2025

INFO 802

Master Advanced Mechatronics

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POLYTECH ANNECY-CHAMBÉRY

ROS

Introduction
Lecture 1

Prerequisites

- Ubuntu installation
  - Ubuntu on a Windows Virtual machine
  - Or Ubuntu **mate** on a Raspberry Pi
  - Or Ubuntu on a a Linux machine

https://moodle.univ-smb.fr/course/view.php?id=242

https://ubuntu-mate.org/raspberry-pi/

https://tutorials.ubuntu.com/tutorial/tutorial-install-ubuntu-desktop

- Installation of ROS Noetic Ninjemys

http://wiki.ros.org/noetic/Installation

What is ROS ?

- ROS (**R**obot **O**perating **S**ystem) is an open-source, meta-operating system for your robot
  - open-source: all code is public. Most people share their code as to be used with ROS
  - meta-operating system: contains many of the components expected in an OS: hardware abstraction, low-level control, package management
- It is rather a middleware (*i.e.* a framework for writing robot software)
  - collection of tools, libraries, and conventions that help to build robot applications working across a wide variety of robotic platforms

Not an operating system !

More info
https://roboticsbackend.com/what-is-ros/

What is a Middleware ?

- Interface allowing the interconnection of several applications or hardware that were not necessarily designed to communicate with each other (not being on the same network, not sharing the same network, the same OS or the same protocols.)
- Software that acts as a bridge between an operating system or database and applications, especially on a network.
- Responsible for handling the communication between programs in a distributed system.

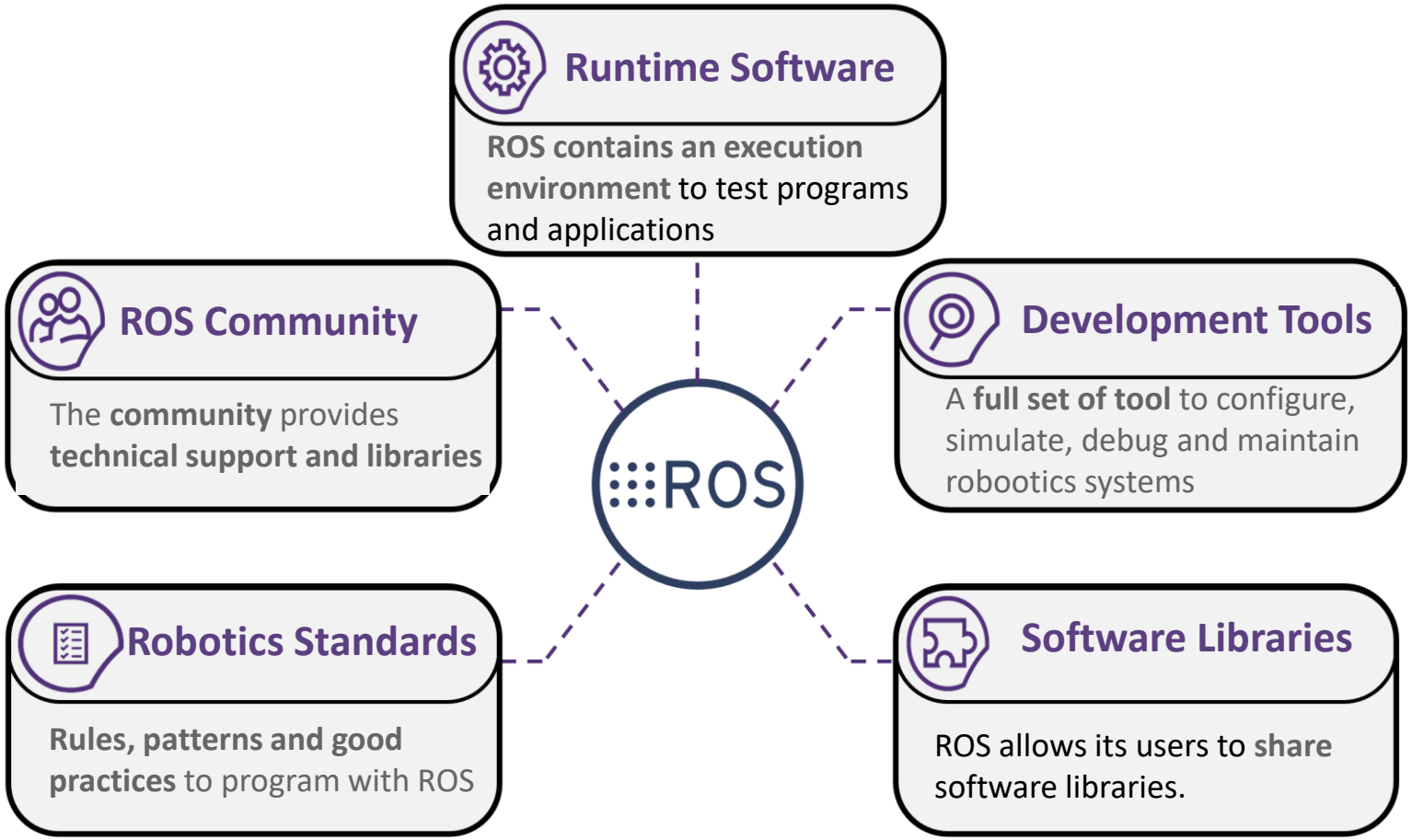
What is ROS ?

- **Plumbing :** ROS provides a message-passing system, often called “middleware” or “plumbing”
- **Tools :** launch, introspection, debugging, visualization, plotting, logging, and playback …
- **Capabilities :** From drivers to algorithms, to user interfaces, ROS provides the building blocks
- **Community :** The ROS community is large, diverse, and global.

More info
https://www.ros.org/blog/ecosystem/

What is ROS ?

- ROS is mainly composed of 2 things:
  - A core (middleware) with communication tools
  - A set of plug & play libraries

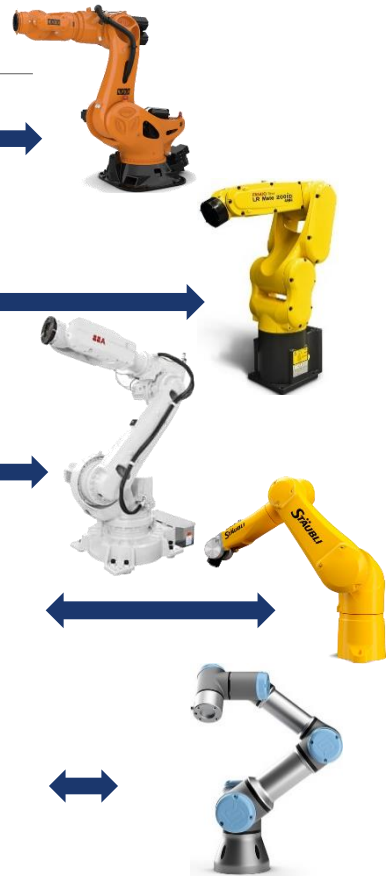


More info
https://roboticsbackend.com/what-is-ros/

Programming languages of industrial robot arms

- Almost every robot manufacturer has developed their **own proprietary** robot programming language → nothing was unified

Manufacturer	Language
KUKA	RAPID
FANUC	KRL
ABB	Karel
STÄUBLI	VAL3
UNIVERSAL ROBOTS	URscript



RAPID

```
MODULE Module1
    PROC Main()
        IF DI_Spustene = 1 THEN
            Path_10;
            Path_20;
            Path_30;
        ELSE
            Break;
            MoveAbsJ Home,v300,fine,efektor_4_1\WObj:=wobj0;
            Reset DO_Zatvor;
            Reset DO_Otvor;
            Reset DO_1Otoc;
            Reset DO_Otoc;
            Reset DO_Vysun;
            Reset DO_Zasun;
        ENDIF
    ENDPROC
    PROC Path_10()
```

KRL

```
DEF RSI_Ethernet( )
; ===========================================
;
; RSI EXAMPLE: ETHERNET communication
; Realtime UDP data exchange with server application
;
; ===========================================

; Declaration of KRL variables
DECL INT ret   ; Return value for RSI commands
DECL INT CONTID   ; ContainerID
INI

; Move to start position
    PTP {A1 0.82, A2 -57.12, A3 94.15, A4 -178, A5 32.92,
  ↳ A6 268.08}

; Create RSI Context
ret = RSI_CREATE("RSI_Ethernet.rsi",CONTID,TRUE)
IF (ret <> RSIOK) THEN
  HALT
ENDIF

; Start RSI execution
ret = RSI_ON(#RELATIVE)
IF (ret <> RSIOK) THEN
  HALT
ENDIF

; Sensor guided movement
RSI_MOVECORR()
; Turn off RSI
ret = RSI_OFF()
IF (ret <> RSIOK) THEN
  HALT
ENDIF
```

VAL3

```
begin
movej(above2,flange,mNomSpeed)

movel(p[0],flange,mNomSpeed)
movel(p[1],flange,mNomSpeed)
movej(above2,flange,mNomSpeed)

movej(above2,flange,mNomSpeed)
waitEndMove()
end
```

Why using ROS ?

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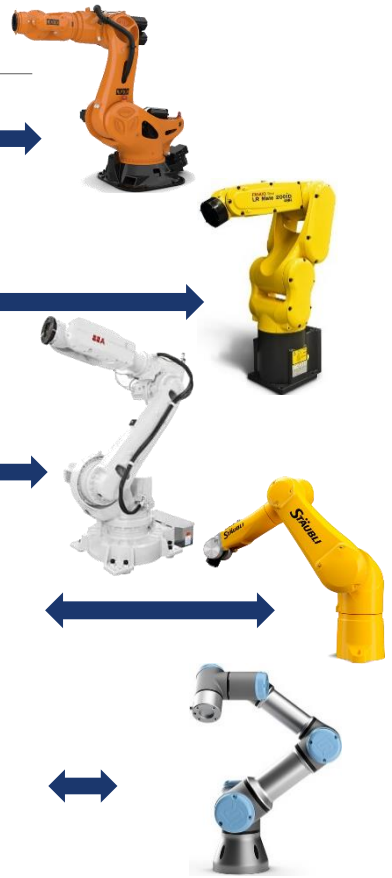

ROS

Standardisation of communications

Coders can develop applications in any environment without worrying about future connectivity with the rest of the system.

Why using ROS ?

- **We use ROS to**
  - Interact between different programs (threads) running in parallel
  - Interact with robot hardware
  - Display data in real time
  - Record and replay sensor data

- **Advantages of ROS**
  - Easy way to share and use code from others
  - It hides the complexity to use several computers talking to each other
  - Use of the speed of C++ in some parts and the flexibility of Python in other parts.
  - Nodes in ROS do not have to be on the same system (multiple computers) or even of the same architecture!

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History

- Originally developed in 2007 at the Stanford Artificial Intelligence Laboratory
- Development continued at Willow Garage founded by Larry Page (also Google cofounder)
- Since 2013 managed by OSRF (**Open Source Robotics Foundation**)
- De facto standard for robot programming

The STAIR (STanford AI Robot) project seeks to develop the software needed to put a general-purpose robot in every home

STANFORD

Willow Garage

Open Source Robotics Foundation

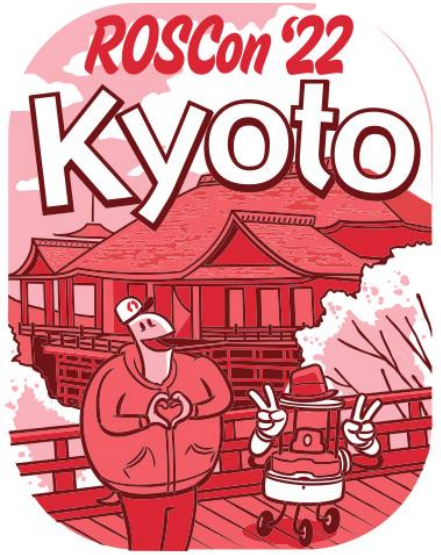
More info - source

http://www.willowgarage.com

https://www.theconstructsim.com/history-ros/

ROScon

- ROSCon is a developers conference.
- Two days learning from and networking with the ROS community.
- Get tips and tricks from experts and meet and share ideas with fellow developers from around the globe.



