ROS-Industrial Basic Developer's Training Class

July 2023

Southwest Research Institute

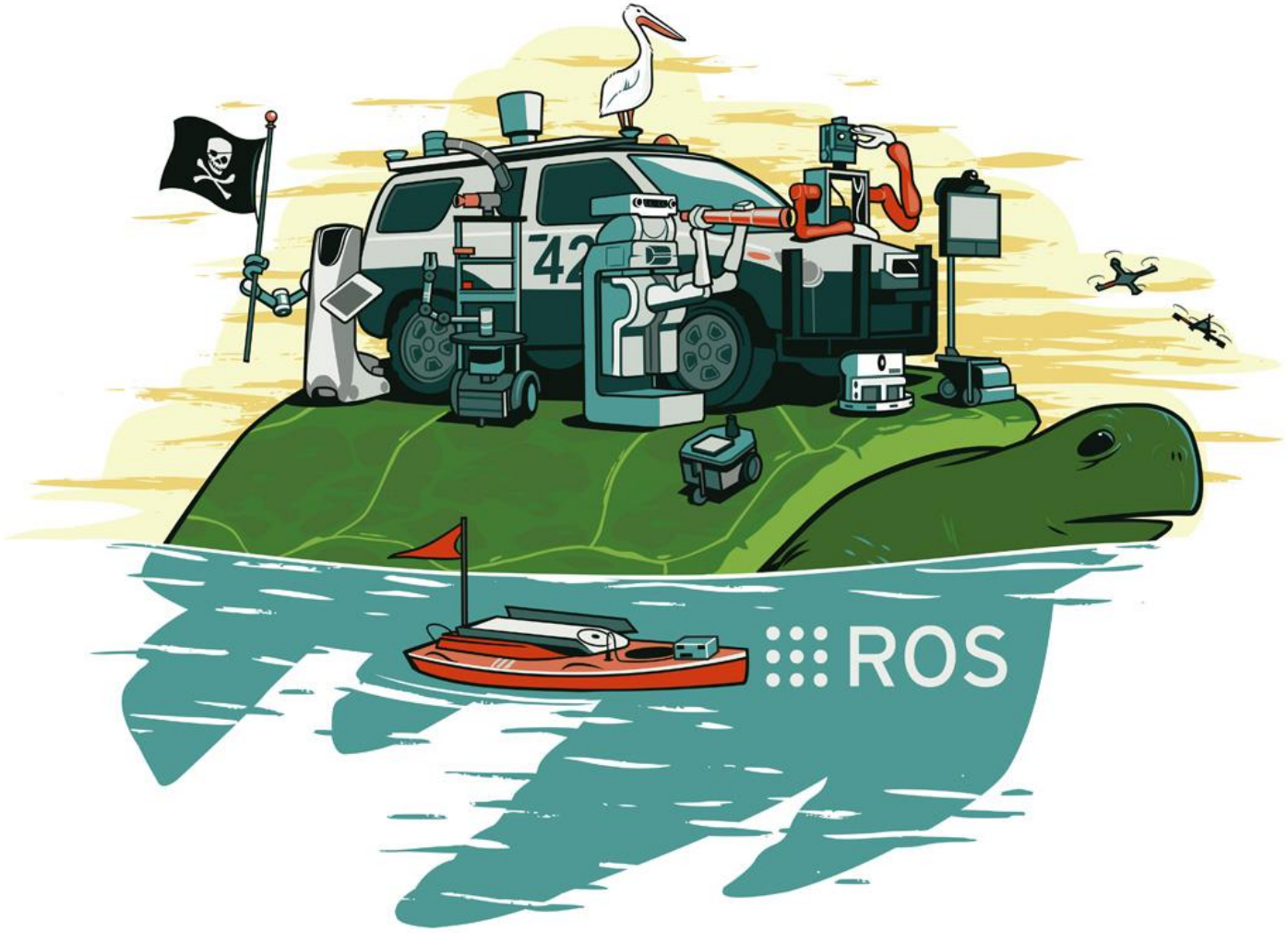
Session 1:
ROS Basics

Southwest Research Institute

Outline

- Intro to ROS
- ROS Workspaces & Colcon
- Installing packages (existing)
- Packages (create)
- Nodes
- Messages / Topics

An Introduction to ROS



(Image taken from Willow Garage's "What is ROS?" presentation)

ROS1 and ROS2

- ROS1 has been around since 2008
  - Uses custom TCP/IP middleware
- ROS2 is a ground-up reimagining of ROS
  - Started in 2014
  - Built on DDS, middleware proven in industry
  - Now on 6th named release

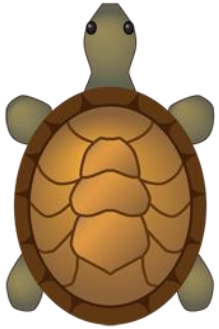
This class will focus on
ROS2

ROS1 and ROS2

- Community is currently in transition!
  - Final ROS1 release (Noetic) is out (EOL in 2025)
  - All critical features are now supported in ROS2
- ROS-Industrial will take time to transition
  - Many breaking changes / conceptual differences
  - Vision is industrial robots will become native ROS devices

ROS Versions

ROS 1



Box Turtle

Mar 2010

…

Lunar

2017 - 2019

Melodic

2018 - 2023

Noetic

2020 - 2025

EOL

ROS 2

Ardent

Dec 2018

…

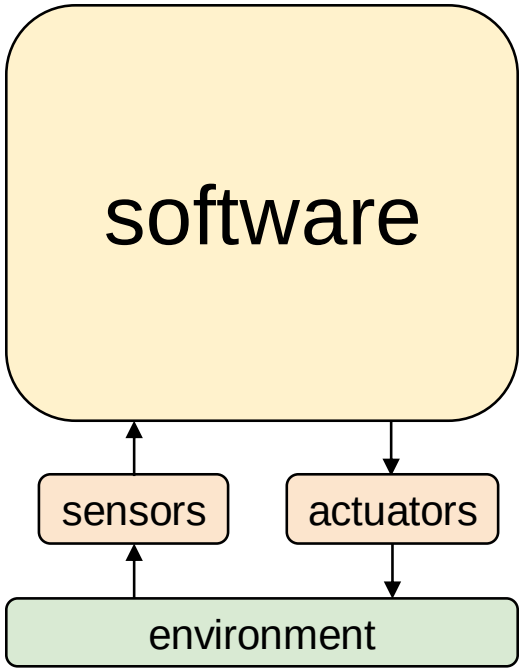
Foxy (LTS)

2020 - 2023

Galactic

2021 - 2022

ROS : The Big Picture

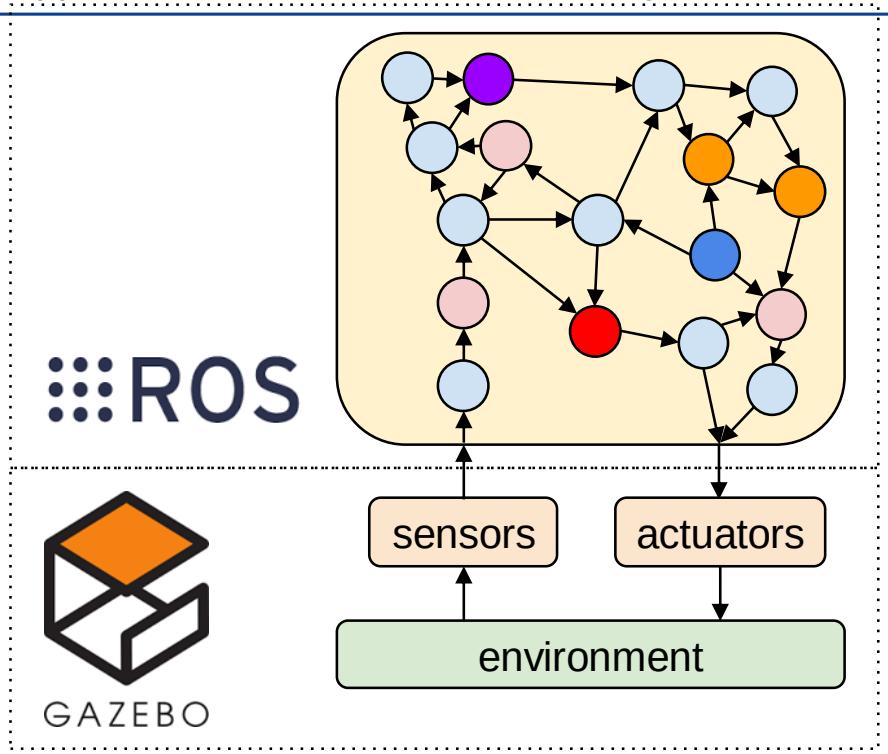


All robots are:

Software connecting Sensors to Actuators to interact with the Environment

(Adapted from Morgan Quigley's "ROS: An Open-Source Framework for Modern Robotics" presentation)

ROS : The Big Picture



- Break Complex Software into Smaller Pieces
- Provide a framework, tools, and interfaces for distributed development
- Encourage re-use of software pieces
- Easy transition between simulation and hardware

(Adapted from Morgan Quigley's "ROS: An Open-Source Framework for Modern Robotics" presentation)

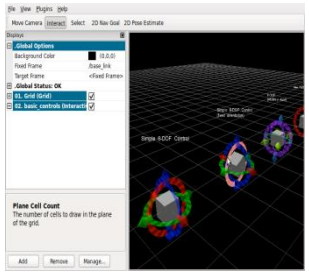
What is ROS?

ROS is…

=

Plumbing

+



Tools

+

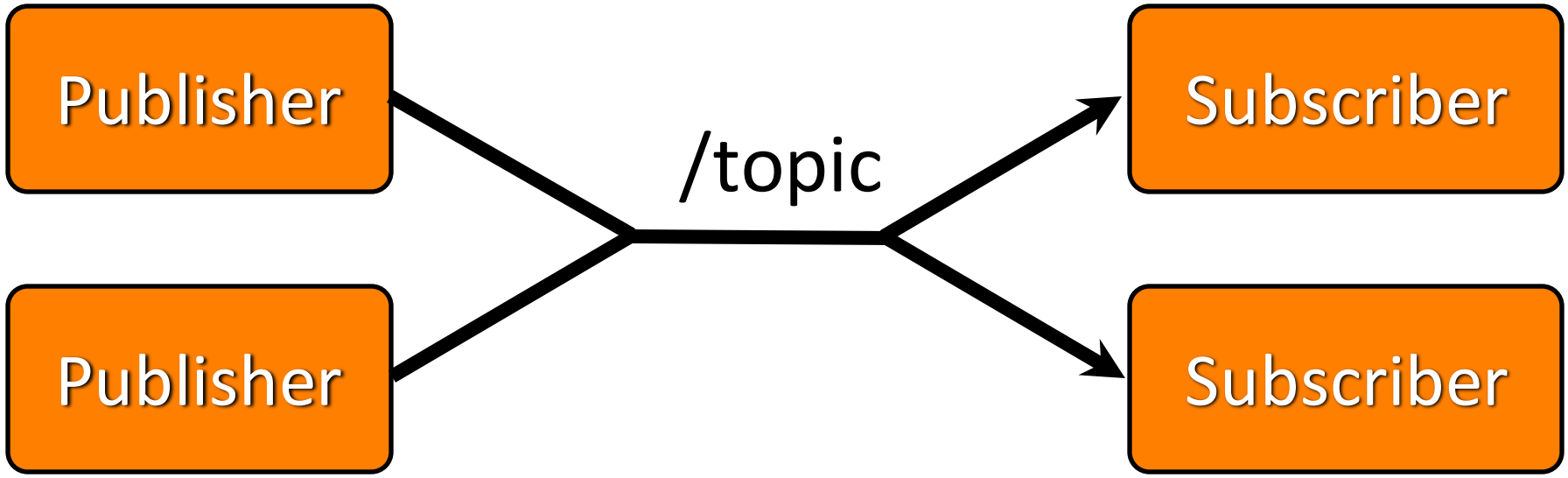
Capabilities

+

Ecosystem

(Adapted from Willow Garage's "What is ROS?" Presentation)

ROS is… plumbing

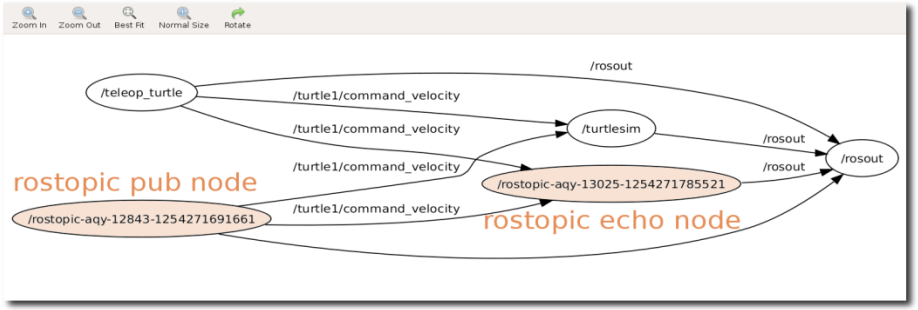


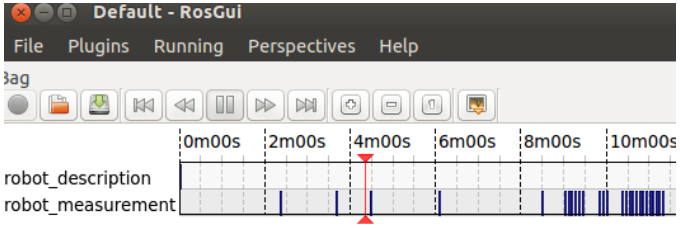
ROS Plumbing : Drivers

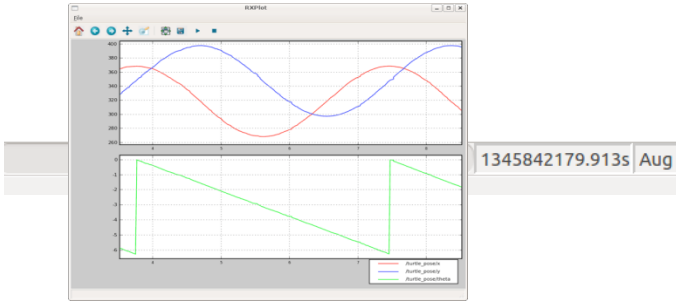
- 2d/3d cameras
- laser scanners
- robot actuators
- inertial units
- audio
- GPS
- joysticks
- etc.

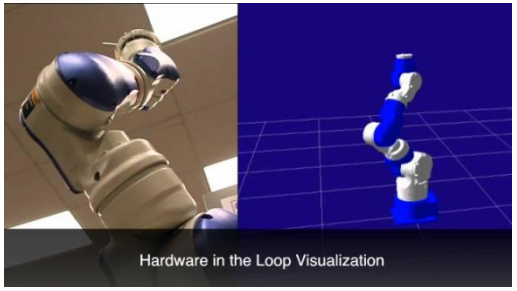
(Adapted from Morgan Quigley's "ROS: An Open-Source Framework for Modern Robotics" presentation)

ROS is …Tools

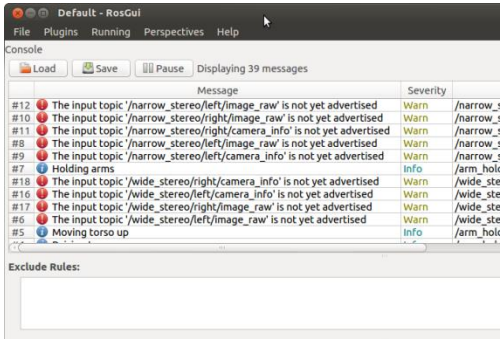






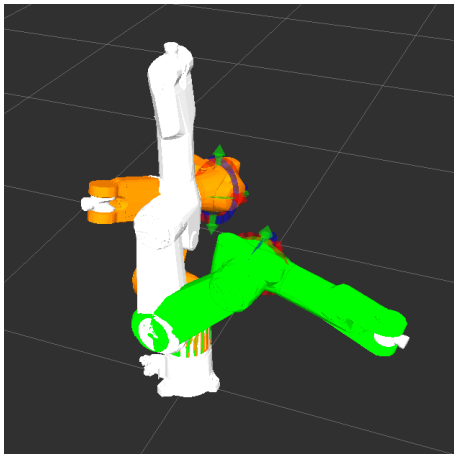


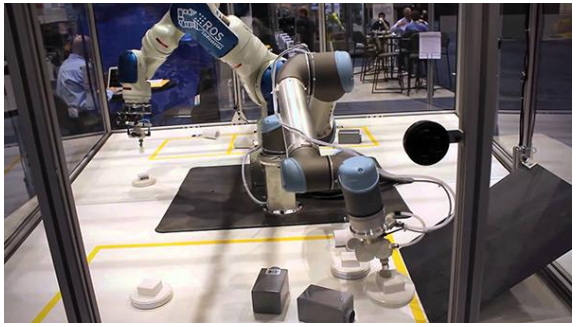
- logging/plotting
- graph visualization
- diagnostics
- visualization

