



2 – Introduction to Linux and Software Development

Robotics and Computer Vision (BPC-PRP)

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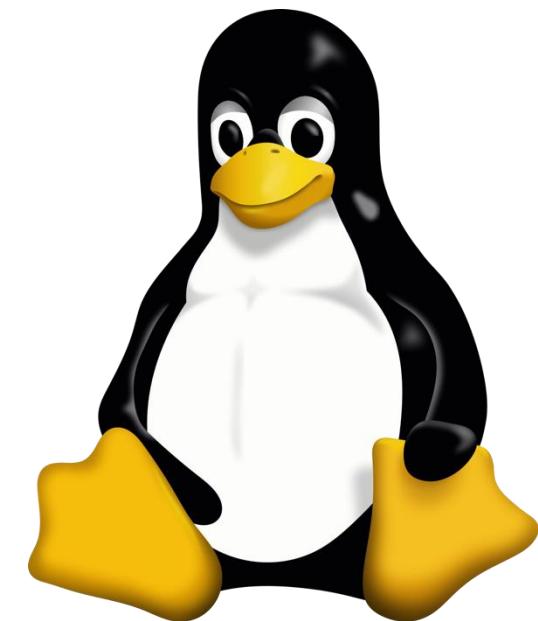
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2026





Why linux?

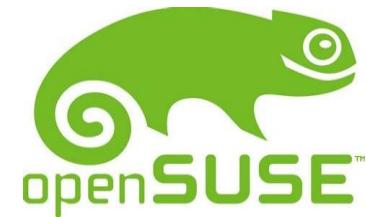
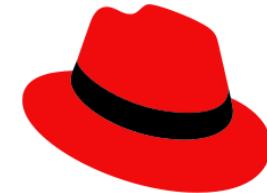
- Open source and free
- Security, stability and reliability
- Flexibility and customizability
- Web servers, supercomputers, routers, cars, smart devices etc.





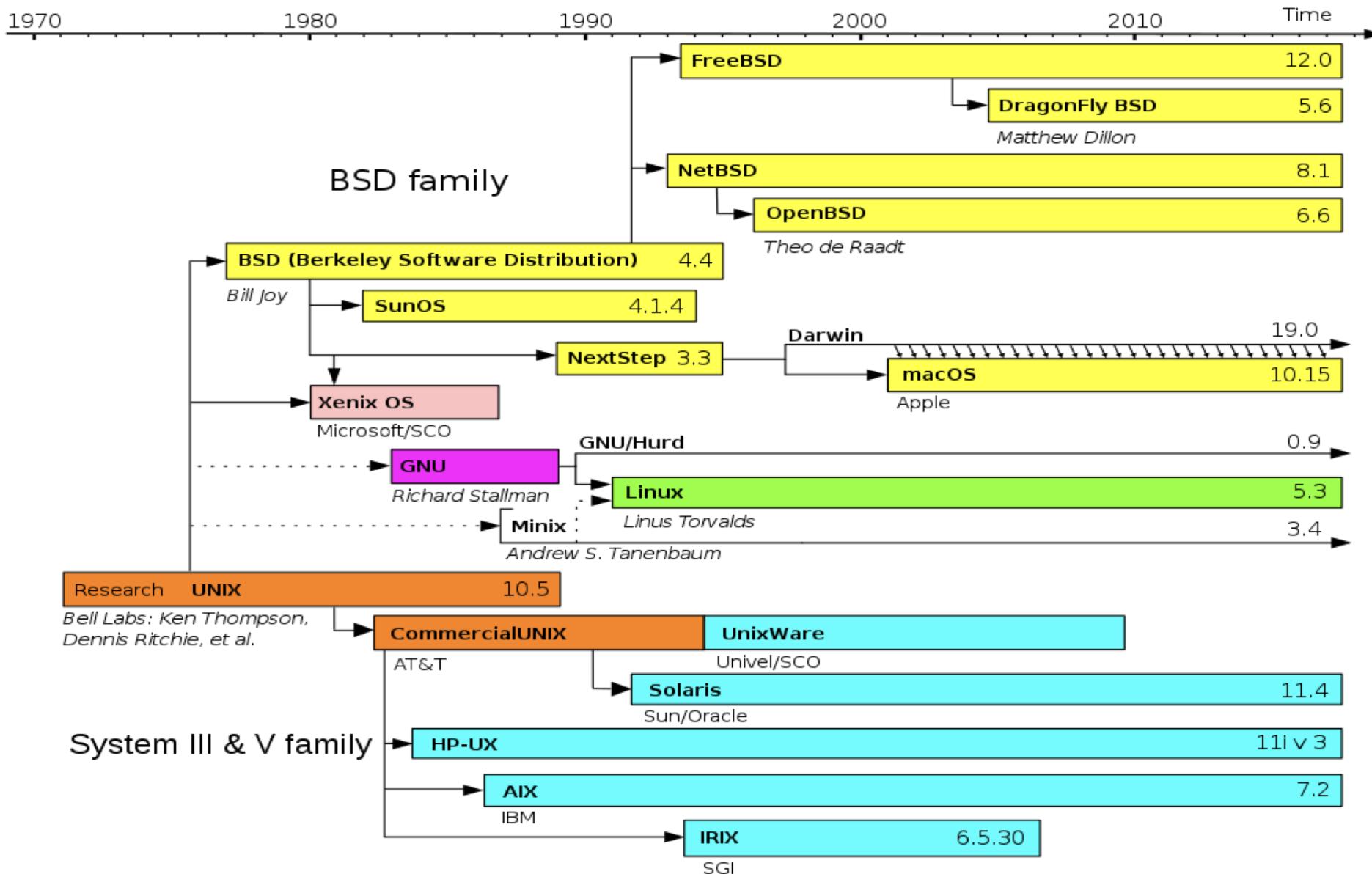
What is linux?

- Linus Torvalds (Linux), Richard Stallman (GNU)
- OS kernel – GNU/Linux
- Multiple distributions, versions, variants...





History





Concepts



File System - permissions

“Everything is a file (descriptor)” -> all I/O operations handled as simple streams of bytes.

Using common tools to operate on different things -> a single read() function instead of “15” different versions.

File mode flags:

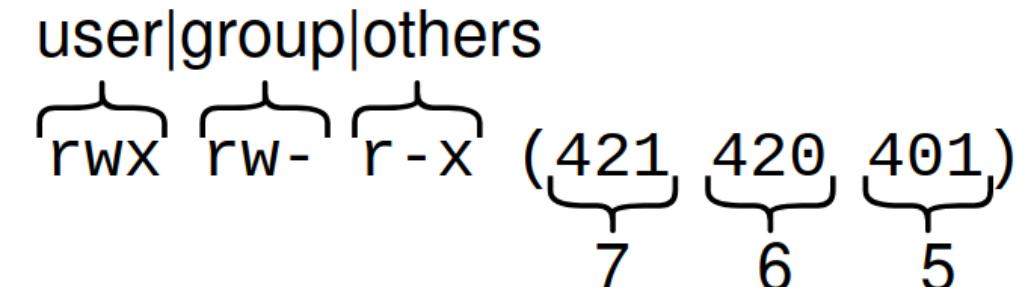
- *-* Regular files
- *d* Directory
- *c* Character device file (peripheral devices, busses, etc.)
- *b* Block device file (usually hard disks)
- *s* Local socket file (inter-processes communication)
- *p* Named pipe (similar to local socket)
- */* Symbolic link (links to files)



