INFO 802

Master Advanced Mechatronics

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ROS

Introduction
Course 1

Prerequisites

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

- ROS Kinetic Kame installation

- Catkin installation

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

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

http://ead-polytech.univ-savoie.fr/pluginfile.php/44312/mod_resource/content/1/How%20to%20Install%20Ubuntu%20on%20VirtualBox.pdf

http://wiki.ros.org/kinetic/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 !

*software that acts as a bridge between an operating system or database and applications, especially on a network

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

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

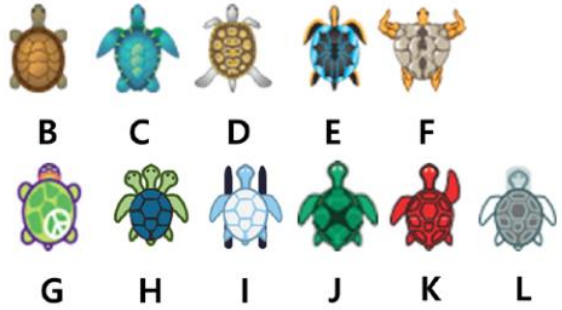
More info
http://wiki.ros.org/Robots

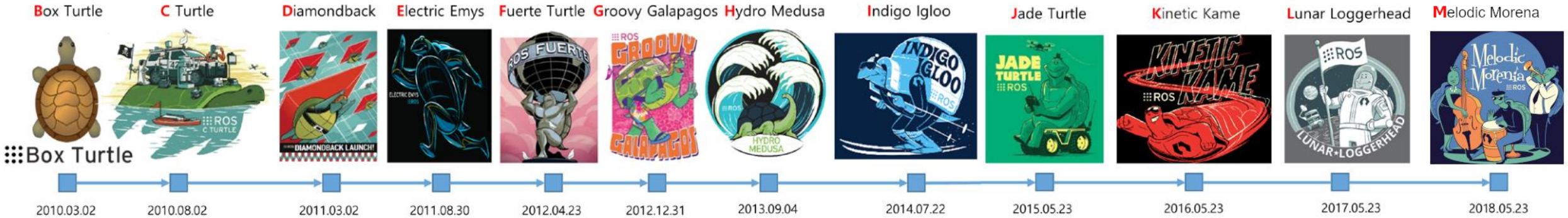
Sensors interfaced with ROS

- 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 will be a LTS release, supported for five years.
  - Releases on odd numbered years are normal ROS releases, supported for two 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

Kinetic Kame

Select Your Platform

Supported:

Ubuntu	Wily	amd64	i386		
	Xenial	amd64	i386	armhf	arm64
Debian	Jessie	amd64	arm64		

Source installation

Experimental:

OS X (Homebrew)

Gentoo

OpenEmbedded/Yocto

Unofficial Installation Alternatives:

Single line install	A single line coommand to install ROS Kinetic on Ubuntu

Melodic Morenia

Select Your Platform

Supported:

Ubuntu	Artful	amd64			
	Bionic	amd64	armhf	arm64	
Debian	Stretch	amd64	arm64		

Source installation

Experimental:

Arch Linux Any amd64 armhf aarch64

Gentoo

Construction zone

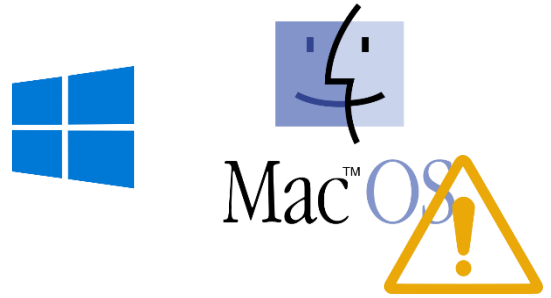
The following links are referring to previous ROS distributions been updated since.

OS X (Homebrew)

OpenEmbedded/Yocto

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)

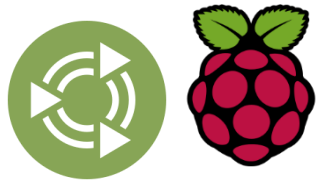


ROS Supported Platforms

- ROS distribution supported is limited to $\leqslant$ 3 latest Ubuntu versions
- ROS Kinetic Kame supports the following Ubuntu versions
  - Wily (15.10)
  - Xenial (16.04 LTS)

- ROS Jade supports the following Ubuntu versions
  - Vivid (15.04)
  - Utopic (14.04)
  - Trusty (14.04 LTS)