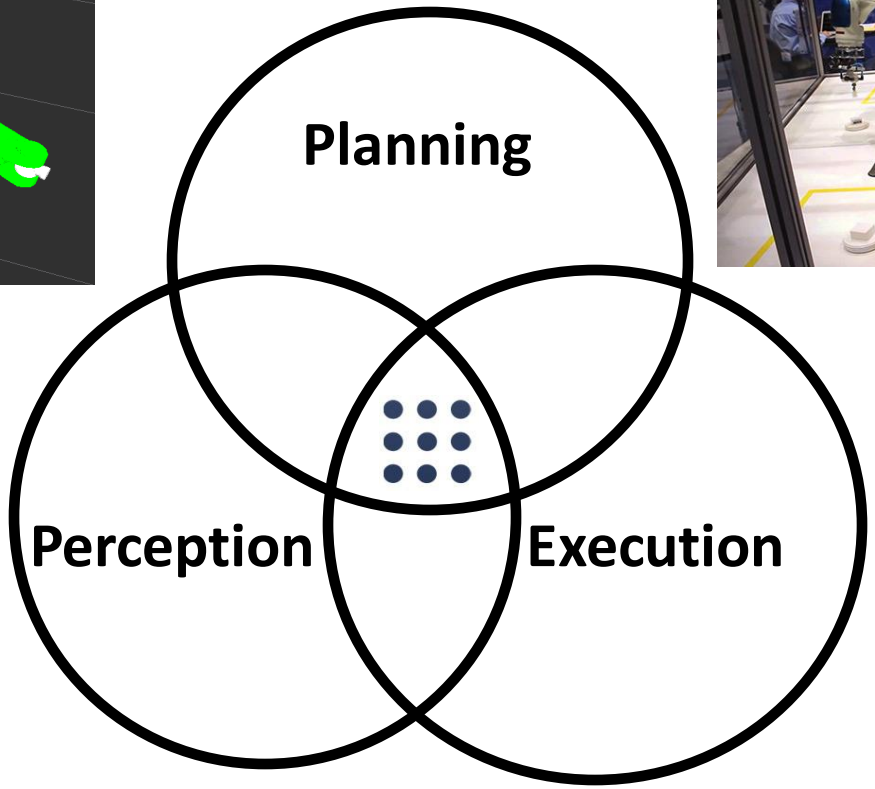


(Adapted from Willow Garage's "What is ROS?" Presentation)

ROS is…Capabilities

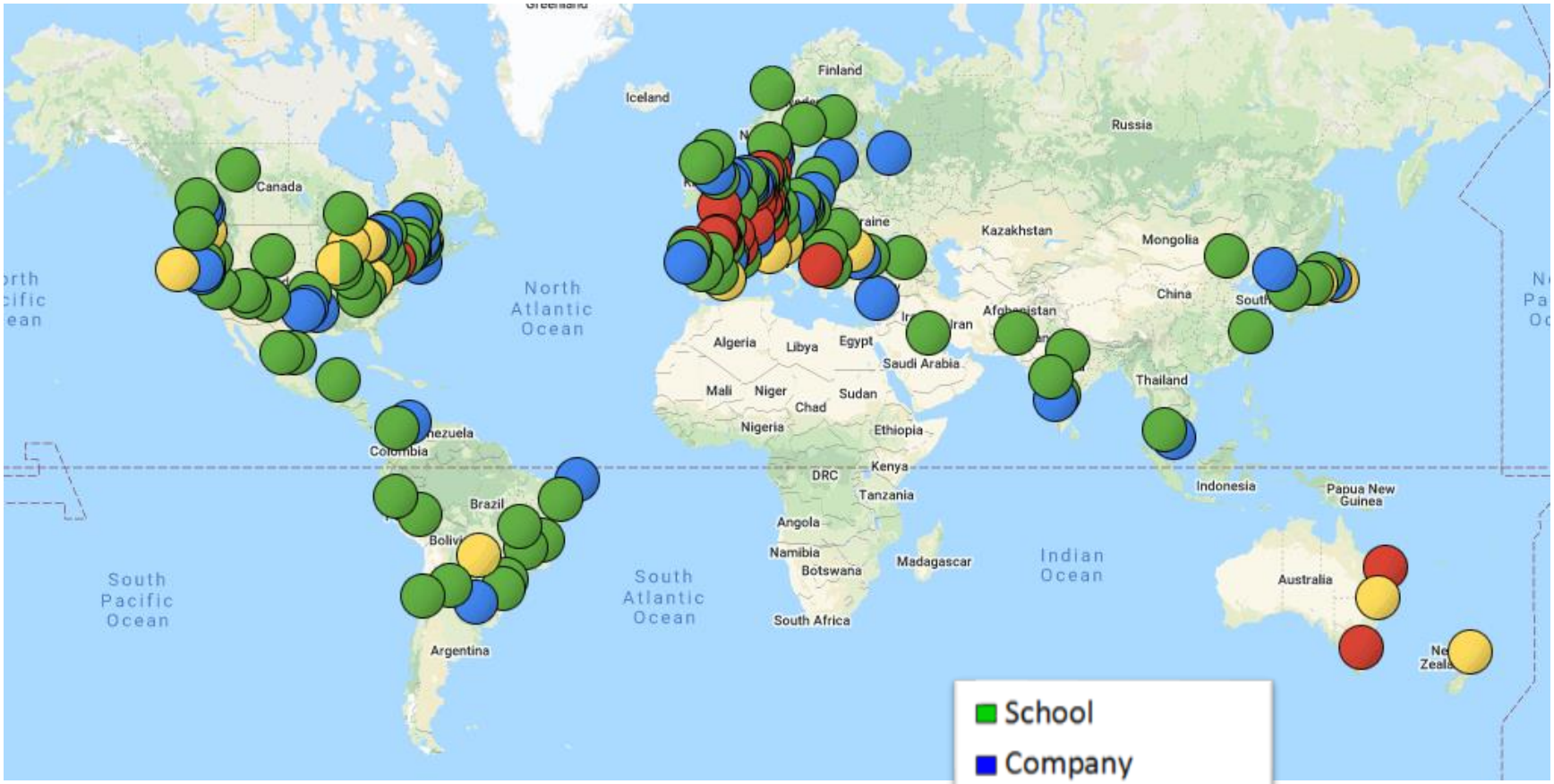






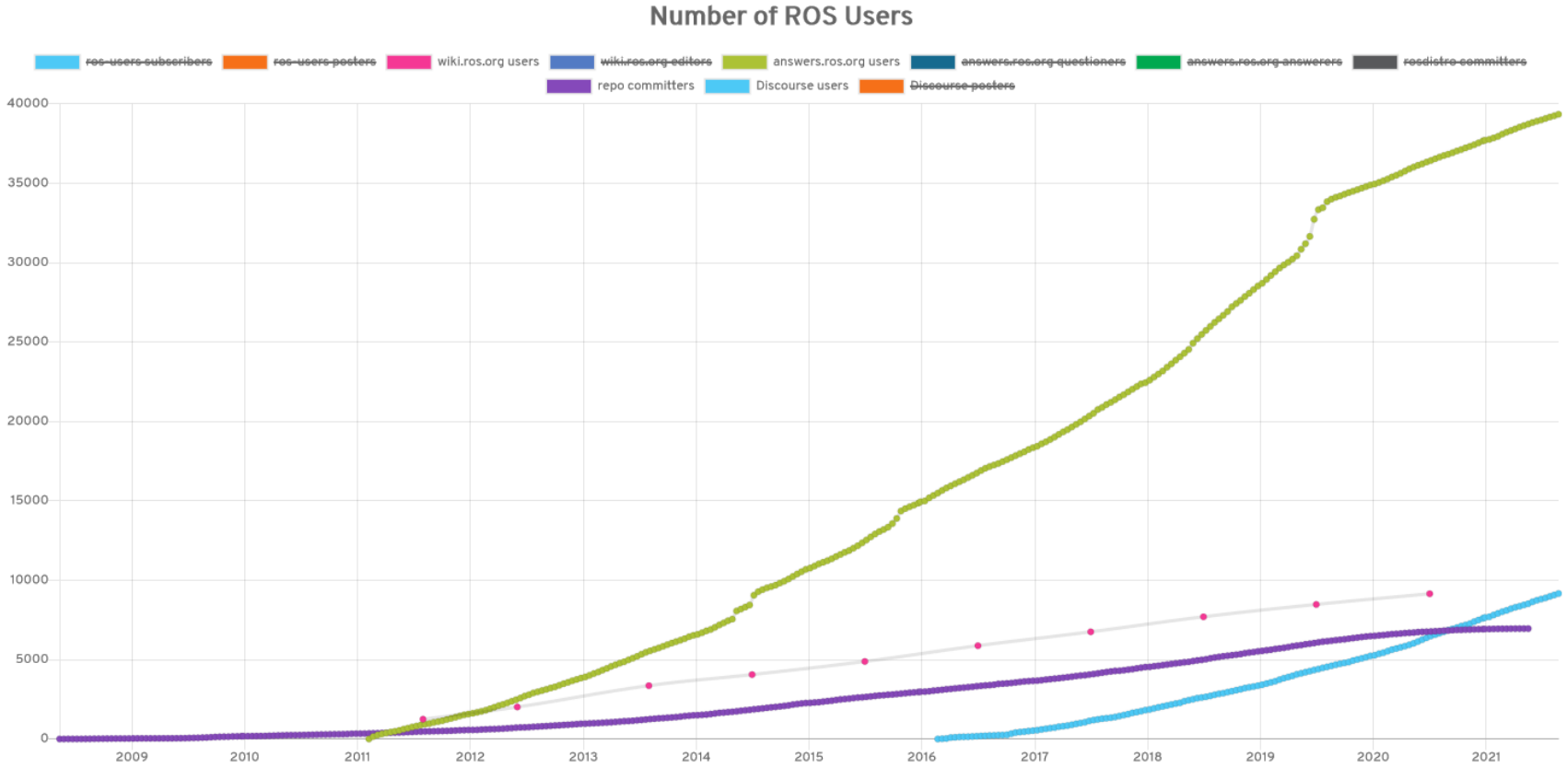
(Adapted from Willow Garage's "What is ROS?" Presentation)

ROS is… an Ecosystem



http://metrorobots.com/rosmap.html

ROS is a growing Ecosystem



A collection of different metrics for measuring the number of users in the ROS community.

https://metrics.ros.org/

ROS is International

unique wiki visitors Jul 2020

1.	China	39,080 (19.26%)
2.	United States	31,853 (15.70%)
3.	Japan	16,766 (8.26%)
4.	Germany	14,521 (7.16%)
5.	South Korea	12,583 (6.20%)
6.	India	10,700 (5.27%)
7.	Taiwan	5,904 (2.91%)
8.	United Kingdom	4,150 (2.05%)
9.	France	3,994 (1.97%)
10.	Singapore	3,881 (1.91%)
11.	Canada	3,748 (1.85%)
12.	Italy	3,590 (1.77%)
13.	Hong Kong	3,509 (1.73%)
14.	Spain	2,936 (1.45%)
15.	Russia	2,820 (1.39%)

visitors per million people

1. Singapore: 683
2. Hong Kong: 475
3. Taiwan: 252
4. South Korea: 244
5. Germany: 175

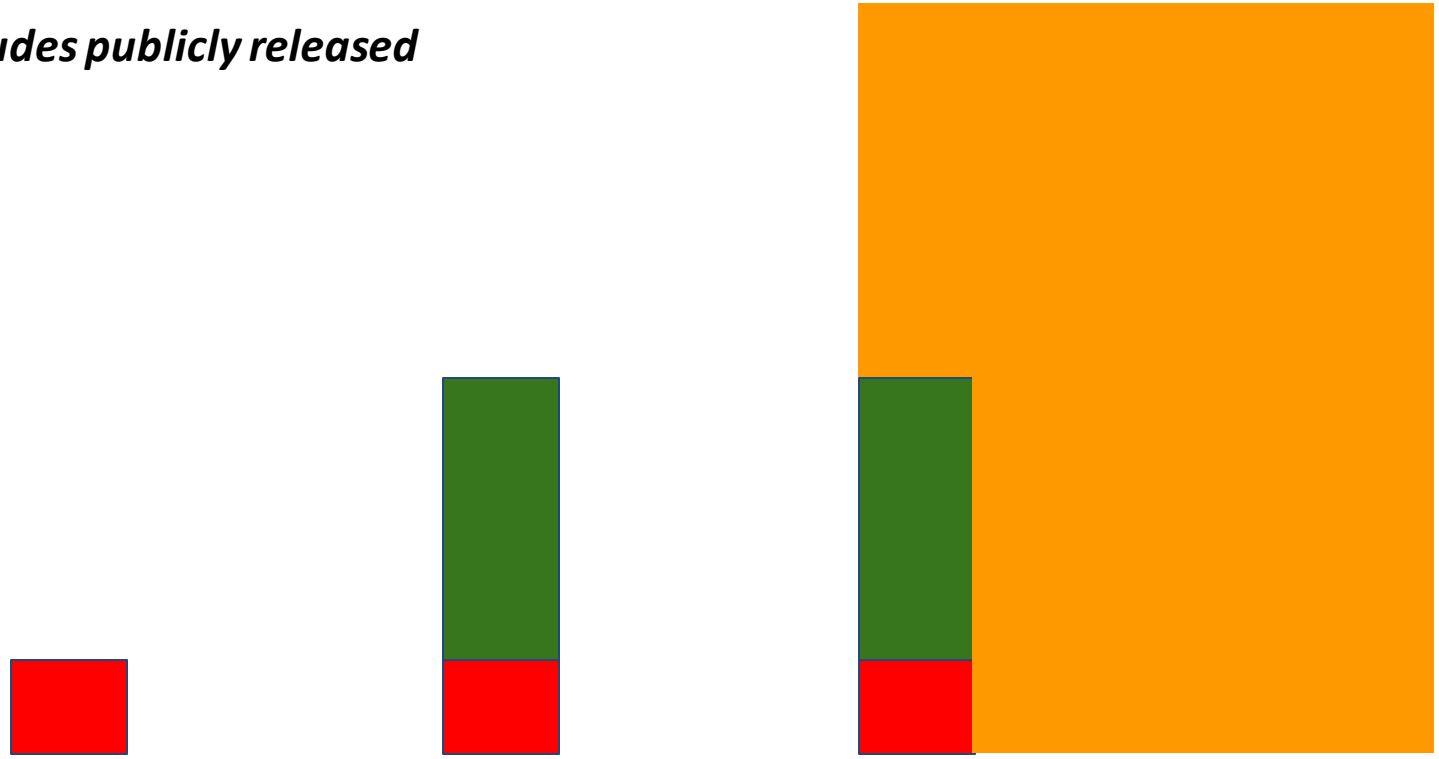
...

9. USA: 96

(http://wiki.ros.org/Metrics "Community Metrics Report" August 2020)

ROS is a Repository

only includes publicly released code!



ros_comm
("core")
100 KLOC

desktop-full
("core+tools")
400 KLOC

all buildfarm
("universe")
4000 KLOC

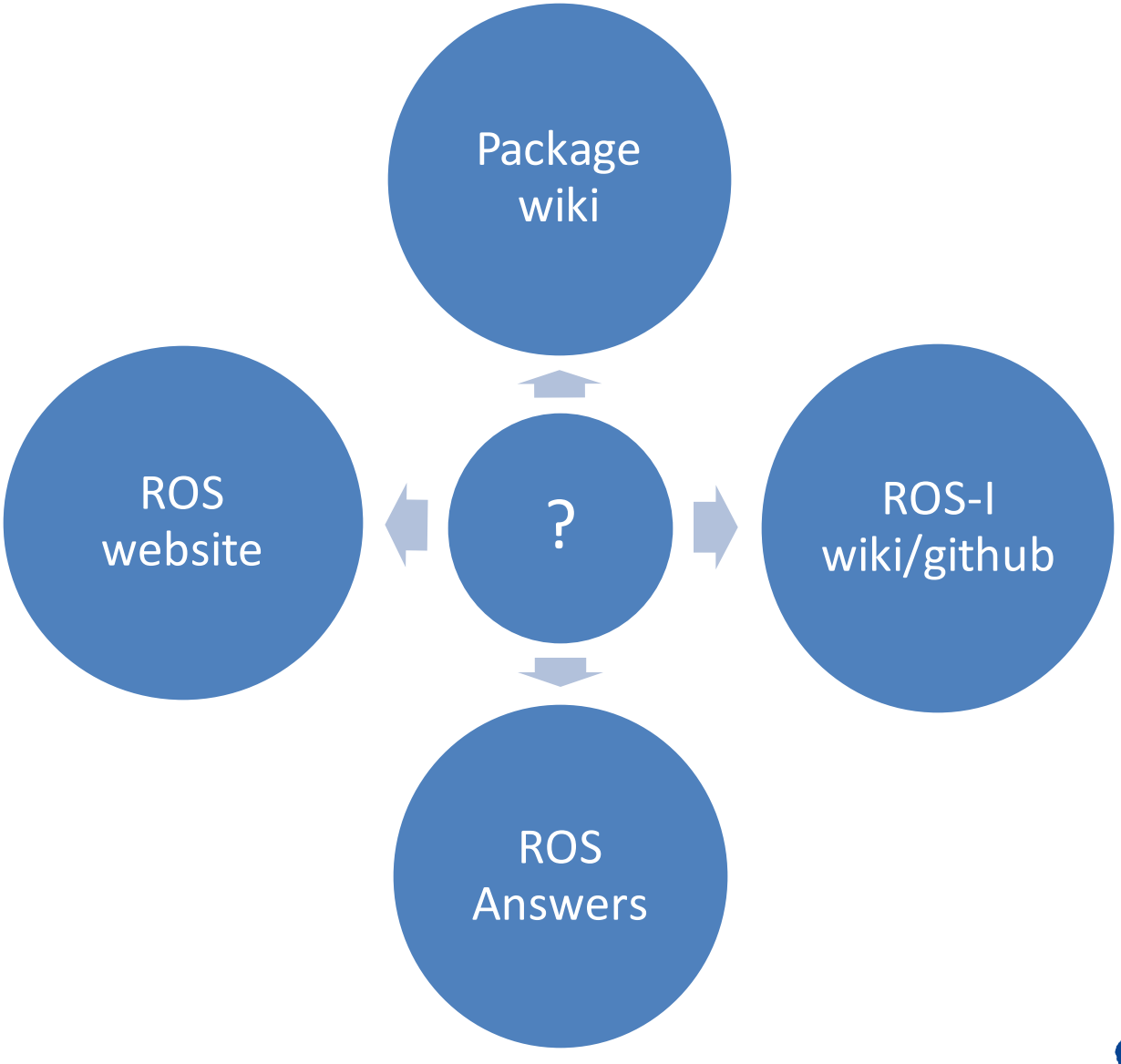
(From Morgan Quigley's "ROS: An Open-Source Framework for Modern Robotics")

ROS Programming

- ROS uses **platform-agnostic** methods for most communication
  - DDS, TCP/IP Sockets, XML, etc.