File System - permissions

File permission flags:

- No permission: - (0)
- Can be read: r (4)
- Can be modified: w (2)
- Can be executed: x (1)



Special flags:

- The setuid (user) or setgid (group) bit, not found in others (implies that x is set): s
- Same as s, but x is not set (rare on regular files, useless on directories): S
- The sticky bit, found only in others (implies that x is set): t
- Same as t, but x is not set (rare on regular files): T



File System - permissions

```
user@user-MS-7A59:~$ ls -lahF /dev/
total 4.0K
drwxr-xr-x  20 root root          5.9K Feb 12 19:10 .
drwxr-xr-x  27 root root          4.0K Aug 23 20:20 ../
crw-r--r--   1 root root        10, 235 Feb 12 18:51 autofs
drwxr-xr-x   2 root root          1.5K Feb 12 19:10 block/
crw-----   1 root root        10, 234 Feb 12 18:51 btrfs-control
drwxr-xr-x   3 root root          60 Feb 12 18:51 bus/
lrwxrwxrwx   1 root root          3 Feb 12 18:51 cdrom -> sr0
lrwxrwxrwx   1 root root          3 Feb 12 18:51 cdrw -> sr0
drwxr-xr-x   2 root root          5.3K Feb 12 19:10 char/
crw-----   1 root root         5,  1 Feb 12 18:51 console
lrwxrwxrwx   1 root root          11 Feb 12 18:51 core -> /proc/kcore
drwxr-xr-x   6 root root          140 Feb 12 18:51 cpu/
crw-----   1 root root        10,  60 Feb 12 18:51 cpu_dma_latency
crw-----   1 root root        10, 203 Feb 12 18:51 cuse
drwxr-xr-x   8 root root          160 Feb 12 18:51 disk/
drwxr-xr-x   3 root root          140 Feb 12 18:51 dri/
lrwxrwxrwx   1 root root          3 Feb 12 18:51 dvd -> sr0
lrwxrwxrwx   1 root root          3 Feb 12 18:51 dvdrw -> sr0
crw-----   1 root root         89,  0 Feb 12 18:51 i2c-0
crw-----   1 root root        239,  0 Feb 12 18:51 nvme0
brw-rw----   1 root disk        259,  0 Feb 12 18:51 nvme0n1
brw-rw----   1 root disk        259,  1 Feb 12 18:51 nvme0n1p1
brw-rw----   1 root disk         8,  0 Feb 12 18:51 sda
lrwxrwxrwx   1 root root          15 Feb 12 18:51 stderr -> /proc/self/fd/2
lrwxrwxrwx   1 root root          15 Feb 12 18:51 stdin -> /proc/self/fd/0
lrwxrwxrwx   1 root root          15 Feb 12 18:51 stdout -> /proc/self/fd/1
crw-rw-rw-   1 root tty          5,  0 Feb 12 18:51 tty
```



File System - hierarchy

The beginning of the file system always starts with the “root” directory, marked with a backslash. → /

- Not to be confused with the root user directory. → /root

You can think of it as C: in Windows (if you’re using just one physical drive).

- Linux doesn’t have drive letters, all additional drives are located (mounted) in /media.
- You can also mount any directory to a specific drive partition.

```
user@user-MS-7A59:~$ tree -L 1 /
/
├── bin
├── boot
├── cdrom
├── dev
├── etc
├── home
├── initrd.img  -> boot/initrd.img-4.15.0-140-generic
├── initrd.img.old -> boot/initrd.img-4.15.0-128-generic
├── lib
├── lib32
├── lib64
├── lost+found
├── media
├── opt
├── proc
├── root
├── run
├── sbin
├── snap
├── srv
├── swapfile
├── sys
└── tmp
└── usr
└── var
└── vmlinuz  -> boot/vmlinuz-4.15.0-140-generic
└── vmlinuz.old -> boot/vmlinuz-4.15.0-128-generic

22 directories, 5 files
```



File System - hierarchy

- /home -> all users' personal directories
- /root -> home directory for the root user (admin)
- /dev -> files (the byte streams) for physical devices (TTYs, USBs, keyboards, mice, drives, joysticks, ...)
- /media -> automatic mount point for new drives (the contents)
- /tmp -> temporary data (deleted after reboot)
- /etc -> all system configuration files
- /bin, /sbin -> executable binaries and scripts (s stands for sudo)
- /boot -> all files required for system boot (DO NOT MESS WITH THIS!)
- /lib -> library files (similar to *.dll files in windows)
- /opt -> some software gets installed here
- /proc, /sys -> hardware-specific files (similar to /dev)
- /usr, /var, ...



TTY (TeleTYpewriter) → used for interacting with the OS.

- Early days: electromechanical device (prints on paper).
- Later: video terminal (prints on screen).
- Modern: terminal emulator/pseudo terminal (prints on a GUI window).

A command line interface for controlling Linux (just like the *PowerShell* (or *cmd*) window in Windows).

Opening a screen terminal: **CTRL + ALT + FX**, where **X** is a number <3,7>

- **F1** – login screen, **F2** – desktop environment

Opening a terminal emulator: **CTRL + ALT + T**

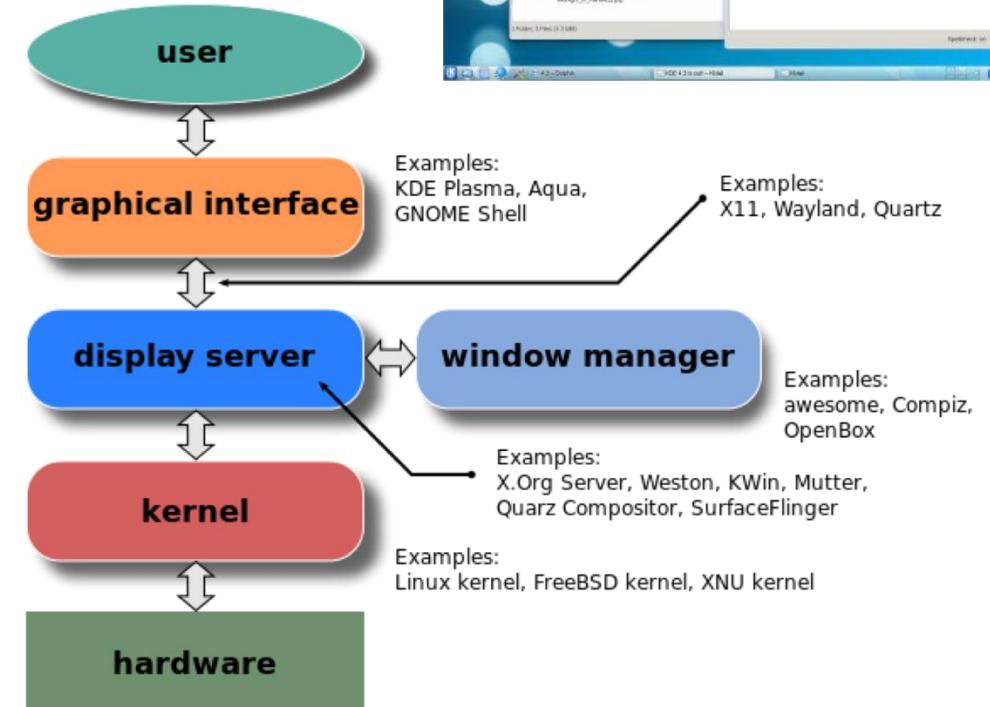
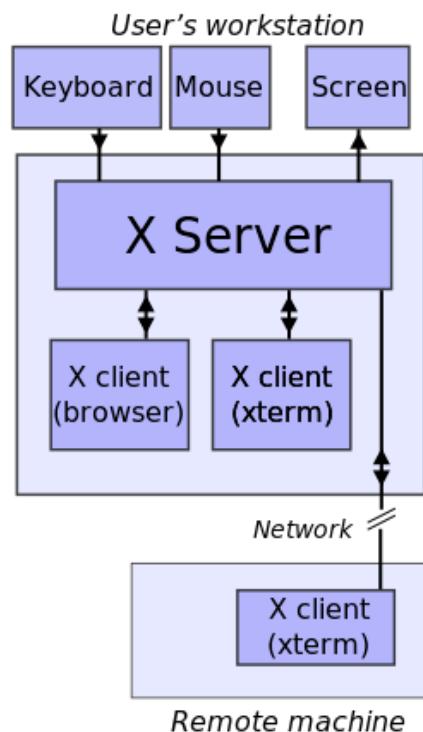
`/dev/tty0`
`/dev/ttys0`
`/dev/pts/0`
`/dev/ttyUSB0`