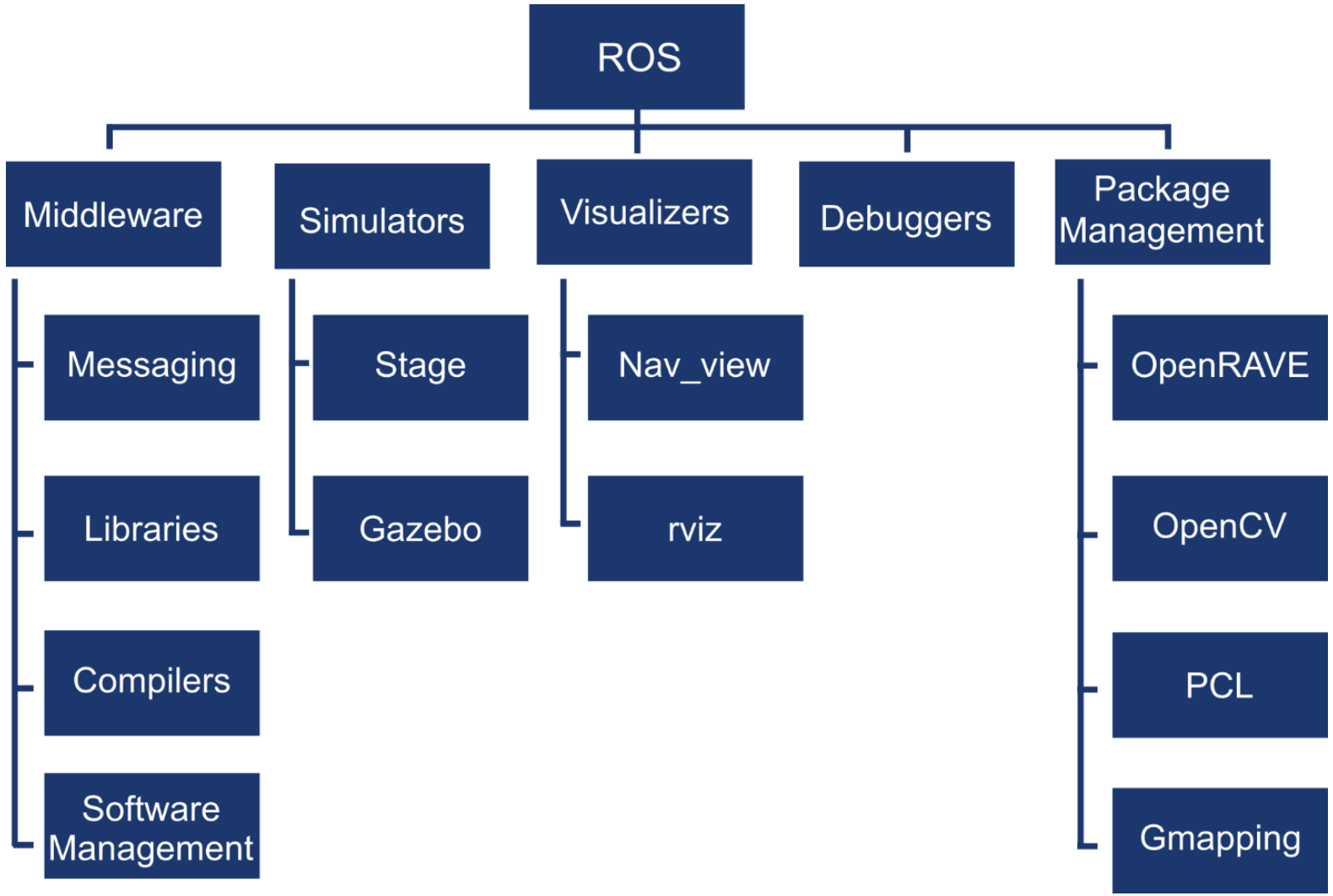
- Recommended Ubuntu version on Raspberry Pi 3 for ROS
  - Ubuntu Mate



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



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!

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.).

