

ROS 2

Workflow and basic communication

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Recap

The **robotics industry** is evolving rapidly towards the best practices adopted in the **software industry** in the last 30 years.

ROS 2 is an open-source **middleware** for the development of robotics software and **distributed** control architectures.

ROS 2 is currently based on the **DDS** and **Zenoh** middleware to implement the communication layer.

Today, it is the **de facto** standard for the development of robotic applications, and it is supported by a **vast community** of developers and researchers.

This lecture is [here](#).

Roadmap

1 ROS 2 development workflow

2 C++ bootstrap

3 Message topics

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Installing ROS 2

HOWTO

On **Ubuntu** systems, the easiest way to install ROS 2 Humble is through [Debian packages](#).

The installation steps can be summarized as follows:

- ➊ ensure that **locales** are properly configured;
- ➋ add and configure **apt repositories**;
- ➌ **install** packages.

We have a script for this: [bin/ros2_jazzy_install.sh](#).

Installing ROS 2

Sourcing the installation

After the installation is complete, in order to use **CLI tools** and have libraries available to **build packages**, you need to **source the installation**:

```
source /opt/ros/jazzy/setup.bash (there are also a .zsh and a .sh)
```

so that your shell, and all its child processes from then on, will know the **paths** of all the **executables**, **shared objects** (libraries), and **include directories** installed by ROS 2, plus many **environment variables**.

Additional commands are required to set up **command line completion** and other useful environment variables.

We have a script for this too: [config/ros2_cmds.sh](#).

Source it, then you're good to go!

Language support

Low- vs high-level programming

Currently, ROS 2 officially supports **two programming languages**:

- **C++** (C++17 in Jazzy)
- **Python** (≥ 3.5 , 3.12 works with Jazzy)

You can develop software packages using **only one** of them, or **both** at the same time (unofficially).

Language support

Low- vs high-level programming

The two languages are both fully supported since they are **complementary**:

- **C++** allows to build complex software using **modern paradigms**, but also to easily access the **hardware**, **libraries**, and **operating system** APIs when required, and to **optimize** the code for **performance**.
- **Python** allows to **rapidly prototype** software, especially high-level modules, and to easily **interact** with the user and **visualize data**.

Note how one prioritizes other features with respect to the other, and vice versa.

This course will focus on C++, because of its better performance, major functionalities, and widespread use in the industry and robotics development community.

The entire [ros2cli](#) suite is written in Python, and is fully **expandable**.

Python examples will still be provided and discussed whenever possible.

Language support

The build system

The ROS 2 build system supports both **C++** and **Python** packages through a common **package manager**: [colcon](#) (collective construction).

Spawned as a child project of the ROS community, its main features are:

- organization of the **build workspace** in a set of standard directories;
- **isolated** builds of packages, with **no pollution** of the system;
- automatic **dependency resolution** and **parallel** builds;
- support for **C/C++** packages through [CMake](#);
- support for **Python** packages through [setuptools](#).

Its configuration for a package can be found in the `package.xml` **manifest file**.

Language support

CMake

CMake is a **cross-platform** build configuration generator, which allows to build software using a **single, unified syntax** on all supported platforms.

Remember **Makefiles**? CMake is a compiler-agnostic **Makefile generator**.

We will write **CMakeLists.txt** files, which are essentially **scripts** that tell CMake how to build our software.

ROS 2 extends CMake with a set of **macros** and **functions**: the [ament](#) library.

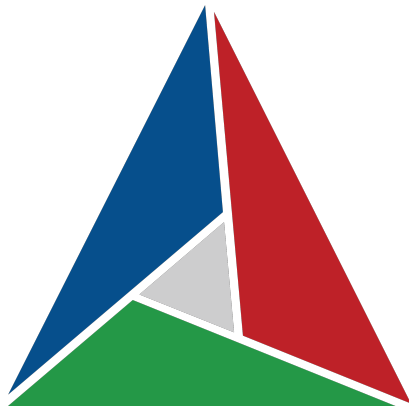


Figure 1: CMake logo.

Language support

setuptools

setuptools is a **Python library** designed to ease the setup of Python projects, namely Python software packages.

Remember nightmarish `import` issues? setuptools is a **dependency resolver**.