More info - source
http://www.willowgarage.com

Robot using ROS

Fraunhofer IPA Care-O-bot

Videre Erratic

TurtleBot

Aldebaran Nao

Lego NXT

Shadow Hand

Willow Garage PR2

iRobot Roomba

Robotnik Guardian

Merlin miabotPro

AscTec Quadrotor

CoroWare Corobot

Clearpath Robotics Husky

Clearpath Robotics Kingfisher

Festo Didactic Robotino

More info
http://wiki.ros.org/Robots

Sensors interfaced with ROS

- 1D/2D/3D Rangefinder.
  - Sharp IR rangefinder / Hokuyo laser scanner / Microsoft Kinect
- Cameras
  - Monocular / stereo / USB / Video streaming (gstreamer)
- Force / torque / touch sensors
- Motion capture systems
- IMU / GPS
- Audio / Speech recognition
- RFID
- Actuators / Interfaces
  - Dynamixel
  - Arduino
  - Lego NXT

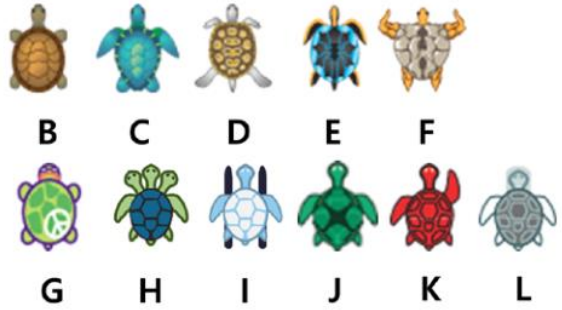


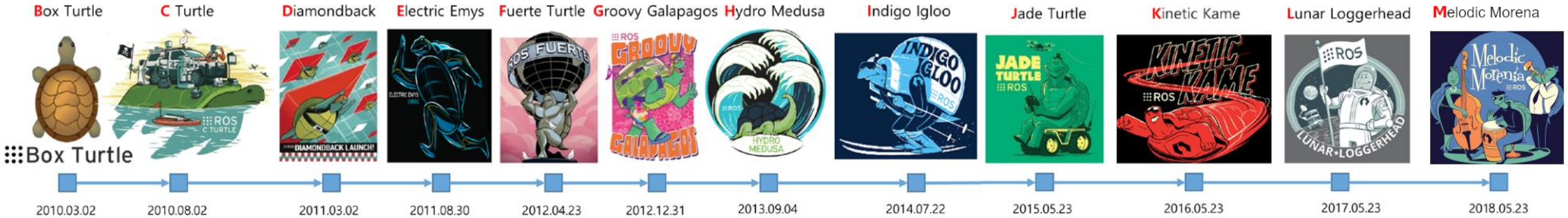




Release Schedule

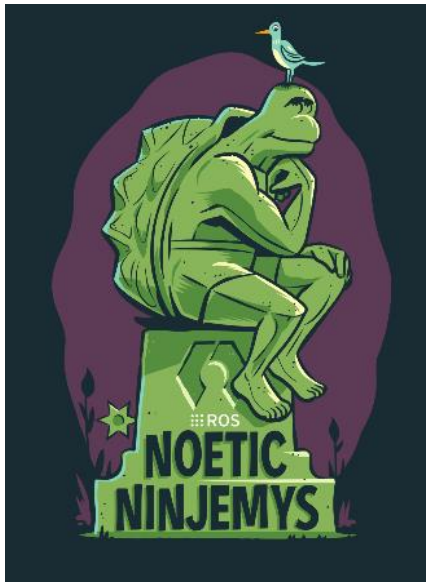
- There is a ROS release every year in May.
  - Releases on even numbered years are LTS release, supported for 5 years.
  - Releases on odd numbered years are normal ROS releases, supported for 2 years.
  - ROS releases will drop support for EOL Ubuntu distributions, even if the ROS release is still supported.





More info
http://wiki.ros.org/

ROS Latest Releases



Noetic Ninjemys
(2020->2025)

Select Your Platform

Supported:

Ubuntu Focal amd64 armhf arm64

Debian Buster amd64 arm64

Source installation

Experimental:

Windows 10 amd64

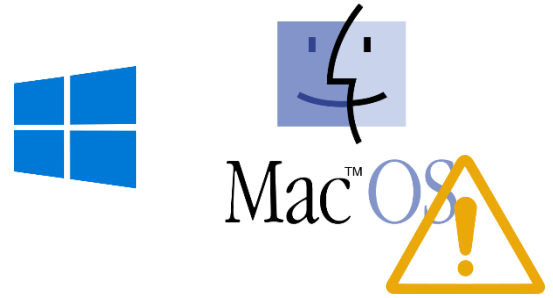
Arch Linux Any amd64 i686 arm armv6h armv7h aarch64

(ROS2)

Humble Hawksbill
(2022 -> 2027)

ROS Supported Platforms

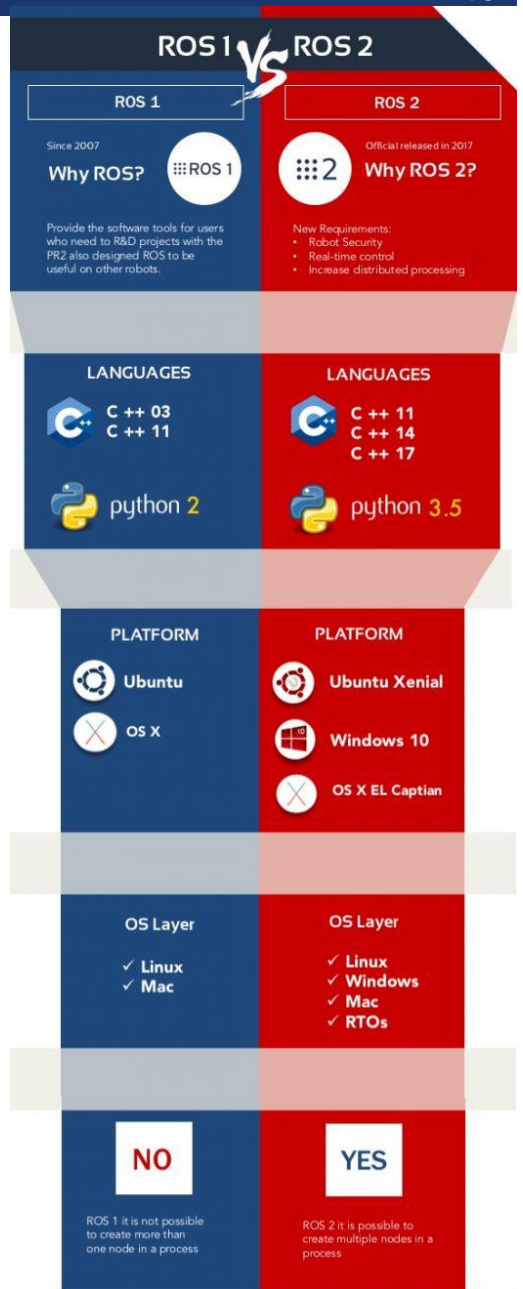
- ROS is currently supported only on **Ubuntu**
  - Fedora
  - Gentoo
  - Arch Linux
  - other variants such as Windows and Mac OS X are considered experimental (will be supported on ROS 2.0)



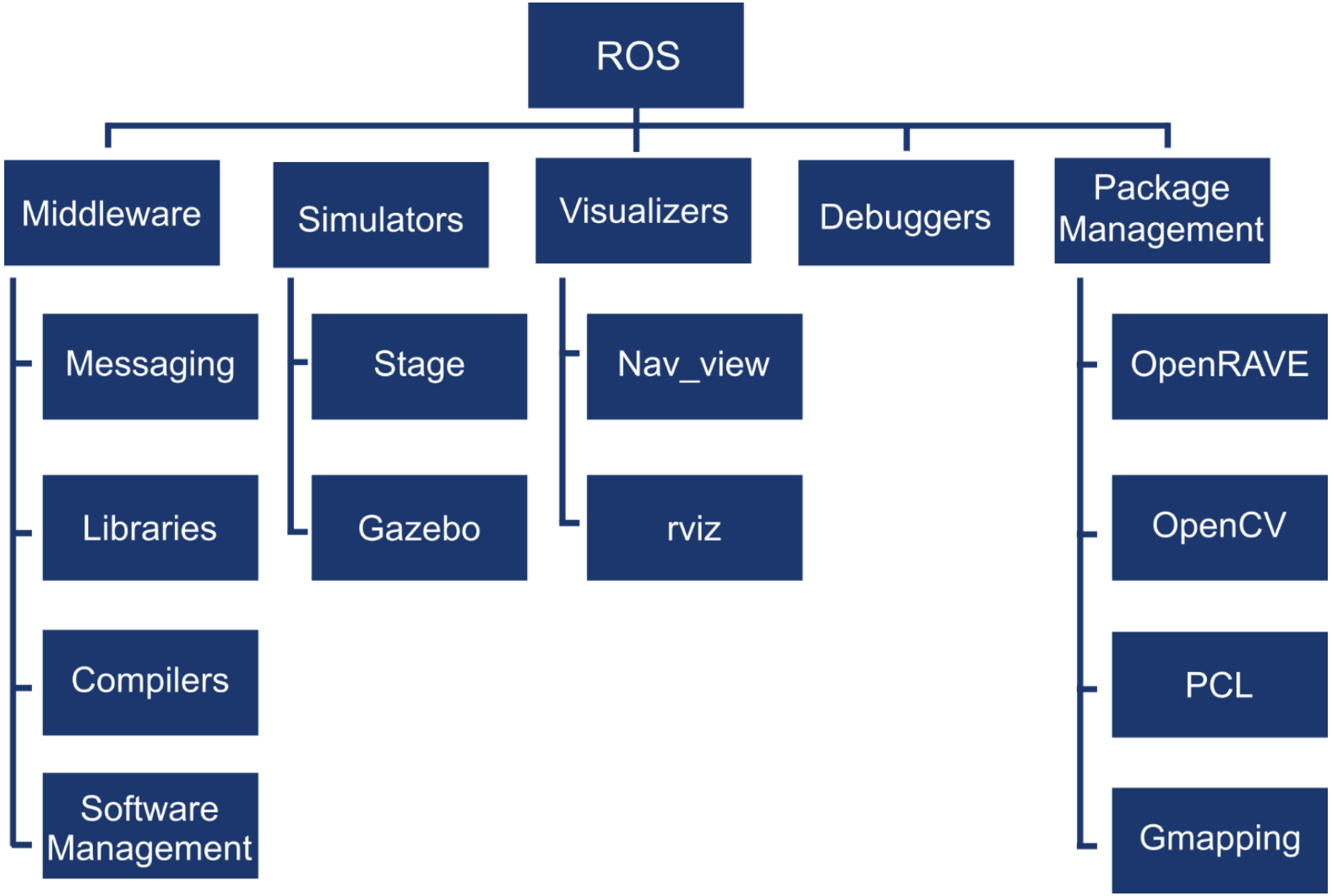
ROS 2

- Since ROS was started in 2007, a lot has changed in the robotics and ROS community.

