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Robot Operating System - ROS

Introduction

Manchester Robotics

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Robot Operating System - ROS

What is ROS?

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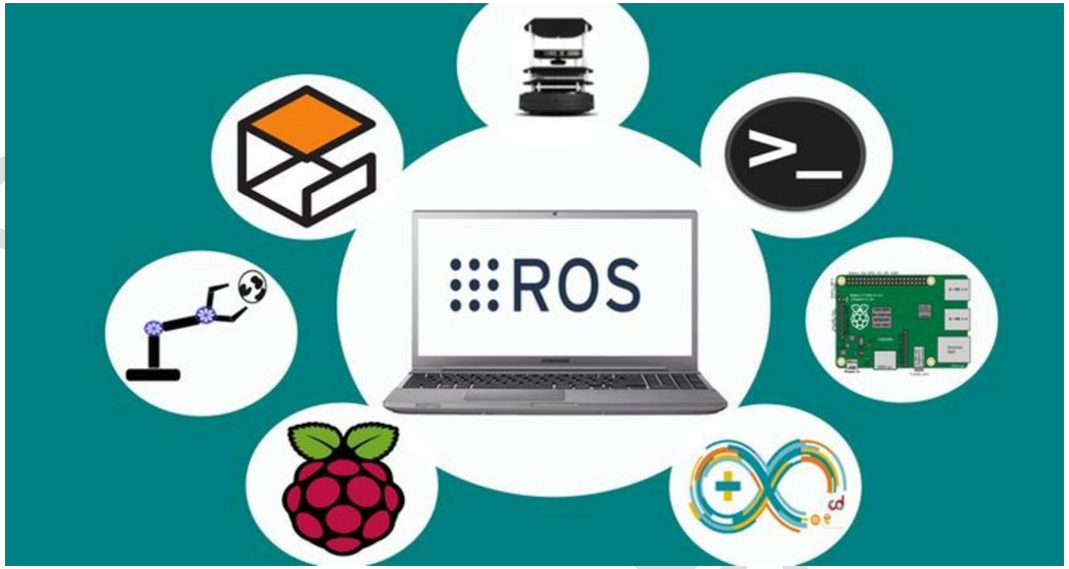
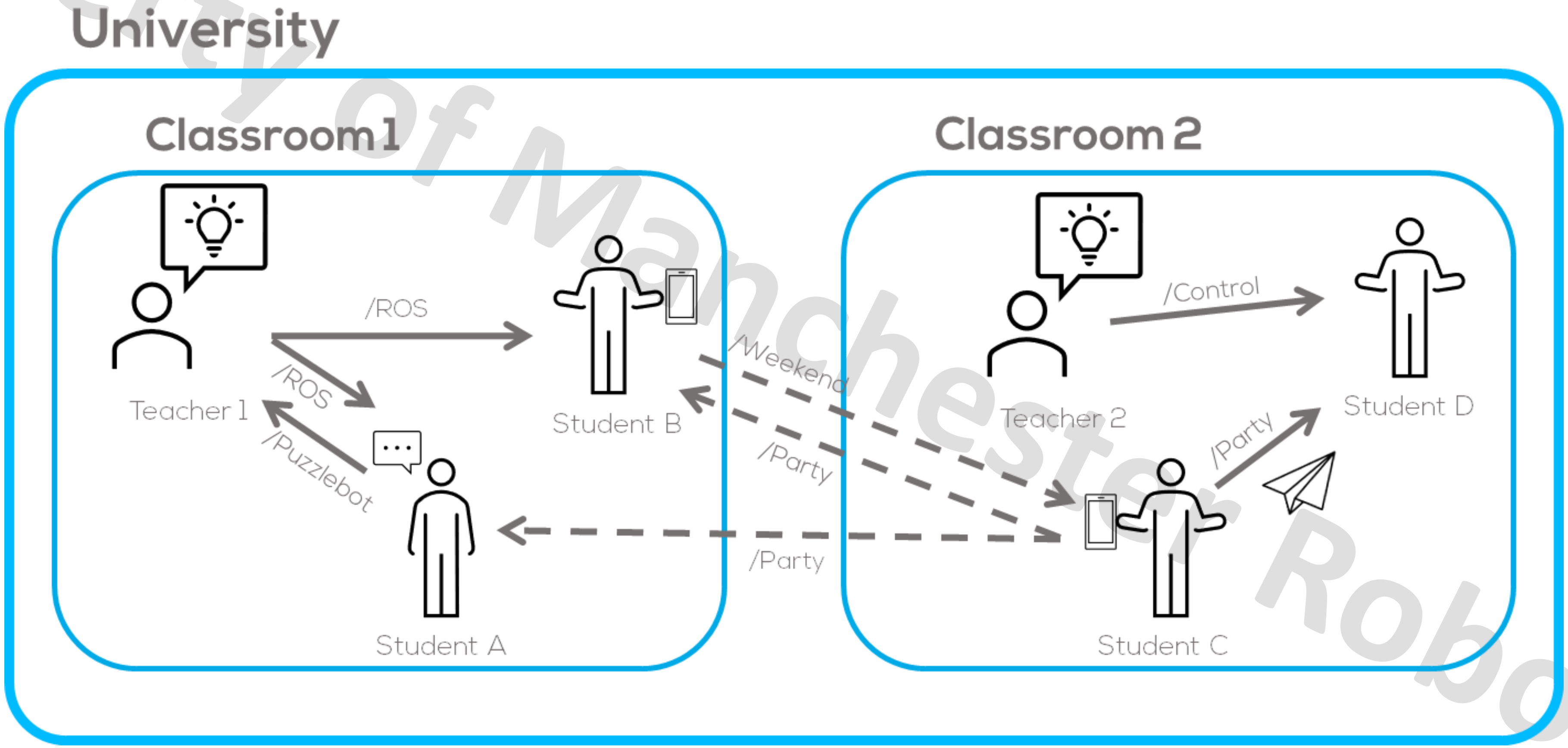
What is ROS?

What is ROS?

“ROS is a set of software libraries and tools for building robot applications. From drivers and state-of-the-art algorithms to powerful developer tools, ROS has the open-source tools you need for your next robotics project.”



ROS Basics

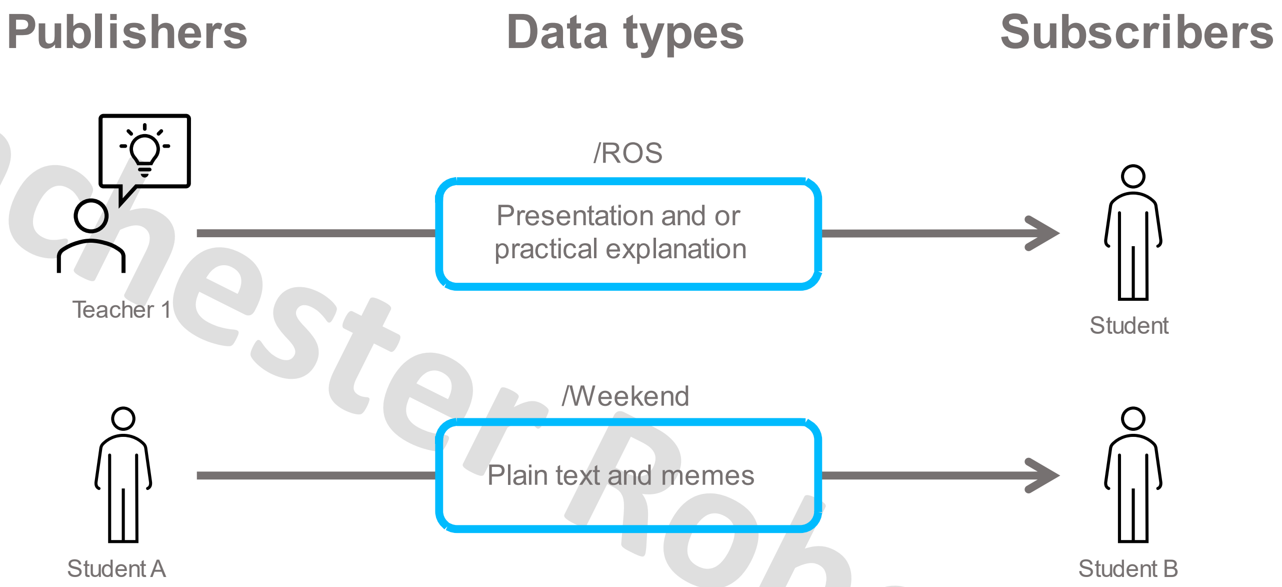


** Any resemblance to reality, is purely coincidental.

ROS Basics

How is the information delivered?

- The information is delivered through messages inside each topic.
- Any message or class has a certain format (is encoded), which both the teacher and the student know off and is expected.
- As an example: Between two students, it is expected some simple messages such as plain text, memes or figures.
- If the structure of the message is incorrect it would not be possible to understand it.



