:~ $` shows the current user, hostname, and current directory

4.3 Help

- Use the `man <command>` command to view the manual pages for commands, e.g., `man ls`
- Use the `--help` option to get help for a specific command, e.g., `ls --help`
- Or google for `man ls` or `ubuntuusers ls`

5 Linux File System

- Linux supports whole range of file systems, e.g.,
  - ext4 (default for most Linux Distros)
  - FAT32 (for USB sticks, SD cards, cameras)
  - NTFS (for Windows compatibility)
  - ZFS (from Sun/Oracle for reliable servers and easy backups)
- A file system organizes persistent data on storage devices in files and directories (folders)
- Directories may contain subdirectories that may contain subdirectories
- Files and directories are organized in a tree structure
- Every file and directory has a unique path
- Directories and subdirectories are separated by slashes / in paths
- Paths are absolute with leading /
- or relative without leading /

5.1 Important Directories in Linux

`/home/lab01`	Home directory of user `lab01`
`/home`	Root directory for all user home directories
`/`	Root directory of Linux
`/etc`	Configuration files for the system and apps
`/var`	Variable data files (logs, databases, caches)
`/usr`	User programs and libraries
`/usr/bin`	Essential commands (e.g., `ls`)
`/usr/lib`	Libraries for user programs
`/usr/local`	Locally installed programs and libraries
`/tmp`	Temporary files (deleted on reboot)
`/dev`	Device files (e.g., USB devices, cameras)
`/proc`	Virtual file system for process information
`/sys`	Virtual file system for system information
`/boot`	Boot files (Linux kernel, initrd)

5.2 Important Commands

`pwd`	show current directory
`ls -al /home/lab01`	list files in home directory of user `lab01`
`cd /home/lab01`	change to home directory of user `lab01`
`cd`	dito
`cd ~`	dito (`~` is shortcut for home directory)
`mkdir src`	create directory src in current directory
`touch src/myaddress.txt`	create empty file in directory `src`
`cp src/myaddress.txt youraddress.txt`	copy existing file `src/myaddress.txt` to new file `youraddress.txt`
`rm youraddress.txt`	remove file
`echo Heilbronn > src/myaddress.txt`	write to file
`cat src/myaddress.txt`	display file content
`cd src`	change to directory `/home/lab01/src`
`cd /home/lab01/src`	dito (using absolute path)
`less myaddress.txt`	display file content with paging (hit `q` to exit)
`cd ..`	change to parent directory
`cd .`	change to current directory (does nothing)
`rmdir src`	remove directory src in current directory (only if empty)
`rm -rf src`	remove directory src and all its contents (use with care!)
`groups`	show groups of current user

5.3 File Permissions

- Every file and directory has permissions for user, group and others
- Permissions are read (**r**), write (**w**) and executable binary/script (**x**)
- Permissions, user, group, size, and modification date/time are displayed with `ls -al` command

```
lab01@madp02:~ $ ls -al
total 100
drwxr-xr-x 16 lab01 lab01 4096 Aug  5 15:01 .
drwxr-xr-x  5 root  root  4096 Aug  5 12:41 ..
-rw-------  1 lab01 lab01   30 Aug  5 12:47 .bash_history
-rw-r--r--  1 lab01 lab01  220 Mar 29  2024 .bash_logout
-rw-r--r--  1 lab01 lab01 3523 Jul  4  2024 .bashrc
drwx------  8 lab01 lab01 4096 Aug  5 12:58 .cache
drwx------  8 lab01 lab01 4096 Aug  5 14:25 .config
drwxr-xr-x  2 lab01 lab01 4096 Aug  5 12:46 Desktop
drwxr-xr-x  2 lab01 lab01 4096 Aug  5 12:46 Documents
```

d	rwx	rwx	rwx
directory or file	user	group	others

- Permissions can be changed with `chmod` command

`chmod u-w <file>`	removes write permission for user
`chmod u+w <file>`	adds write permission for user
`chmod u+x <file>`	adds executable permission for user
`chmod g-w <file>`	removes write permission for group
`chmod o+r <file>`	adds read permission for others
`chmod a+rw <file>`	adds read/write permissions for user, group, others