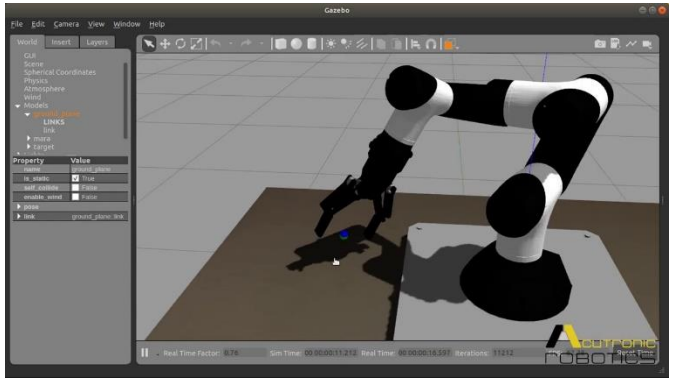
- The goal of the ROS 2 project is to adapt to these changes, leveraging what is great about ROS 1 and improving what isn't.



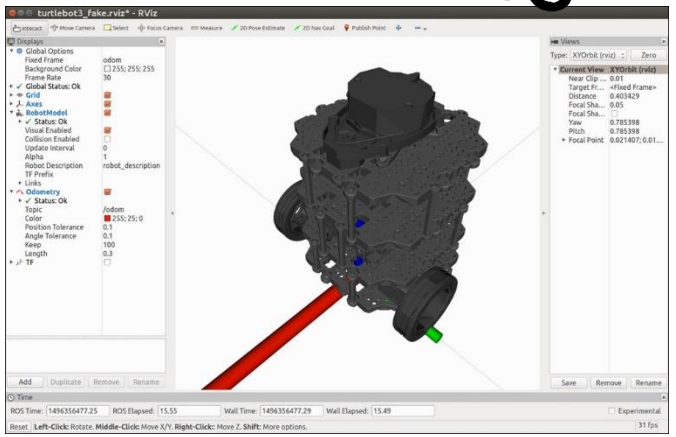
ROS Components



GAZEBO



RViz



What makes the difference?

Conventional OS	ROS
Explicitly a general purpose	Exclusive for Robotic Platform
Native Language Programming	Language-independent architecture
Programming IDE	Software Frameworks
Propriety/Open-Source	Open-source under BSD license
Programs	Nodes
Communication	Message
Kernel is Included	Kernelless

ROS Philosophy

- **Peer to peer**

  Individual programs communicate over defined API (ROS messages, services, etc.)

- **Distributed**

  Programs can be run on multiple computers and communicate over the network.

- **Multi-lingual**

  ROS modules can be written in any language for which a client library exists (C++, Python, MATLAB, Java, LISP, Ruby, etc.).

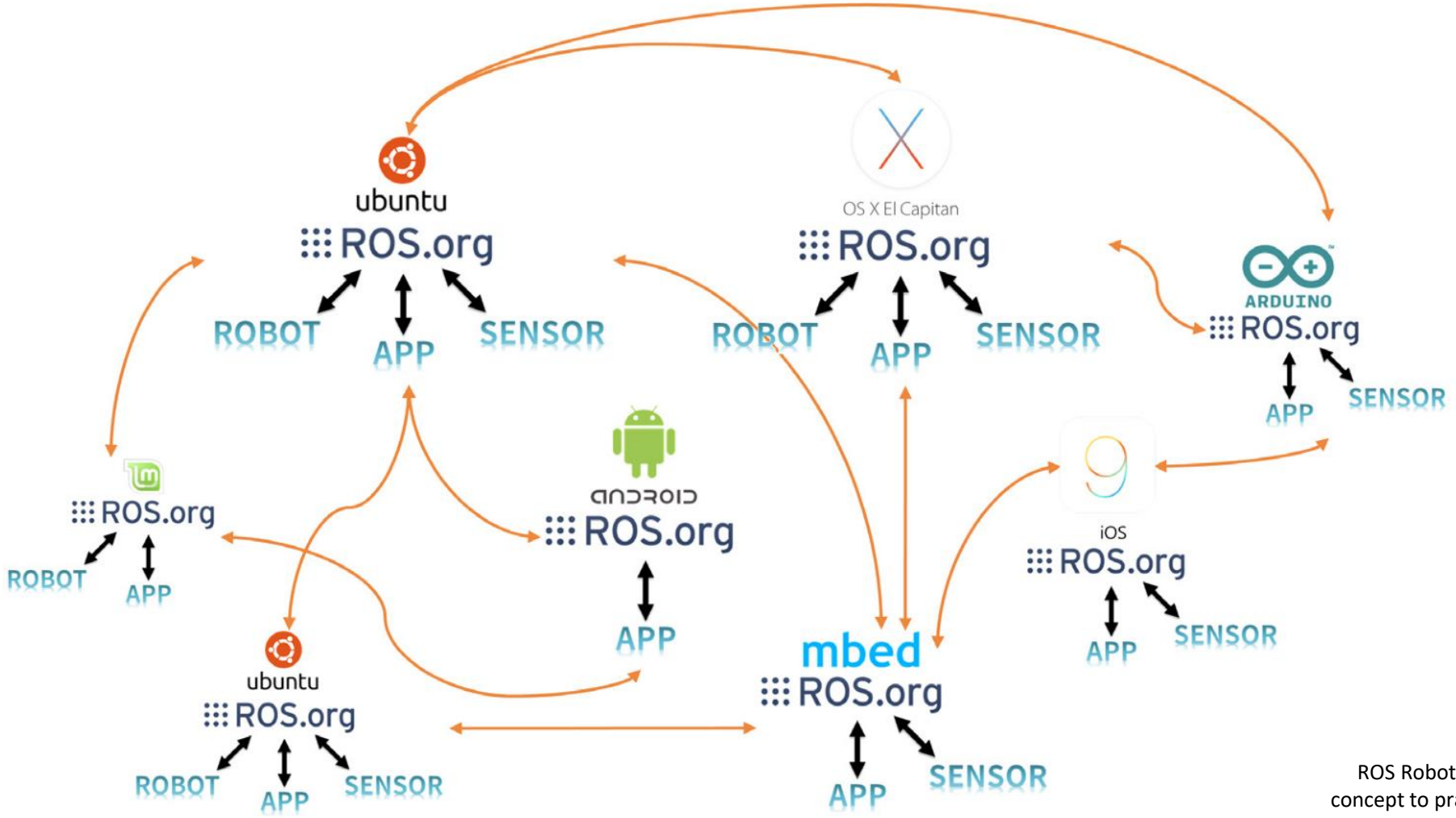
- **Thin**

  Stand-alone libraries are wrapped around with a thin ROS layer.

- **Free and open-source**

  Most ROS software is open-source and free to use.

Communication between Heterogenous Devices



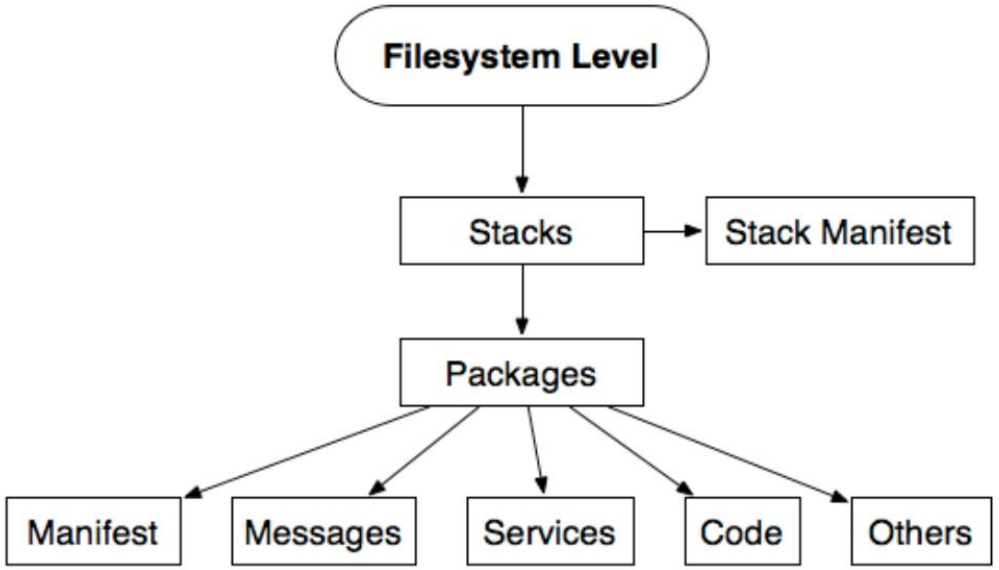
More info - source

ROS Robot Programming - From the basic concept to practical programming and robot application

ROS code hierarchy

- **Repository**: contains all the code from a particular development group
- **Stack**: groups all code on a particular subject / device
- Packages: separate modules that provide different services
- Nodes: executable that exist in each model

Repository



ROS Communication Protocol

- ROS Communication Protocol helps in Connecting nodes over the network. These capabilities are built entirely on two high-level communication API's

- **ROS Topics**
  - Asynchronous 'stream-like' communication
  - TCP/IP or UDP Transport
  - Strongly-typed (ROS.msg spec)
  - Can have one or more publishers
  - Can have one or more subscribers

- **ROS Services**
  - Synchronous 'function-call-like' communication
  - TCP/IP or UDP Transport
  - Strongly-typed (ROS.srv spec)
  - Can have only one server
  - Can have one or more clients

How to decide what to use ?

- **Topics**: used mainly for sending **data streams** between nodes.

Example: you're monitoring the temperature of a motor on the robot. The node monitoring this motor will send a data stream with the temperature. Now, any other node can subscribe to this topic and get the data

- **Services**: execution of fast tasks. Allows you to create a simple synchronous client/server communication between nodes. Very useful for changing a setting on your robot, or ask for a specific action: enable freedrive mode, ask for specific data, etc.

- **Actions**: execution of tasks that need to be tracked and should be preempted in some cases.

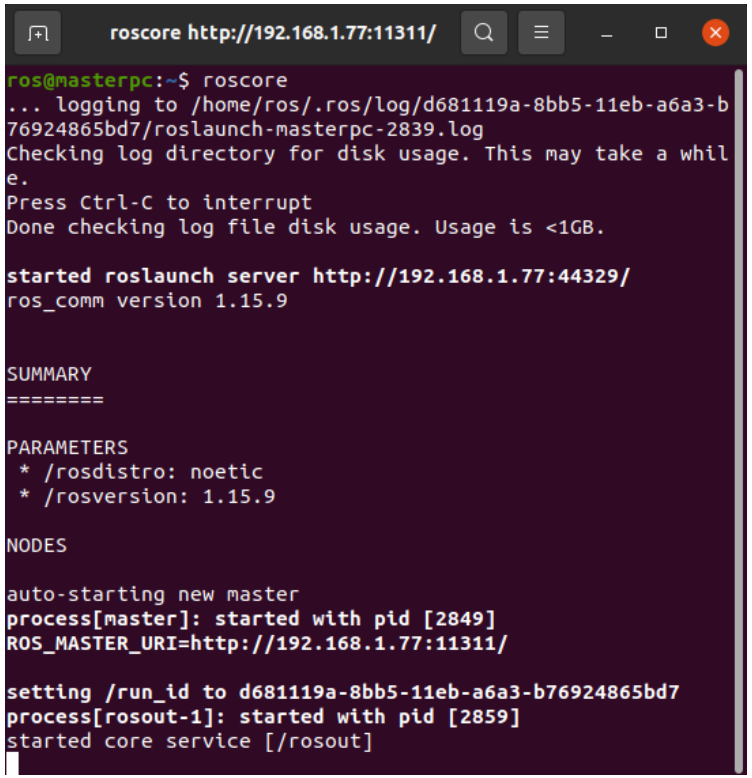
Also, where the client can send a request that takes a long time (ex: asking to move the robot to a new location). The client can asynchronously monitor the state of the server, and cancel the request anytime.