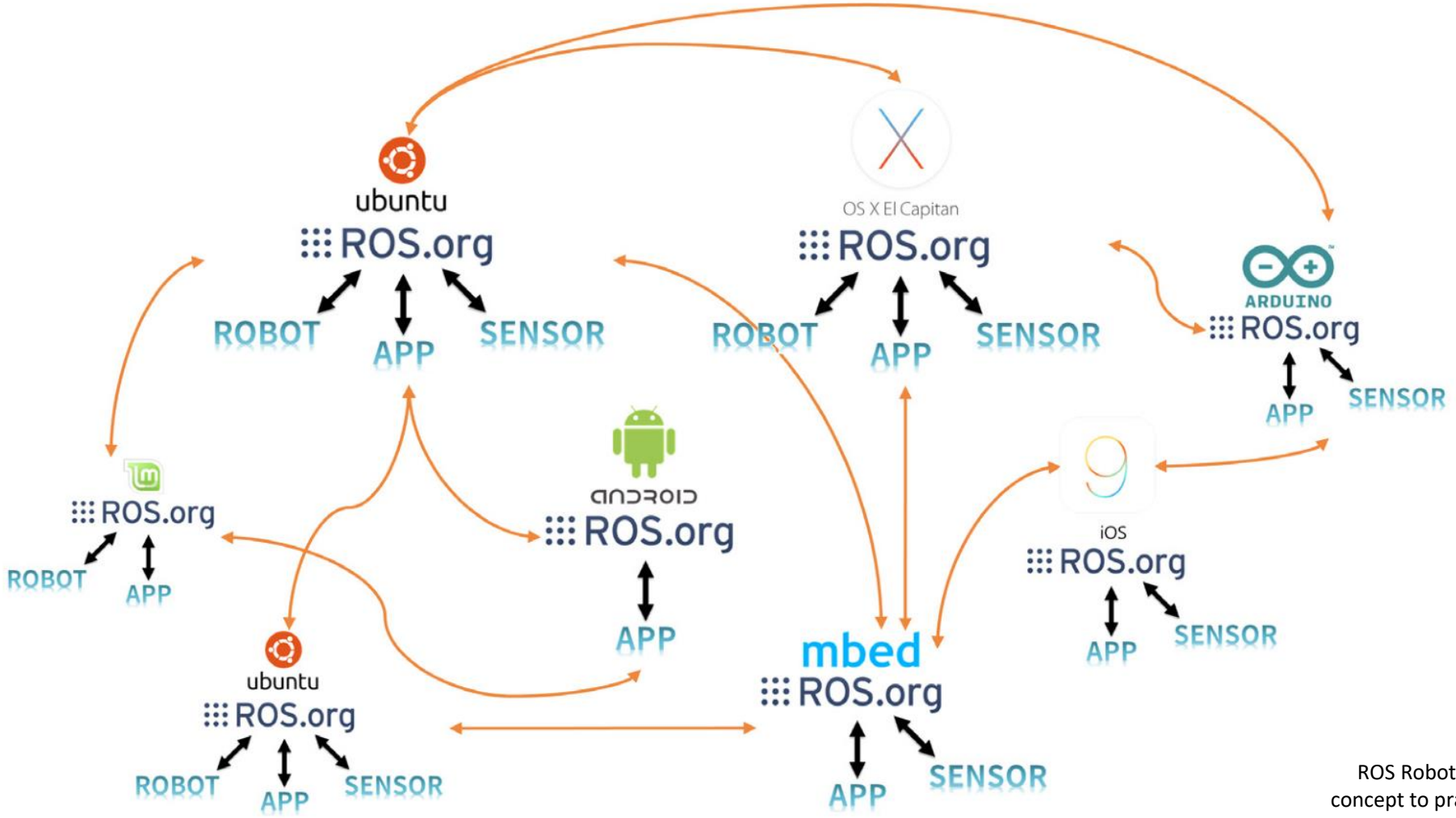
- **Thin**

  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



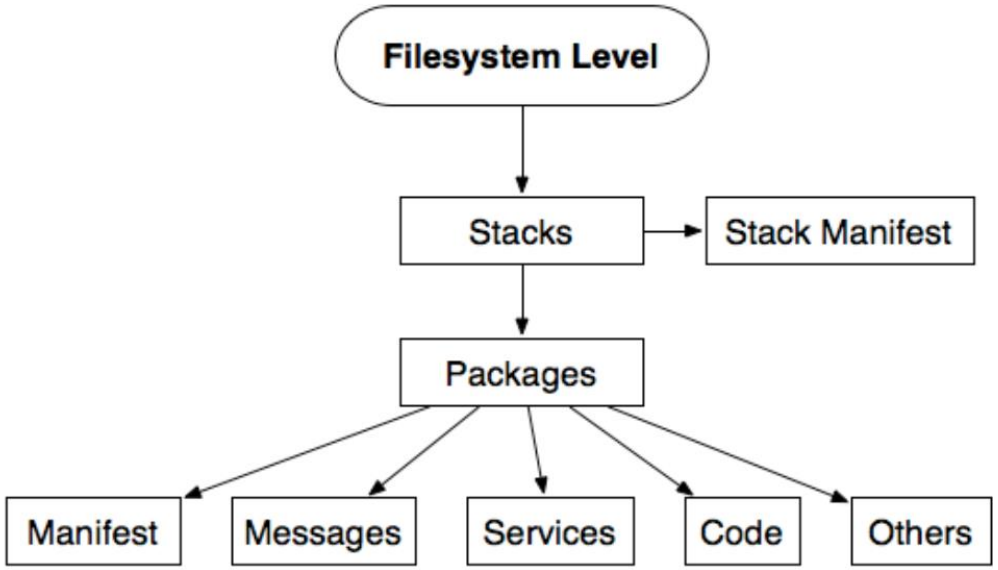
More info - source

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

ROS Master