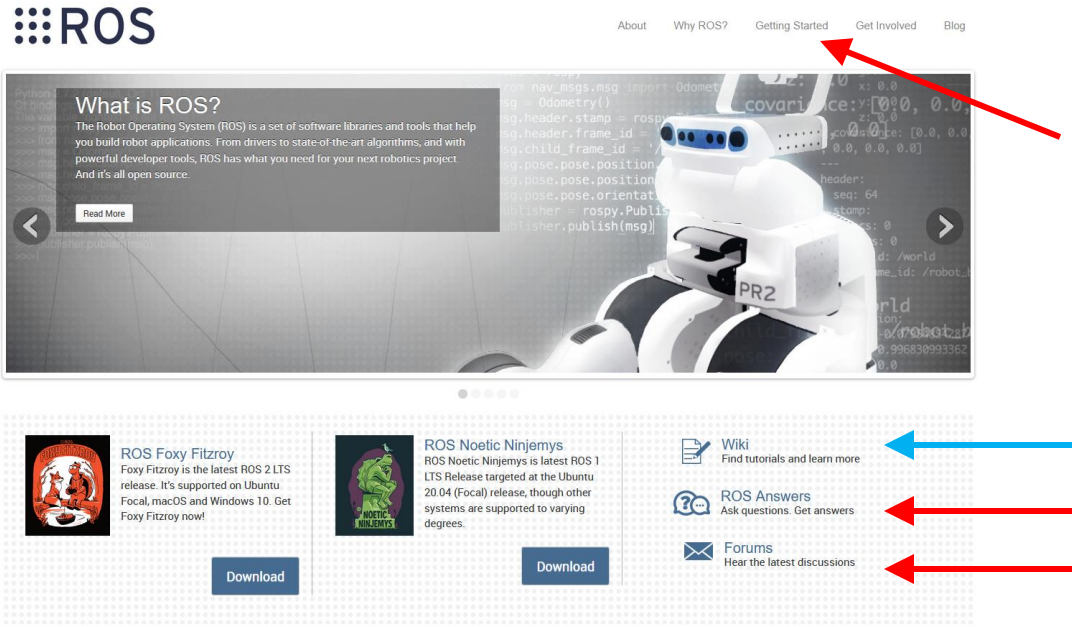
- Can intermix programming languages
  - Current 1st Tier support: C, C++, Python
  - We will be using C++ for our exercises

ROS Resources



ROS.org Website

http://ros.org



ROS1

but still relevant

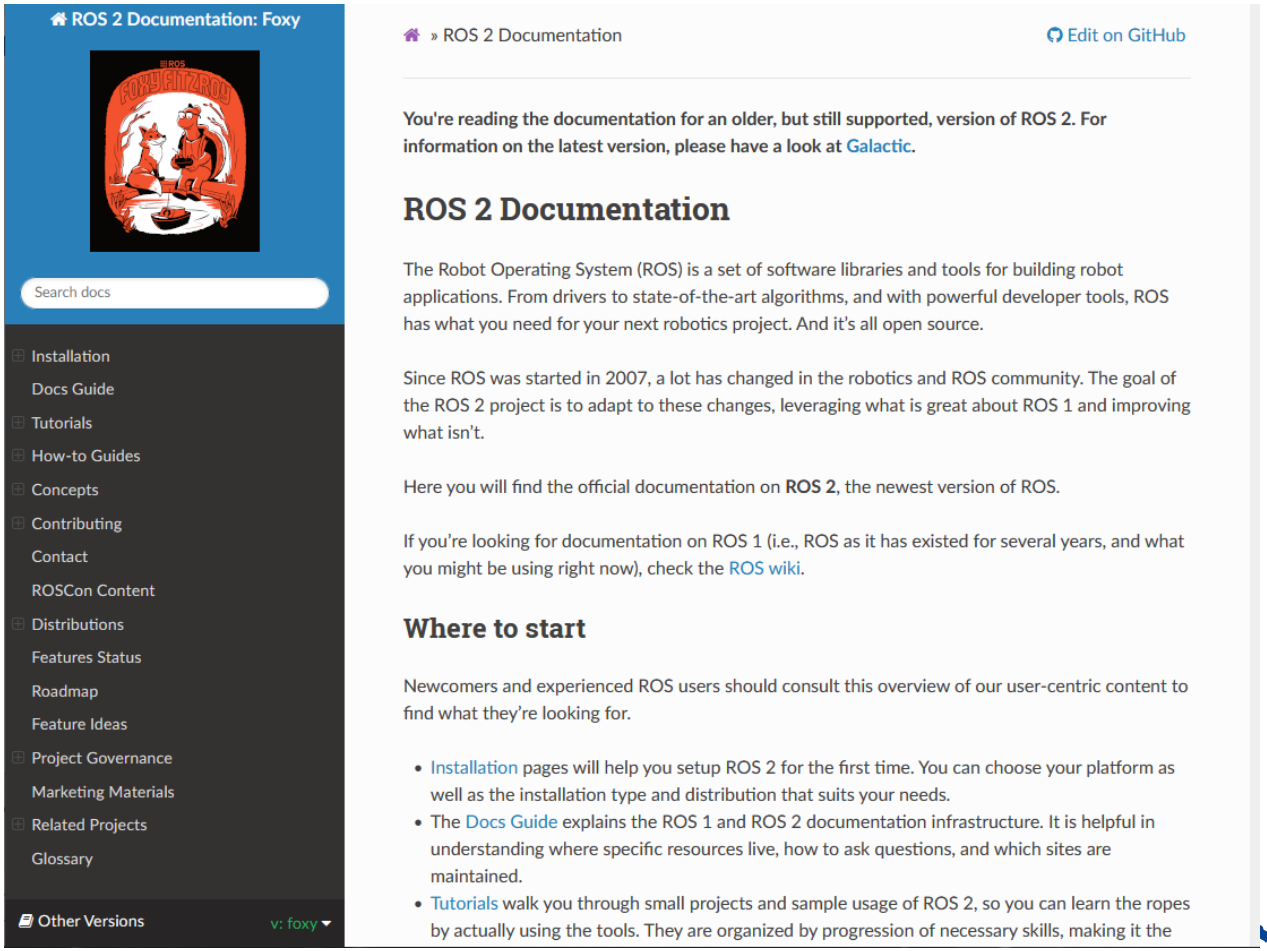
- Install Instructions
- ROS Answers
- Forums (Discourse)

ROS2 Documentation

http://docs.ros.org

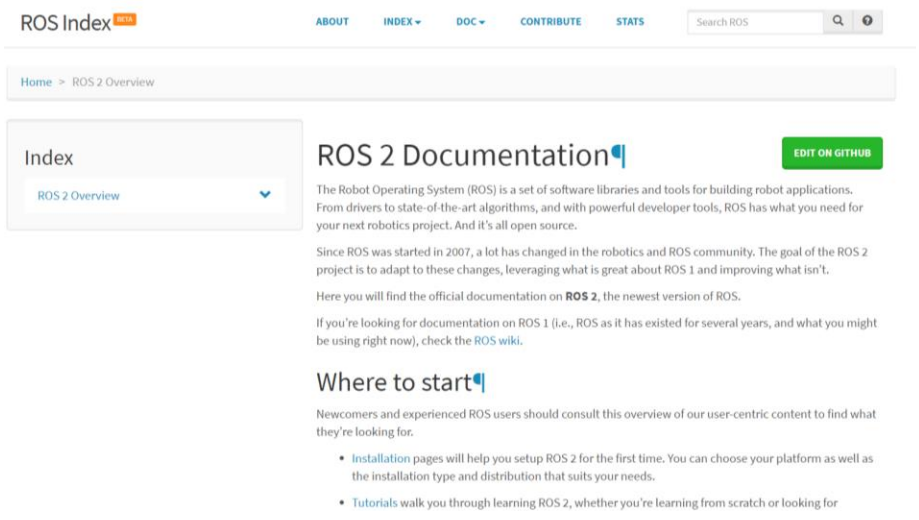
- Install
- Tutorials
- Concepts

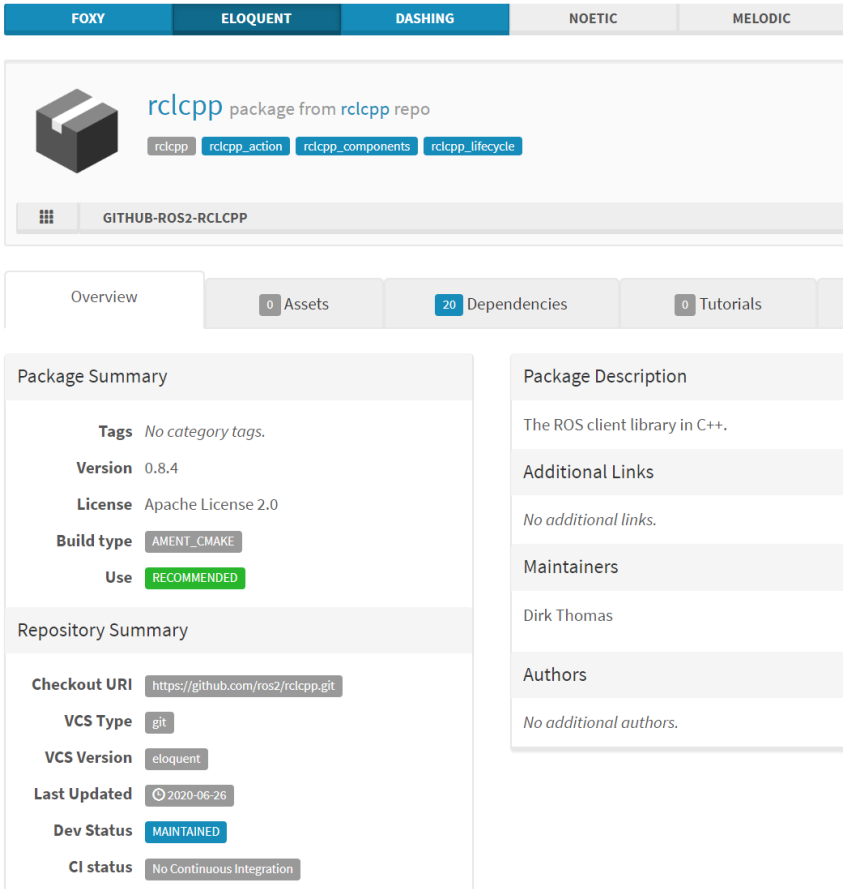
...



ROS Package Index

http://index.ros.org

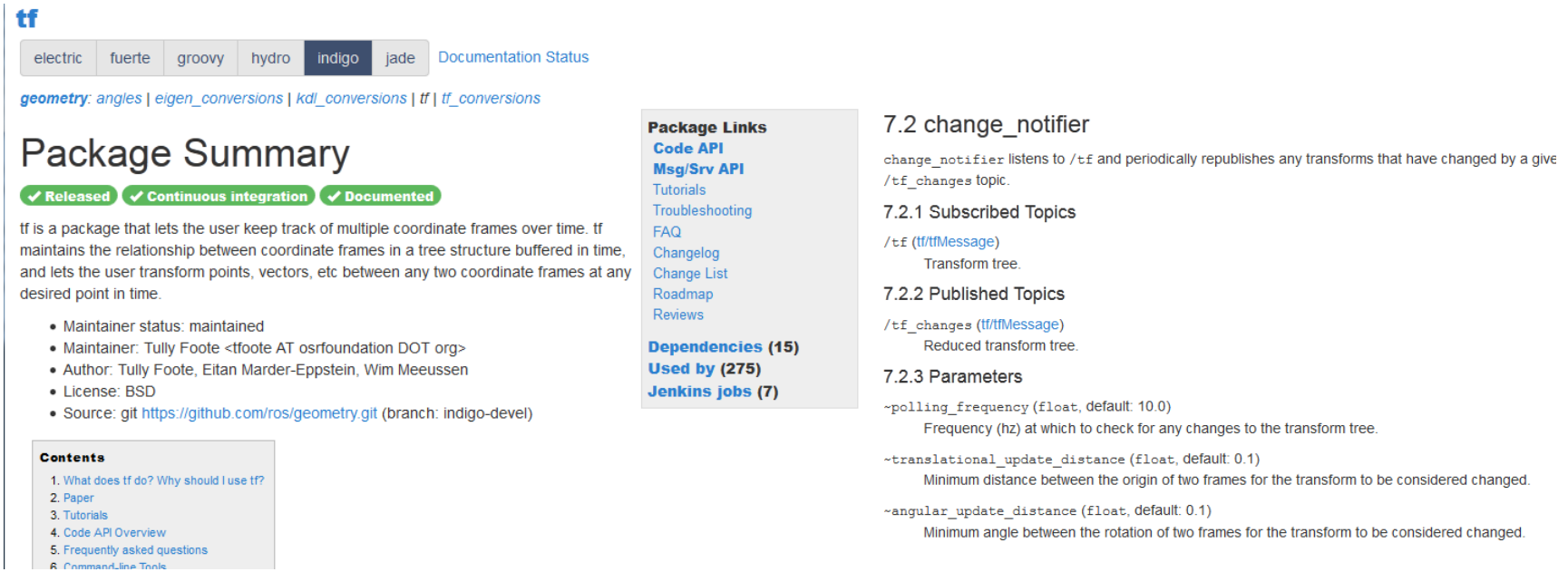




- Install Instructions
- Tutorials
- Package Info
- Still NEW – see ROS1 Wiki

Package Wiki

http://wiki.ros.org/<packageName>



tf

electric | fuerte | groovy | hydro | indigo | jade | Documentation Status

geometry: *angles* | *eigen_conversions* | *kdl_conversions* | *tf* | *tf_conversions*

Package Summary

✔ Released ✔ Continuous integration ✔ Documented

tf is a package that lets the user keep track of multiple coordinate frames over time. tf maintains the relationship between coordinate frames in a tree structure buffered in time, and lets the user transform points, vectors, etc between any two coordinate frames at any desired point in time.

- Maintainer status: maintained
- Maintainer: Tully Foote <tfoote AT osrfoundation DOT org>
- Author: Tully Foote, Eitan Marder-Eppstein, Wim Meeussen
- License: BSD
- Source: git https://github.com/ros/geometry.git (branch: indigo-devel)

Contents

1. What does tf do? Why should I use tf?
2. Paper
3. Tutorials
4. Code API Overview
5. Frequently asked questions
6. Command-line Tools

Package Links
Code API
Msg/Srv API
Tutorials
Troubleshooting
FAQ
Changelog
Change List
Roadmap
Reviews

Dependencies (15)
Used by (275)
Jenkins jobs (7)

7.2 change_notifier

`change_notifier` listens to `/tf` and periodically republishes any transforms that have changed by a give `/tf_changes` topic.

7.2.1 Subscribed Topics

`/tf` (tf/tfMessage)
Transform tree.

7.2.2 Published Topics

`/tf_changes` (tf/tfMessage)
Reduced transform tree.

7.2.3 Parameters

`~polling_frequency` (`float`, default: 10.0)
Frequency (hz) at which to check for any changes to the transform tree.

`~translational_update_distance` (`float`, default: 0.1)
Minimum distance between the origin of two frames for the transform to be considered changed.

`~angular_update_distance` (`float`, default: 0.1)
Minimum angle between the rotation of two frames for the transform to be considered changed.

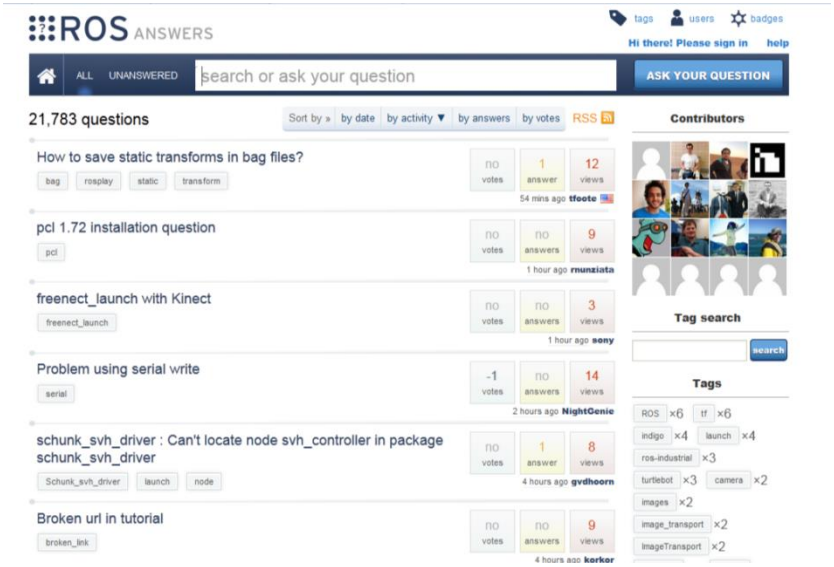
- Description / Usage
- Tutorials
- Code / Msg API
- Source-Code Link
- Bug Reporting

"ROS1 Only"

But still relevant for most packages

ROS Answers

http://answers.ros.org



- Quick responses to Good Questions
- Search by text or tag
- Don’t re-invent the wheel!