Source
https://roboticsbackend.com/what-is-ros/

ROS Overview

- Launch roscore
- Launch Node 1
- Launch Node 2

```
> roscore
```



ROS Master

- Manages the communication between nodes
- Every node registers at startup with the master
- Exactly **one** master per system

Start a master with

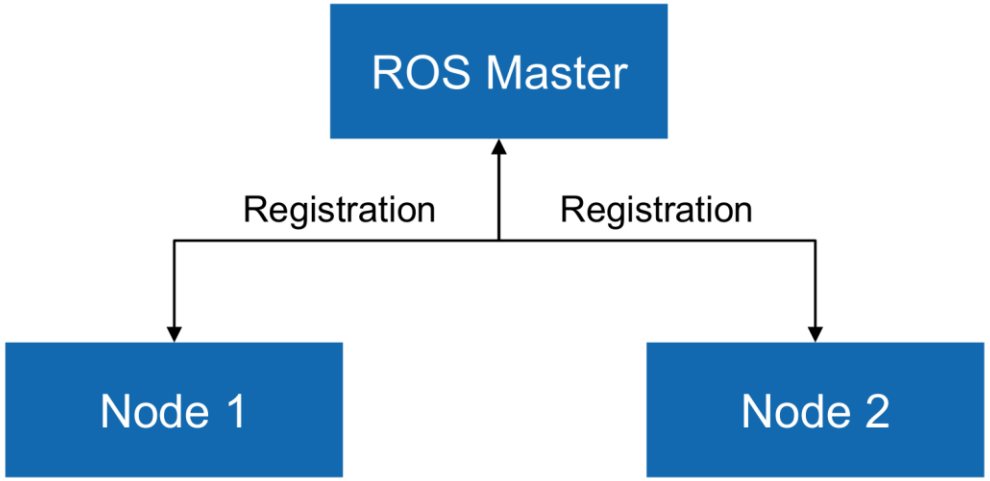
```
> roscore
```

- ROS uses socket communication to facilitate networking.
  The roscore starts on http://my_computer:11311
- roscore will start up:
  - a ROS Master
  - a ROS Parameter Server
  - a rosout logging node

More info
http://wiki.ros.org/Master

ROS Nodes

- Executable programs that uses ROS to communicate with other nodes
- Individually compiled, executed, and managed
- Organized in *packages*
- Nodes are written using a ROS **client library**
  - roscpp : C++ client library
  - rospy : python client library
- Nodes can publish or subscribe to a Topic
- Nodes can also provide or use a Service



More info
http://wiki.ros.org/rosnode

ROS Nodes

Run a node with

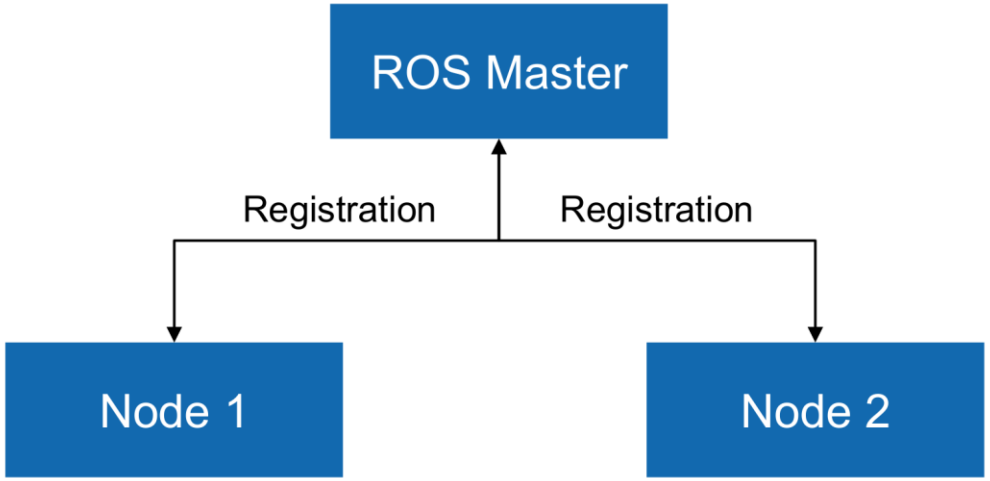
```
> rosrun [package_name] [node_name]
```

See active node with

```
> rosnode list
```

Retrieve information about a node with

```
> rosnode info [node_name]
```



More info
http://wiki.ros.org/rosnode

ROS Topics

- Nodes communicate over *topics*
  - Nodes can *publish* or *subscribe* to a topic
  - Typically, 1 publisher and *n* subscribers
- Topic is a name for a stream of *messages*

List active topics with

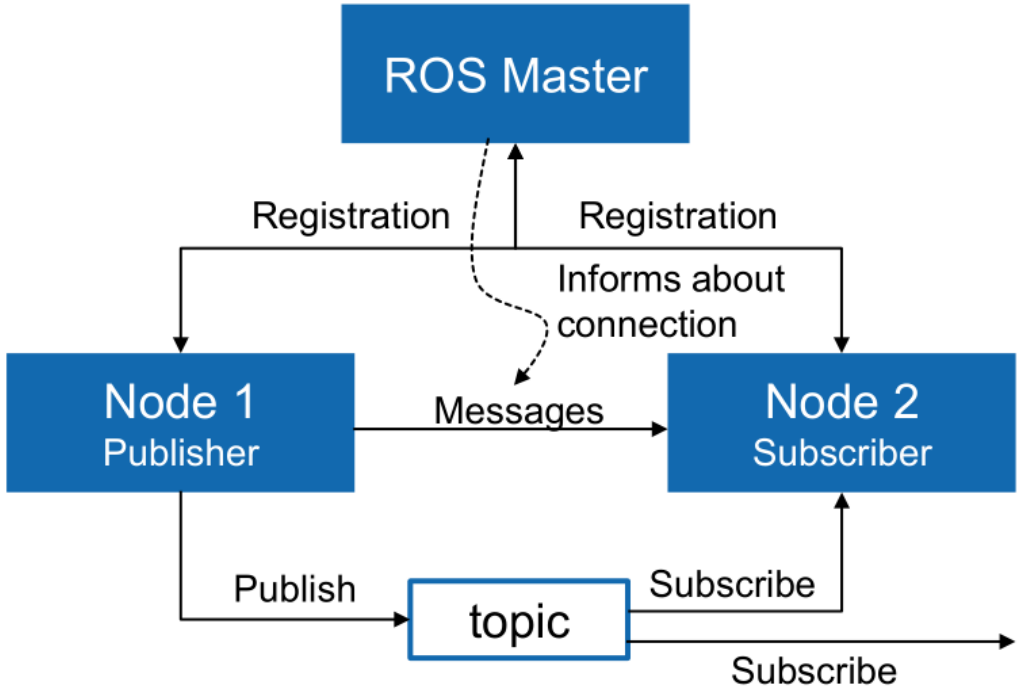
```
> rostopic list
```

Subscribe and print the contents of a topic with

```
> rostopic echo /topic
```

Show information about a topic with

```
> rostopic info /topic
```



More info
http://wiki.ros.org/rostopic

ROS Messages

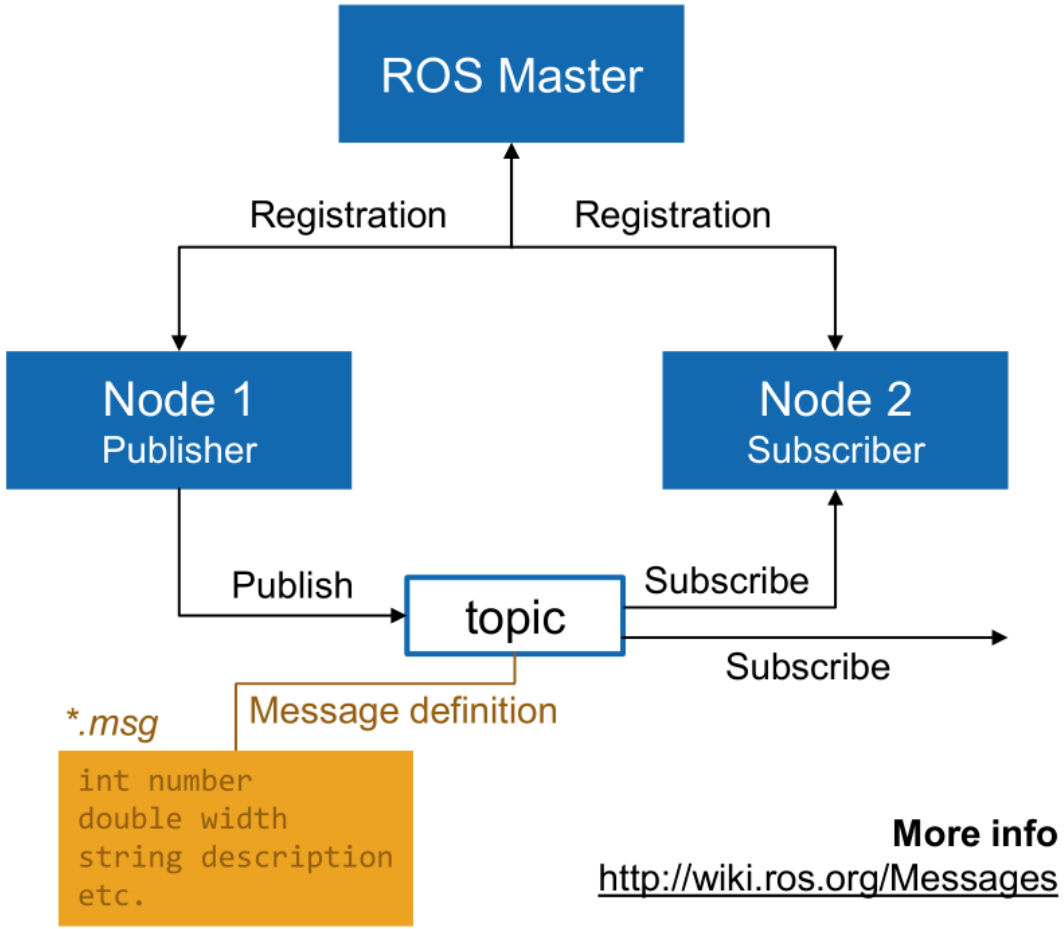
- Data structure defining the *type* of a topic
- Comprised of a nested structure of integers, floats, booleans, strings etc. and arrays of objects
- Defined in **.msg* files