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

Start a master with

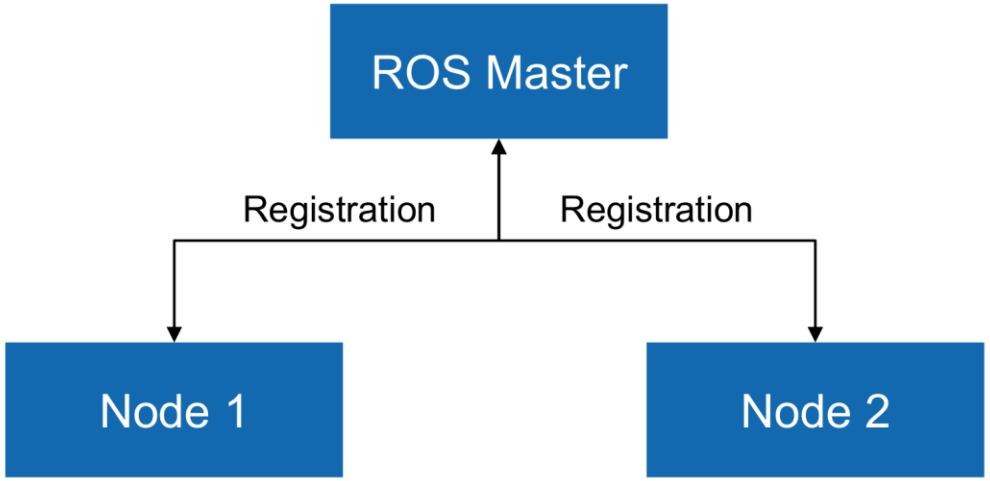
```
> roscore
```

- 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

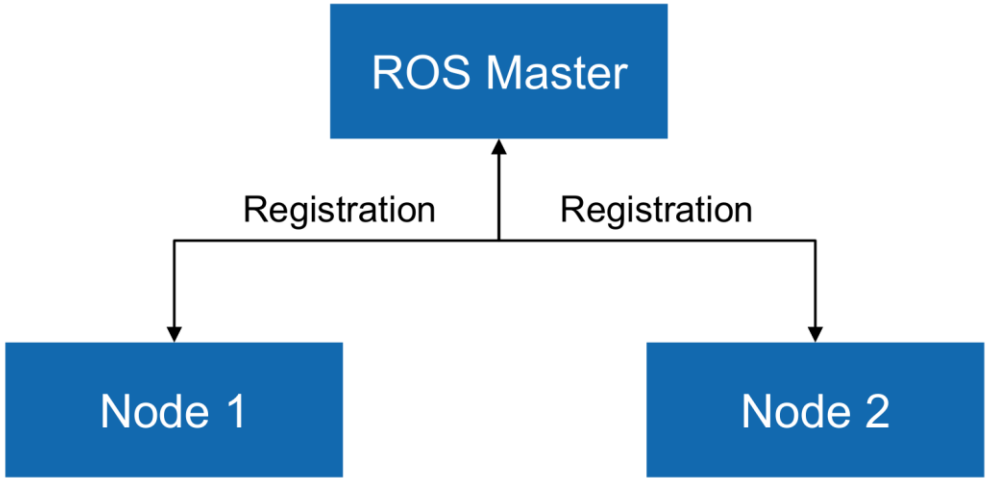
```
> rosrun [package_name] [node_name]
```