We will write:

- **setup.py** files, in which the `setup(...)` function specifies the package's metadata and dependencies;
- **setup.cfg** files, which specify the location of all **executable scripts** in the package.



Figure 2: setuptools logo.

Language support

Building packages with colcon

The `colcon` command you will use the most is

```
colcon build
```

which builds all packages in the current workspace (*i.e.*, directory and child directories).

It has many options, but the most useful ones are:

- `--event-handlers` to specify which **build events** to log (e.g., `console_direct+`);
- `--packages-select` to specify which packages to build;
- `--symlink-install` to **symlink** the executables into the `install/` directory, instead of copying them (useful for Python packages);
- `--packages-up-to` to build a package and all its dependencies;
- `--packages-ignore` to ignore a package and all its dependencies.

Language support

A note

Beware!

During development, a good 85% of all issues happens during integration and build.

We will see later on tools that help with this...

The workspace

Anatomy of a ROS 2 development directory

The organization of directories in a ROS 2 workspace is **standardized** because of colcon. We have, at least:

- build/ (autogenerated), which contains the **build artifacts** of all packages;
- install/ (autogenerated), which contains the **build products**;
- log/ (autogenerated), which contains the **build logs**;
- src/, which contains the **source code** of all packages.

If you use Git, remember to add build/, install/, and log/ to your .gitignore file!

Similarly, colcon ignores them when recursively looking for packages to build.

The workspace

Package creation

In the beginning was

```
ros2 pkg create <package_name>
```

which has way too many options. The main ones are:

- `--destination-directory src/`
- `--build-type <build_type> (ament_cmake or ament_python)`
- `--dependencies <package_name> ...`

Most of this stuff can be specified afterwards, eventually modifying the `package.xml` file.

Roadmap

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Code examples

Find all course materials on **GitHub** at [ros2-examples](#) (jazzy branch).

The repository is organized as a **ROS 2 workspace** ready to be built, and intended to support [Visual Studio Code](#) as **IDE**. Find all information in [README.md](#).

It is also organized with **Docker containers** in mind, and supports the automated build of development containers in VS Code (more on this later).

Such containers are based on our [Distributed Unified Architecture](#) project, which is part of Roberto Masocco's PhD thesis.

Their inner workings are totally transparent, but if you're curious see [dua-template.md](#).

Suggestion: clone it and checkout your own branch locally, to be still able to get and merge updates from remote.

C++ fundamentals

Back to basics

C++ has been developed from C, and is a **compiled, strongly-typed** (mostly) language. Its main features began as extensions of C to support modern **object-oriented programming** and **generic programming** paradigms, but it has evolved into much more.

In order to get started with ROS 2, a minimal subset of its features is required. Dust off your C programming skills, then add:

- [Object-oriented programming](#)
- [Namespaces](#)
- [Templates](#)
- [Smart pointers](#)

C++ fundamentals

Object-oriented programming

```
1 class MyClass : public ParentClass
2 {
3     public:
4         MyClass();
5         // ...
6     protected:
7         // ...
8     private:
9         // ...
10 };
```

Listing 1: Example of definition of a C++ class.

Pay attention to [inheritance](#) rules.

C++ was designed to allow for the development of large codebases, which integrated libraries and code from potentially different sources.

Subdivision of the **global namespace** is necessary to avoid naming collisions between multiple libraries, resolved with the **:: operator**.

It works like the dot in web URLs (e.g., `ing.uniroma2.it`).

Names may become very long, so usually they are hidden with `typedef`.

C++ fundamentals

Namespaces

```
1 namespace MyLib {
2     void foo() { /* Does something */ }
3 } // This is typically done for libraries
4
5 class MyClass
6 {
7 public:
8     void foo() { /* Does something as well */ }
9 } my_obj; // Watch out for the ';'!
10
11 MyLib::foo(); // This is calling foo from MyLib!
12 my_obj.foo(); // This is calling foo from MyClass!
```

Listing 2: Example of namespaces usage.

C++ fundamentals

Templates

Classes or functions whose **implementation depends on some data type**.
When instantiated or called with a specific type, **the corresponding code is generated by the compiler**.

```
1 std::vector<int> int_vector;  
2 std::vector<double> double_vector;
```

Listing 3: Example of objects of the template class `std::vector`.

It is possible to write **specialized code** for a specific data type in the template definition. These too make names very long, so are usually typedef'd.