See the type of a topic

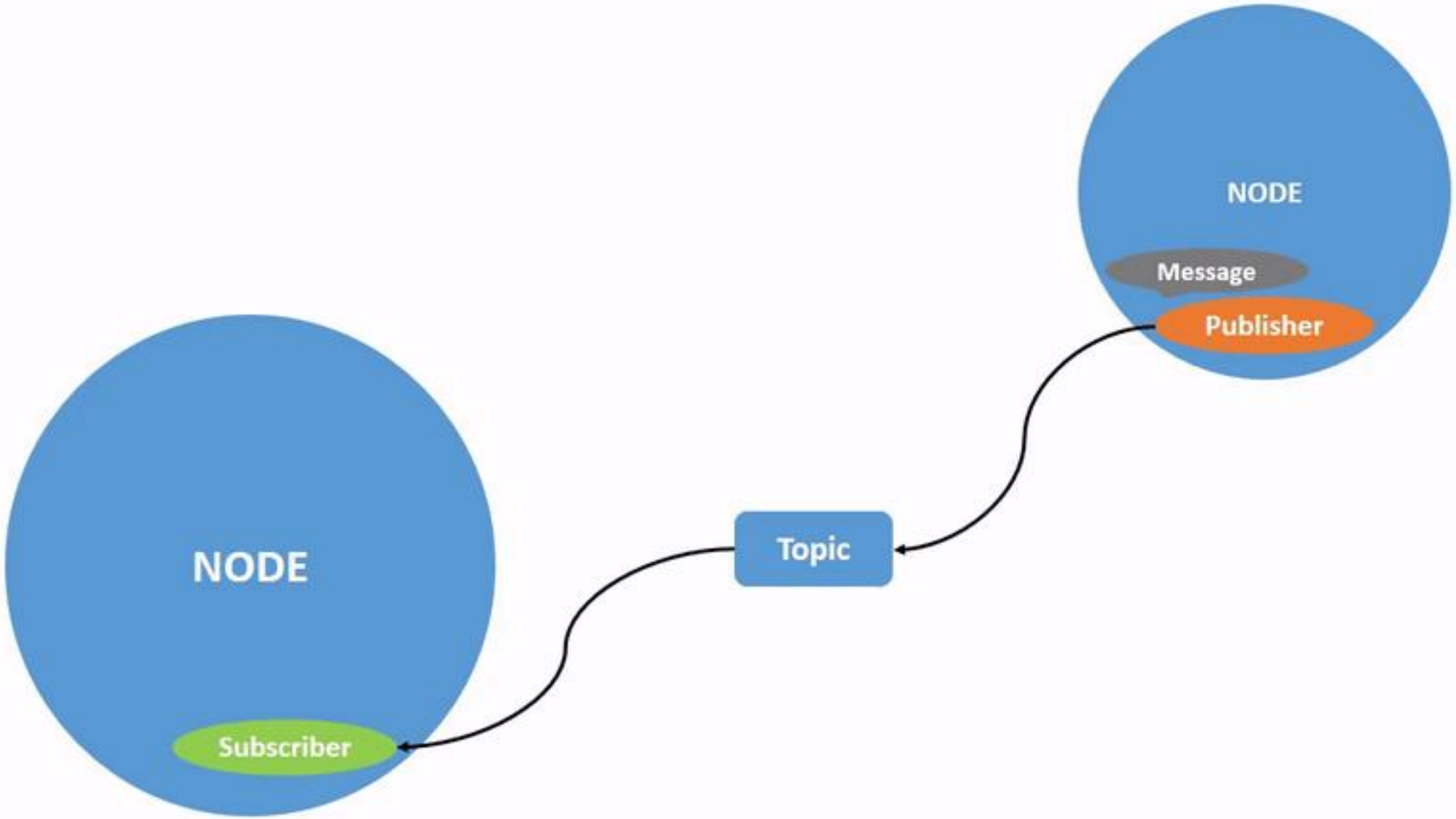
```
> rostopic type /topic
```

Publish a message to a topic

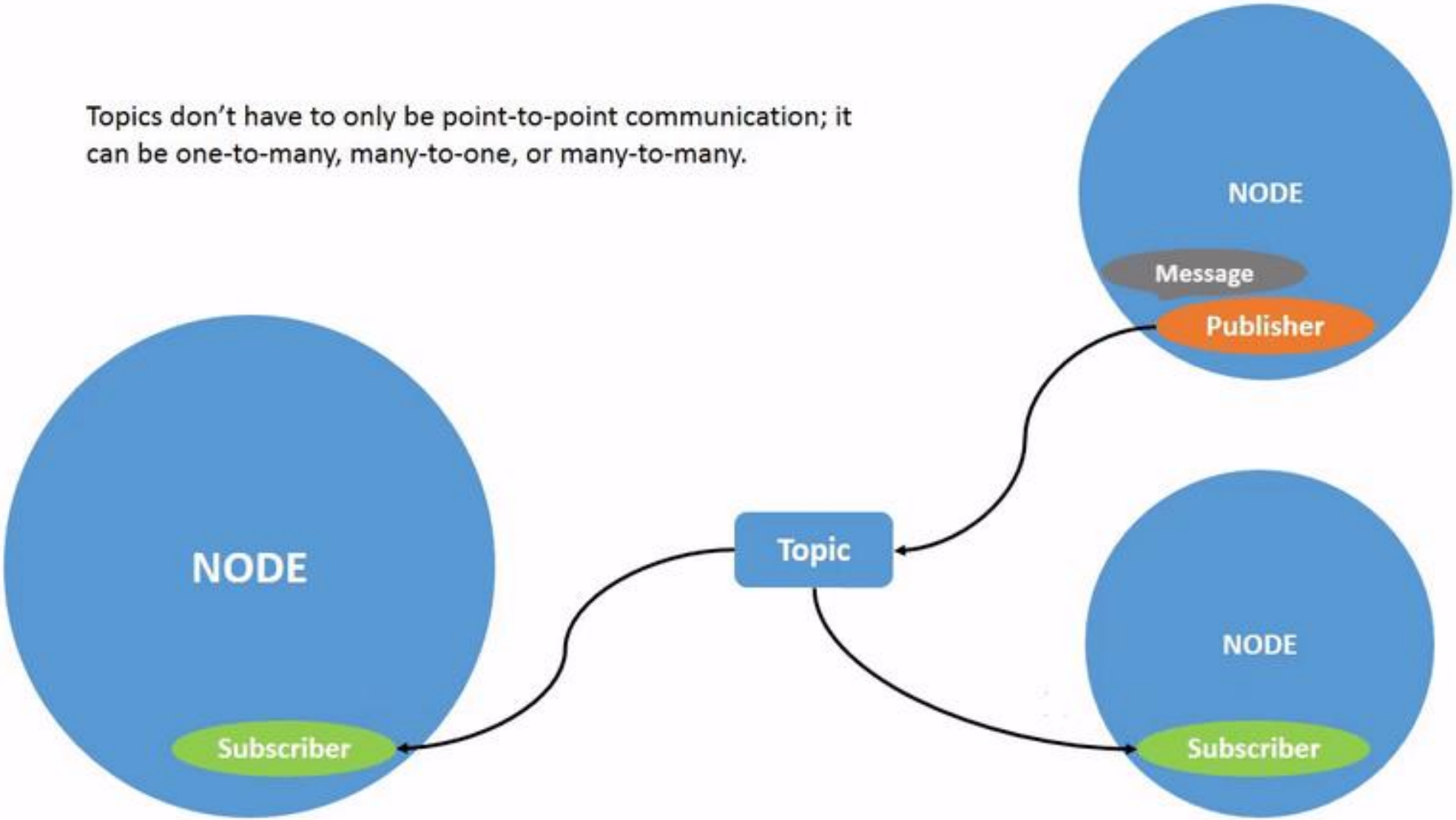
```
> rostopic pub /topic type data
```



More info
http://wiki.ros.org/Messages


NODE
Message
Publisher
Topic
NODE
Subscriber

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



Messages Communication Flow

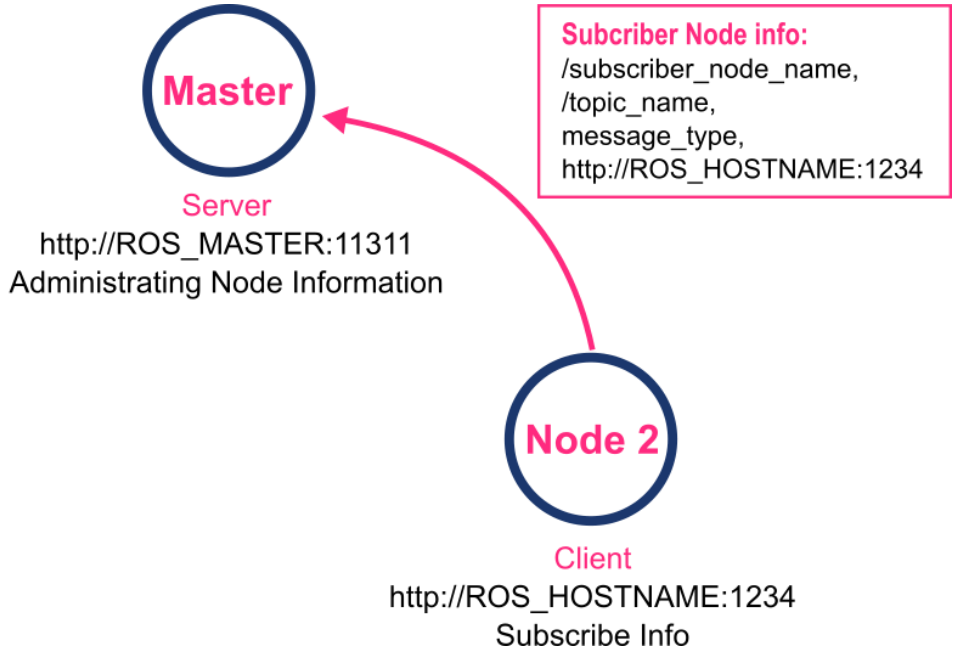
Running the Master

- The master registers the name of nodes, topics, services, action, message types, URI addresses

Messages Communication Flow

Running the Subscriber Node

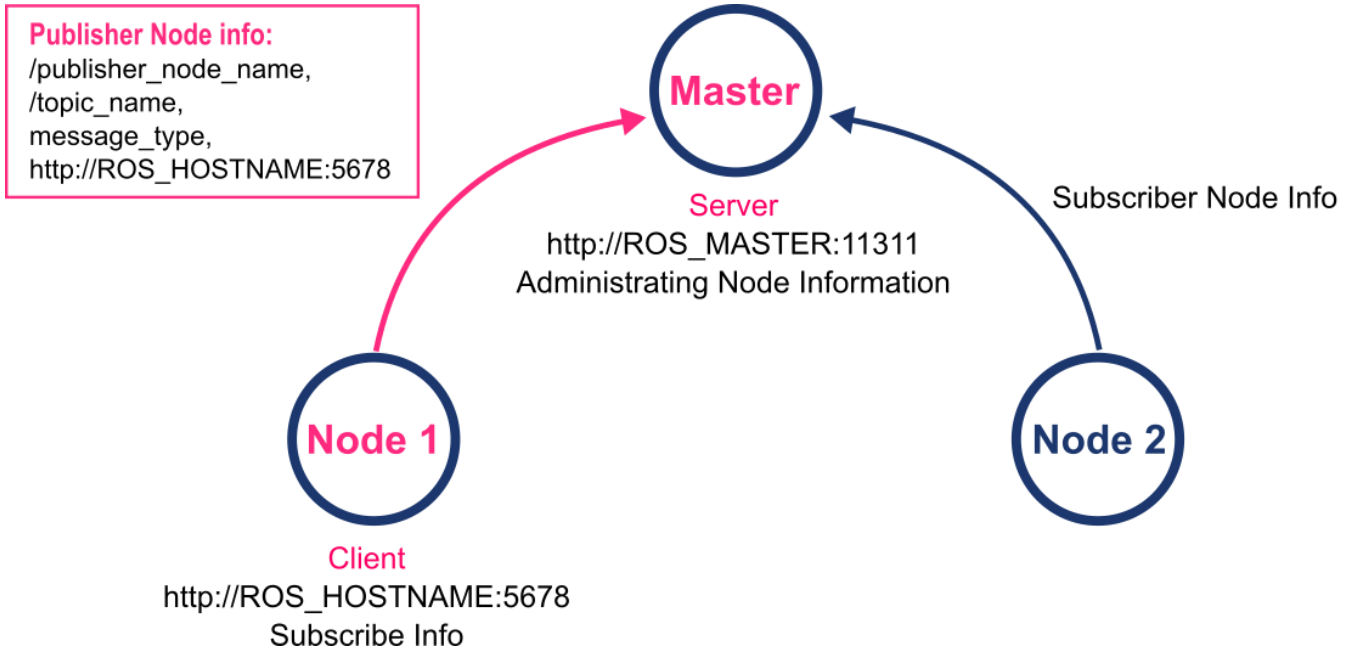
- The subscriber node registers its node name, topic name, message type, URI address, and port with the master