The X Server

Running programs (clients) communicate with X Server to visualize graphical outputs and to interact with the user.

X Server only defines the interface and is extended by window mangers, graphical interfaces (KDE, GNOME, Xfce, ...), and applications.





A language used to interact with and control Linux (in Windows this is the *PowerShell*).

Uses the terminal for interactive input and output:

- *shell* (Bourne shell) -> default on all machines
- *bash* (Bourne-Again shell) -> most common default
- *zsh* (Z shell) -> more modern, mostly backwards-compatible with bash

Also used to write scripts that can be executed when necessary.





SHELL Commands

ls -> (list) prints all files in the current working directory

cd -> (change directory) changes the working directory

- `cd ~` -> into the home directory
- `cd /` -> into the root directory
- `cd ..` -> one level above the current directory
- `cd .` -> current directory (no change)
- `cd some_folder` -> into a local sub-directory
- `cd /home/username/some_folder` -> into a specific directory

pwd → (print working directory) prints the current location

mkdir → (make directory) creates a directory of a given name

cp → (copy) copies a given file to another location

- `cp ./folder_a/file.txt ./folder_b/file.txt`
- `cp -r ./folder_a/ ./folder_b/`

mv → (move) moves a file from one location to another (also changes the filename)

- `mv ./folder_a/file.txt ./folder_b/file.txt`
- `mv file.txt log.txt`

rm → (remove) removes a given file

- `rm not_so_cool_file.txt`
- `rm -r not_so_cool_directory`

chmod → (change mode) changes permissions of the given file

- `chmod 444 read_only.txt` → r--r--r--
- `chmod +x executable_for_all` → adds x for all groups
- `chmod -x not_executable` → removes x from all groups



SHELL Commands

- **ssh** - opens an ssh connection
- **touch** - creates a new empty file
- **ln** - creates a link
- **df** - file system usage
- **kill** - kills the process of given PID
- **pgrep** – finds the process PID from name
- **pkill** – kills the process of given name
- **mc** - midnight commander
- **nano** - the n00b text editor
- **vim (or vi)** - the l33t text editor
- **ping** - tests network connection
- **ps** - display current processes
- **cat** - prints contents of a given file
- **grep** – finds a given pattern in a given file



Get Some Help

Each command always has a useful help section or a full manual:

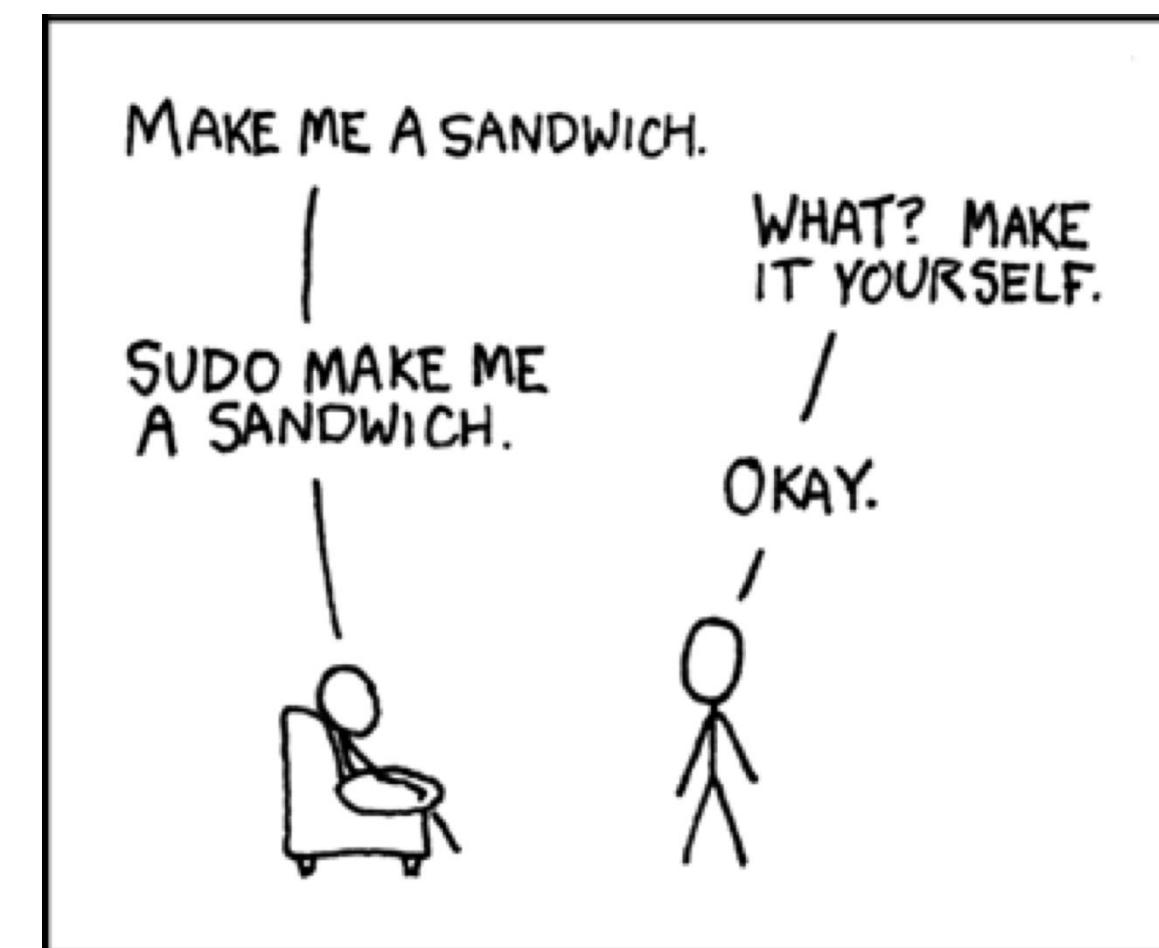
- **ls --help** - prints a relatively short help with available flags and use-cases for the ls command.
- **man ls** - prints a full manual for the ls command.

T

sudo

This command allows you to run commands with the superuser security privileges.

To use this command, you have to be a member of sudo group.