ROS is a Community

- No Central "Authority" for Help/Support
  - Many users can provide better (?) support
  - ROS-I Consortium can help fill that need

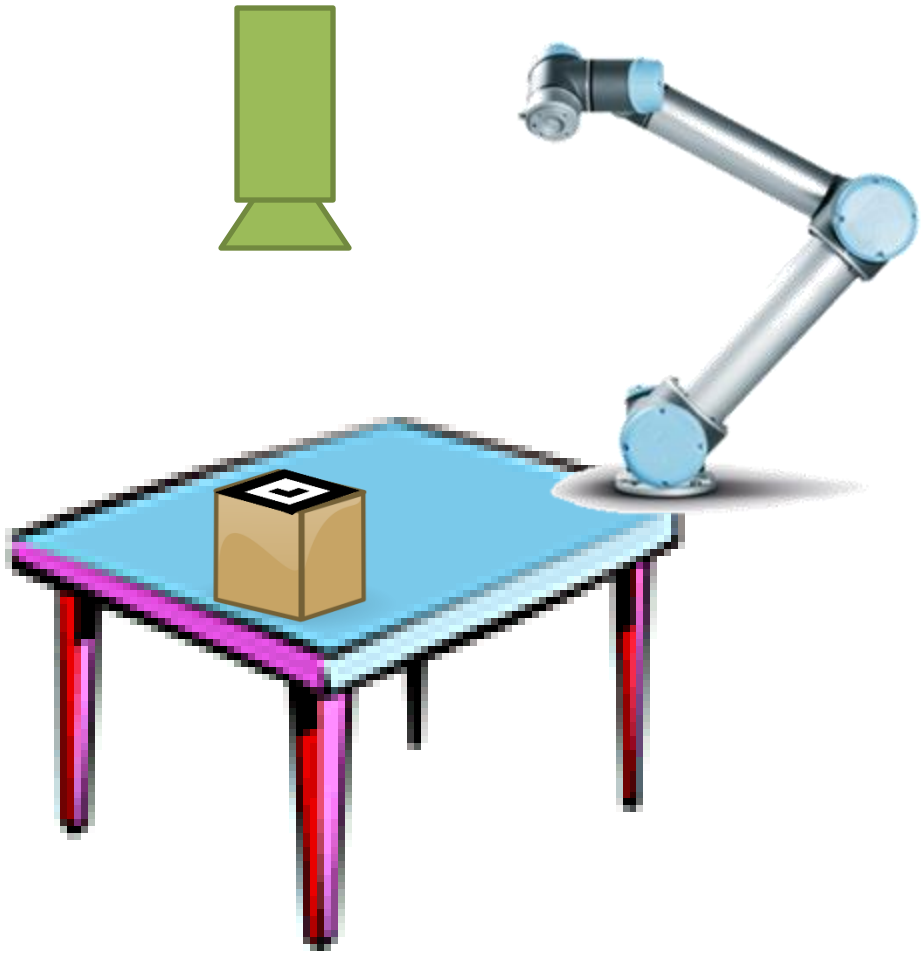
- Most ROS-code is open-source
  - can be reviewed / improved by everyone
  - we count on **YOU** to help ROS grow!

What is ROS to you?

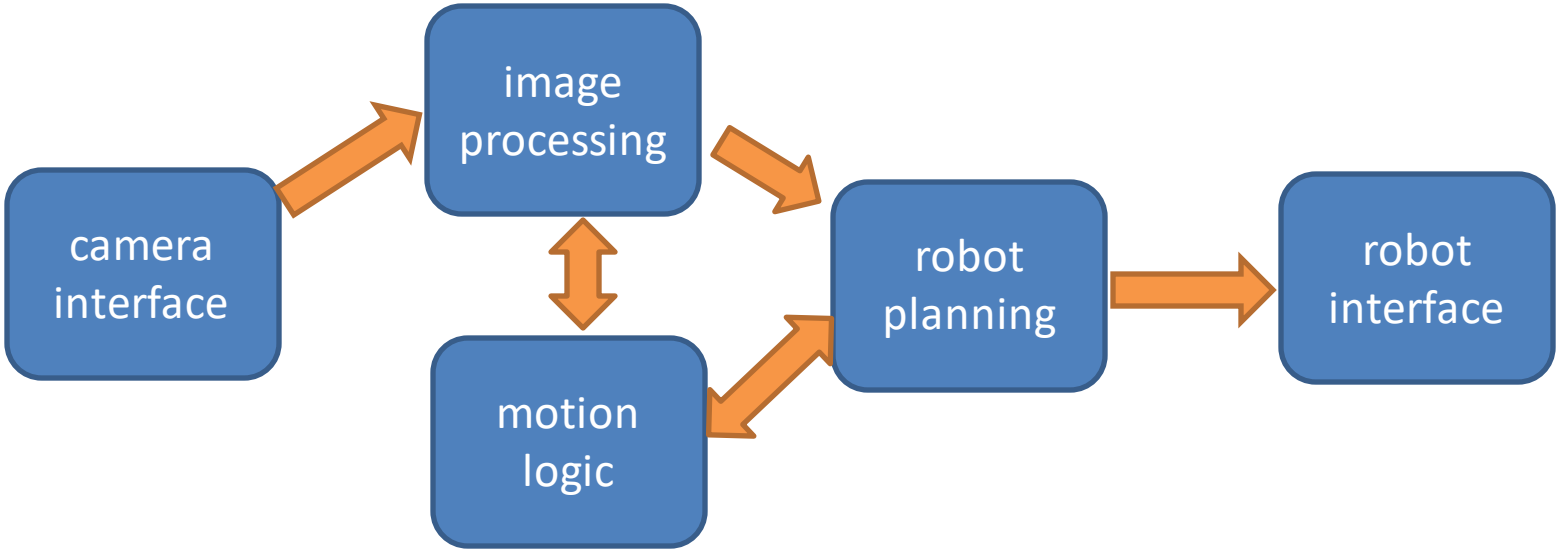
Training Goals:

- Show you ROS as a software framework
- Show you ROS as a tool for problem solving
- Apply course concepts to a sample application
- Ask lots of questions and break things.

Scan & Plan “Application”

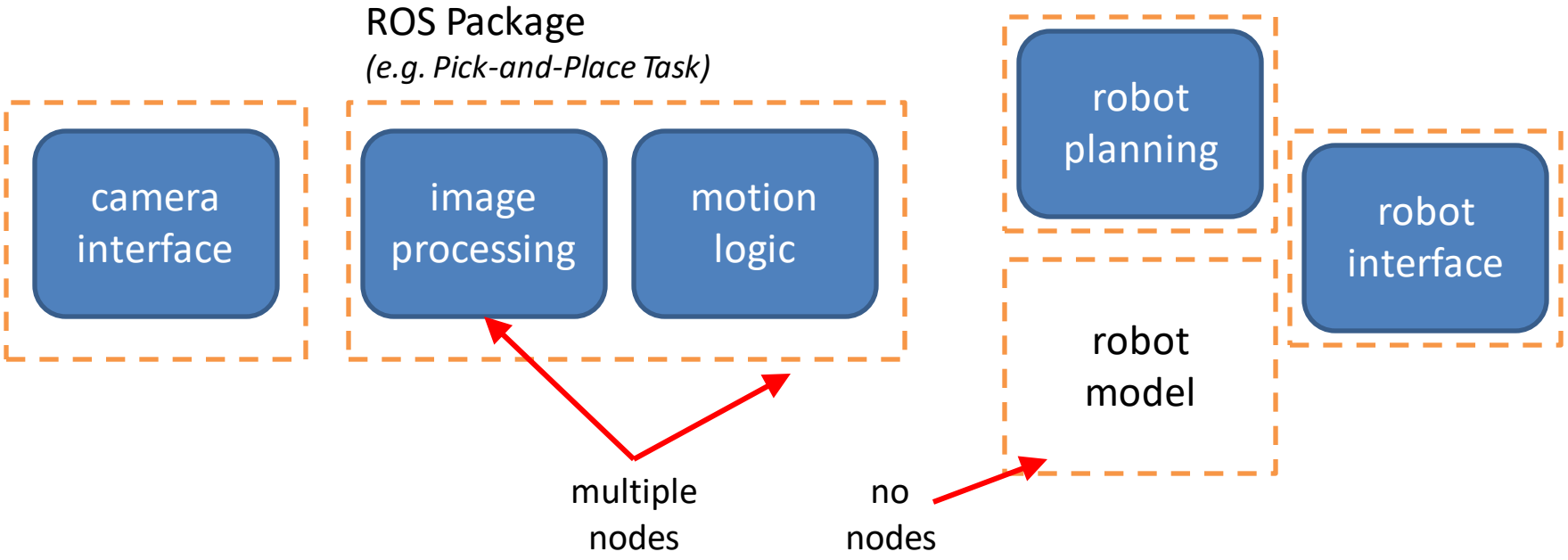


ROS Architecture: Nodes



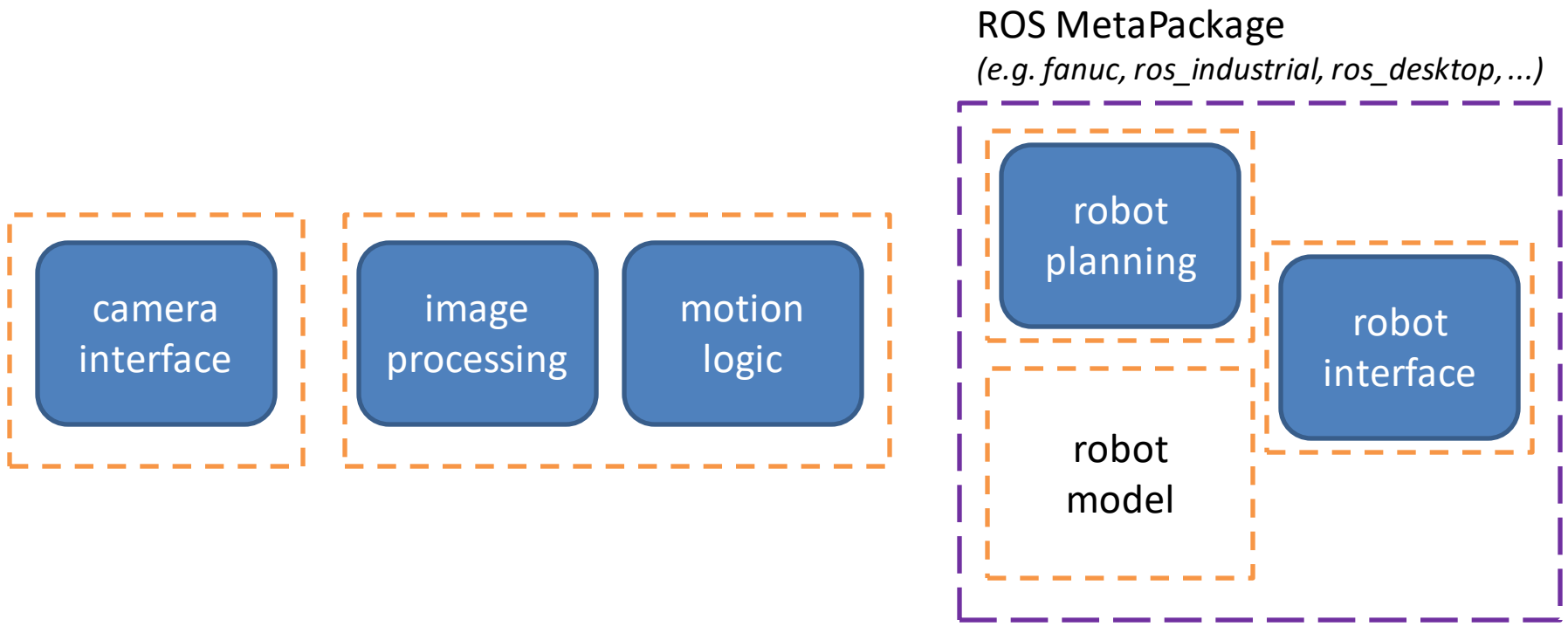
- A **Node** is a *standalone* piece of functionality
  - Most communication happens **between** nodes
  - Nodes can run on many different **devices**
  - Often one node per process, but not always

ROS Architecture: Packages



- ROS **Packages** are groups of related nodes/data
  - Files grouped in a single **directory**, with key **metafiles**
  - Many ROS commands are **package-oriented**

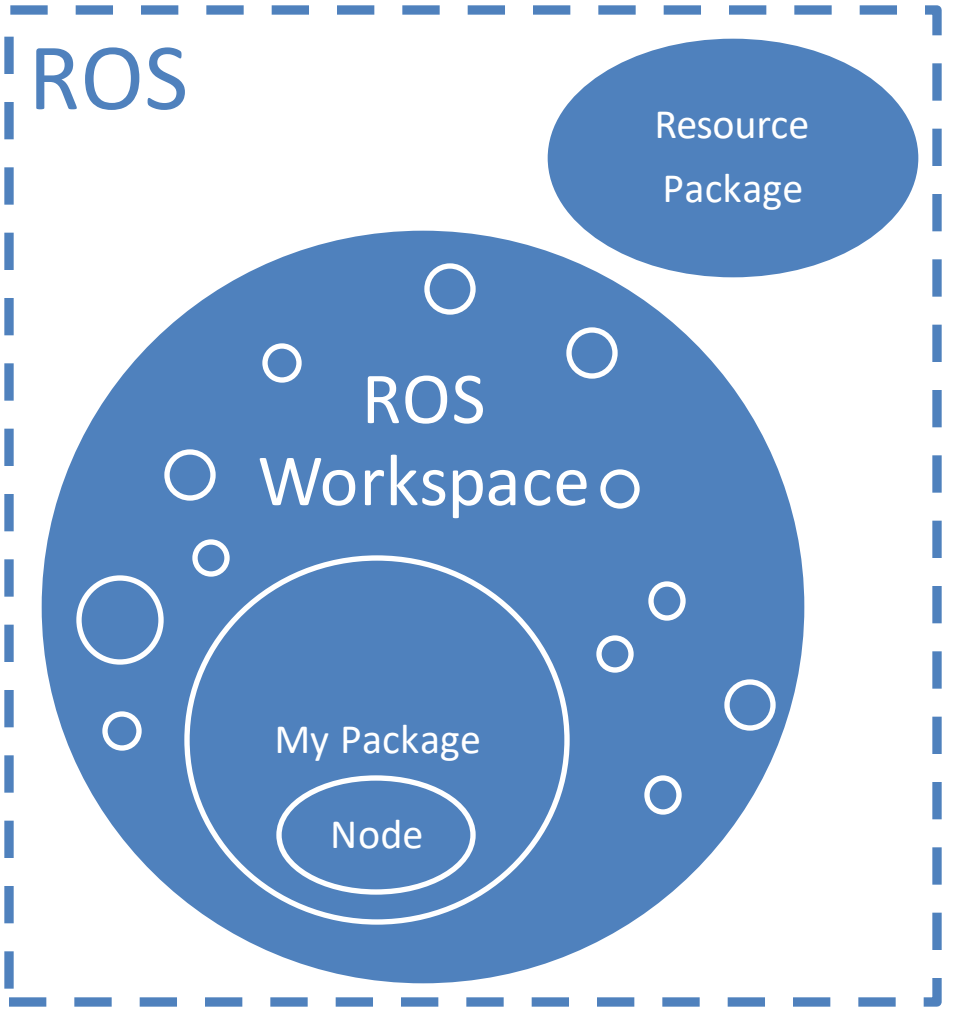
ROS Architecture: MetaPkg



- Some "**MetaPackages**" don't have any content
  - Only dependency references to other packages
  - Mostly for convenient install/deployment

Day 1 Progression

- ❑ Install ROS
- ❑ Create Workspace
- ❑ Add “resources”
- ❑ Create Package
- ❑ Create Node
  - ❑ Basic ROS Node
  - ❑ Interact with other nodes
    - ❑ Messages
    - ❑ Services
- ❑ Run Node
  - ❑ ros2 run
  - ❑ ros2 launch