Messages Communication Flow

Running the Publisher Node

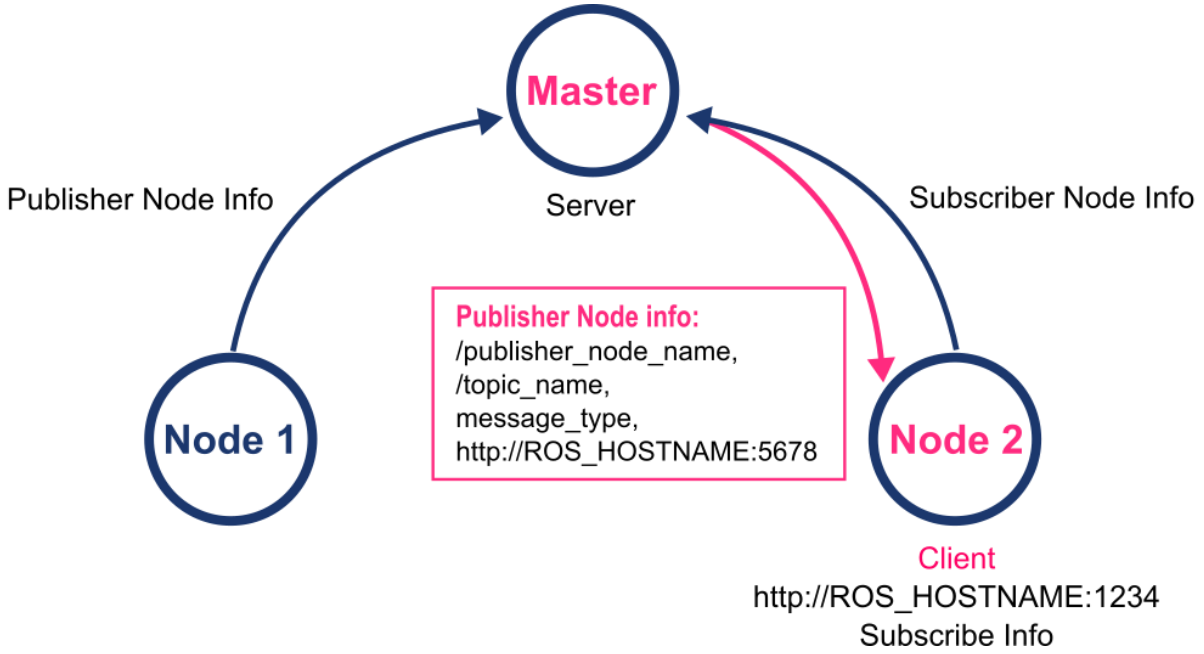
- The publisher node registers its node name, topic name, message type, URI address and port with the master.



Messages Communication Flow

Providing Publisher Information

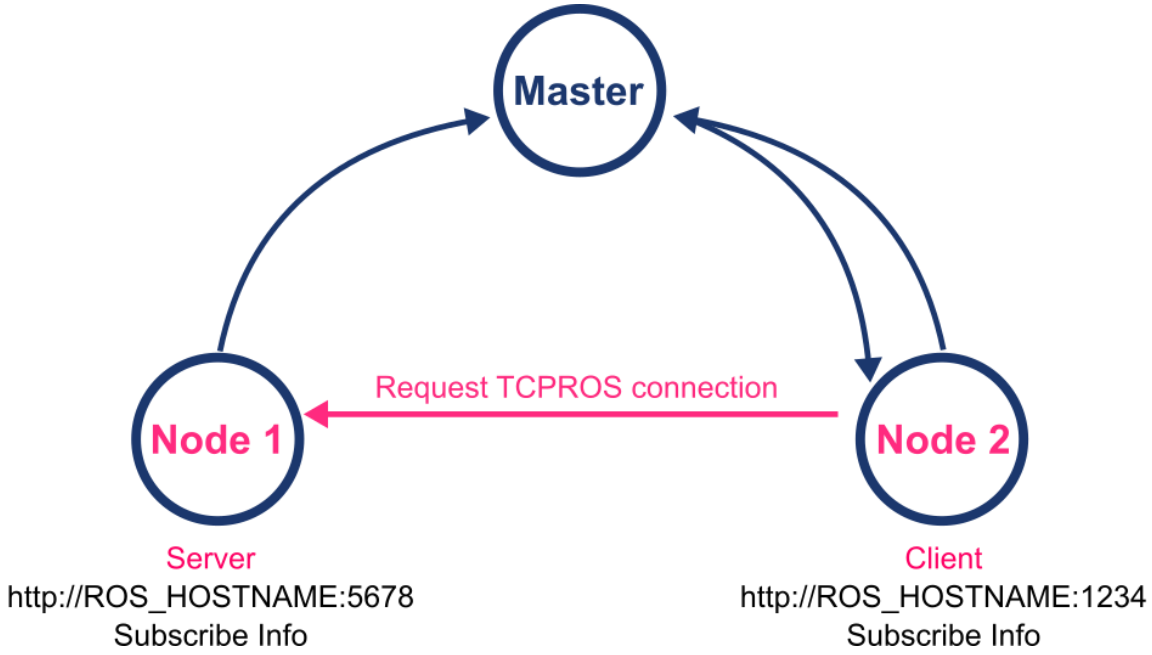
- The master distributes information such as the publisher's name, topic name, message type, URI address and port number of the publisher to subscribers that want to connect to the publisher node



Messages Communication Flow

Connection Request from the Subscriber Node

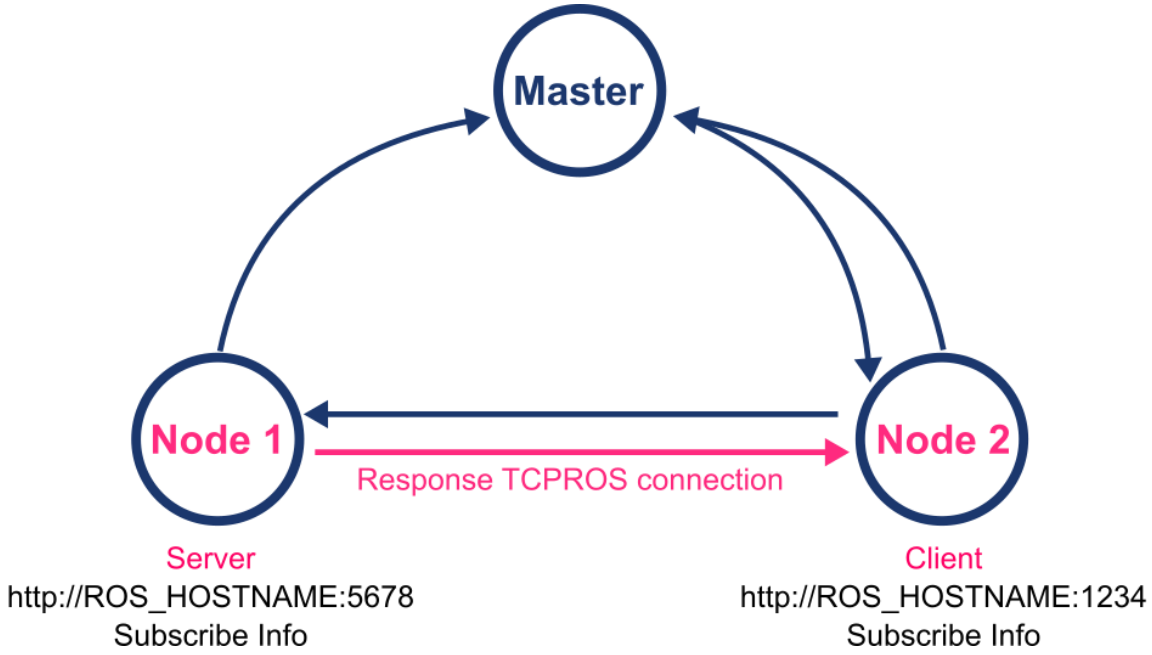
- The subscriber node requests a direct connection to the publisher node based on the publisher information received from the master.



Messages Communication Flow

Connection Response from the Publisher Node

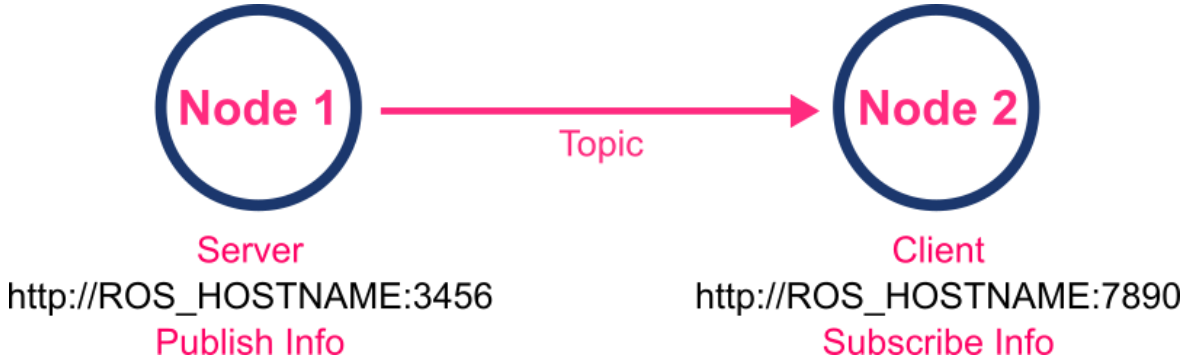
- The publisher node sends the URI address and port number of its TCP server in response to the connection request from the subscriber node.



ROS Communication Protocol

Topics

- Unidirectional
- Used when exchanging data continuously
- uses the same type of message for both publisher and subscriber



- The subscriber node receives the information of publisher node corresponding to the identical topic name registered in the master.

ROS Communication Protocol

Services

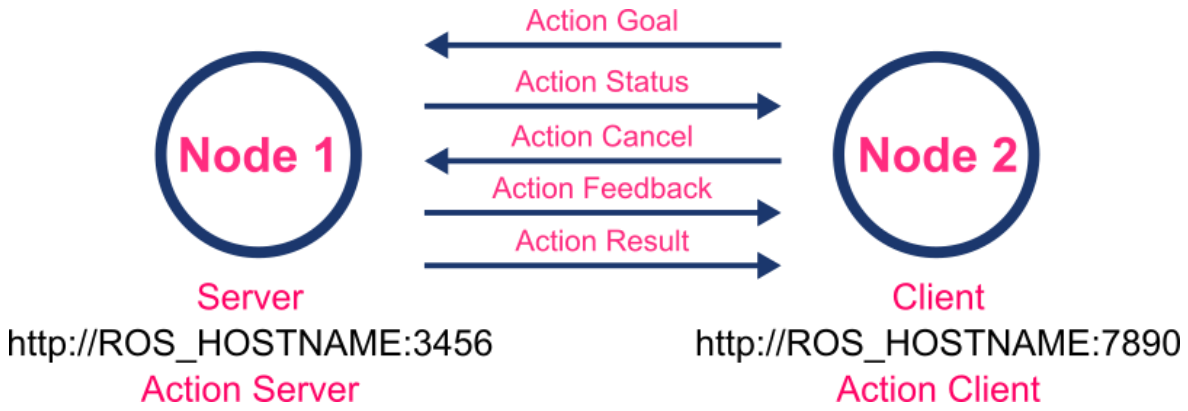
- Synchronous
- Bi-didirectional
- Used when request processing requests and responds current states

- Unlike the topic, the service is one-time message communication. Therefore, when the request and response of the service are completed, the connection between two nodes will be disconnected.