Robot Operating System - ROS

ROS Architecture

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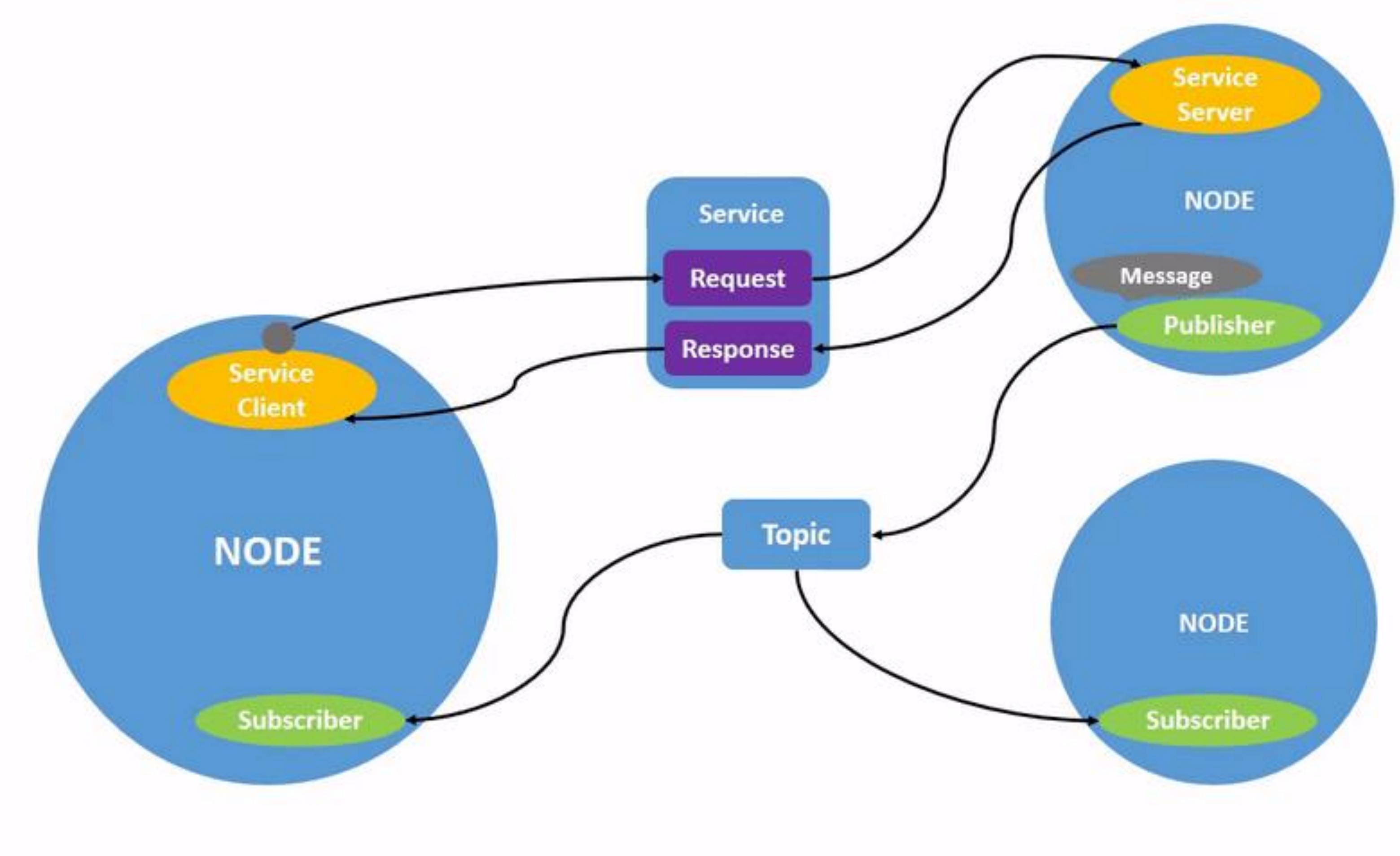
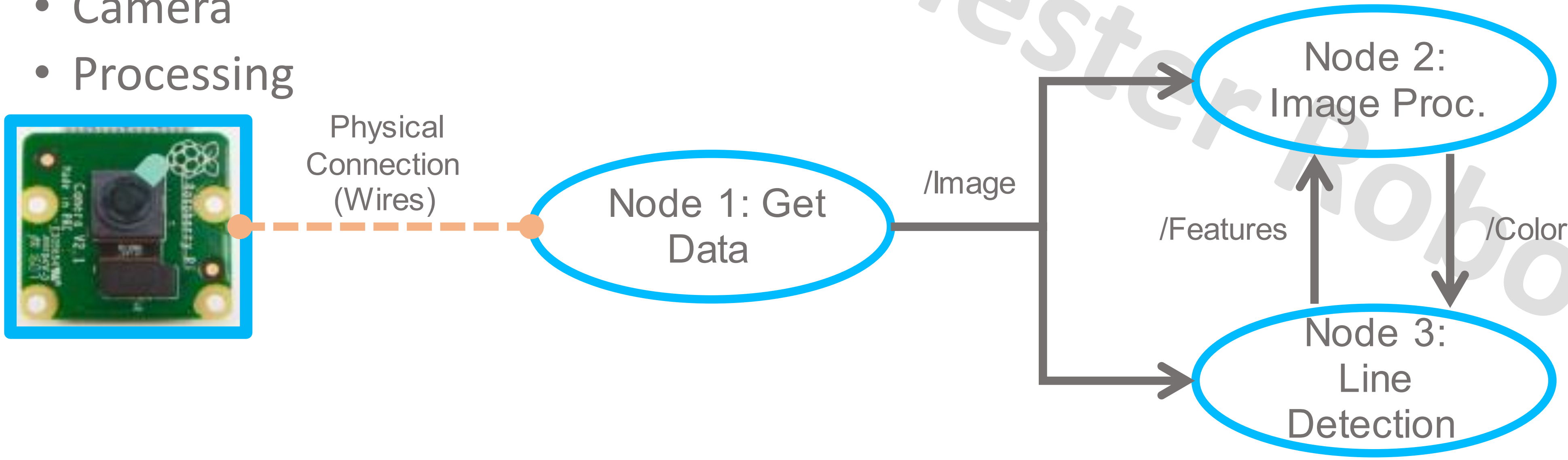
ROS2 graph


Service
Server
NODE
Service
Request
Response
Message
Publisher
Service
Client
NODE
Topic
NODE
Subscriber
Subscriber

Nodes

- Fundamental ROS 2 element that serves a single, modular purpose in a robotics system
  - LRF
  - Wheel control
  - Camera
  - Processing

- It is a piece of software that acts as an element in the network.
- Executes part of a code and can be programmed in C++ or Python.

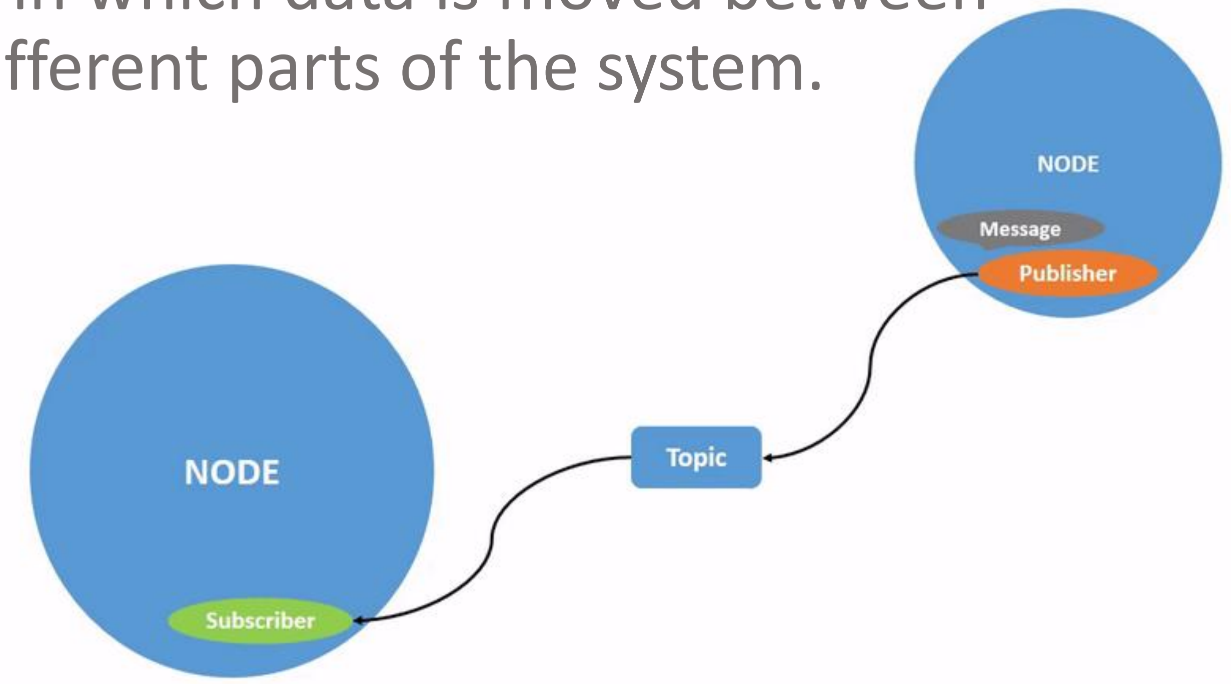


Nodes

- Launching a node
  - ros2 run <package_name> <executable_name>
- Show all the running nodes
  - ros2 node list
- Detailed information of the available nodes
  - ros2 node info <node_name>