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

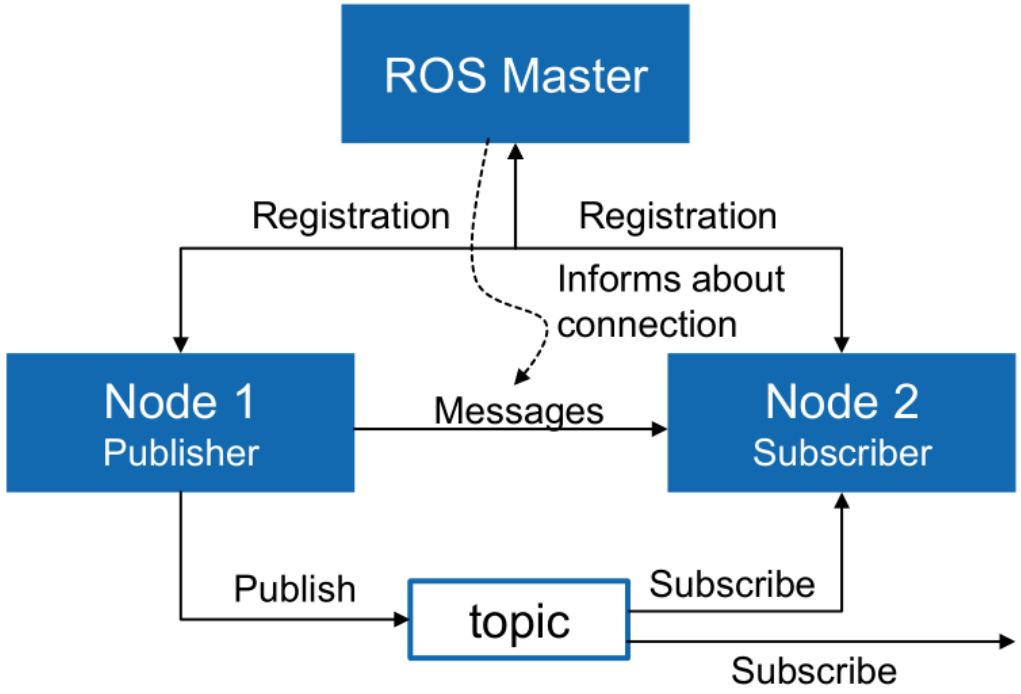
```
> rostopic list
```

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

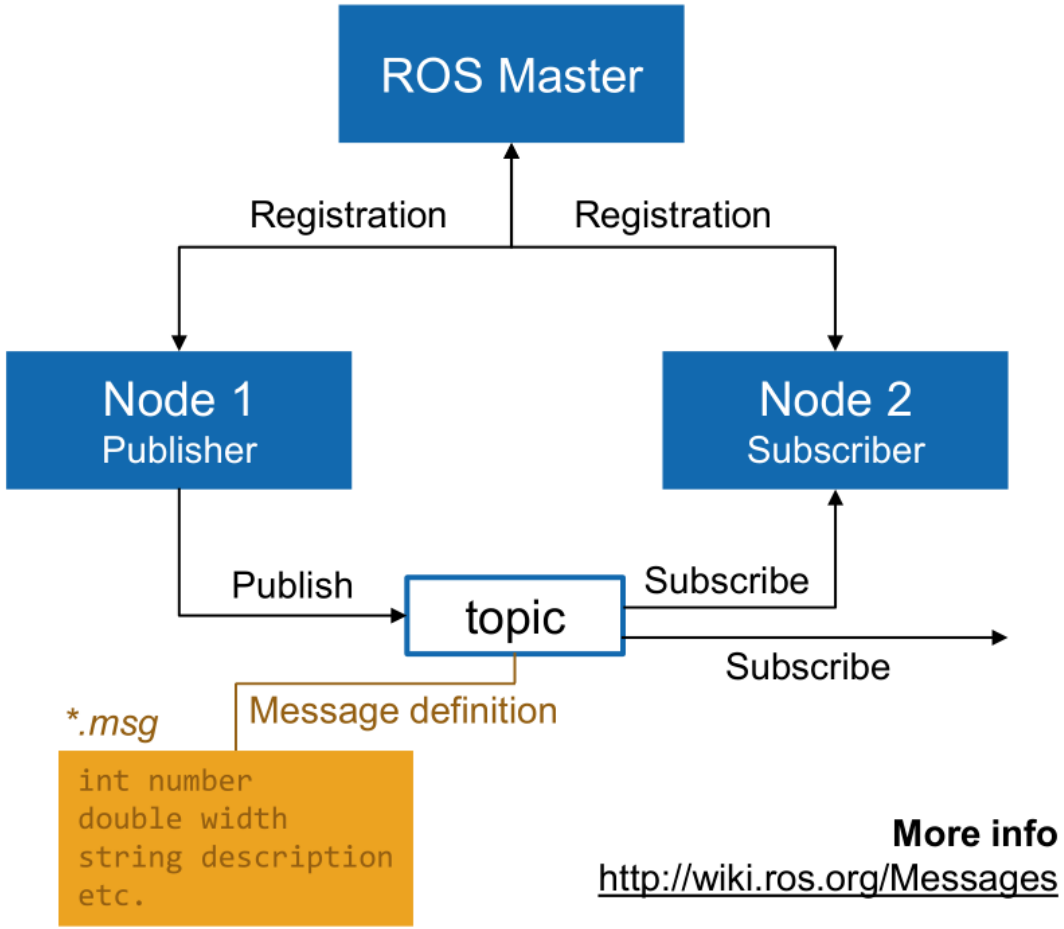
- Data structure defining the *type* of a topic
- Comprised of a nested structure of integers, floats, booleans, strings etc. and arrays of objects
- Defined in **.msg* files

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

Messages Communication Flow

Running the Master

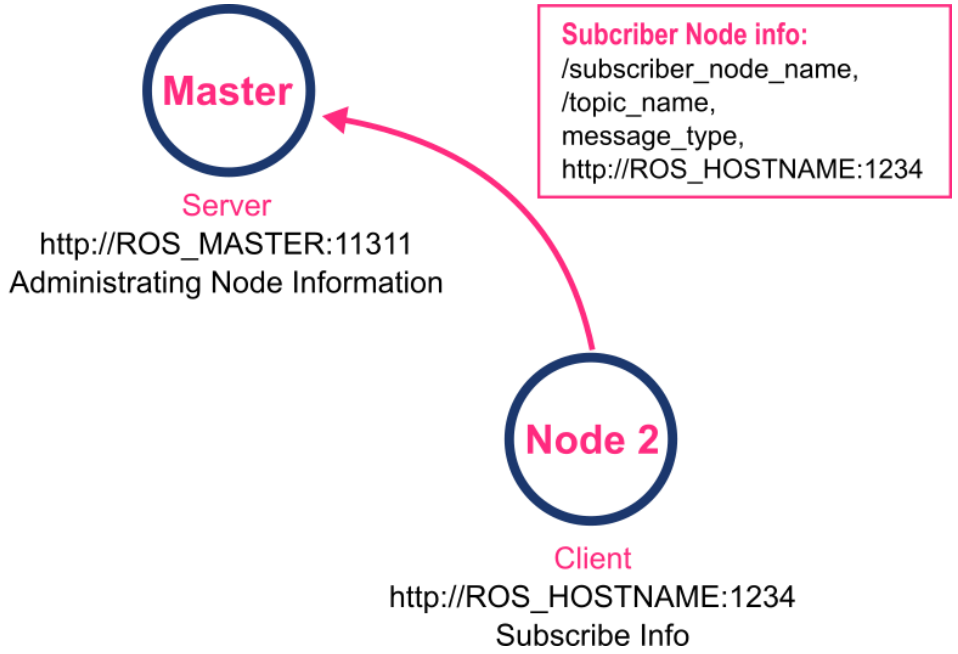
- The master registers the name of nodes, topics, services, action, message types, URI addresses