ROS Communication Protocol

Actions

- Asynchronous
- Bi-directional
- Used when it is difficult to use the service due to long response times after the request or when a feedback value is needed
- Similar to the service where ‘goals’ and ‘results’ correspond to ‘requests’ and ‘responses’ respectively. In addition, the ‘feedback’ is added to report feedbacks to the client periodically when intermediate values are needed.



What is a Workspace?

Any ROS project begins with making a workspace.

In this workspace, you will put all the things related to this particular project.

A workspace is a directory containing these parts:

- Software packages
- Build artifacts
- Logs
- Install artifacts

Catkin is a command line tool to improve the workflow of building, testing and using multiple software packages.

Catkin Workspace Environment

- A set of directories in which a set of related ROS code lives
- Defines context for the current workspace
- Default workspace loaded with

```
> source /opt/ros/kinetic/setup.bash
```

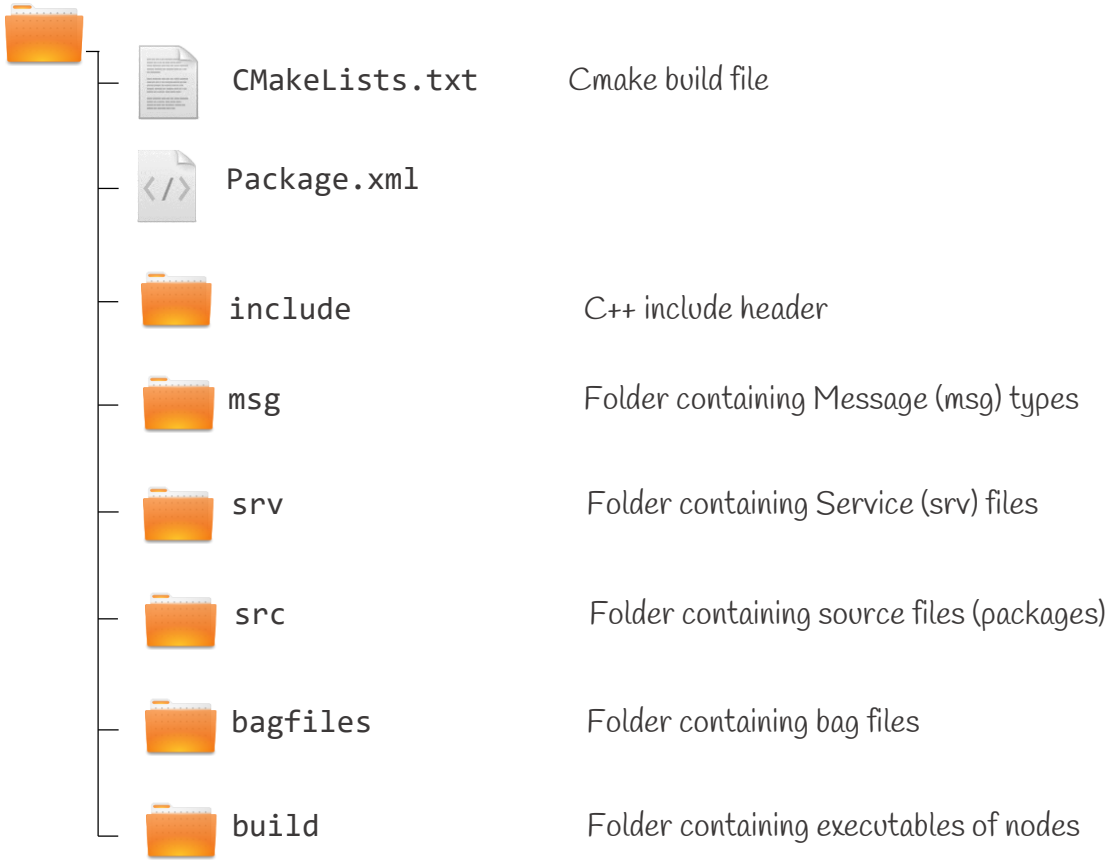
Overlay your catkin workspace with

```
> cd ~/catkin_ws
> source devel/setup.bash
```

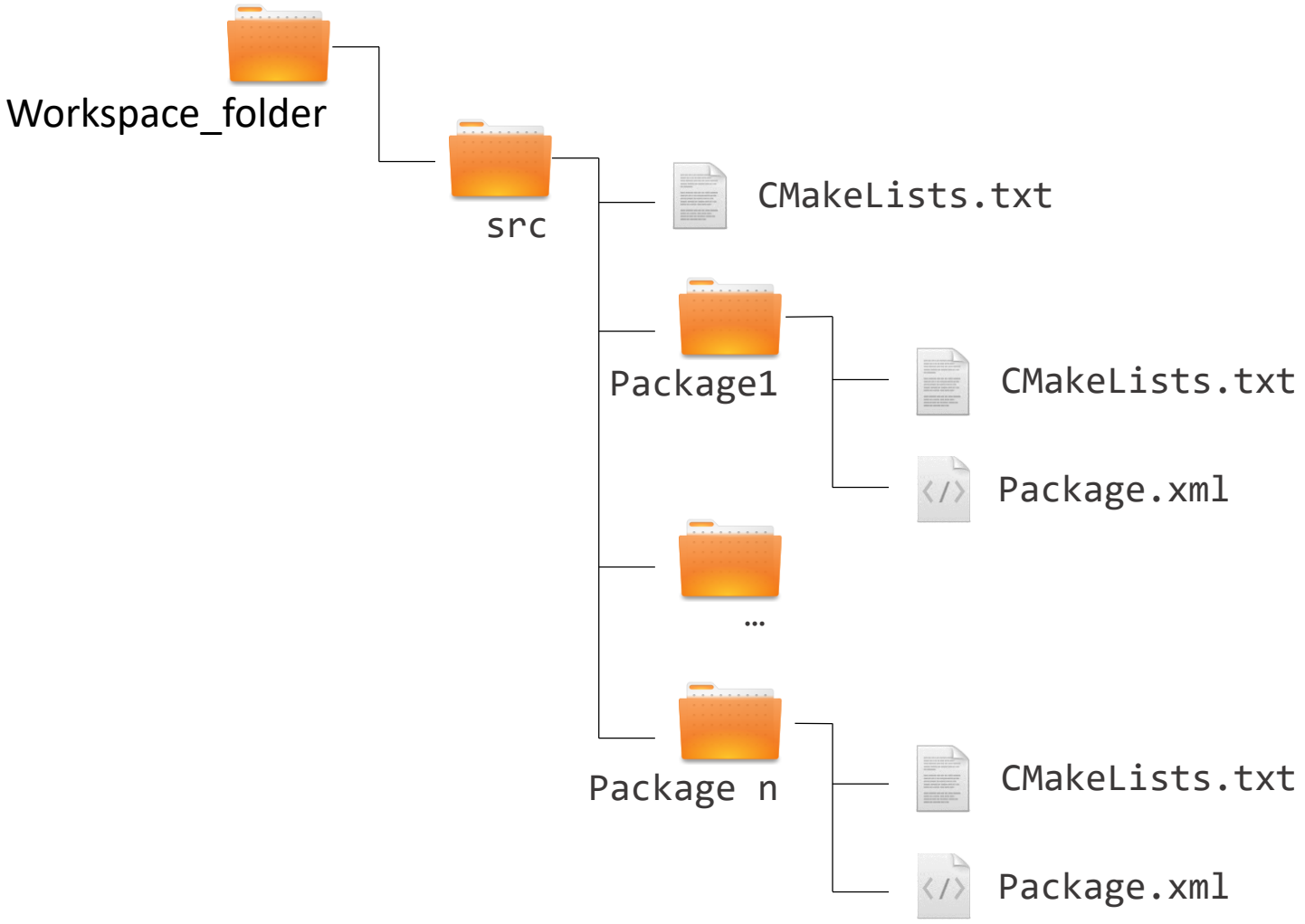
Check your workspace with

```
> echo $ROS_PACKAGE_PATH
```

Workspace_folder



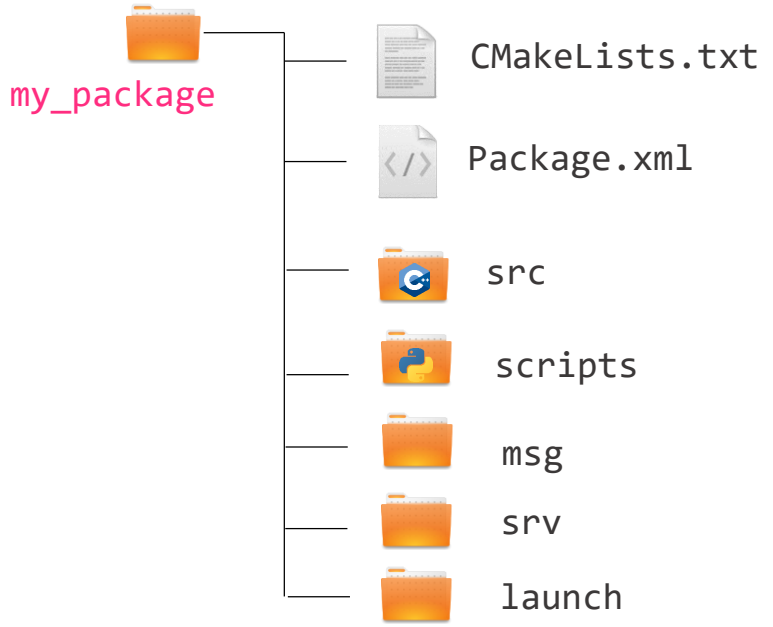
ROS Workspace Environment



ROS Package

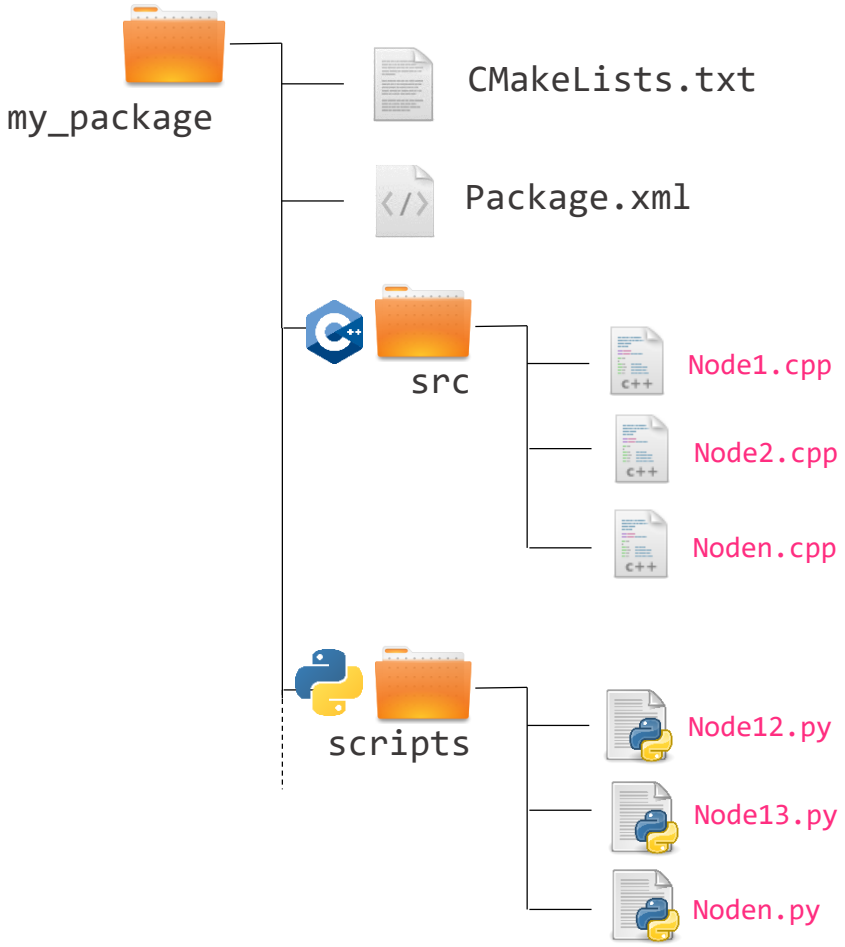
- Software in ROS is organized in *Packages*.
- A package contains one or more *Nodes* and provides a ROS interface
- A ROS package is simply a directory inside a catkin workspace that has a package.xml file in it