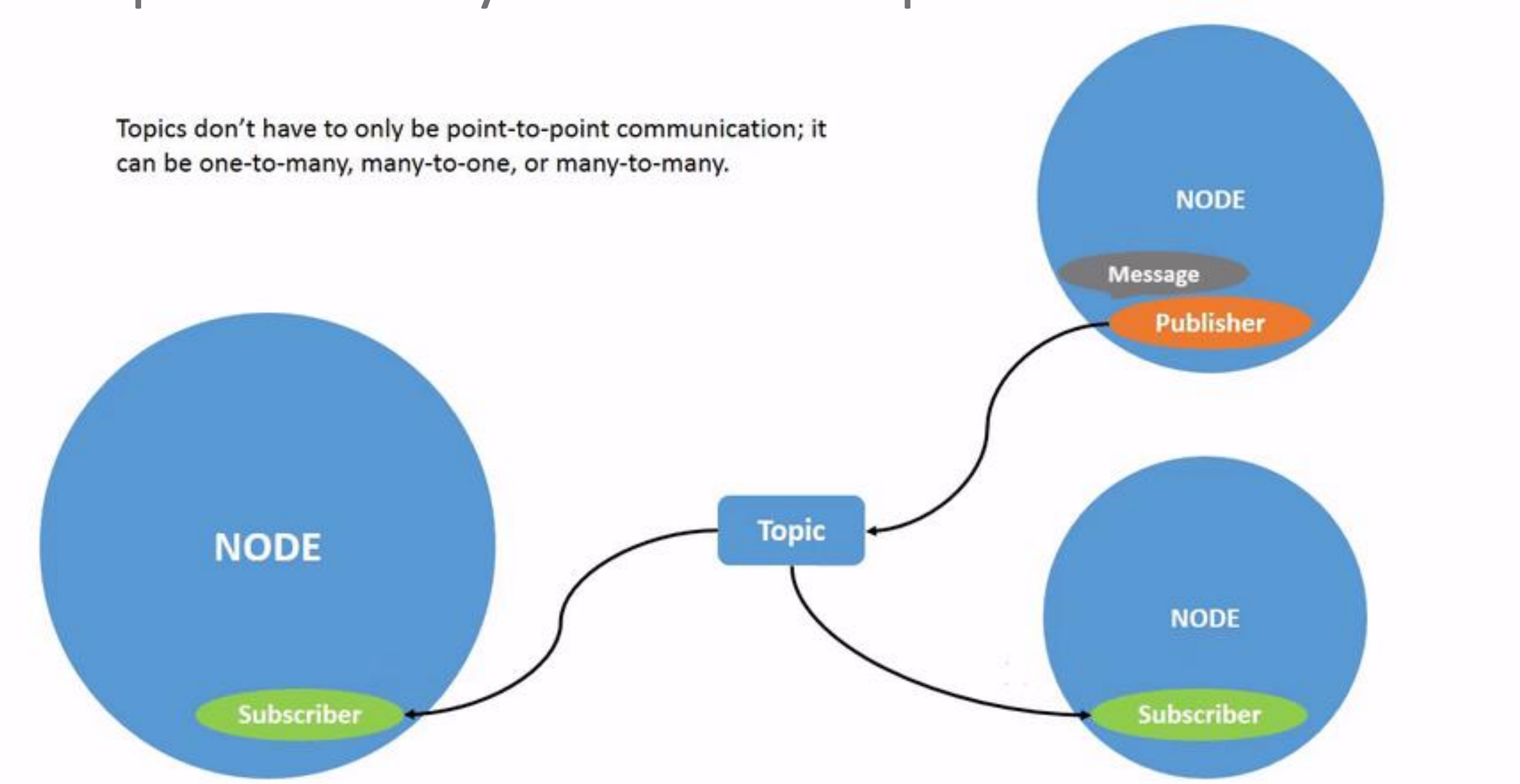
Topics

- Topics are a vital element of the ROS graph that act as a bus for nodes to exchange messages.
- Topics are one of the main ways in which data is moved between nodes and therefore between different parts of the system.



Topics

- A node may publish data to any number of topics and simultaneously have subscriptions to any number of topics.



Topics don't have to only be point-to-point communication; it can be one-to-many, many-to-one, or many-to-many.

Topics

- List of all the topics currently active in the system
  - ros2 topic list
- List of all the topics currently active in the system with message information
  - ros2 topic list -t
- See the data being published on a topic
  - ros2 topic info <topic_name>

    - Type: geometry_msgs/msg/Twist
    - Publisher count: 1
    - Subscription count: 2

Interface (Messages)

- Nodes send data over topics using messages.
- Publishers and subscribers must send and receive the same type of message to communicate.
- Many types of data are supported such as integers, floating point, Boolean, etc. Messages can include nested structures and arrays.

- ros2 topic list –t
- /turtle1/cmd_vel [geometry_msgs/msg/Twist

Interface (Messages)

- ros2 interface show geometry_msgs/msg/Twist
- # This expresses velocity in free space broken into its linear and angular parts.

- Vector3 linear
  - float64 x
  - float64 y
  - float64 z
- Vector3 angular
  - float64 x
  - float64 y
  - float64 z

Interface (Messages)

std_msgs/Float32

```
float32 data
```

geometry_msgs /Point

```
float64 x
float64 y
float64 z
```

geometry_msgs/Pose

```
geometry_msgs/Point position
    float64 x
    float64 y
    float64 z
geometry_msgs/Quaternion orientation
    float64 x
    float64 y
    float64 z
    float64 w
```

Topics

- Publish data onto a topic directly from the command line
  - ros2 topic pub <topic_name> <msg_type> '<args>'
  - '<args>’ - data to pass to the topic in YAML syntax

- View the rate at which data is published
  - ros2 topic hz <topic_name>

Robot Operating System - ROS

ROS Example

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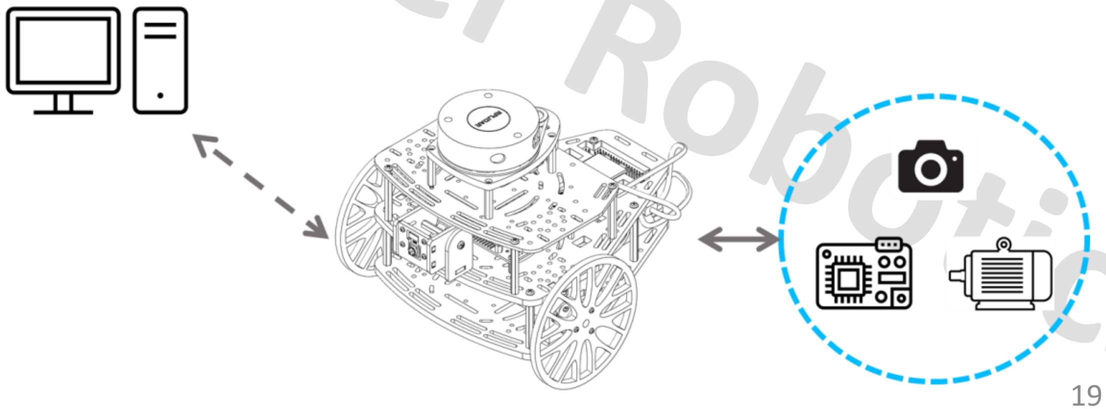
ROS Practical Example

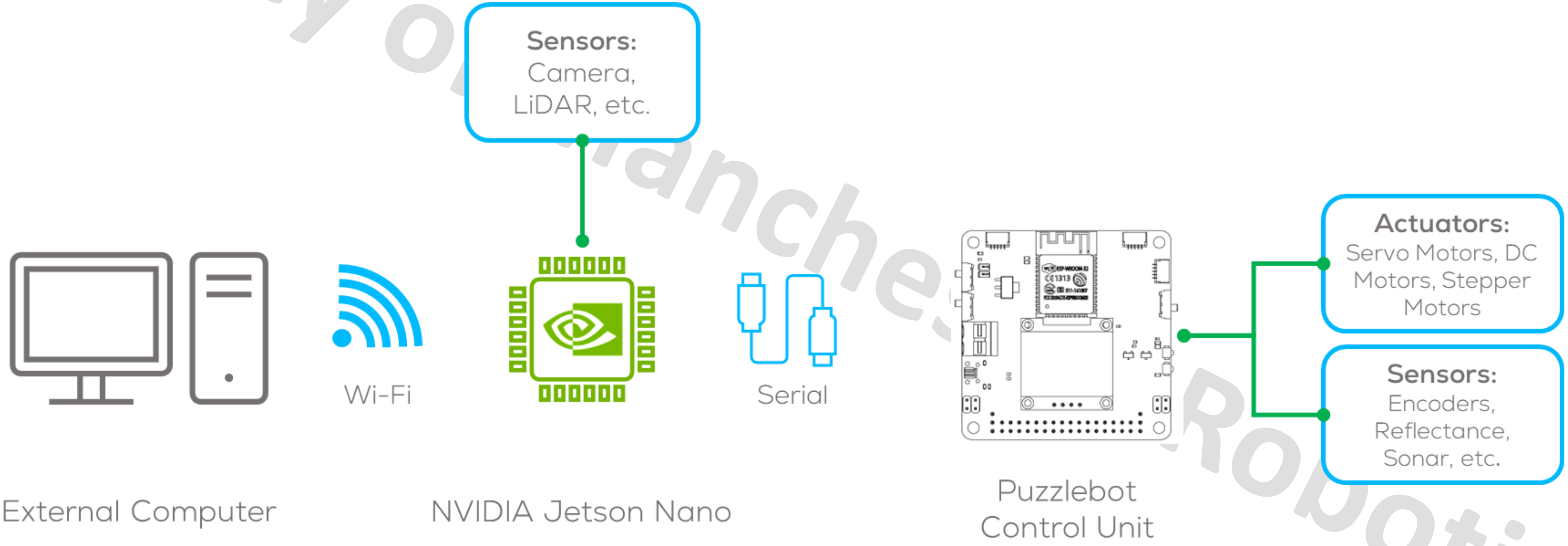
- The system presented is a mobile robot called Puzzlebot® by Manchester Robotics.
- The robot is comprised of an on-board computing unit from NVIDIA the Jetson Nano used for high level control algorithms and a microcontroller for low level control tasks.
- The robot also contains different sensors and actuators such as motors, encoders, and cameras.