C++ fundamentals

Shared pointers

A kind of **smart pointer** (there are also unique and weak) that also holds an **usage counter**, incremented by every function or object that is handling the pointer.

When the `shared_ptr` is destroyed, if the counter is zero the pointed object is also destroyed and its memory deallocated.

```
1 {  
2     // A new scope starts here  
3     std::shared_ptr<rcldcpp::Node> node =  
4         std::make_shared<rcldcpp::Node>("my_node");  
5 }  
6 // Here the node and its pointer have been destroyed!
```

Listing 4: Example of shared pointer creation.

Obviously `std::shared_ptr` is a template class.

ROS 2 heavily relies on them, and the `SharedPtr` alias is frequently defined.

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ROS 2 messages

A message is a **single data packet** sent over a **topic**, from **publisher nodes** to **subscriber nodes**, with a specific **QoS policy**.

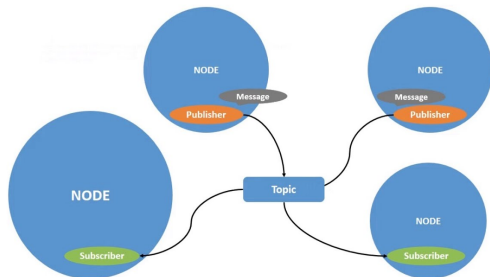


Figure 3: Example of a topic with multiple publisher and subscriber nodes.

Figure 3 is also an example of a simple **node graph**, a pivotal concept in a distributed context.

Interface files

Messages

Interface files format is **derived from the DDS standard**, with data types resolved to machine types according to the platform being used¹.

Message file names end with **.msg**.

Things start very simply...

```
1 int64 data
```

Listing 5: Definition of the std_msgs/msg/Int64 message.

```
1 string data
```

Listing 6: Definition of the std_msgs/msg/String message.

¹[About ROS 2 interfaces](#) (ROS 2 Humble docs)

Interface files

Messages

... then escalate quickly!

```
1 std_msgs/Header header
2 # ^ This includes another message type as a sub-structure
3
4 uint32 height
5 uint32 width
6
7 string encoding
8
9 uint8 is_bigendian
10 uint32 step
11 uint8[] data # This specifies a variable-length uint8 array
```

Listing 7: Definition of the sensor_msgs/msg/Image composite message.

Interface files

Messages

Special values (*i.e.*, **constants**) or **default values** may be specified.

```
1 int64 MYNUM=1 # Must be of compatible type
2
3 int64 number
4 int64 number_with_default 2
```

Listing 8: Definition of an example message with a constant and a default value.

They are not bound to any field and will appear as **special selectable values** in the generated C++/Python libraries code.

ROS 2 adds its own **guidelines**², and installed interfaces can be inspected with

```
ros2 interface show
```

²[ros2-examples/interfaces.md](https://ros2-examples.github.io/interfaces.md)

Message topics

Quality of Service

A **QoS policy** for publishers/subscribers is a data structure with the following attributes:

- **History** (*keep last N or all*)
- **Depth** (queue size N)
- **Reliability** (*best-effort or reliable*, default: reliable)
- **Durability** (publishers resend all messages to "late-joiners")
- Deadline
- **Lifespan** (message expiration date)
- Liveliness
- Lease duration

Default **profiles** are available (e.g. **Sensor data**, **Service...**), see the [docs](#).

Message topics

Inspection tools

The command line tool `ros2 topic` can be used to **inspect topics** and related entities. It has a lot of **verbs**, the most important ones are:

- `list` (list all topics)
- `echo` (print messages to the console)
- `pub` (publish messages from the console)
- `hz` (print publishing rate and statistics)
- `info` (print information about a topic)
- `type` (print the message type)

each with many useful options.

Nodes can be inspected with the `ros2 node` command, and its many verbs.

Example

Topic pub/sub

Now go have a look at the first two example packages:

[ros2-examples/src/cpp/topic_pubsub_cpp](#)

[ros2-examples/src/python/topic_pubsub_py](#)

- Install ROS 2 on a platform of your choice.
- Run the [demo nodes](#).
- Inspect the demo topics.
- Interact with the demo nodes from the command line.
- Clone [ros2-examples](#) as suggested and rebuild the first example packages.
- Listen to the `/rosout` topic from the command line while other nodes run.