Pipes & Redirects

The Unix philosophy:

- Write programs that do one thing and do it well.
- Write programs to work together.
- Write programs to handle text streams, because that is a universal interface.

We can redirect or chain programs like this:

- `cat some_file.txt` → outputs the contents to screen
- `cat some_file.txt > new_file.txt` → redirects the output to a different file
- `cat some_file.txt | grep hello` → pipes the output to grep, grep searches for hello in the output and prints result to screen
 - `grep hello some_file.txt` → this is better if only searching in files

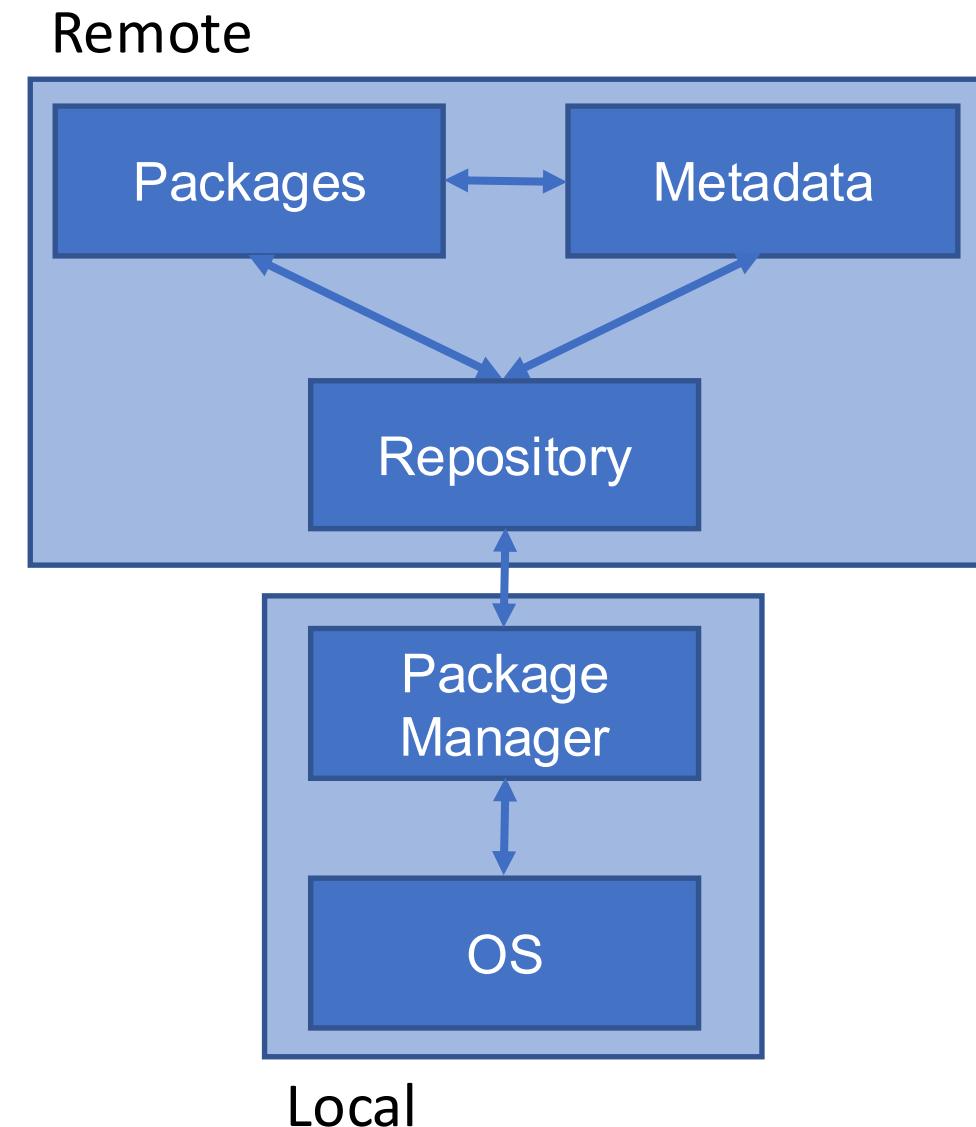


Package Managers

Package Managers are programs, that download software from online repositories and install them into your OS.

- sudo apt update
 - sudo apt upgrade
 - sudo apt install cool_package
-
- sudo snap install cool_package
 - sudo flatpak install cool_package

<https://packages.ubuntu.com>





Linux (Ubuntu) installation



Where to install?

- Only one system on PC
- Dual boot with other OS e.g. Windows
 - Different disk
 - On different partition
 - Risk of losing data of both system when installing (or updating)
- Virtual machine
 - No risk, but could be slower
- WSL2 – Windows subsystem for linux
 - Some restrictions, e.g. I/O

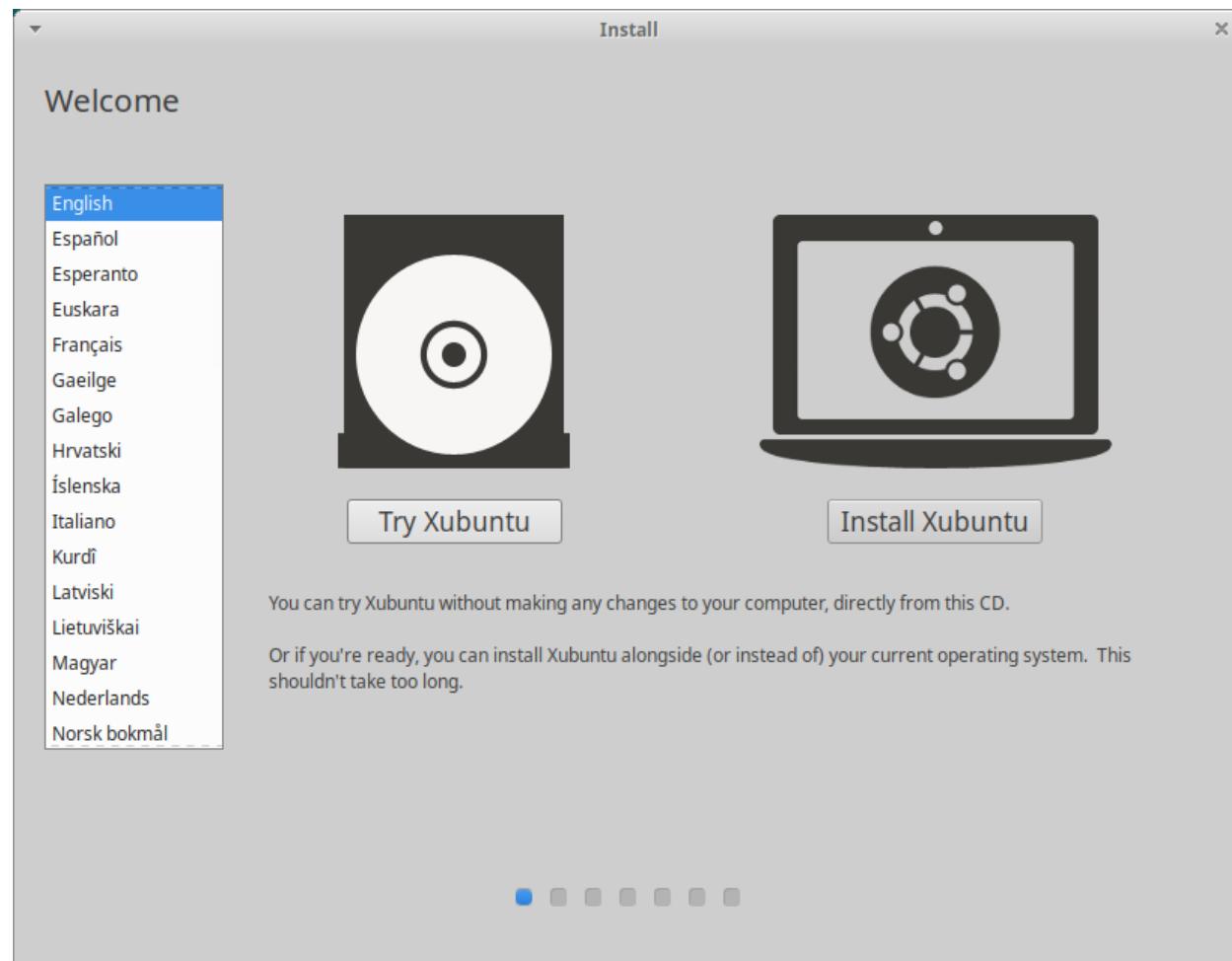
Download an image from the official Ubuntu web page (22.04 LTS)