ROS Practical Example

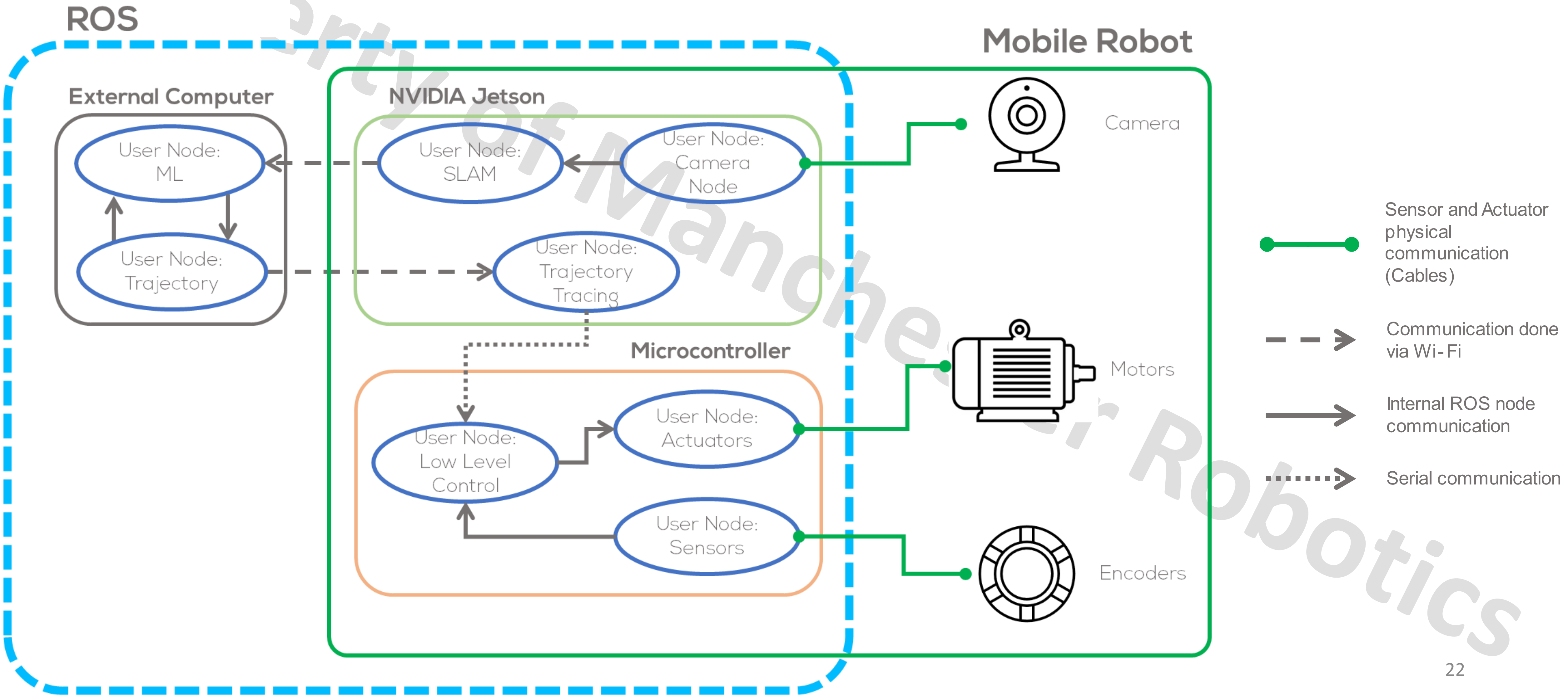
- The robot is controlled by a computer running a ROS node and communicated to the robot via Wi-Fi.
- The on-board computer runs Ubuntu as OS and uses ROS nodes to perform different tasks and communicate with the external computer, microcontroller and the peripherals.
- The microcontroller contains several ROS nodes and provides access to the sensors and actuators.

ROS Example



Sensors: Camera, LiDAR, etc.
Wi-Fi
Serial
Actuators: Servo Motors, DC Motors, Stepper Motors
Sensors: Encoders, Reflectance, Sonar, etc.
External Computer
NVIDIA Jetson Nano
Puzzlebot Control Unit

ROS Example


ROS
Mobile Robot
External Computer
User Node: ML
User Node: Trajectory
NVIDIA Jetson
User Node: SLAM
User Node: Camera Node
User Node: Trajectory Tracing
Microcontroller
User Node: Low Level Control
User Node: Actuators
User Node: Sensors
Camera
Motors
Encoders
Sensor and Actuator physical communication (Cables)
Communication done via Wi-Fi
Internal ROS node communication
Serial communication

Robot Operating System - ROS

ROS Organization

Hands-on theoretical activity

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Workspace

- ROS projects are organized in workspaces, which are a collection of grouped codes called packages.
- Commonly there is a *src* subdirectory. Inside that subdirectory is where the source code of ROS packages will be located. Typically, the directory starts empty.

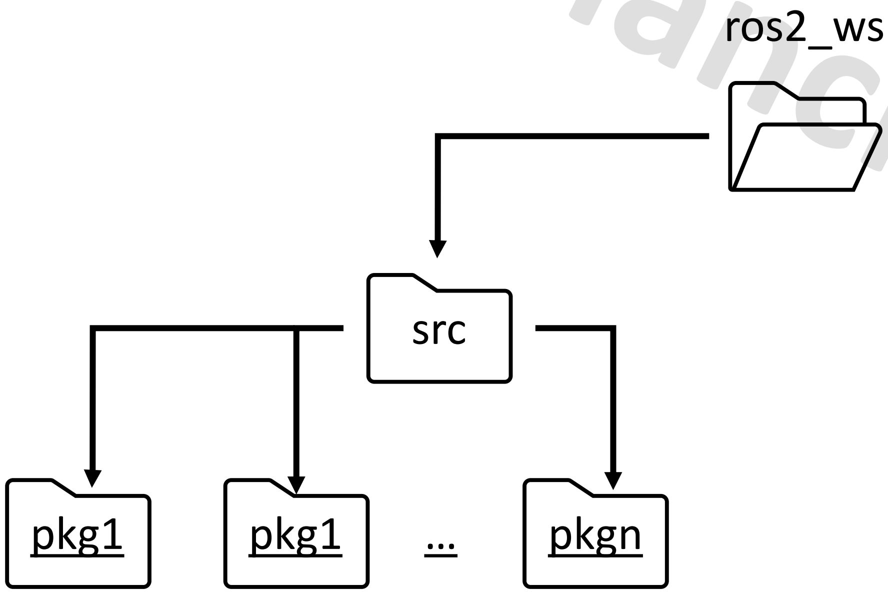
- *colcon* is an iteration on the ROS build tools *catkin_make*, *catkin_make_isolated*, *catkin_tools* and *ament_tools*.
- *colcon* does out of source builds. By default, it will create the *build*, *install* and *log* directories as peers of the *src* directory:

Workspace

- The *build* directory will be where intermediate files are stored. For each package a subfolder will be created in which e.g. CMake is being invoked.
- The *install* directory is where each package will be installed to. By default, each package will be installed into a separate subdirectory.
- The *log* directory contains various logging information about each colcon invocation.

Create a workspace

- Create a directory to contain our workspace
  - mkdir -p ~/ros2_cadi_ws/src
  - cd ~/ros2_cadi_ws



Build the workspace

- Before building a workspace make sure you are in the root of it.
  - cd ~/ros2_cadi_ws

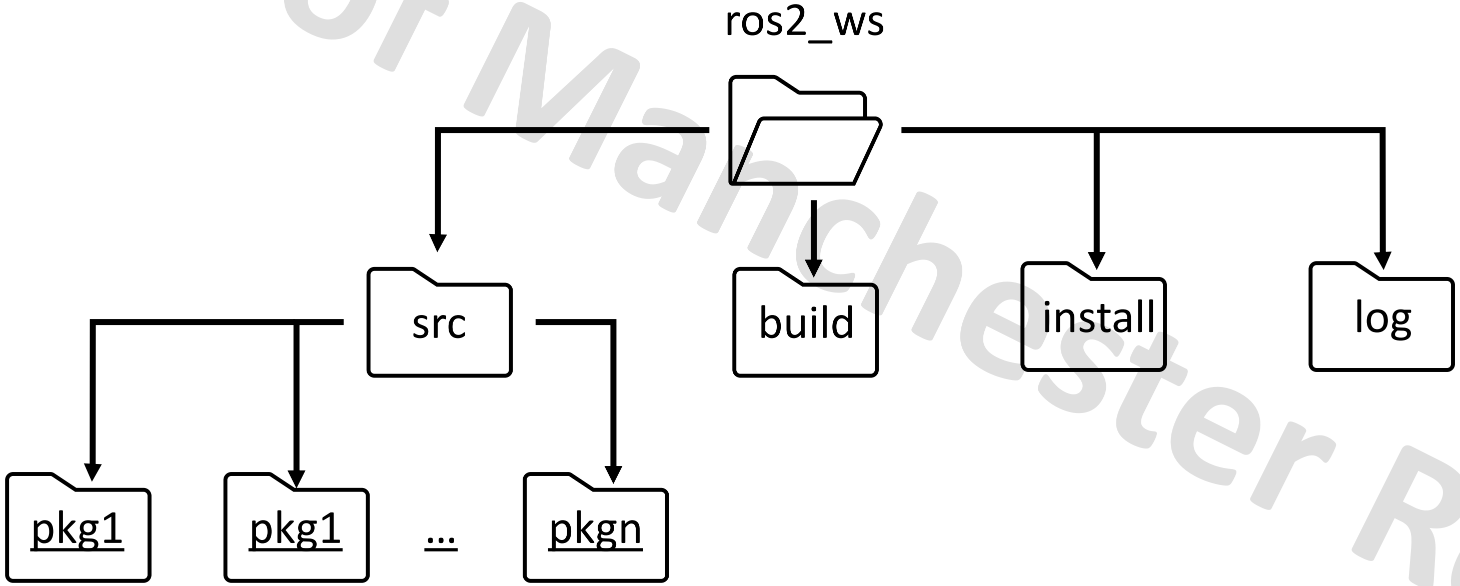
- colcon supports the option --symlink-install.
- This allows the installed files to be changed by changing the files in the source space (e.g. Python files or other not compiled resourced) for faster iteration.
  - colcon build

After building the workspace

- To run tests for the just built packages
  - colcon test

- Before you can use any of the installed executables or libraries, you will need to add them to your path and library paths.
- *colcon* will have generated bash/bat files in the *install* directory to help setup the environment.
- These files will add all of the required elements to your path and library paths as well as provide any bash or shell commands exported by packages.
  - source install/setup.bash

Workspace



ROS2 Package

- A package can be considered a container for ROS2 code.
- Packages allow to release ROS2 work and allow others to build and use it easily.
- Package creation in ROS2 uses ament as its build system and colcon as its build tool.
- CMake or Python can be used to create a package.