Server
http://ROS_MASTER:11311
Administrating Node Information

Messages Communication Flow

Running the Subscriber Node

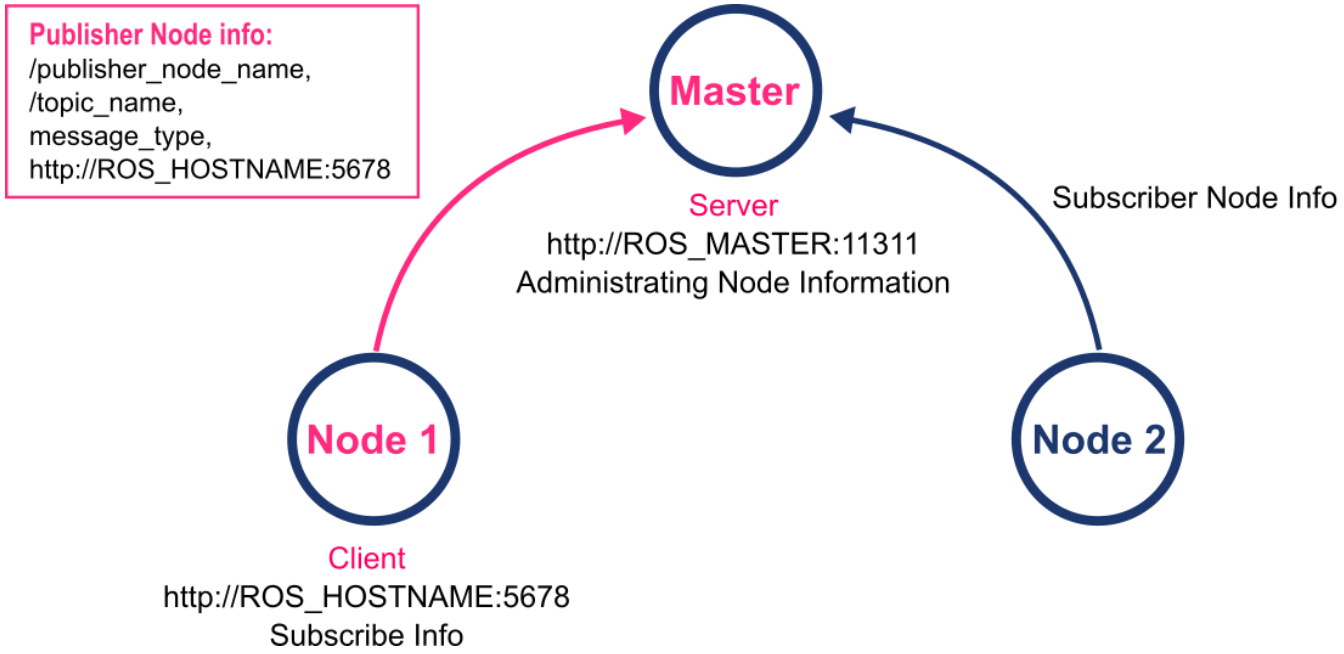
- The subscriber node registers its node name, topic name, message type, URI address, and port with the master