Create a bootable usb:

- <https://www.balena.io/etcher/>
- <https://unetbootin.github.io>
- <https://rufus.ie/en/>
- *dd* command

Be aware of:

- Dual boot setup
- Swap area
- Deleting existing Windows partitions





Installing under WSL (2) – Windows Subsystem for Linux

If you have Windows version 1903 or higher and your machine supports virtualization, you can install Linux under WSL in Windows:

Run this in *cmd* or *powershell*:

- `wsl --install -d Ubuntu-22.04`

or install Ubuntu 22.04 from the Windows store:

- <https://apps.microsoft.com/store/detail/ubuntu-22041-Its/9PN20MSR04DW?hl=cs-cz&gl=US>

or install manually from an AppxBundle:

- <https://aka.ms/wslubuntu2204>

```
PS C:\Windows\system32> wsl --list --verbose
  NAME      STATE      VERSION
* Ubuntu    Running    2
PS C:\Windows\system32> wsl --list --online
The following is a list of valid distributions that can be installed.
Install using 'wsl --install -d <Distro>'.
```

NAME	FRIENDLY NAME
Ubuntu	Ubuntu
Debian	Debian GNU/Linux
kali-linux	Kali Linux Rolling
openSUSE-42	openSUSE Leap 42
SLES-12	SUSE Linux Enterprise Server v12
Ubuntu-16.04	Ubuntu 16.04 LTS
Ubuntu-18.04	Ubuntu 18.04 LTS
Ubuntu-20.04	Ubuntu 20.04 LTS



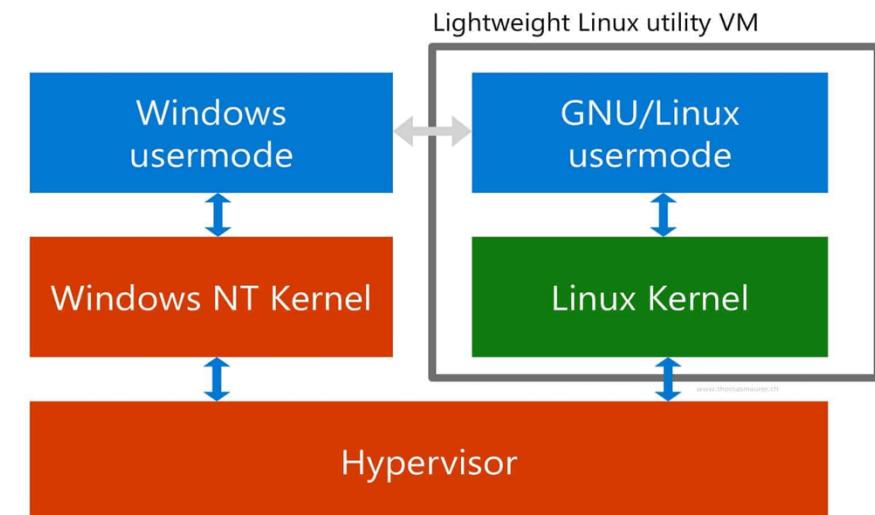
Installing under WSL (2) – Windows Subsystem for Linux

With WSL 2 you are as close to bare hardware as possible.

More detailed steps:

- <https://learn.microsoft.com/en-us/windows/wsl/install>
- <https://learn.microsoft.com/en-us/windows/wsl/install-manual>

WSL 2 architecture overview



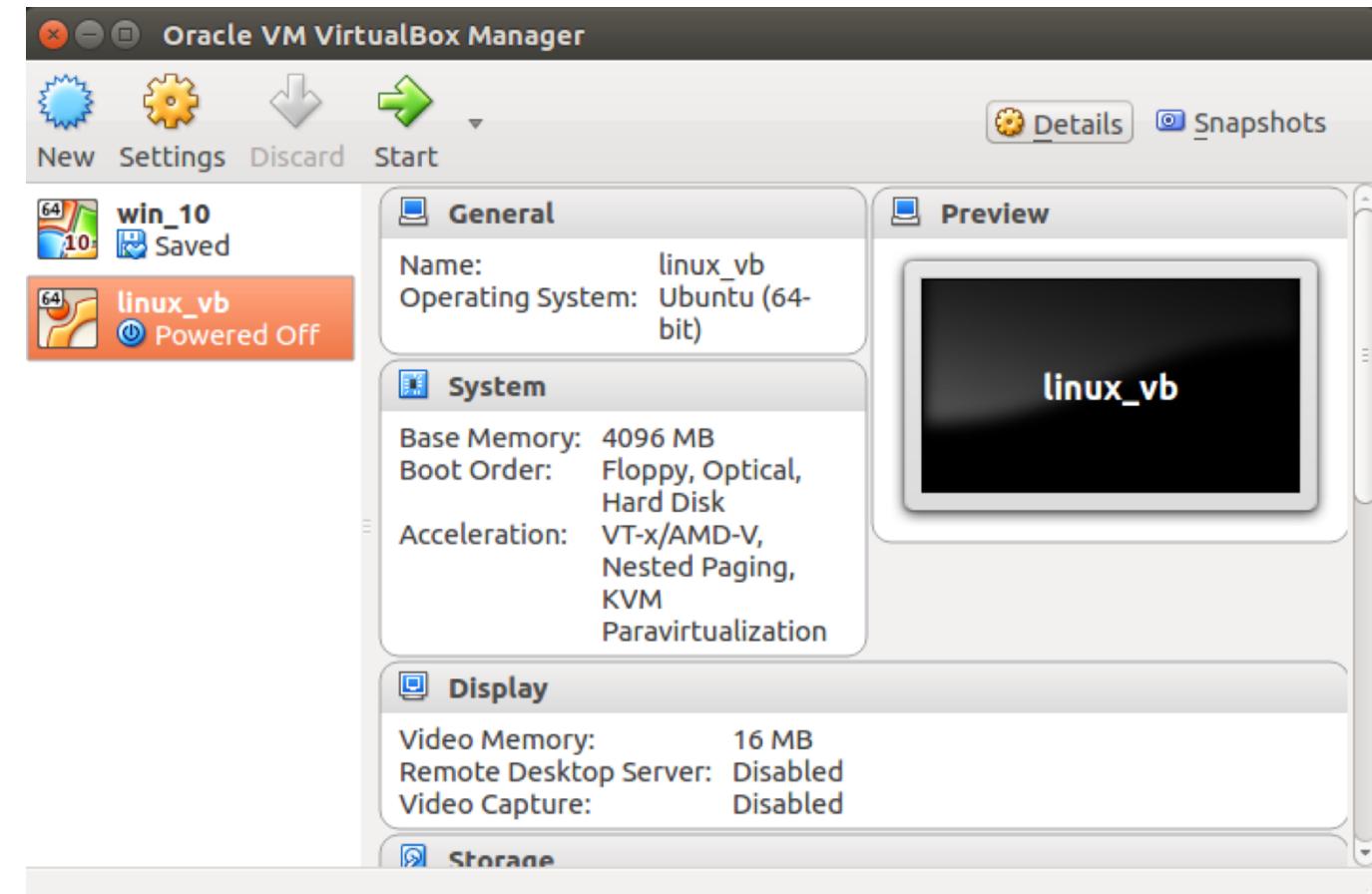
```
user@DESKTOP-112MLLI: /mnt/c/Windows/system32$ uname -a
Linux DESKTOP-112MLLI 5.10.102.1-microsoft-standard-WSL2 #1 SMP Wed Mar 2 00:30:59 UTC 2022 x86_64 x86_64 x86_64 GNU/Linux
user@DESKTOP-112MLLI: /mnt/c/Windows/system32$ lsb_release -a
No LSB modules are available.
Distributor ID: Ubuntu
Description:    Ubuntu 20.04.5 LTS
Release:        20.04
Codename:       focal
user@DESKTOP-112MLLI: /mnt/c/Windows/system32$
```