ROS2 CMake Package

Minimum required content:

- package.xml file containing meta information about the package
- CMakeLists.txt file that describes how to build the code within the package

Simplest file structure

- my_package/
-     CMakeLists.txt
-     package.xml

ROS2 Python Package

Minimum required content:

- package.xml file containing meta information about the package
- setup.py containing instructions for how to install the package
- setup.cfg is required when a package has executables, so ros2 run can find them
- /<package_name> - a directory with the same name as your package, used by ROS 2 tools to find your package, contains __init__.py

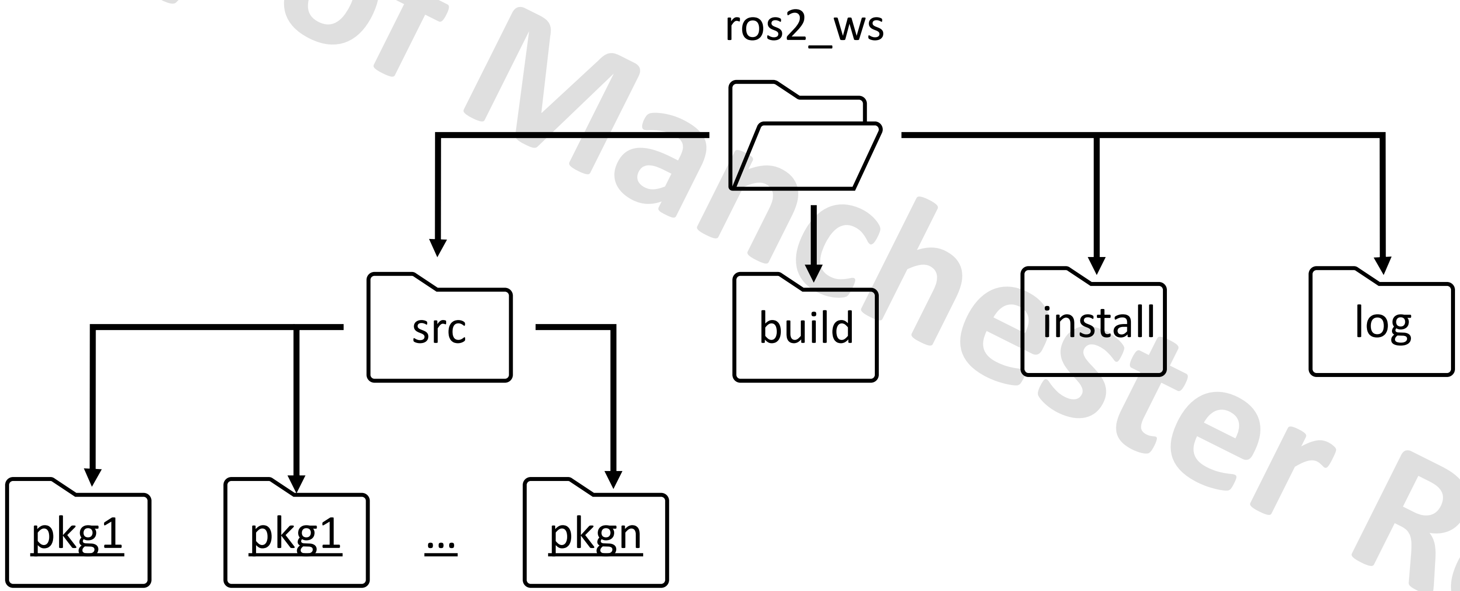
Simplest file structure

- my_package/
-     setup.py
-     package.xml
-     resource/my_package

Packages in a workspace

- A single workspace can contain as many packages as wanted, each in their own folder.
- A workspace can also have packages of different build types in one workspace (CMake, Python, etc.). You cannot have nested packages.
- Best practice is to have a src folder within your workspace, and to create your packages in there. This keeps the top level of the workspace “clean”.

Workspace



Create a new package

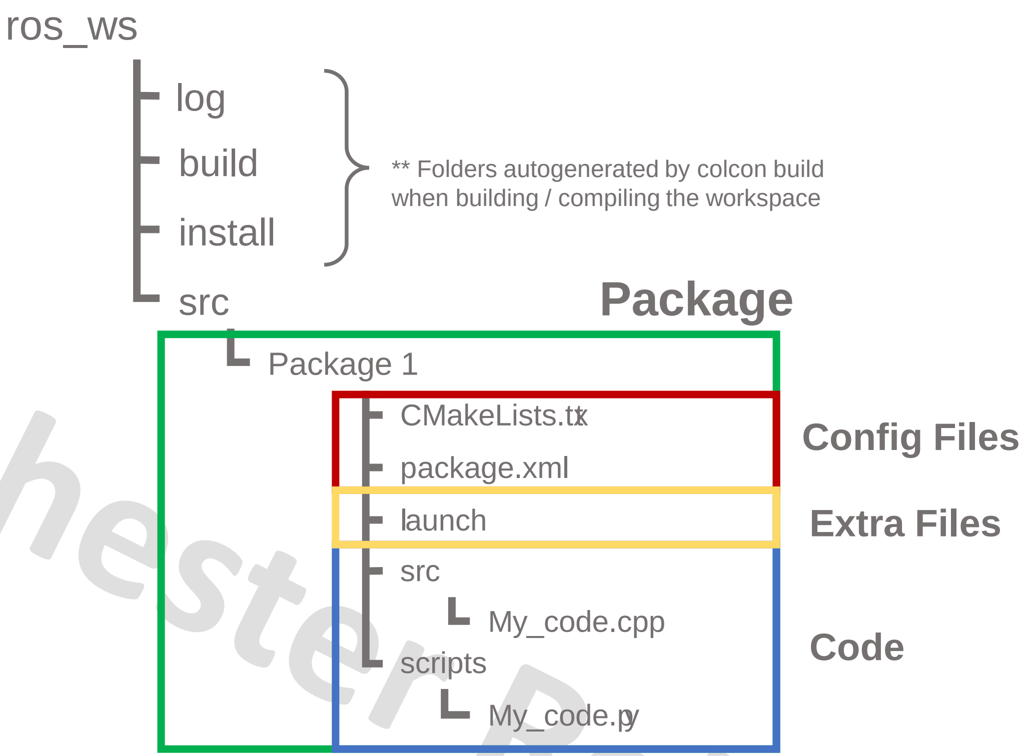
- To create a package
  - C++
  - ros2 pkg create --build-type ament_cmake <package_name>

  - Python
  - ros2 pkg create --build-type ament_python <package_name>

ROS Organization

ROS Packages

- Each package in ROS requires different attributes to be compiled.
- These attributes are usually dependencies related with other packages, external libraries or custom messages, services and actions.
- The preferred compilation tool is known as **colcon** and uses two separated files, **package.xml** and **CMakeLists.txt**.
- Instructions for the compiler need to be allocated in CMake and Package files.