Messages Communication Flow

Running the Publisher Node

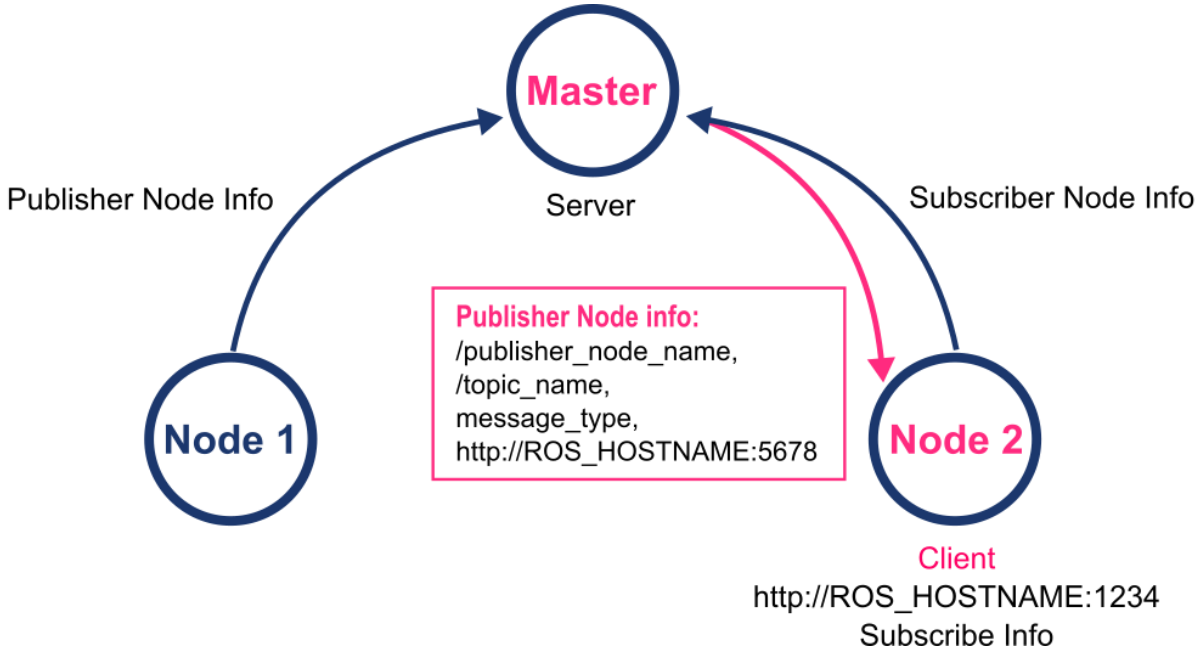
- The publisher node registers its node name, topic name, message type, URI address and port with the master.



Messages Communication Flow

Providing Publisher Information

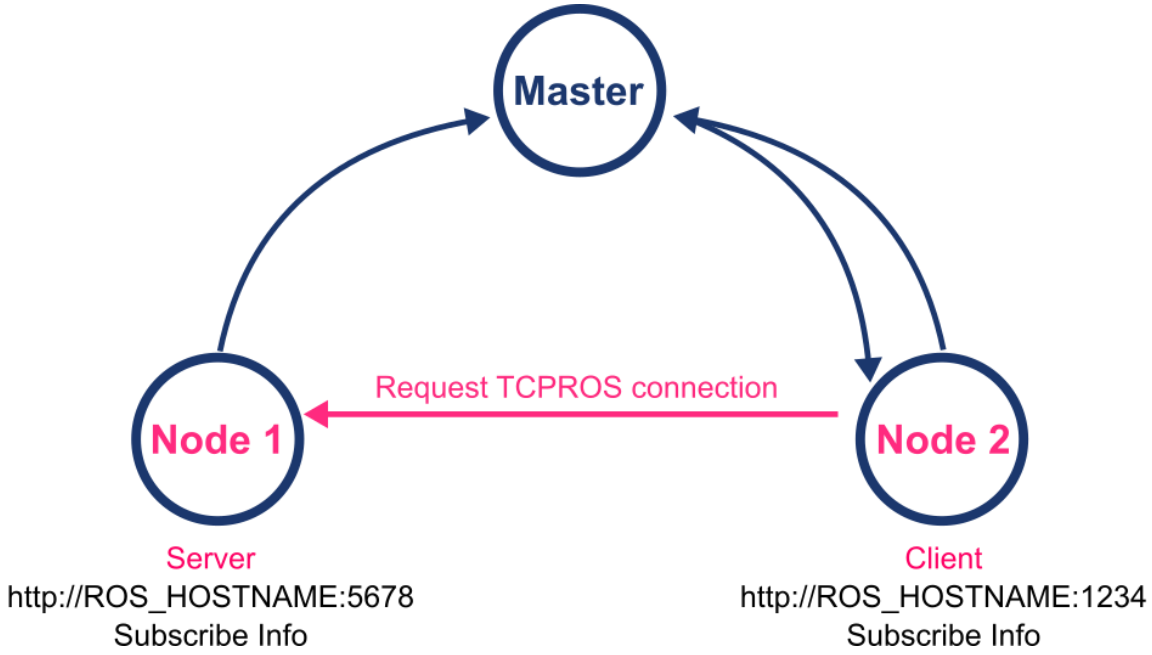
- The master distributes information such as the publisher's name, topic name, message type, URI address and port number of the publisher to subscribers that want to connect to the publisher node