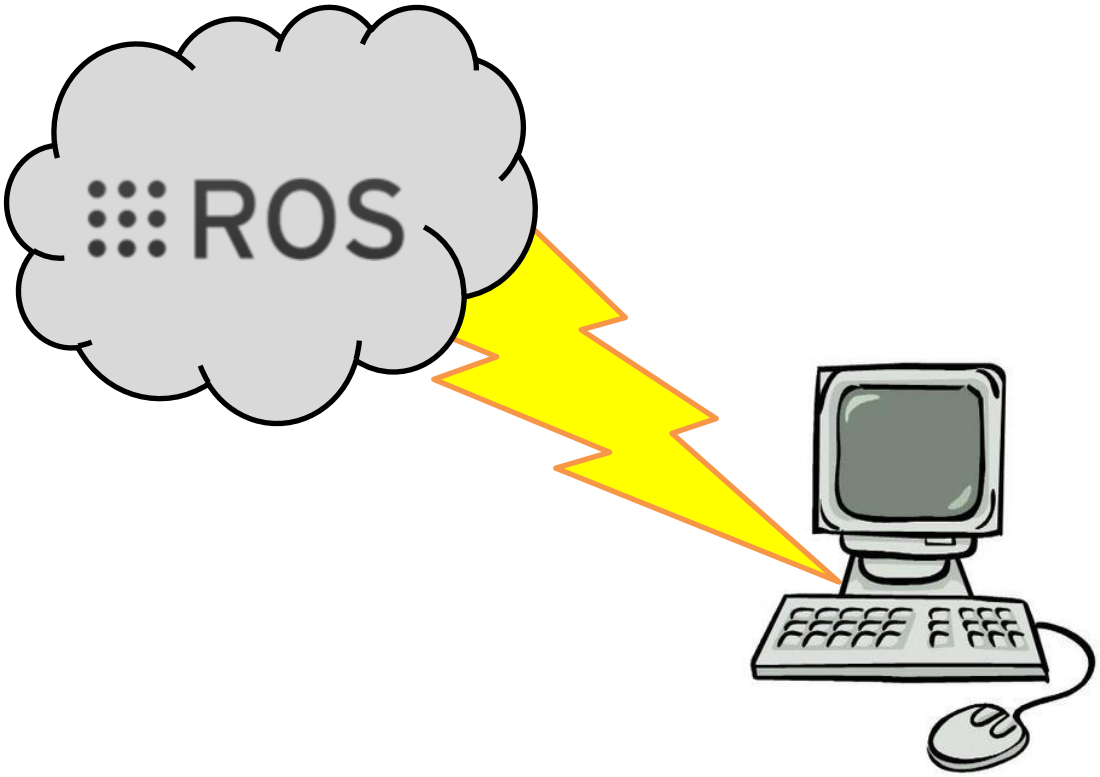
Installing ROS

Getting ROS2

https://index.ros.org/doc/ros2/Installation/humble/

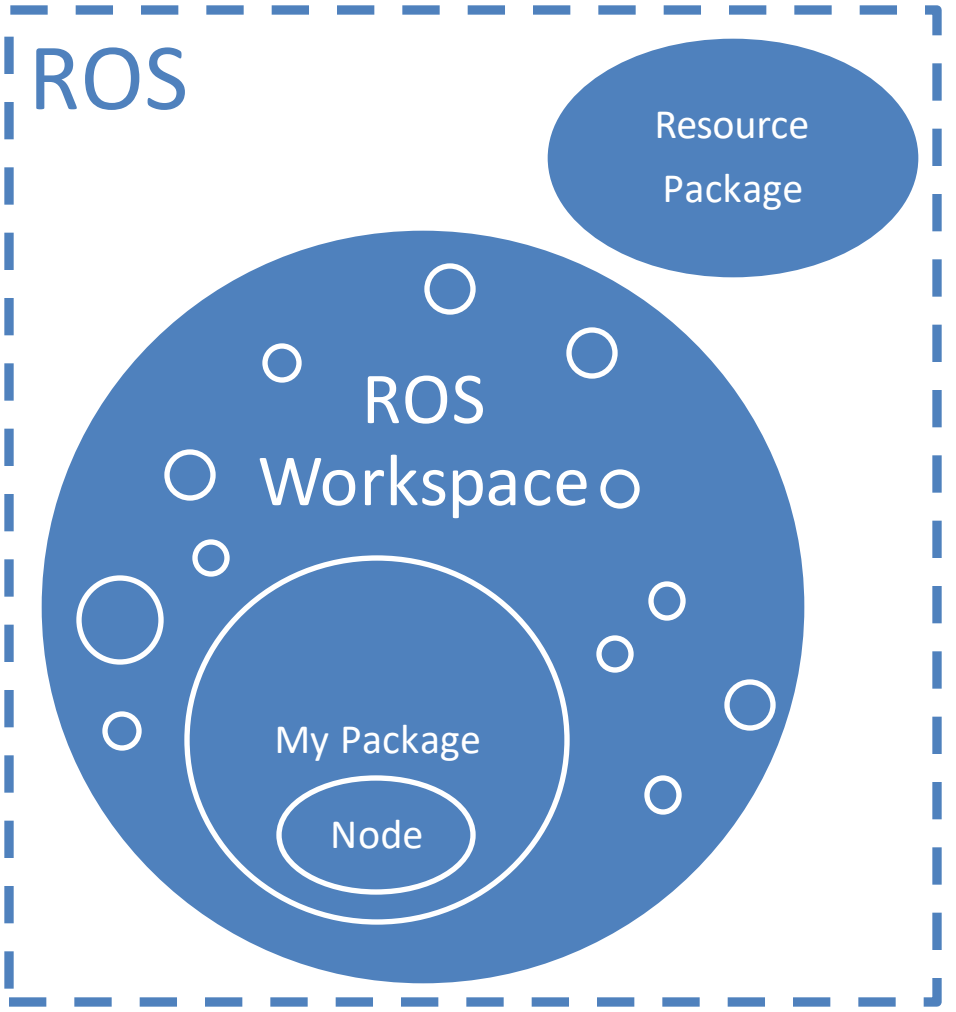
Exercise 1.0

Basic ROS Install/Setup



Day 1 Progression

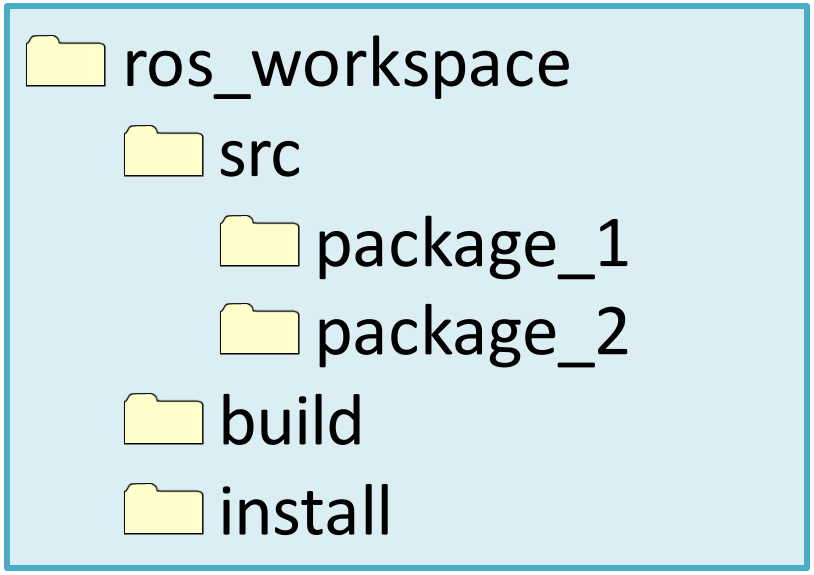
- ✓ Install ROS (check install)
- ❑ Create Workspace
- ❑ Add “resources”
- ❑ Create Package
- ❑ Create Node
  - ❑ Basic ROS Node
  - ❑ Interact with other nodes
    - ❑ Messages
    - ❑ Services
- ❑ Run Node
  - ❑ ros2 run
  - ❑ ros2 launch



Creating a ROS Workspace

ROS Workspace

- ROS uses a specific directory structure:
  - each “project” typically gets its own **workspace**
  - all packages/source files go in the **src** directory
  - temporary build-files are created in **build**
  - results are placed in **install**



Build System

- ROS2 uses the **ament** build system
  - based on CMake
  - cross-platform (Ubuntu, Windows, embedded...)
  - simplifies depending on packages and exporting outputs to other packages

Build System

- ROS2 also uses the **colcon** build tool
  - Pure Python framework
  - Generates the workspace outputs:
    - Finds all packages in the src directory
    - Defines the build order based on dependencies
    - Invokes the build system for each package
      - CMake/Ament for C++ packages
      - Setuptools for pure Python packages
  - Can build ROS1 packages
    - but some packages may prefer to be built with the ROS1-legacy “catkin” build tools.

Colcon Build Process

Setup (one-time)

1. Create a workspace (arbitrary name and location)
   - `ros_ws`
   - `src` sub-directory must be created manually
   - `build`, `install` directories created automatically
2. Download/create **packages** in `src` subdir

Compile-Time

1. Run `colcon build` from the workspace root
2. Run `source install/setup.bash` to make this workspace visible to ROS

Colcon Build Notes

Colcon Build

- Always run from the workspace root
- Source workspaces of any dependencies before running build.
  - e.g. source /opt/ros/humble/setup.bash
- Can chain multiple workspaces together:
  - base humble -> pcl_ws -> my_ws
- Don't run from a terminal where you have "sourced" this workspace's setup file (can cause circular issues).

➢ Best Practice: Use a dedicated terminal window for building.

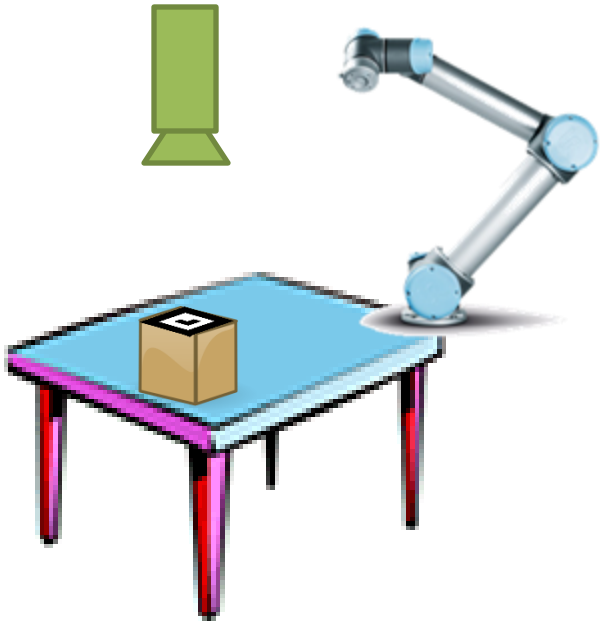
- Don't do anything in that terminal window other than colcon build.

Source install/setup.bash

- Remember to source this setup file in EACH new terminal
- No need to also source the underlays' setup files
- May need to re-source after adding new packages
- Can add to ~/.bashrc to automate this step
  - not recommended if using multiple ROS distros or working on multiple projects in parallel

Exercise 1.1

Create a ROS Workspace



fake_ar_pub

myworkcell_node

myworkcell_support

vision_node

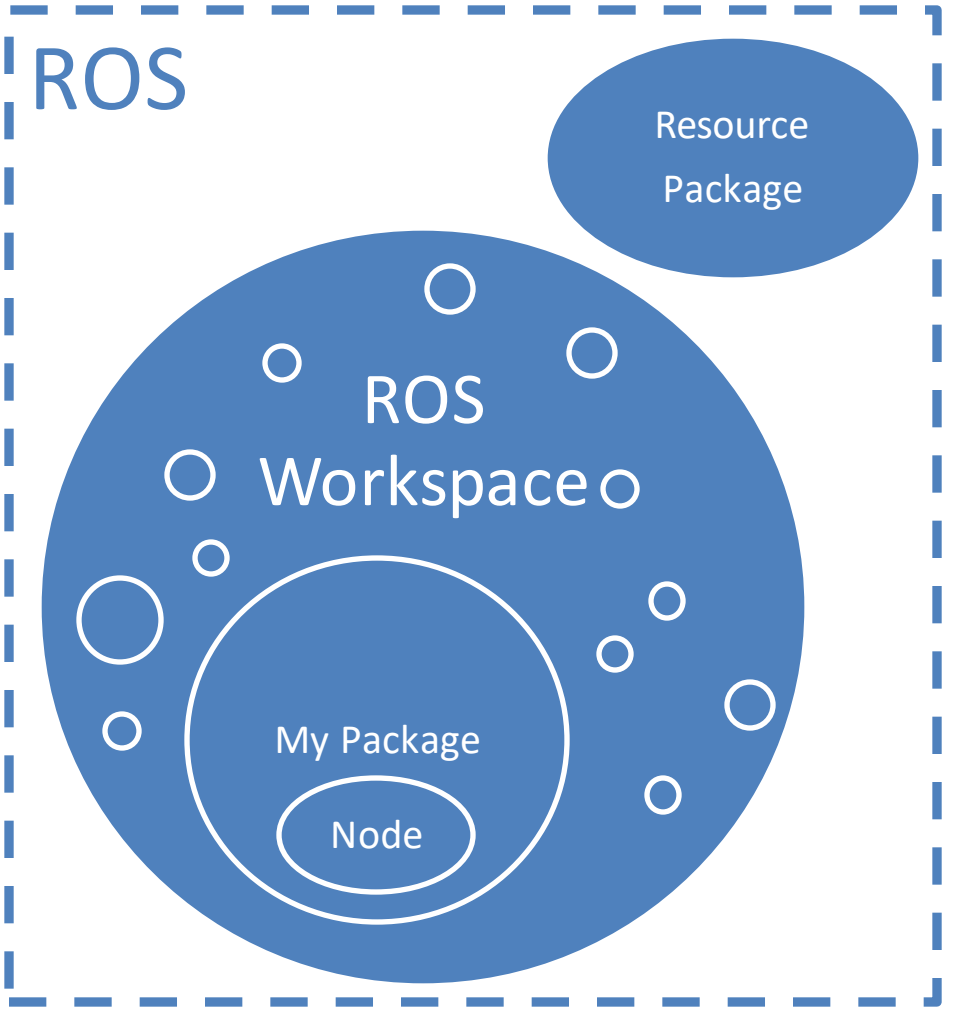
descartes_node

myworkcell_moveit_cfg

ur5_driver

Day 1 Progression

- ✓ Install ROS
- ✓ Create Workspace
- ❑ Add “resources”
- ❑ Create Package
- ❑ Create Node
  - ❑ Basic ROS Node
  - ❑ Interact with other nodes
    - ❑ Messages
    - ❑ Services
- ❑ Run Node
  - ❑ ros2 run
  - ❑ ros2 launch



Add 3rd-Party Packages

(a.k.a. “Resource” Packages)

Install options

Debian Packages

- Nearly “automatic”
- Recommended for end-users
- Stable
- Easy

Source Repositories

- Access “latest” code
- Most at Github.com
- More effort to setup
- Unstable*

Can mix both options, as needed

Finding the Right Package

- ROS Website (http://index.ros.org)
  - Search for known packages

- ROS Answers (http://answers.ros.org)
  - When in doubt... ask someone!

Install using Debian Packages

```
sudo apt install ros-humble-package
```

admin permissions	manage ".deb"	install new ".deb"	all ROS pkgs start with `ros-`	ROS distribution	ROS package name

Use "-" not "_"

- Fully automatic install:
  - Download .deb package from central ROS repository
  - Copies files to standard locations (`/opt/ros/humble/...`)
  - ➢ Also installs any other required dependencies

- `sudo apt-get remove ros-<distro>-<package>`
  - Removes software (but not dependencies!)

Installing from Source

- Find GitHub repo
- Clone repo into your workspace src directory

```
cd ros_ws/src
git clone http://github.com/user/repo.git
```

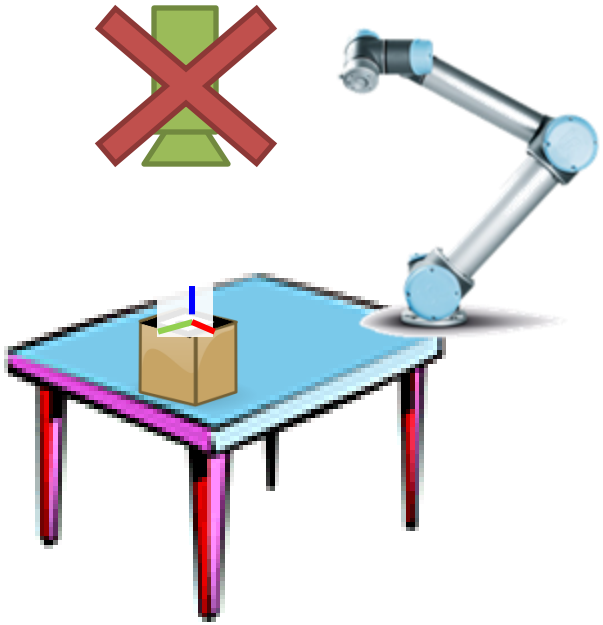
- Build your colcon workspace

```
cd ros_ws
colcon build
```