ros_ws

log

build

install

src

** Folders autogenerated by colcon build when building / compiling the workspace

Package

Package 1

CMakeLists.txt

package.xml

launch

src

My_code.cpp

scripts

My_code.py

Config Files

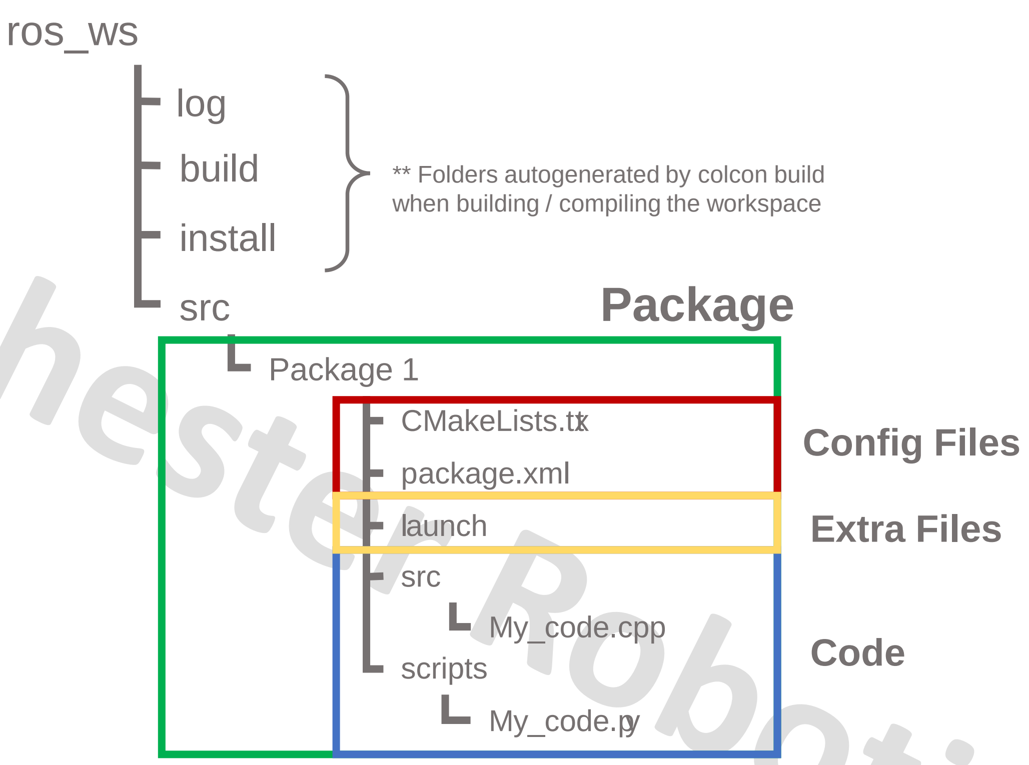
Extra Files

Code

ROS Organization

A Closer Look Into a ROS Package

- Packages: Files that can be exported between projects
- Configuration files used to stablish code dependencies.
- Extra files and folders: They are files/folders dedicated for specific tasks. In this case the launch file allow us to execute several nodes at the same time
- Nodes : Code that we will execute inside each node.



** Folders autogenerated by colcon build when building / compiling the workspace

ROS Activities

Activity #1 : Talker – Listener

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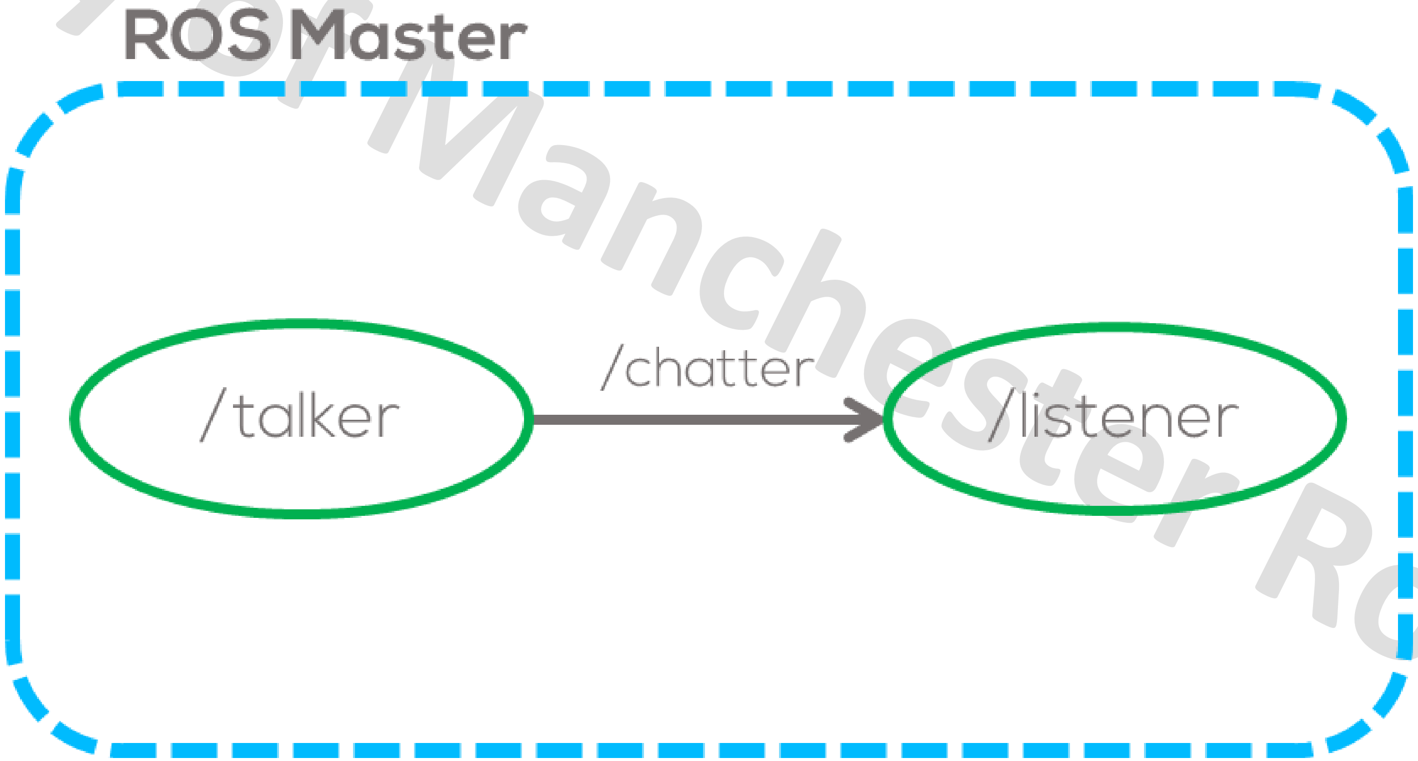
ROS Activity 1

- Talker - Listener framework
- In this activity, the student will learn about nodes, topic and messages.
- The simplest task to perform in ROS is to communicate 2 nodes.
- The first node to be created will be the “talker” node. This node will send a simple message inside the topic “/chatter”.
- The second node to be programmed, will be the “listener” node. This node will subscribe to the topic “/chatter” of the “talker” node and print on the screen the message.


ROS Master
/talker
/chatter
/listener

ROS Activity 1 – Requirements

- Ubuntu in VM (MCR2 VM) or dual booting
- ROS installed (if not follow the steps in this link and select full installation)
- Workspace “ros2_ws” created following the steps here (if you are using the VM this is already done for you).

ROS Activity 1 – create package

- Create a package called *basic_comms*. Open a terminal and type the following
  - ros2 pkg create --build-type ament_python --node-name talker basic_comms
  - Beware that the command must be run inside the "src" folder.

- Once the package is created you will be able to see the package folder in ~/ros2_ws/src.
- Build the package you just created and add it to your environment
  - colcon build

ROS Activity 1 – validate package

- Source the current workspace
  - source install/setup.bash

- Check the executable that was recently created
  - ros2 run basic_comms talker

Talker node

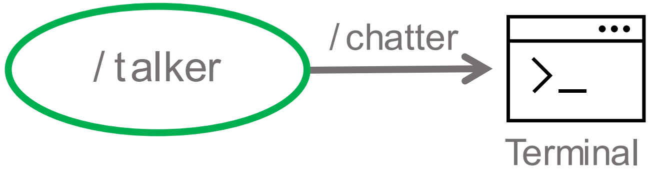
- Create the publisher node file in ~/ros2_ws/src/basic_comms/basic_comms/src
  - touch talker.py
  - chmod +x talker.py

- Recall that this directory is a Python package with the same name as the ROS 2 package it's nested in.
- Open talker.py in a text editor (e.g. gedit, vscode, vim, …)

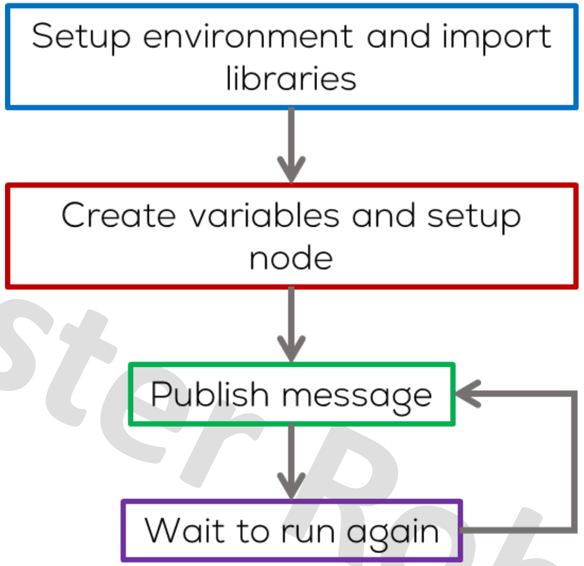
ROS Activity 1

Coding the Talker node

- This node will publish a message (string) into the "/chatter" topic.
- To start, the message will be seen in the terminal to verify that the node is working properly (debug).
- A graphical representation of this task will look as follows



- Nodes in ROS usually have a structure when programmed.


Setup environment and import libraries

Create variables and setup node

Publish message

Wait to run again

- Your code will be written in the file "talker.py".
- Use any word processor or IDE (nano, VS Code, Vim, etc.) to open the file.