- The package must contain a package.xml file.
  - That package.xml file provides meta information about the package.
- The package must contain a CMakeLists.txt which uses catkin.
- Each package must have its own folder



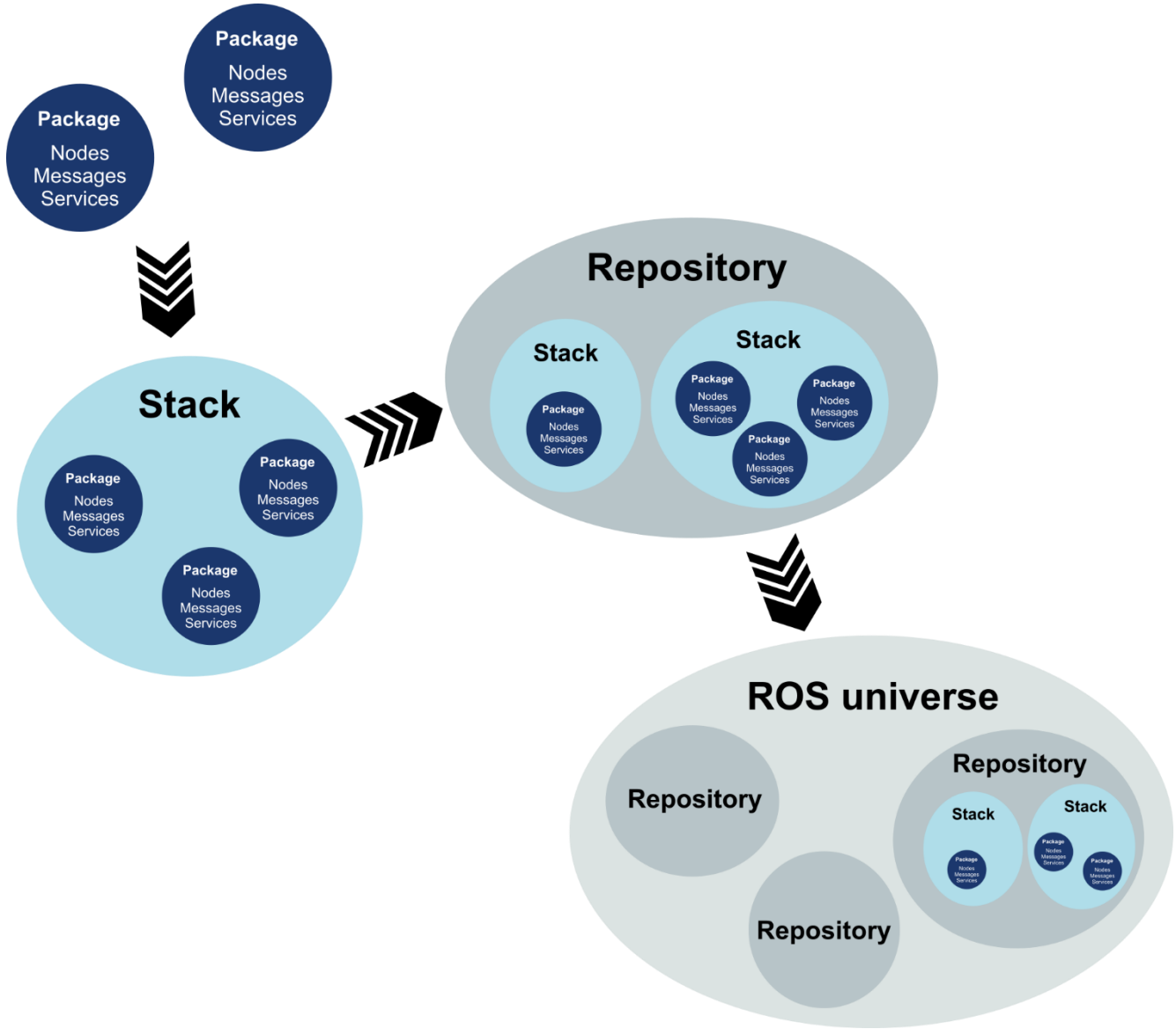
ROS Node

- Node = file containing the code of the executable
- File written in C++ should be saved in the source folder *src* of the package
- File written in Python should be saved in the scripts folder *srcipts* of the package



ROS universe

- Most of ROS packages are hosted in GitHub



Catkin Build System

- *catkin* is the ROS build system to generate executables, libraries, and interfaces. (*i.e* make and compile *packages*)
- Collection of CMake macros and Python scripts
- A build system is responsible for generating 'targets' from raw source code that can be used by an end user.
- You can have multiple ROS workspaces, but you can only work in one of them at any one time

Navigate to your catkin workspace with

```
> cd ~/catkin_ws
```

Create a package with

```
> catkin_create_pkg [package_name] [dependencies ...]
```

Whenever you build a new package, update your environment !!!

```
> source ./devel/setup.bash
```

catkin Build System

The catkin workspace contains the following spaces

Work here

The *source space* contains the source code. This is where you can clone, create, and edit source code for the packages you want to build.

Don't touch

The *build space* is where CMake is invoked to build the packages in the source space. Cache information and other intermediate files are kept here.

Don't touch

The *development (devel) space* is where built targets are placed (prior to being installed).

If necessary, clean the entire build and devel space with

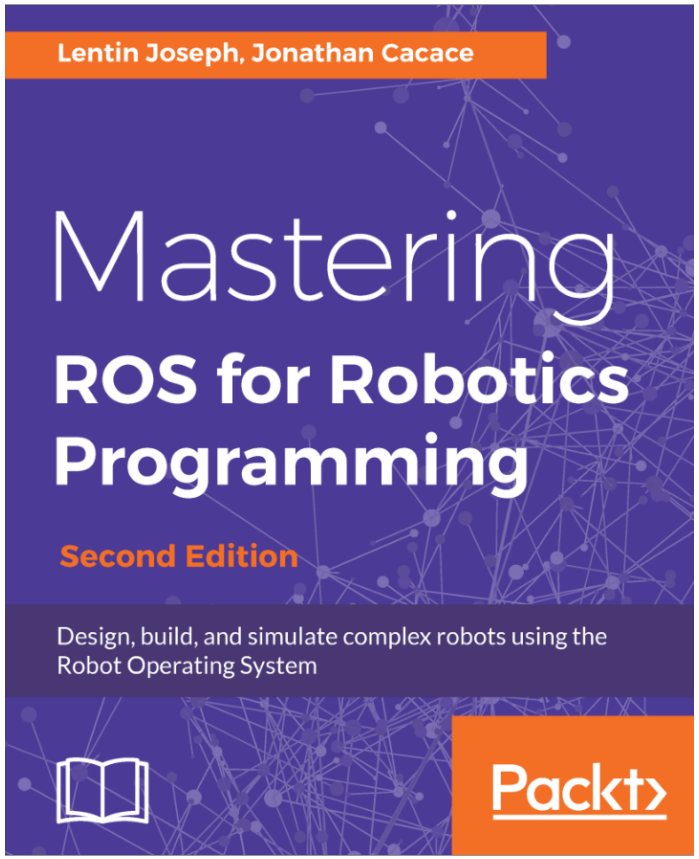
```
> catkin clean
```

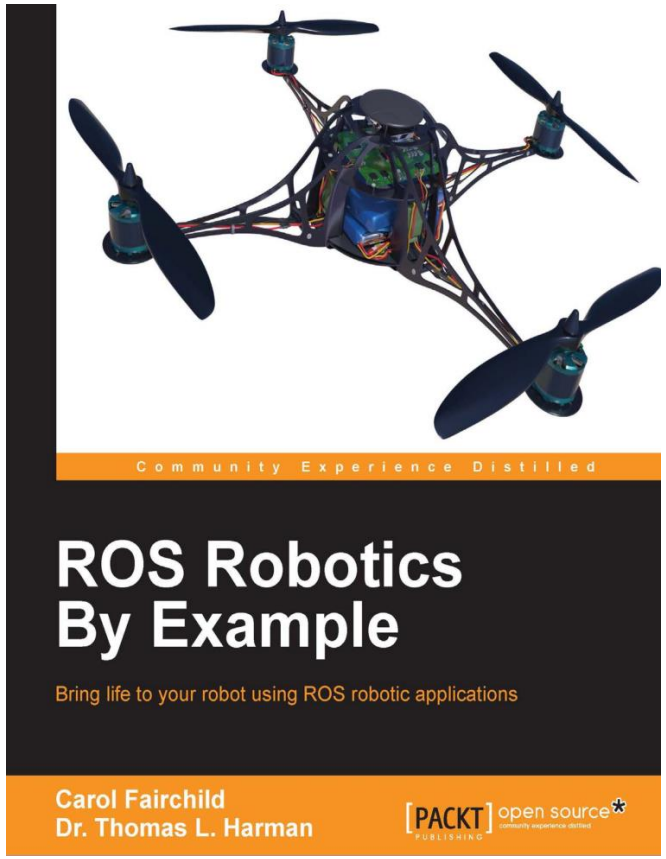
More info
http://wiki.ros.org/catkin/workspaces

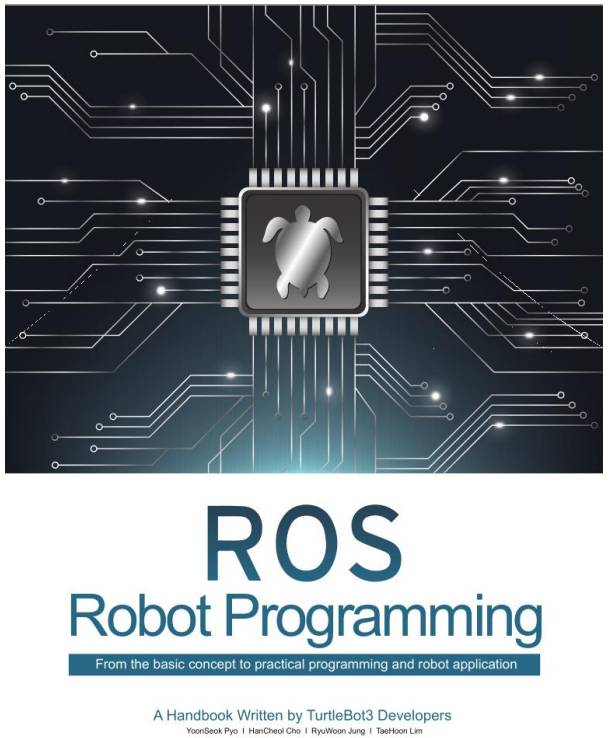
Further References

- ROS Wiki
  - http://wiki.ros.org/
- Installation
  - http://wiki.ros.org/ROS/Installation
- Tutorials
  - http://wiki.ros.org/ROS/Tutorials
- Available packages
  - http://www.ros.org/browse/
- ROS Cheat Sheet
  - https://www.clearpathrobotics.com/ros-robot-operating-system-cheat-sheet/
  - https://kapeli.com/cheat_sheets/ROS.docset/
- ROS Best Practices
  - https://github.com/leggedrobotics/ros_best_practices/wiki
- ROS Package Template
  - https://github.com/leggedrobotics/ros_best_practices/tree/master/ros_package_template

Relevant books







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