- Now the package and its resources are available to you

Exercise 1.2

Install "resource" packages



fake_ar_pub

myworkcell_node

myworkcell_support

vision_node

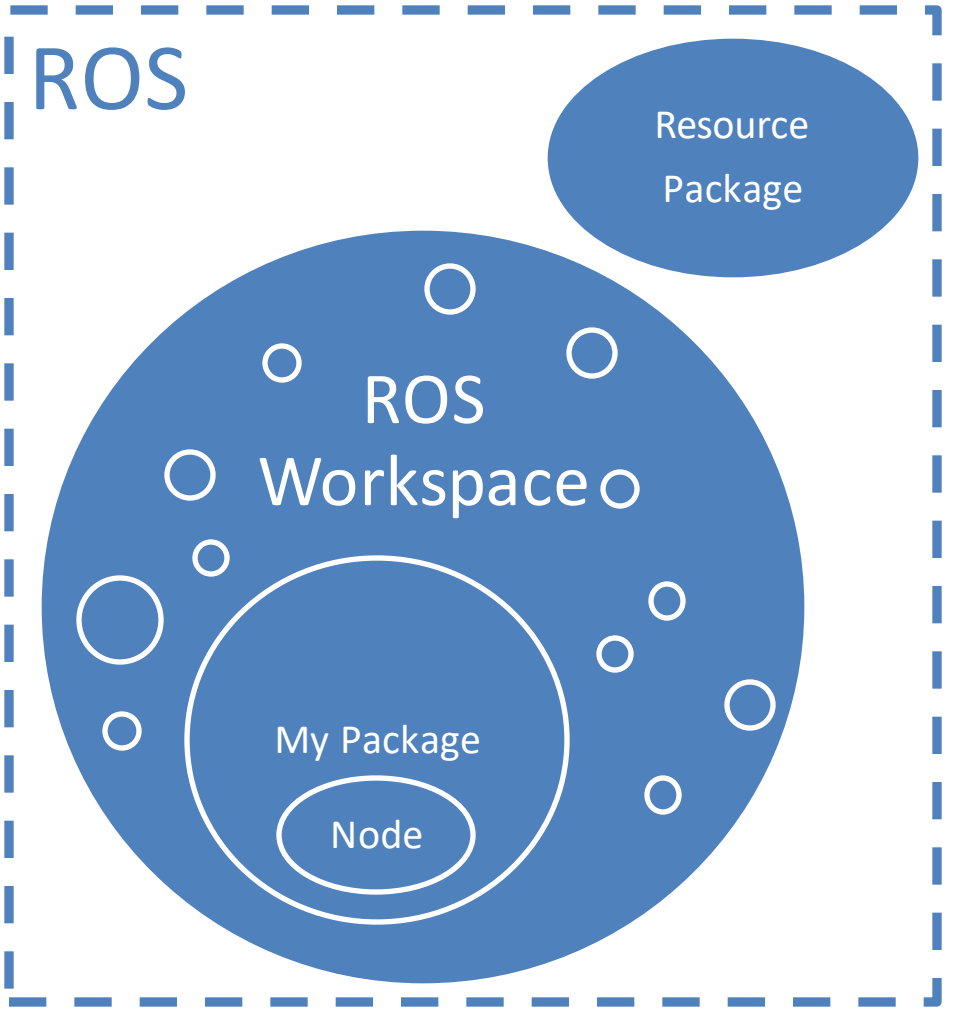
descartes_node

myworkcell_moveit_cfg

ur5_driver

Day 1 Progression

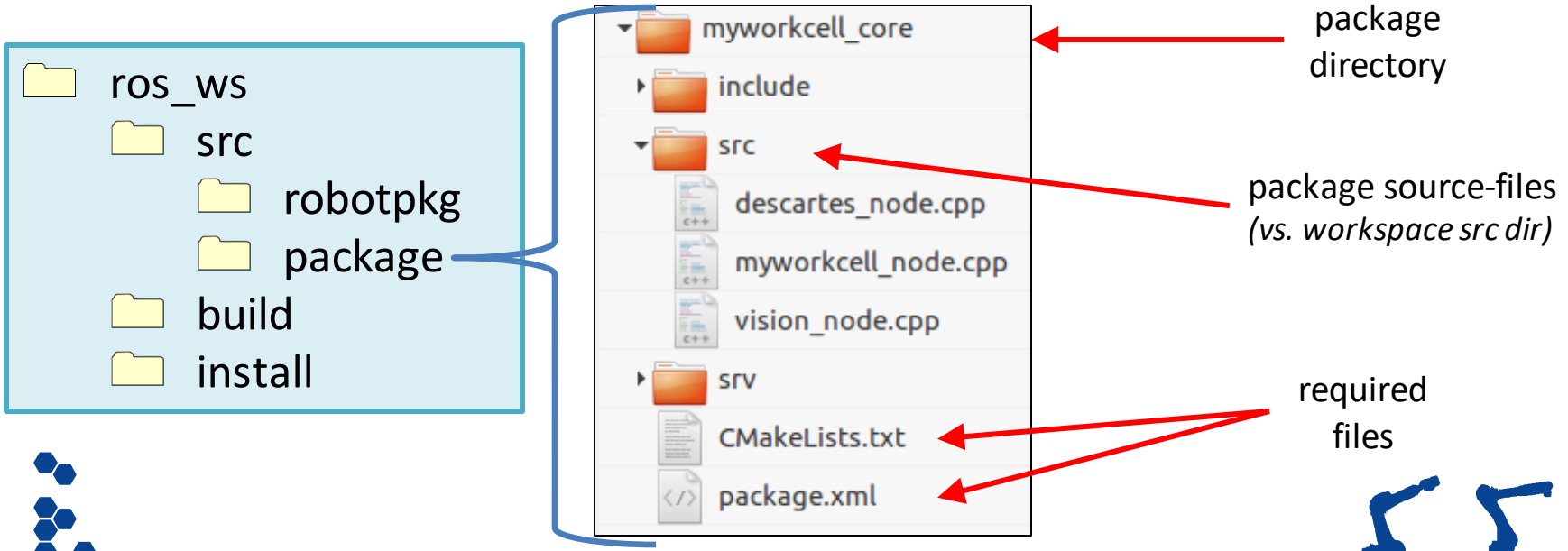
- ✓ Install ROS
- ✓ Create Workspace
- ✓ Add “resources”
- ❑ Create Package
- ❑ Create Node
  - ❑ Basic ROS Node
  - ❑ Interact with other nodes
    - ❑ Messages
    - ❑ Services
- ❑ Run Node
  - ❑ ros2 run
  - ❑ ros2 launch



ROS Packages

ROS Package Contents

- ROS components are organized into **packages**
- Packages contain several **required files**:
  - `package.xml`
    - **metadata** for ROS: package name, description, dependencies, ...
  - `CMakeLists.txt`
    - **build rules** for ament



package.xml

- Metadata: name, description, author, license ...

```
<?xml version="1.0"?>
<package format="2">
  <name>myworkcell_core</name>
  <version>0.0.0</version>
  <description>The myworkcell_core package</description>

  <!-- One maintainer tag required, multiple allowed, one person per tag -->
  <!-- Example:  -->
  <!-- <maintainer email="jane.doe@example.com">Jane Doe</maintainer> -->
  <maintainer email="ros-industrial@todo.todo">ros-industrial</maintainer>


  <!-- One license tag required, multiple allowed, one license per tag -->
  <!-- Commonly used license strings: -->
  <!--   BSD, MIT, Boost Software License, GPLv2, GPLv3, LGPLv2.1, LGPLv3 -->
  <license>TODO</license>


  <!-- Url tags are optional, but multiple are allowed, one per tag -->
  <!-- Optional attribute type can be: website, bugtracker, or repository -->
  <!-- Example: -->
  <!-- <url type="website">http://wiki.ros.org/myworkcell_core</url> -->


  <!-- Author tags are optional, multiple are allowed, one per tag -->
  <!-- Authors do not have to be maintainers, but could be -->
  <!-- Example: -->
  <!-- <author email="jane.doe@example.com">Jane Doe</author> -->

  <buildtool_depend>catkin</buildtool_depend>
  <build_depend>message_generation</build_depend>
  <exec_depend>message_runtime</exec_depend>
  <depend>roscpp</depend>
  <depend>geometry_msgs</depend>
</package>
```

package.xml

- Metadata: name, description, author, license ...
- Dependencies:
  - Common
    - `<buildtool_depend>`: Needed to **build** itself. (Typically ***ament_cmake***)
    - `<build_depend>`: Needed to **build** this package.
    - `<exec_depend>`: Needed to **run** code in this package.
    - `<depend>`: Needed to **build**, **export**, and **execution** dependency.
  - Uncommon
    - `<build_export_depend>`: Needed to **build against** this package.
    - `<test_depend>`: Only ***additional*** dependencies for unit tests.
    - `<doc_depend>`: Needed to generate documentation.

CMakeLists.txt

- Provides **rules** for **building software**
  - template file contains many examples

```
add_executable(myNode src/myNode.cpp src/widget.cpp)
```

Builds program `myNode`, from `myNode.cpp` and `widget.cpp`

```
ament_target_dependencies(myNode rclcpp std_msgs)
```

Links node `myNode` to dependency headers and libraries

```
install(TARGETS myNode DESTINATION lib/${PROJECT_NAME})
```

Copies nodes/libraries to workspace's "install" directory

ROS Package Commands

- **ros2 pkg**
  - ros2 pkg create package_name

    Create a new package, including template files

    Common options (not required, but will help pre-fill templtes):

    ```
    --build-type ament_cmake
    --node-name my_node
    --dependencies dep_pkg_1 dep_pkg_2
    ```
  - ros2 pkg prefix package_name

    Show directory where `package_name` is installed
  - ros2 pkg list

    List all ros packages installed (this is a BIG LIST!)
  - ros2 pkg xml package_name

    Show the package.xml file of `package_name`

Create New Package

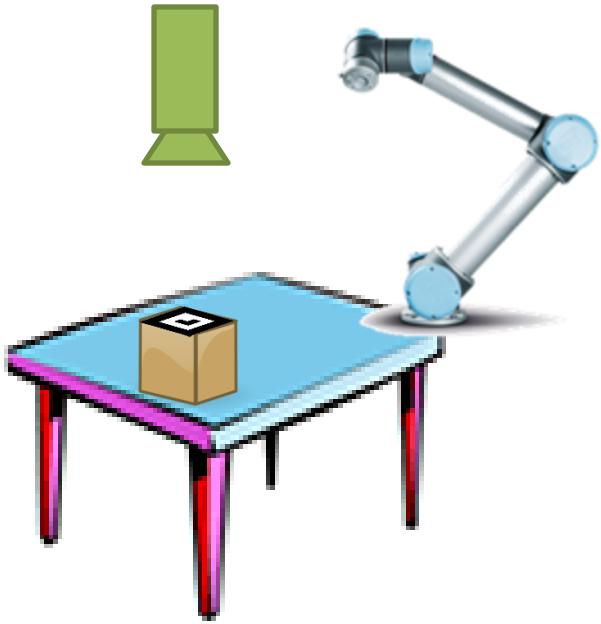
```
ros2 pkg create mypkg --node-name mynode
                      --dependencies dep1 dep2
```

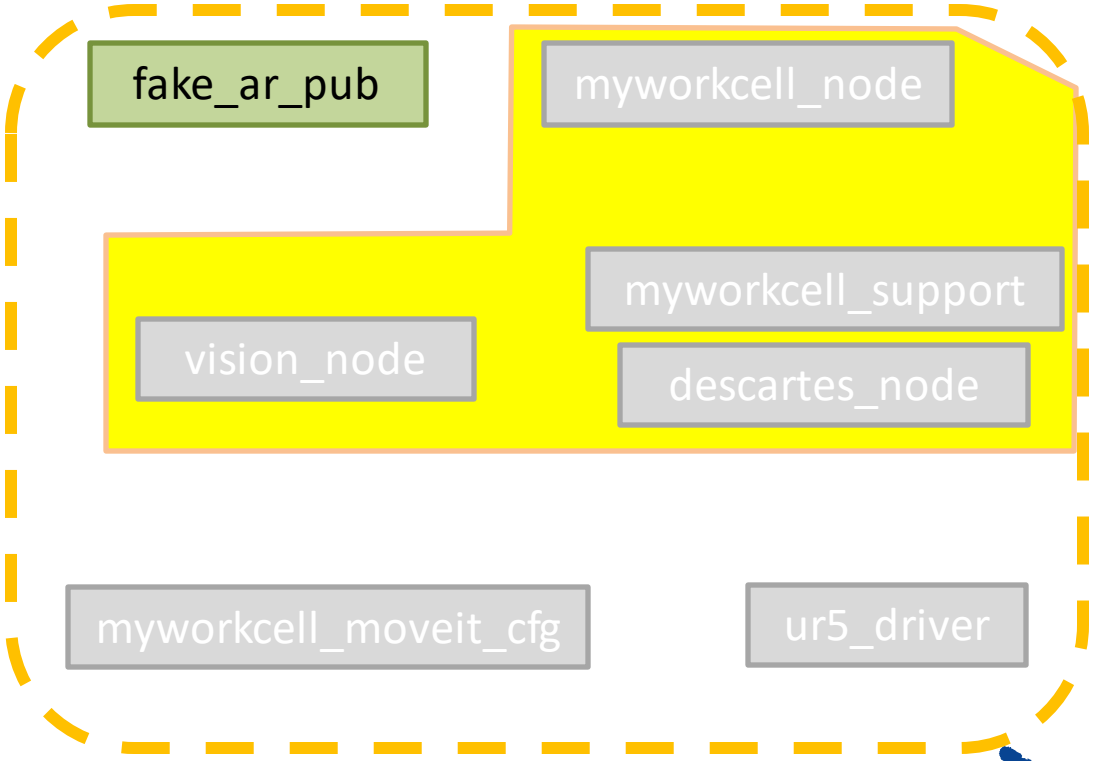
Easiest way to start a new package

- create directory, required template files
- `mypkg` : name of package to be created
- `mynode` : name of node (main executable)
- `dep1/2` : dependency package names
  - automatically added to `CMakeLists` and `package.xml`
  - can manually add additional dependencies later

Exercise 1.3.1

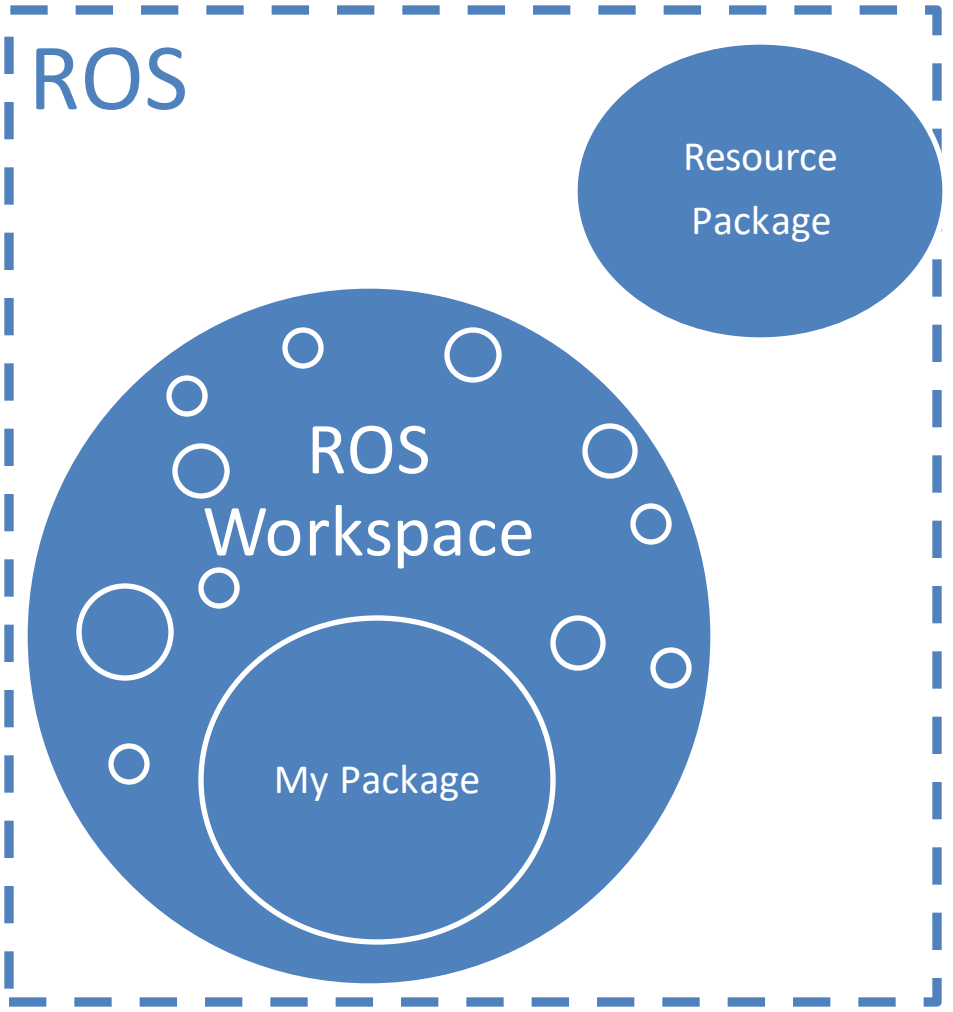
Create Package





Day 1 Progression

- ✓ Install ROS
- ✓ Create Workspace
- ✓ Add “resources”
- ✓ Create Package
- ❑ Create Node
  - ❑ Basic ROS Node
  - ❑ Interact with other nodes
    - ❑ Messages
    - ❑ Services
- ❑ Run Node
  - ❑ ros2 run
  - ❑ ros2 launch



ROS Nodes

A Simple C++ ROS Node

Simple C++ Program

```
#include <iostream>

int main(int argc, char* argv[])
{



    std::cout << "Hello World!";

   return 0;
}
```

Simple C++ ROS2 Node

```
#include <rclcpp/rclcpp.h>

int main(int argc, char* argv[])
{
  rclcpp::init(argc, argv);
  auto node = make_shared<rclcpp::Node>("hello");

  RCLCPP_INFO(node->get_logger(), "Hello World!");

  return 0;
}
```

ROS2 Node Commands

- `ros2 run package_name node_name`

  execute ROS node

- **`ros2 node`**
  - `ros2 node list`

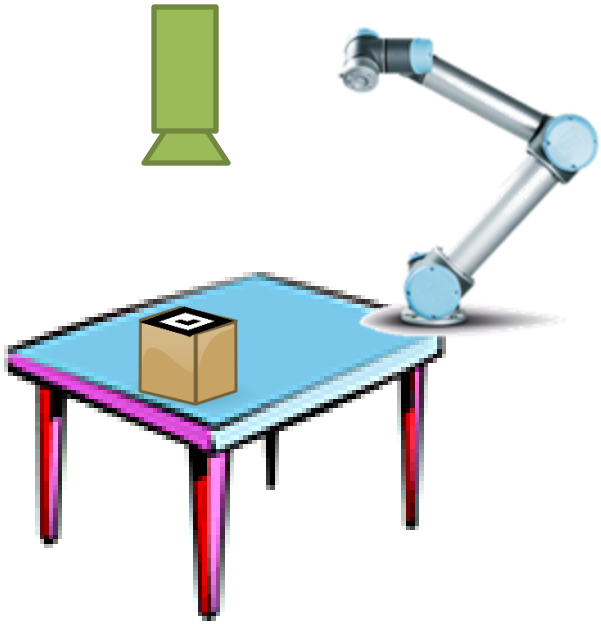
    View running nodes
  - `ros2 node info node_name`