OOP - Talker node

Imports

```
import rclpy
from rclpy.node import Node

from std_msgs.msg import String
```

Constructor

```
class MinimalPublisher(Node):

    def __init__(self):
        super().__init__('talker_node')
        self.publisher_ = self.create_publisher(String, 'chatter', 10)
        timer_period = 0.5  # seconds
        self.timer = self.create_timer(timer_period, self.timer_callback)
        self.i = 0
```

Timer callback

```
    def timer_callback(self):
        msg = String()
        msg.data = 'Hello World: %d' % self.i
        self.publisher_.publish(msg)
        self.get_logger().info('Publishing: "%s"' % msg.data)
        self.i += 1
```

Main

```
def main(args=None):
    rclpy.init(args=args)

    minimal_publisher = MinimalPublisher()

    rclpy.spin(minimal_publisher)

    # Destroy the node explicitly
    # (optional - otherwise it will be done automatically
    # when the garbage collector destroys the node object)
    minimal_publisher.destroy_node()
    rclpy.shutdown()
```

Execute code

```
if __name__ == '__main__':
    main()
```

Add dependencies

- Open package.xml with your text editor.
- After the license, add the following dependencies corresponding to your node’s import statements:

```
<exec_depend>rclpy</exec_depend>
<exec_depend>std_msgs</exec_depend>
```

Add an entry point

- Open the setup.py file

```
entry_points={
        'console_scripts': [
            'talker = basic_comms.talker:main',
        ],
    },
```

ROS Exercise 1 – Running the node

- Open a terminal and build your package

```
$ cd ~/ros2_ws
$ colcon build --symlink-install
$ source install/setup.bash
```

- Open a new terminal and run the node

```
$ ros2 run basic_comms talker
```

- To visualize the output of the node, open another terminal and use the command “echo” as follows

```
$ ros2 topic echo /chatter
```

Listener node

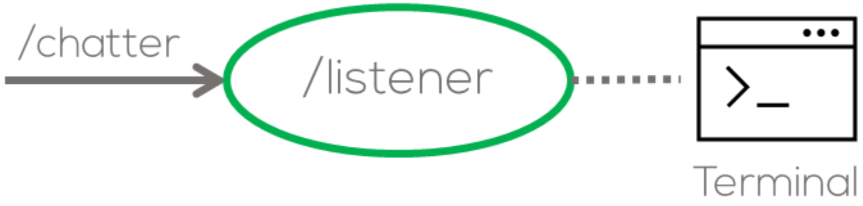
- Create the publisher node file in ~/ros2_ws/src/basic_comms/basic_comms/src
  - touch listener.py
  - chmod +x listener.py

- Recall that this directory is a Python package with the same name as the ROS 2 package it's nested in.
- Open listener.py in a text editor (e.g. gedit, vscode, vim, …)

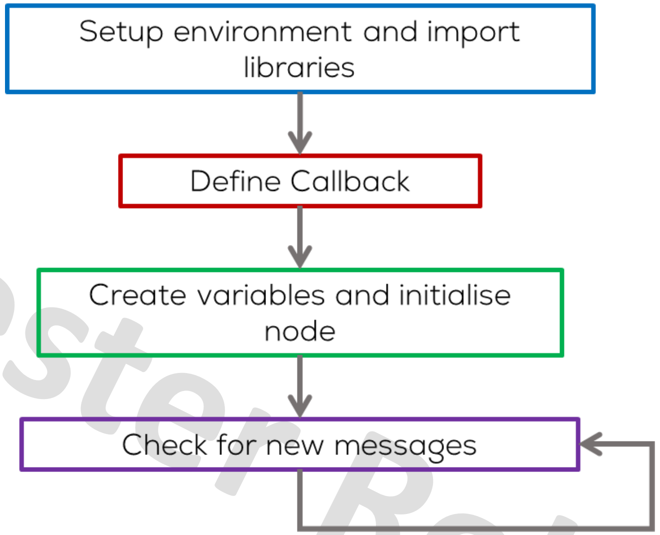
ROS Activity 1

Coding the Listener node

- This node will subscribe to the "/chatter" topic and display on terminal the message (String) it has received.
- To start, the message will be sent form the terminal (manually) to verify that the node is working properly (debug).
- A graphical representation of this task will look as follows



- The structure to be used for this node is thefollowing.


Setup environment and import libraries
Define Callback
Create variables and initialise node
Check for new messages

- Your code will be written in the file "listener.py".
- Use any word processor or IDE (nano, VS Code, Vim, etc.) to open the file .

OOP - Listener node

Imports

```
import rclpy
from rclpy.node import Node

from std_msgs.msg import String
```

Constructor

```
class MinimalSubscriber(Node):

    def __init__(self):
        super().__init__('listener_node')
        self.subscription = self.create_subscription(
            String,
            'chatter',
            self.listener_callback,
            10)
        self.subscription  # prevent unused variable warning
```

Timer callback

```
    def listener_callback(self, msg):
        self.get_logger().info('I heard: "%s"' % msg.data)
```

Main

```
def main(args=None):
    rclpy.init(args=args)

    minimal_subscriber = MinimalSubscriber()

    rclpy.spin(minimal_subscriber)

    # Destroy the node explicitly
    # (optional - otherwise it will be done automatically
    # when the garbage collector destroys the node object)
    minimal_subscriber.destroy_node()
    rclpy.shutdown()
```

Execute code

```
if __name__ == '__main__':
    main()
```

ROS Exercise 1 – Running the node

- Open a terminal and build your package

```
$ cd ~/ros2_ws
$ colcon build --symlink-install
$ source install/setup.bash
```

- Open a new terminal and run the node

```
$ ros2 run basic_comms listener
```

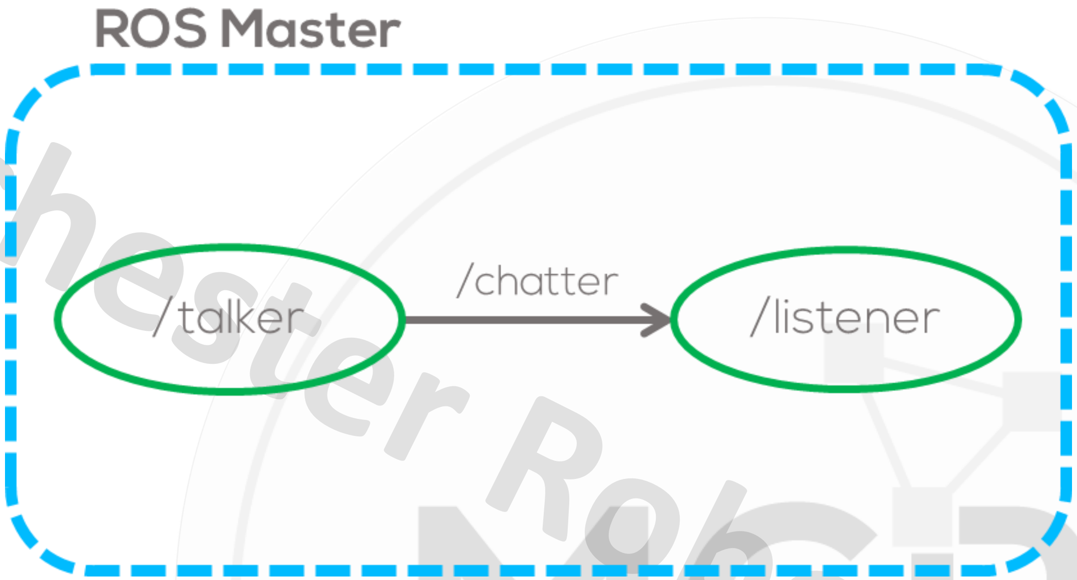
- To visualize the output of the node, open another terminal and use the command “echo” as follows

```
$ ros2 topic pub --once /chatter std_msgs/msg/String "data: hola"
```

ROS Activity 1

Talker – Listener Nodes

- Having developed both nodes, now is time to put everything together and let the nodes to communicate.
- This can be achieved in two different ways, manually and via a ROS tool called launch file.



ROS Activity 1 – Running the nodes

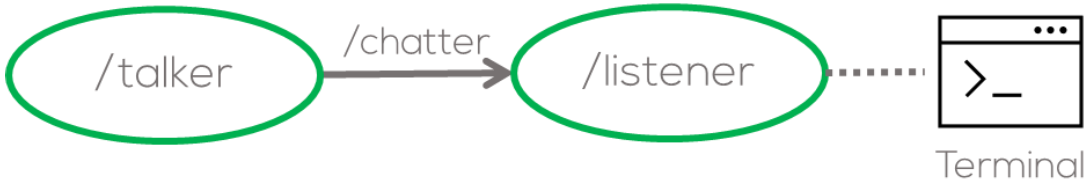
- Open a new terminal and run the talker node you just made using the following command

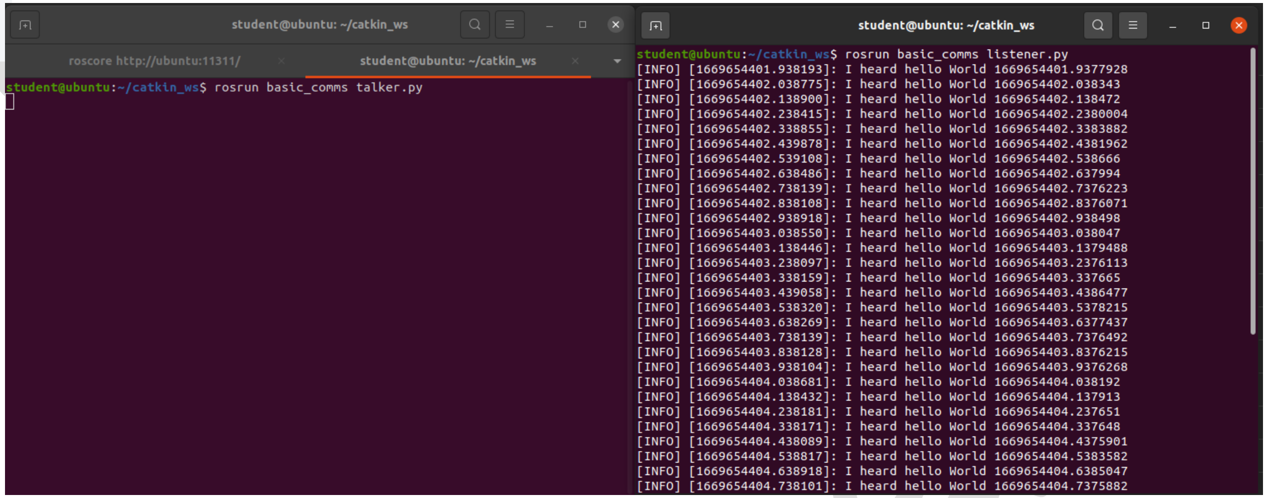
```
$ source install/setup.bash
$ rosrun basic_comms talker.py
```