Installing in Virtual Box

In case you cannot create dual boot on your computer, or you have Mac.

Remember to add more than one CPU core, add more GPU memory, enable virtualization acceleration.

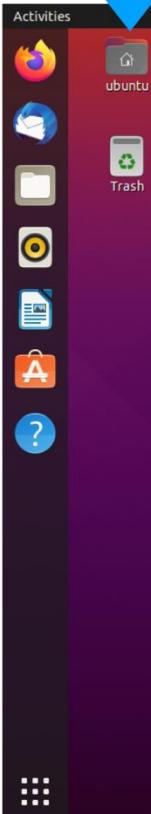
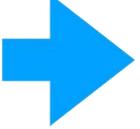




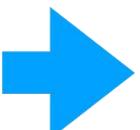
Working Environment

File Manager (Nemo)

Favorites



Program List
(Win Key)



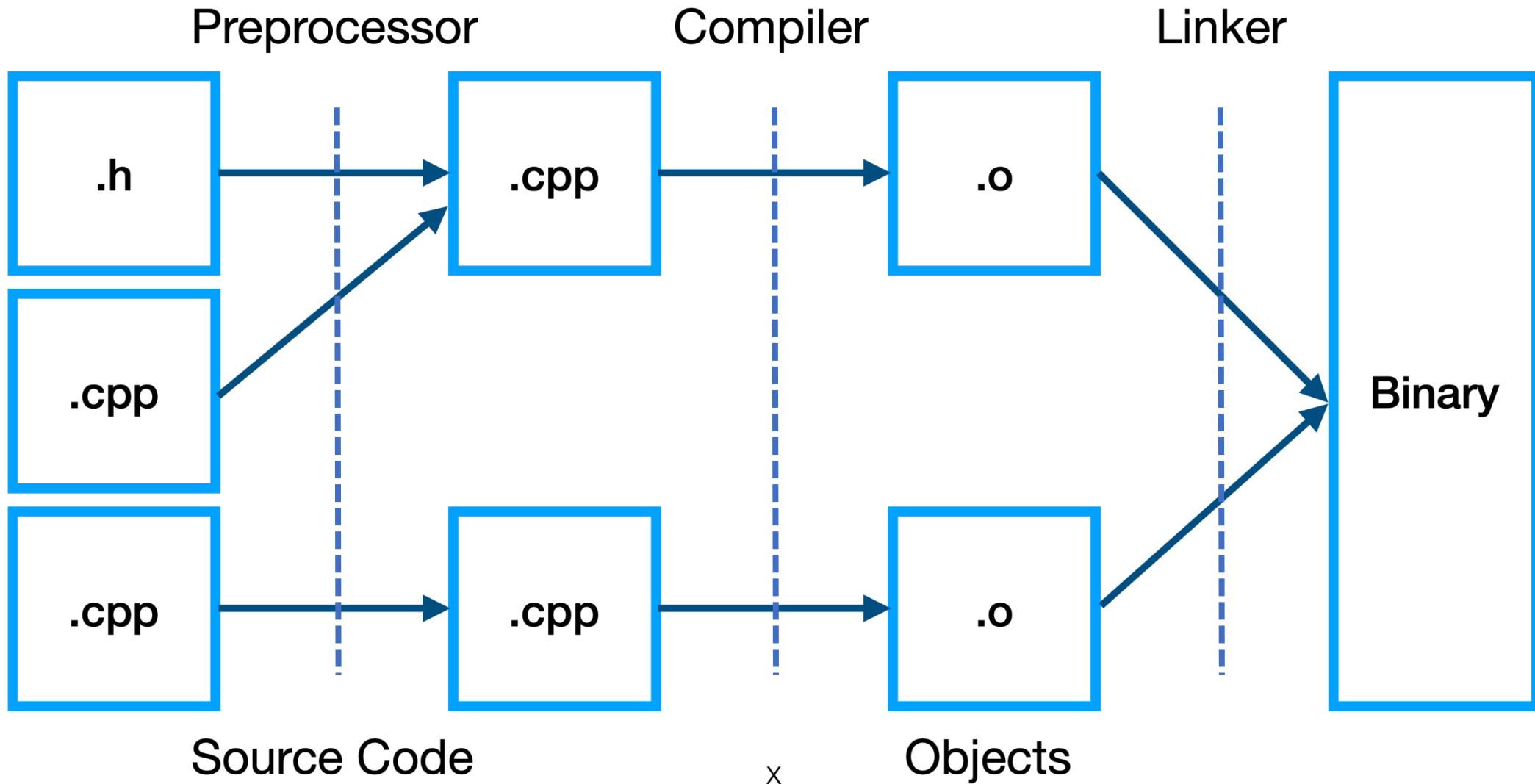
Power Off
Restart
Sleep
Logout
...



C++ and CMake



Compilation Process Overview





Calling the Compiler in CLI directly

Let's write a simple program:

To compile, type this in the same directory:

- g++ main.cpp -o my_bin

```
// main.cpp
#include <iostream>
```

```
int main(int argc, char **argv) {
    std::cout << "Hello" << std::endl;
    return 0;
}
```

But things can get worse:

- g++ src_1.cpp src_2.cpp ... src_n.cpp -I include/ -Wall -Werror -Wpedantic -Wextra -pthread -ldl -llib1 ... -llibn -o mybin



Now, let's make a compilation recipe -> the makefile.

- nano makefile

```
all: my_bin  
my_bin: main.o  
        g++ -o main main.o  
main.o: main.cpp  
        g++ -c main.cpp
```

To compile according to the makefile definitions, simply type:

- make

Look into the file system, you'll see the *.o (object) files.