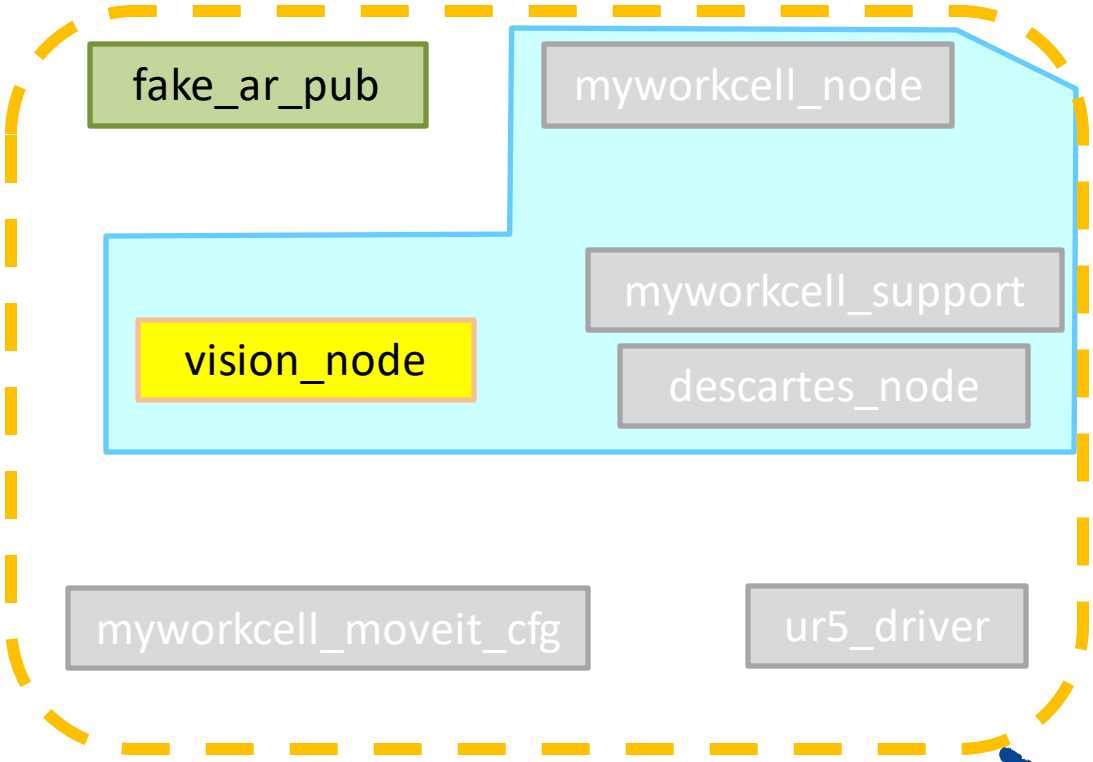
    View node details (publishers, subscribers, services, etc.)

Exercise 1.3.2

Create a Node:

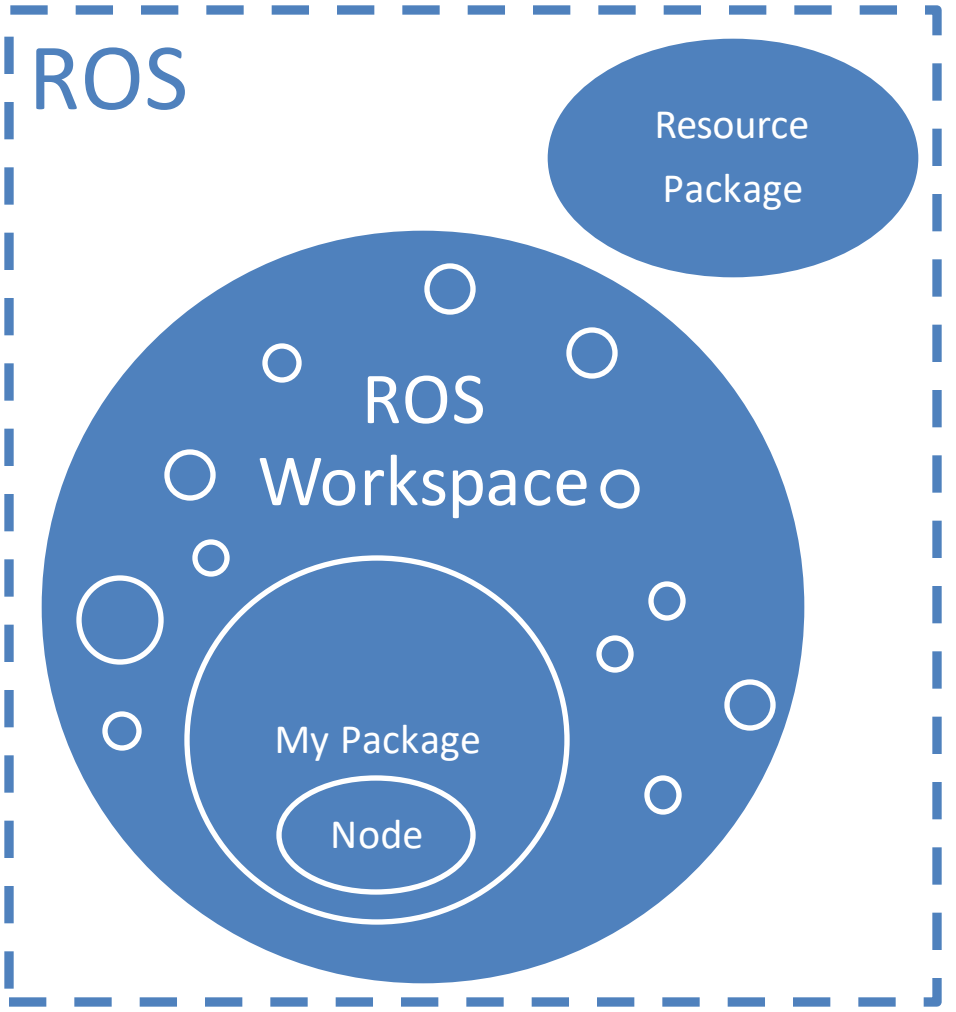
In myworkcell_core package called vision_node





Day 1 Progression

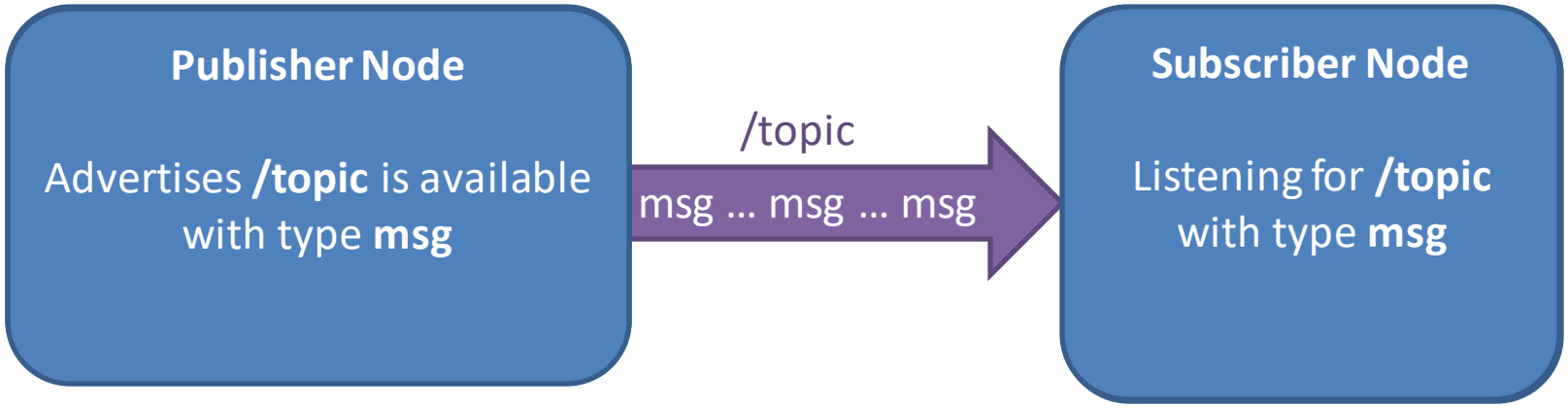
- ✓ Install ROS
- ✓ Create Workspace
- ✓ Add “resources”
- ✓ Create Package
- ✓ Create Node
  - ✓ Basic ROS Node
  - ❑ Interact with other nodes
    - ❑ Messages
    - ❑ Services
- ✓ Run Node
  - ✓ ros2 run
  - ❑ ros2 launch



Topics and Messages

ROS Topics/Messages

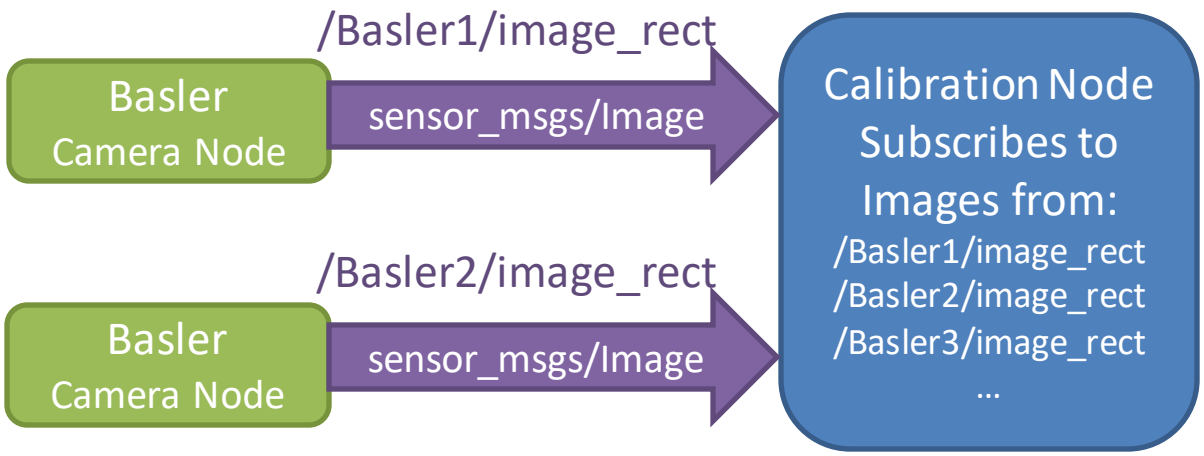
Topics are for **Streaming Data**



Topics vs. Messages

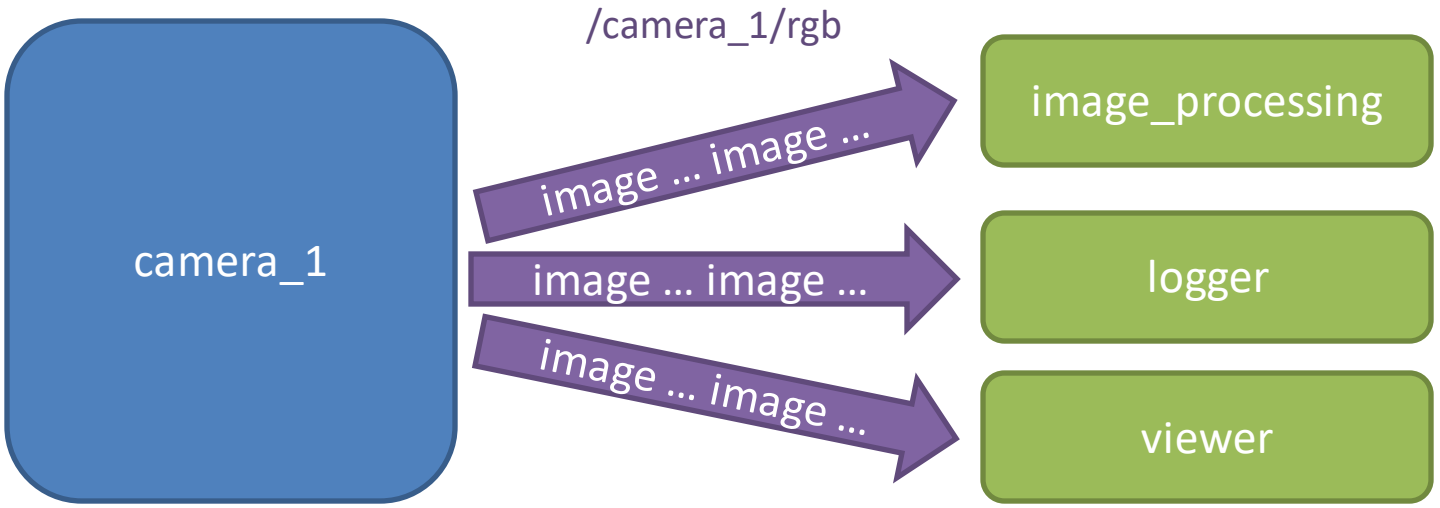
- Topics are **channels**, Messages are **data types**
  - Different topics can use the same Message type

Practical Example



Multiple Pub/Sub

- Many nodes can pub/sub to same topic
  - comms are direct node-to-node



Topics : Details

- Each **Topic** is a stream of **Messages**:
  - sent by **publisher(s)**, received by **subscriber(s)**
- Messages are **asynchronous**
  - publishers don't know if anyone's listening
  - messages may be dropped
  - subscribers are event-triggered (by incoming messages)
- Typical Uses:
  - Sensor Readings: camera images, distance, I/O
  - Feedback: robot status/position
  - Open-Loop Commands: desired position

Quality of Service

- All ROS2 comms define a “Quality of Service” (QoS)
  - History/Depth - buffer N prior messages
  - Reliability - retry or discard dropped messages?
  - Durability - cache messages for late-joining subscribers?
  - Deadline - expected interval between messages
  - etc.
- All participants in a topic must have compatible QoS
  - Publishers - maximum QoS they can provide
  - Subscribers - minimum QoS they require
  - e.g. “reliable” subscriber won’t connect to “best-effort” publisher

QoS Profiles

- ROS provides default QoS profiles for different comms types.
  - Use these defaults, tweak them, or define your own application-specific QoS.

– Default Profile (messages)	queue=10, reliable, volatile
– Services Profile	queue=10, reliable, volatile
– Sensor Profile	queue=5, best-effort, volatile
– Parameters Profile	queue=1000, reliable, volatile

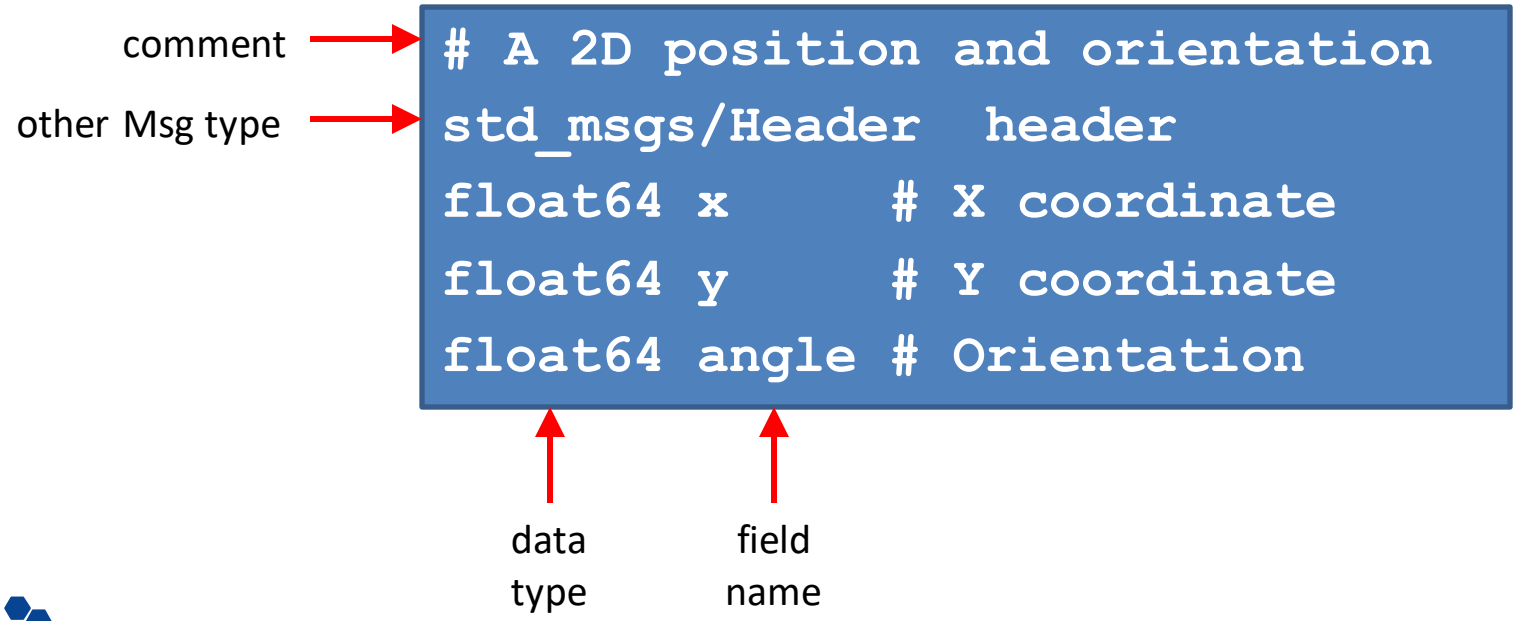
ROS Messages Types

- Similar to C structures
- Standard data primitives
  - Boolean: `bool`
  - Integer: `int8,int16,int32,int64`
  - Unsigned Integer: `uint8,uint16,uint32,uint64`
  - Floating Point: `float32, float64`
  - String: `string`
- Fixed length arrays: `bool[16]`
- Variable length arrays: `int32[]`
- Other: Nest message types for more complex data structure

Message Description File

- All Messages are defined by a **.msg** file

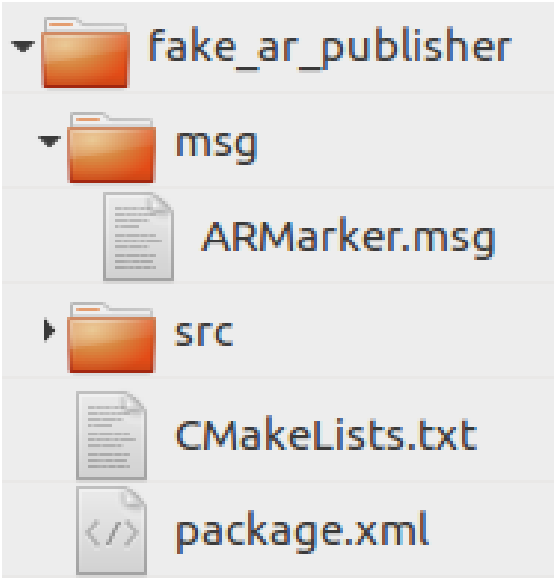
PathPosition.msg



Custom ROS Messages

- Custom message types are defined in `msg` subfolder of packages

- Modify `CMakeLists.txt` to enable message generation.