- Open a new terminal and run the listener node you just made using the following command

```
$ source install/setup.bash
$ rosrun basic_comms listener.py
```

Results




student@ubuntu: ~/catkin_ws
roscore http://ubuntu:11311/
student@ubuntu: ~/catkin_ws
student@ubuntu: ~/catkin_ws

```
student@ubuntu:~/catkin_ws$ rosrun basic_comms talker.py
```

```
student@ubuntu:~/catkin_ws$ rosrun basic_comms listener.py
[INFO] [1669654401.938193]: I heard hello World 1669654401.9377928
[INFO] [1669654402.038775]: I heard hello World 1669654402.038343
[INFO] [1669654402.138900]: I heard hello World 1669654402.138472
[INFO] [1669654402.238415]: I heard hello World 1669654402.2380004
[INFO] [1669654402.338855]: I heard hello World 1669654402.3383882
[INFO] [1669654402.439878]: I heard hello World 1669654402.4381962
[INFO] [1669654402.539108]: I heard hello World 1669654402.538666
[INFO] [1669654402.638486]: I heard hello World 1669654402.637994
[INFO] [1669654402.738139]: I heard hello World 1669654402.7376223
[INFO] [1669654402.838108]: I heard hello World 1669654402.8376071
[INFO] [1669654402.938918]: I heard hello World 1669654402.938498
[INFO] [1669654403.038550]: I heard hello World 1669654403.038047
[INFO] [1669654403.138446]: I heard hello World 1669654403.1379488
[INFO] [1669654403.238097]: I heard hello World 1669654403.2376113
[INFO] [1669654403.338159]: I heard hello World 1669654403.337665
[INFO] [1669654403.439058]: I heard hello World 1669654403.4386477
[INFO] [1669654403.538320]: I heard hello World 1669654403.5378215
[INFO] [1669654403.638269]: I heard hello World 1669654403.6377437
[INFO] [1669654403.738139]: I heard hello World 1669654403.7376492
[INFO] [1669654403.838128]: I heard hello World 1669654403.8376215
[INFO] [1669654403.938104]: I heard hello World 1669654403.9376268
[INFO] [1669654404.038681]: I heard hello World 1669654404.038192
[INFO] [1669654404.138432]: I heard hello World 1669654404.137913
[INFO] [1669654404.238181]: I heard hello World 1669654404.237651
[INFO] [1669654404.338171]: I heard hello World 1669654404.337648
[INFO] [1669654404.438089]: I heard hello World 1669654404.4375901
[INFO] [1669654404.538817]: I heard hello World 1669654404.5383582
[INFO] [1669654404.638918]: I heard hello World 1669654404.6385047
[INFO] [1669654404.738101]: I heard hello World 1669654404.7375882
```

Press “Ctrl+c” at each open terminal to stop the nodes and ROS

Robot Operating System - ROS

ROS Launch Files

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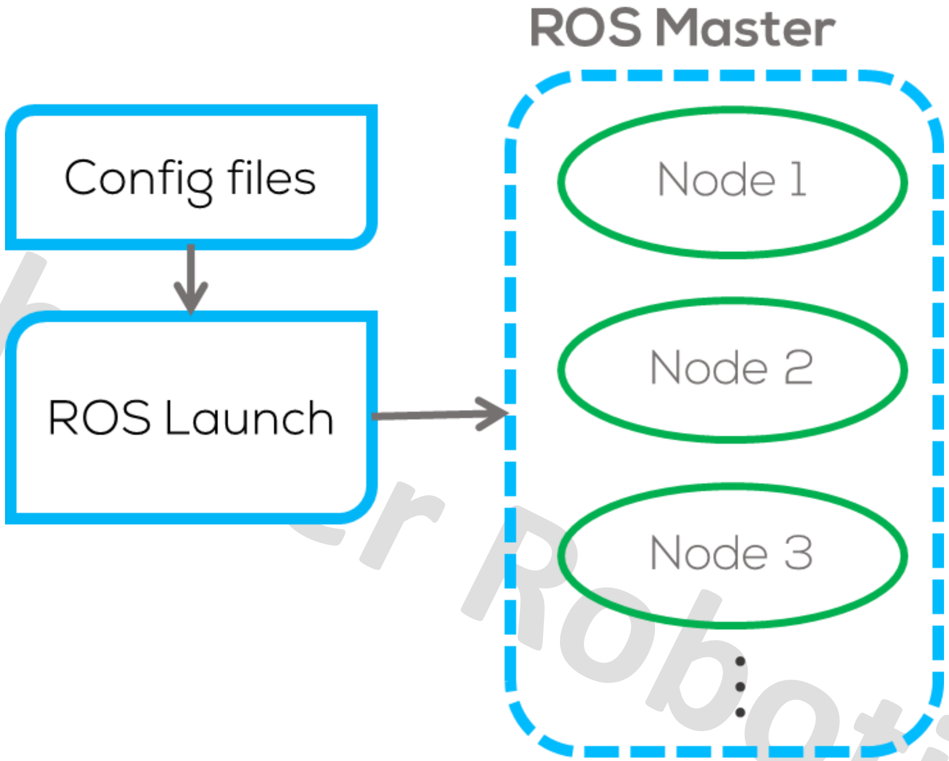
ROS2 Launch file

- Launch files are sets of commands written in Python, xml, and yaml that allow executing various scripts at the same time.
- Launch files allow to run any object used within the ROS2 architecture and has a wide variety of tools that allow to parametrize the launch file so that it can be adapted to the requirements of a project.



Launch files

- Launch files allow you to start up and configure a number of executables containing ROS 2 nodes simultaneously.
- Running a single launch file with the ros2 launch command will start up your entire system - all nodes and their configurations - at once.

- To use a launch file
  - ros2 launch <package_name> <file_name>

ROS2 Launch file

- The user can set parameters used by the nodes in ROS.
- The user can also set arguments used by the roslaunch files and nodes in ROS.
- All the processes will shut down when the roslaunch process is killed (ctrl+C).
- ROS Launch files are usually located inside a folder called “launch” in each package.

ROS Activity 1(Launch file)

- For exercise 1, it is possible to develop a ROS Launch file as follows.

```
$ cd ~/ros2_ws/src/basic_comms
$ mkdir launch
$ cd launch
$ touch chatter_launch.py
$ chmod +x chatter_launch.py
```

- Your code will be written in the file “activity1.launch”.
- For this exercise, the talker and listener nodes will be launched.
- The following code will launch the two nodes previously done (talker and listener).

ROS2 Launch file

```python
import os
from ament_index_python import get_package_share_directory
from launch import LaunchDescription
from launch.actions import IncludeLaunchDescription
from launch.launch_description_sources import PythonLaunchDescriptionSource
from launch_ros.actions import Node
```

Imports

```python
def generate_launch_description():

    talker_node = Node(
            package='basic_comms',
            executable='talker',
            output='screen',
        )

    listener_node = Node(
            package='basic_comms',
            executable='listener',
            output='screen',
        )
```

Launch body

```python
    l_d = LaunchDescription([talker_node, listener_node])

    return l_d
```

Set launch content

Dependencies

- Add the following line to the package.xml file
  - `<exec_depend>ros2launch</exec_depend>`

- Add the following line to the setup.py file
  - Make sure it is located inside `data_files`

  -
    ```
    (os.path.join('share', package_name, 'launch'), glob(os.path.join('launch', '*launch.[pxy][yma]*')))
    ```
  - Do not forget to include the following lines at the top
    - `import os`
    - `from glob import glob`

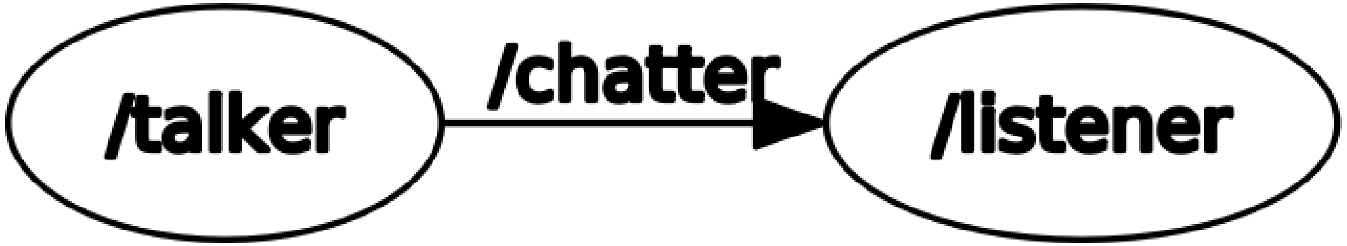
ROS Activity 1 (Launch file)

- To run the roslaunch file, open a terminal and type

```
$ colcon build
$ source install/setup.bash
$ roslaunch basic_comms chatter.launch.py
```

- Running the ROS tool “rqt_graph” it is possible to observe the nodes currently active

```
$ ros2 run rqt_graph rqt_graph
```



Q&A

Questions?

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Thank You

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