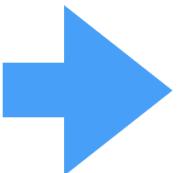
CMake vs Makefile

```
cmake_minimum_required(VERSION 3.13)
project(bpc_prp_opencv_lib)
```

```
set(CMAKE_CXX_STANDARD 17)
find_package(OpenCV REQUIRED)
```

```
set(library_name bpc prp opencv lib)
```

```
include_directories(include)
add_library(${library_name} SHARED src/ImageProcessor.cpp)
target_link_libraries(${library_name} ${OpenCV_LIBS})
```

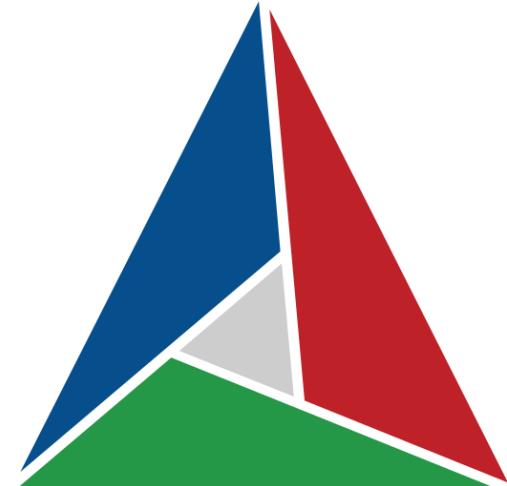




CMake is an open-source, cross-platform family of tools designed to build, test, and package software.

CMake is used to control the software compilation process using simple platform and compiler independent configuration files.

Generates native makefiles and workspaces that can be used in the compiler environment of your choice.





- Scripting language – has variables, conditions, loops, macros and functions
- Create and configure targets – *add_executable*, *add_library*, *add_custom_target*
- Manage dependencies just with *find_package*, *find_library*



Basic CMakeLists.txt

```
cmake_minimum_required(VERSION 3.10)
project(my_cool_project)

set(CMAKE_C_COMPILER "gcc")

set(SOURCES src/main.c src/library.c)

add_executable(program ${SOURCES})

target_include_directories(program PUBLIC include)
```



Typical CMake Project Structure

Your typical project structure often looks like this:

```
/my_cool_project
| -- CMakeLists.txt
| -- build/
| -- include/
|   \-- library.hpp
\-- src/
    | -- library.cpp
    \-- main.cpp
```



Integrated Development Environment (IDE)



CLion

CLion is an “lightweight” (~1GB on-disk-size) integrated development environment for C/C++ development.

Integrates all modern functions, like code generation, on-the-fly static code analysis, integrated debugger, remote development, 3rd party plugins, etc ...



Available free for academic use



CLion

The screenshot shows the CLion IDE interface. The top bar includes icons for file operations, a project named "untitled1", version control, and a search bar. The main window has a "Project" view on the left showing a directory structure with "untitled1", "cmake-build-debug", "CMakeLists.txt", and "main.cpp". The "main.cpp" tab is selected in the center editor area, displaying the following code:

```
1 #include <iostream>
2
3 // To Run code, press Shift F10 or click the ▶ icon in the gutter.
4
5 int main() {
6     // Press Shift F6 when your caret is at the lang variable name to see how CLion can help
7     // you rename it.
8     auto lang = "C++";
9     std::cout << "Hello and welcome to " << lang << "!\n";
10
11    for (int i = 1; i <= 5; i++) {
12        // Press Shift F9 to start debugging your code. We have set one ● breakpoint for
13        // you, but you can always add more by pressing Ctrl F8.
14        std::cout << "i = " << i << std::endl;
15    }
16
17    return 0;
18}
19
20
21
```

A red circular breakpoint marker is visible on line 17. A tooltip on this marker indicates: "Press Shift F9 to start debugging your code. We have set one ● breakpoint for you, but you can always add more by pressing Ctrl F8." The status bar at the bottom shows "clang-tidy 16:1 LF UTF-8 4 spaces* C++ | untitled1 | Debug".



Visual Studio Code

VSC is a lightweight, modular and open-source text editor made by Microsoft

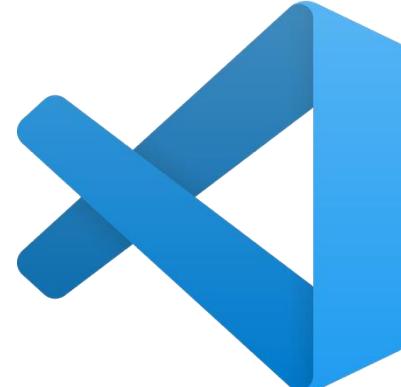
Allows to install plugins and customize functionality for any language/technology

According to the Stack Overflow Survey the VSC is the most used IDE worldwide

```
sudo snap install --classic code
```

<https://github.com/microsoft/vscode>

The screenshot shows the Visual Studio Code interface. On the left, the Explorer sidebar displays a file tree for a workspace named 'theCatSaidNo'. It contains folders for '.github', '.vscode', 'assets', 'static', 'images', and 'javascript'. Under 'javascript', there is a file named 'main.js'. In the center, there are three tabs open: '# style.css' (containing CSS code), '# main.js' (containing JavaScript code), and another tab for 'main.js'. At the bottom, the status bar shows 'Ln 11, Col 1 Spaces: 4 UTF-8 LF (JavaScript Layout: US)

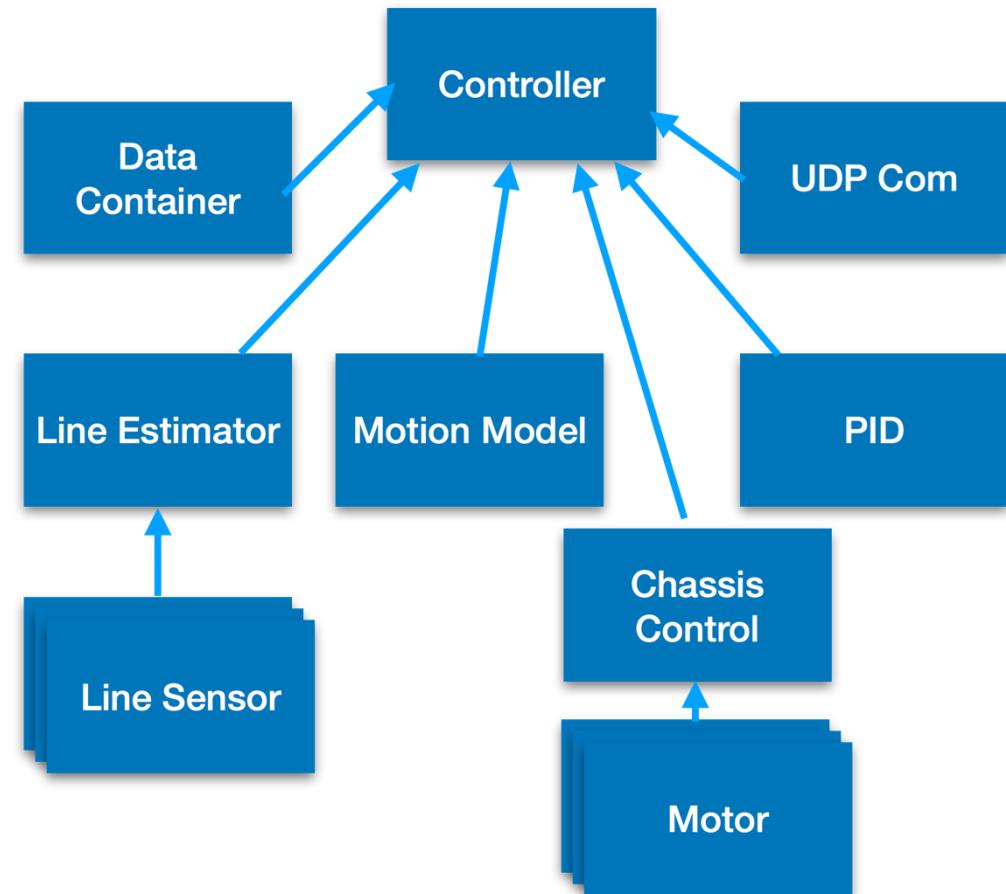




C/C++ Coding Tips

Use OOP paradigm

- Design classes as black-boxes, where each box handles just one problem.
- Be able to describe your class and methods with one sentence.
- The connection between black boxes is called an API.
- Separate **Data** from **Algorithms**.