CMakeLists.txt

- Lines needed to generate custom msg types

```
find_package(rosidl_default_generators
REQUIRED)

rosidl_generate_interfaces(
  msg/CustomMsg.msg
  DEPENDENCIES ...)
```

package.xml

<build_depend> **rosidl_default_generators** </build_depend>

<exec_depend>**rosidl_default_runtime**</exec_depend>

<member_of_group>**rosidl_interface_packages**</member_of_group>

ROS Interface Commands

These commands show info about known ROS message types (+ services/actions, discussed later)

- `ros2 interface list`
  - Show all ROS message types currently available
- `ros2 interface package <package>`
  - Show all ROS message types in package `<package>`
- `ros2 interface show <package>/<message_type>`
  - Show the structure of the given message type

ROS Topic Commands

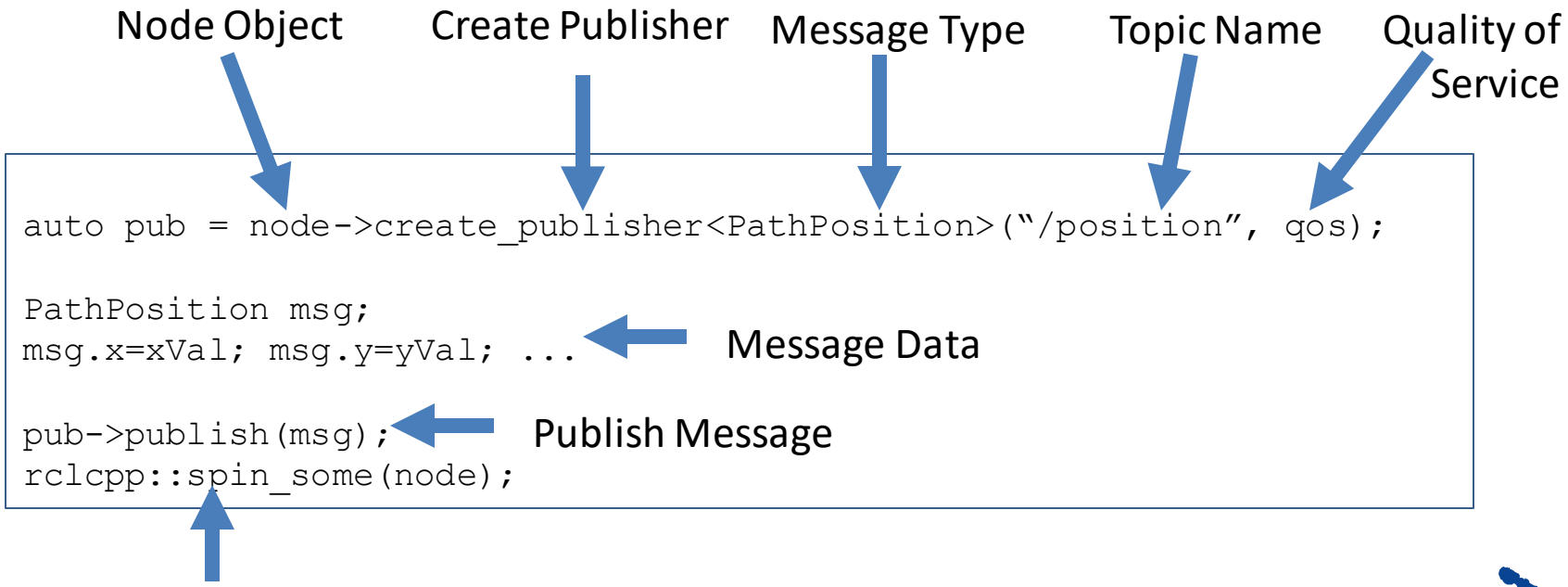
- `ros2 topic list`
  - List all topics currently subscribed to and/or publishing
- `ros2 topic type <topic>`
  - Show the message type of the topic
- `ros2 topic info <topic>`
  - Show topic message type, subscribers, publishers, etc.
- `ros2 topic echo <topic>`
  - Echo messages published to the topic to the terminal
- `ros2 topic find <message_type>`
  - Find topics of the given message type

“Real World” – Messages

- Use *rqt_msg* to view:
  - `sensor_msgs/JointState`
  - `trajectory_msgs/JointTrajectory`
  - `sensor_msgs/Image`
  - `rcl_interfaces/Log`

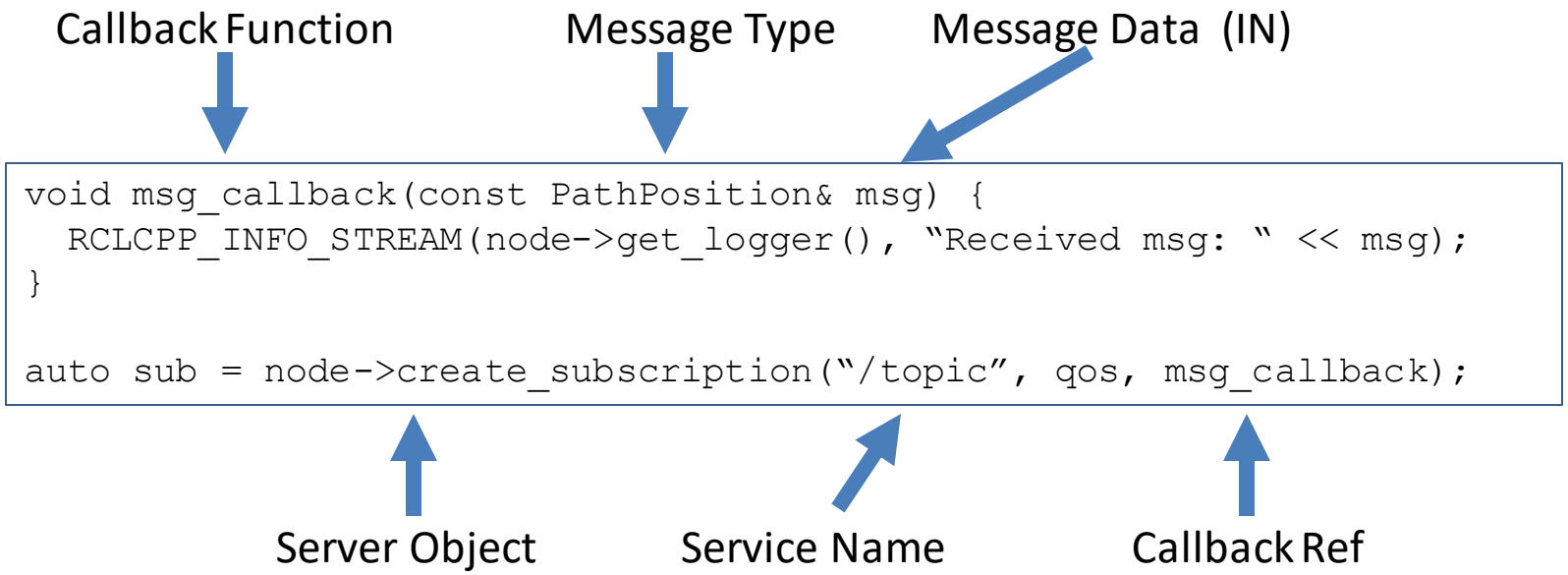
Topics: Syntax

- Topic **Publisher**
  - Advertises available topic *(Name, Data Type, QoS)*
  - Populates message data
  - Periodically publishes new data



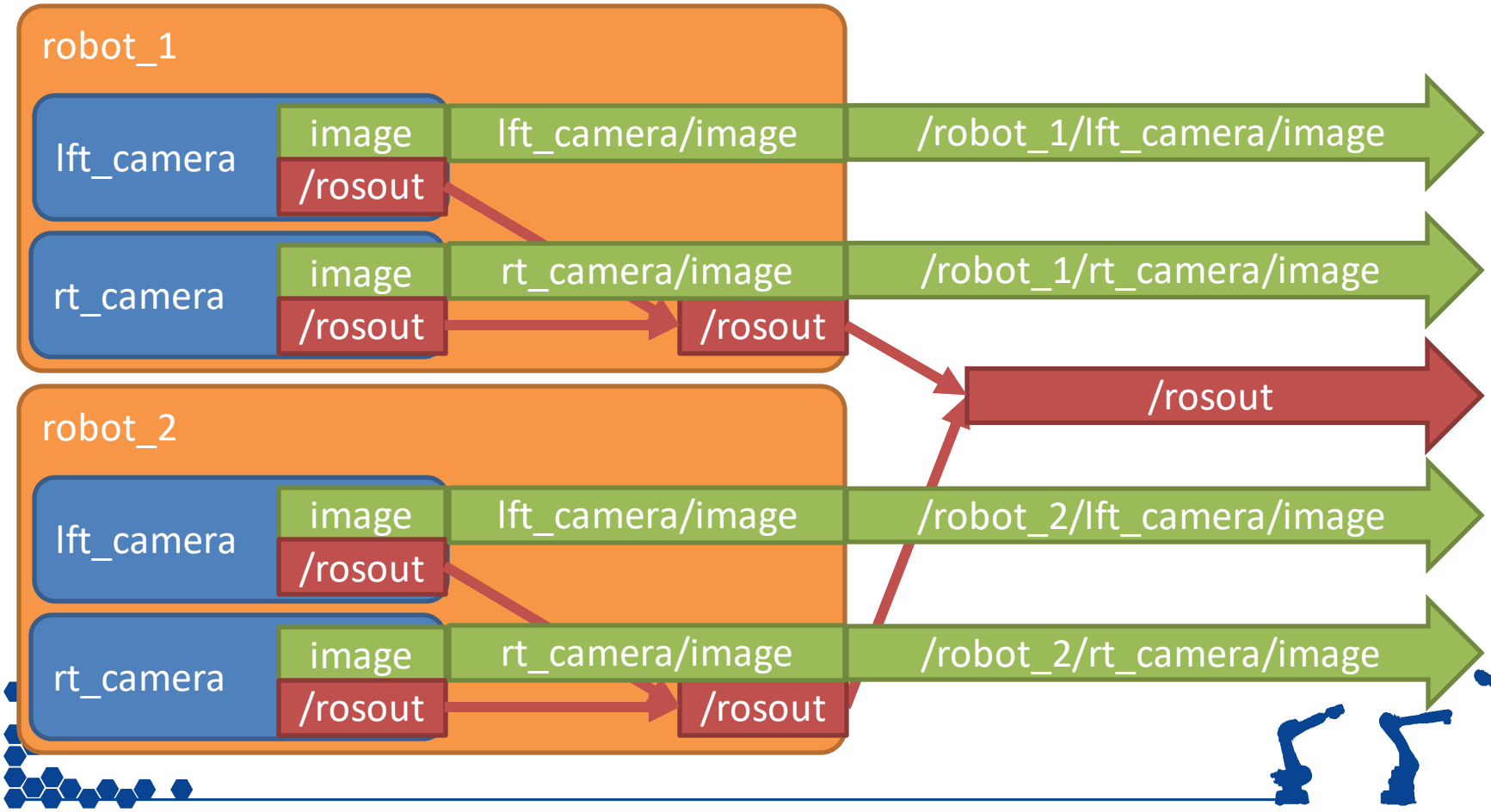
Topics: Syntax

- Topic **Subscriber**
  - Defines callback function
  - Listens for available topic *(Name, Data Type, QoS)*



Namespaces

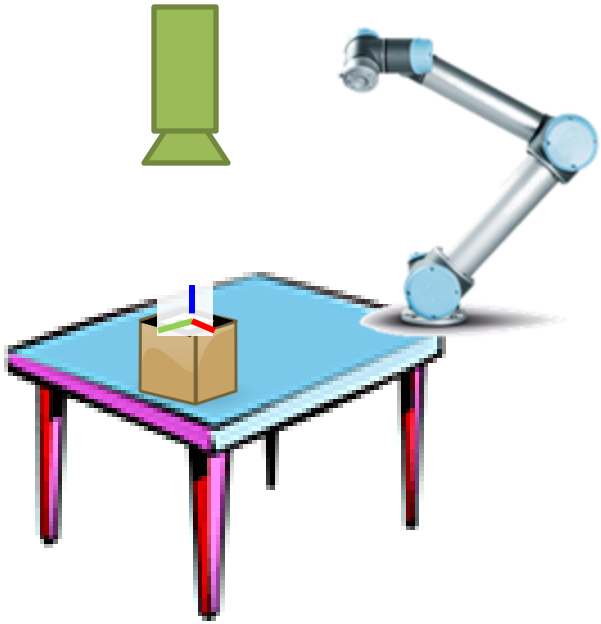
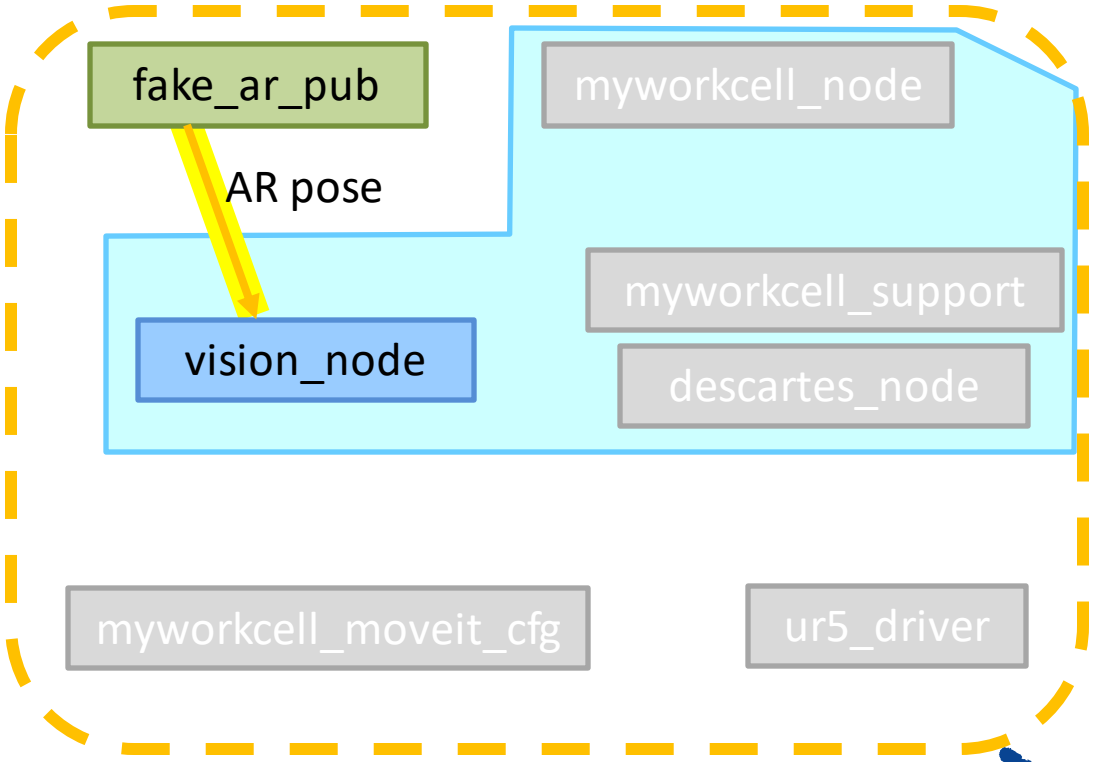
- ROS requires unique names for nodes/topics/etc.
- Namespaces allow separation:
  - *Similar nodes can co-exist, in different "namespaces"*
  - *relative vs. absolute name references*



Instead of text editor and building from terminal…

Use an IDE! (detailed instructions here)

1. Launch QtCreator IDE from desktop shortcut
2. File -> New Project
3. Other Project -> ROS Workspace
4. Enter Project Properties:
    1. Name = “ROS2_Training” (or whatever)
    2. Distribution (should be auto-detected)
    3. Build System = Colcon
    4. Path = ~/ros2_ws
5. Build -> Build All
    1. you should see success in the “Compile” tab

Exercise 1.4

Subscribe to fake_ar_publisher