- Permissions can also be set with octal numbers

`chmod 755 <file>`	sets permissions to `rwxr-xr-x`
`chmod 644 <file>`	sets permissions to `rw-r--r--`
`chmod 700 <file>`	sets permissions to `rwx------`

- User and group can be set with `chown` command

`chown <user> <file>`	changes user of file
`chown <user>:<group> <file>`	changes user and group of file

6 Networking Basics

- Networking is communicating data and events
- Networking is on different levels
  - *distributed computing*: inter-computer commmunication
    - on the internet
    - in the intranet / local area network (LAN): school, company, home
  - *multi-processing*: intra-computer between processes
  - *multi-threading*: intra-computer between threads (sub-processes)
- Linux is a networking operating system

6.1 Internet Communication

- Internet communication can be applied on all levels: internet, intranet, processes, threads
- Internet communication is based on the TCP/IP and UDP/IP protocol stacks (and more)
  - Transmission Control Protocol (TCP)
  - User Datagram Protocol (UDP)
  - Internet Protocol (IP)
- TCP/IP and UDP/IP have always been supported by Unix OS, but not by Windows
- Today it is the de-facto standard for many OS
- TCP/IP and UDP/IP support many network layers: Ethernet, WiFi, Bluetooth, 5G, etc.
- Communication partner is identified by
  - IP address (32bit IPv4 or 128bit IPv6)
  - and port number (e.g., 80 for HTTP, 443 for HTTPS, 22 for SSH)

- TCP/IP is connection-oriented, reliable, and ordered (like phone calls)
  - Connection must be established between client and server
  - Data is sent in packets, which are acknowledged by the receiver
  - 1982 US standard for military computer communication
  - Protocols on top of TCP/IP: HTTP, HTTPS, FTP, SSH, SMTP, ROS2 (DDS)
- UDP/IP is connectionless, unreliable, and unordered (like postal mail)
  - No connection is established between client and server
  - Data is sent in packets, which are not acknowledged by the receiver
  - faster than TCP/IP
  - but packets can be lost or arrive out of order
  - Protocols on top of UDP/IP: DNS, DHCP, ROS2 (DDS)

- Example 1: Web browser

```
chromium https://www.hs-heilbronn.de # port defaults to 443
chromium https://www.hs-heilbronn.de:443 # explicit port number
```

  - Web browser `chromium` is a client app
  - `https` is the protocol
  - `www.hs-heilbronn.de` is the host and domain name
  - HTML is the format of the data being communicated
  - Web browser uses the HTTP protocol to communicate with a web server or HTTPS protocol to protect data by encryption

- Example 2: Domain Name System (DNS)

```
nslookup www.hs-heilbronn.de
```

  - DNS is a protocol for resolving domain names to IP addresses (IPV4 or IPV6)

- Example 3: Hostname and IP addresses of your computer

```
hostname
ifconfig -a
```

- Example 4: Two students communicate by TCP/IP (primitive chat)
  - Student 1 runs a server on computer `madp03`

```
nc -lk -p 11111 # -l: listen, -k: listen again, -p: port number
```

  - Student 2 runs a client on computer `madp04` and sends a message

```
echo "Hello from madp04" | nc madp03 11111
```

  - `nc` or `netcat` is a testing utility for TCP/IP and UDP/IP communication
  - Bash pipe | is used to send data from one command to another

6.2 Intra-Computer Communication

- Intra-computer communication is between processes and threads
- Communication schemes supported by Linux

sockets	bidirectional communication using TCP/IP or UDP/IP protocols, similar to network ports
pipes	unidirectional communication using first-in-first-out (FIFO) queues, similar to files
message queues	unidirectional communication using named queues
shared memory	bidirectional communication between processes using shared memory regions (fast for huge data)
semaphores	synchronization between processes and threads using resource locking
signals	asynchronous notifications between processes and threads
remote procedure calls (RPC)	function calls between processes

References

[1] Ellen Siever et al. *Linux in a Nutshell. A Desktop Quick Reference*. 6th. O'Reilly Media, 2009. ISBN: 978-0596154486.