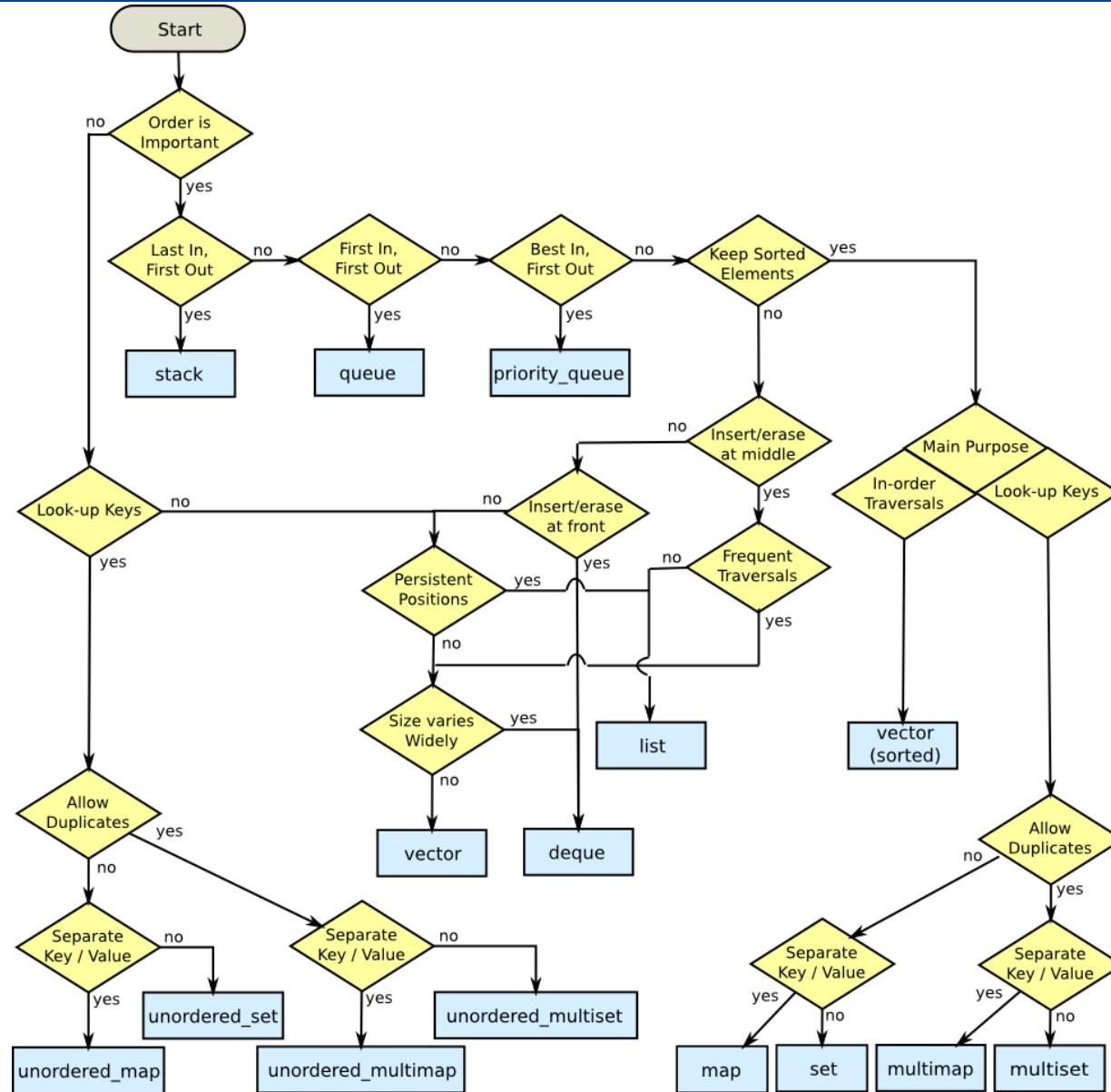


Use C++17

- Minimize using `new` and `delete`
- Use references - &
- Don't be afraid to use `auto` and templates, but don't abuse it...
- Use `constexpr` instead of macros
- Use scoped enums – `enum class`
- Avoid using raw C pointers use smart pointers instead:
`std::unique_ptr<>` - single ownership
`std::shared_ptr<>` - multiple ownership
`std::weak_ptr<>` - temporary ownership
- Use STL functions and containers like – `std::vector<>`, `std::array<>`, `std::string`, `std::find`, ...



STL Containers





Use CONST

When designing classes and methods think about their purpose, and how can they be reused.

Mark data that are not going to be modified as `const`.

Mark member methods that do not modify member data as `const`.

Return a `const &` if the data should not be modified and is “non-trivially copyable”.

`const` helps to keep a clear program design and better optimisations in compile time.

It also prevents you from making unwanted changes and hard to find bugs.



Testing – Unit Testing



Why write unit tests?

- Catch bugs early – you can test new code right away
- Save time in long run – easier to catch or find bugs
- Easy to verify changes – immediately verify changes to old code
- Improve quality – think about design before implementing
- Easier collaboration – no more commits which breaks everything



Write Tests

Think about how your class (and methods) should and shouldn't be used.

Write tests for each scenario.

This will save you with debugging in the future. `#include <gtest/gtest.h>`

If you solve a bug → Write a test for it!

```
#include <my_project/MyLibrary.h>
```

```
TEST(MyLibraryTests, someCoolTest) {  
    bool stuffWorks = true;  
    ASSERT_TRUE(stuffWorks);  
}
```

```
int main(int argc, char **argv) {  
    testing::InitGoogleTest(&argc, argv);  
    return RUN_ALL_TESTS();  
}
```



EXPECT && ASSERT

Non-fatal failure - EXPECT_*

Fatal failure - ASSERT_*

EXPECT_FALSE(*condition*)

EXPECT_TRUE(*condition*)

ASSERT_EQ(*val1*, *val2*)

EXPECT_NE(*val1*, *val2*)

ASSERT_LT(*val1*, *val2*)

EXPECT_THROW(*statement*, *exception_type*)

ASSERT_ANY_THROW(*statement*)

ASSERT_STREQ(*str1*, *str2*)

EXPECT_DOUBLE_EQ(*val1*, *val2*)

ASSERT_DEATH(*statement*, *matcher*)



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Robotics and AI
Research Group