Messages Communication Flow

Connection Request from the Subscriber Node

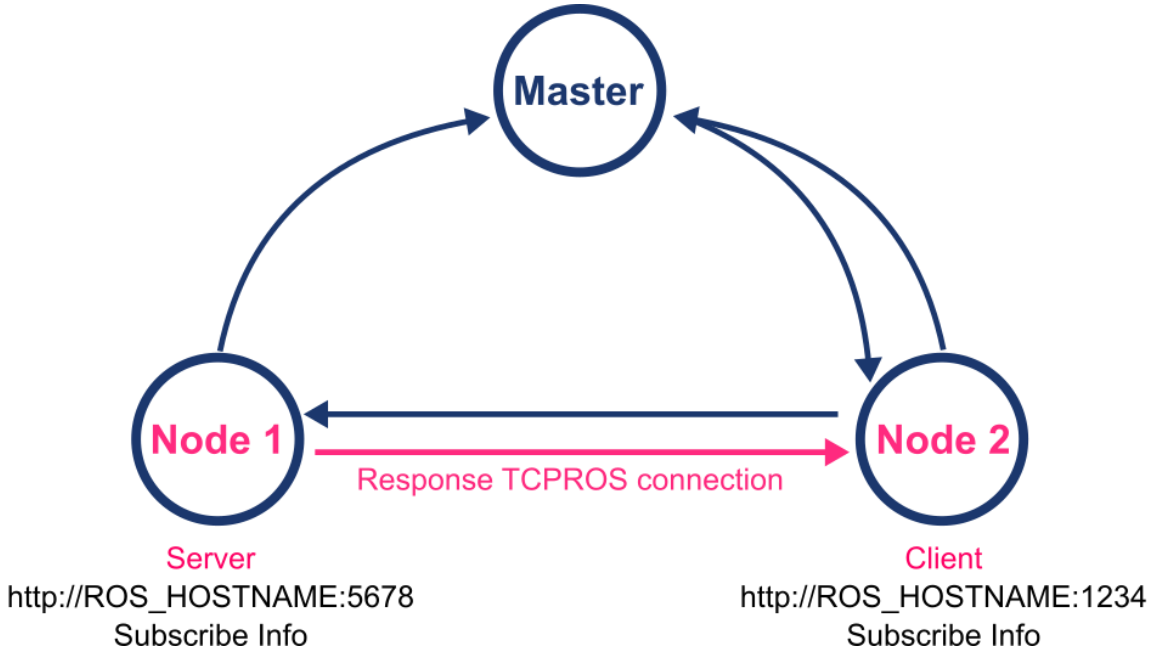
- The subscriber node requests a direct connection to the publisher node based on the publisher information received from the master.



Messages Communication Flow

Connection Response from the Publisher Node

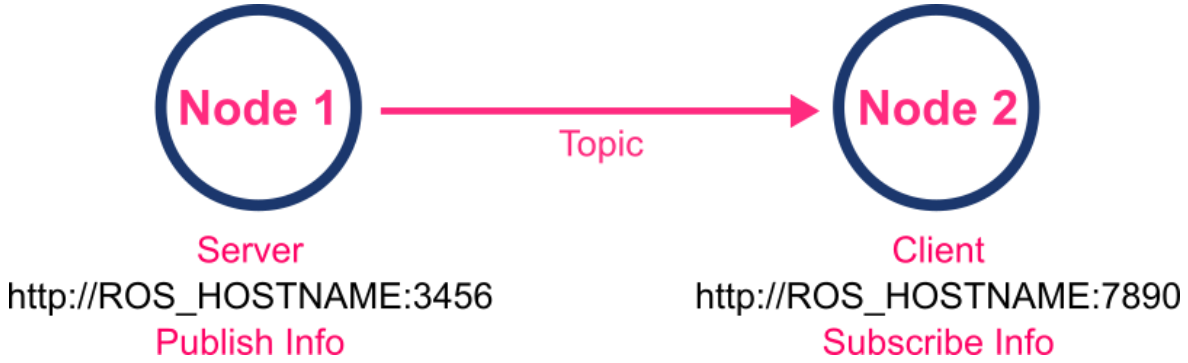
- The publisher node sends the URI address and port number of its TCP server in response to the connection request from the subscriber node.



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

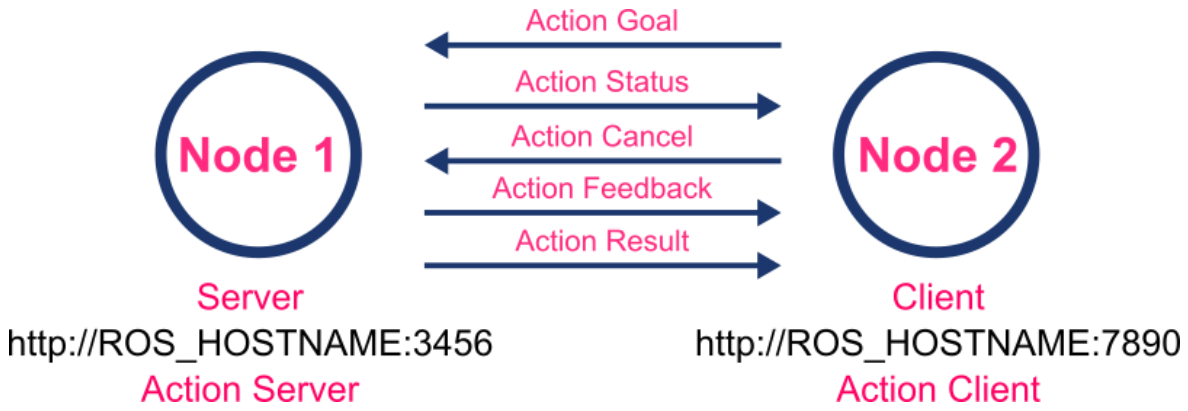
- Synchronous
- Bi-didirectional
- Used when request processing requests and responds current states

- 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.



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
```

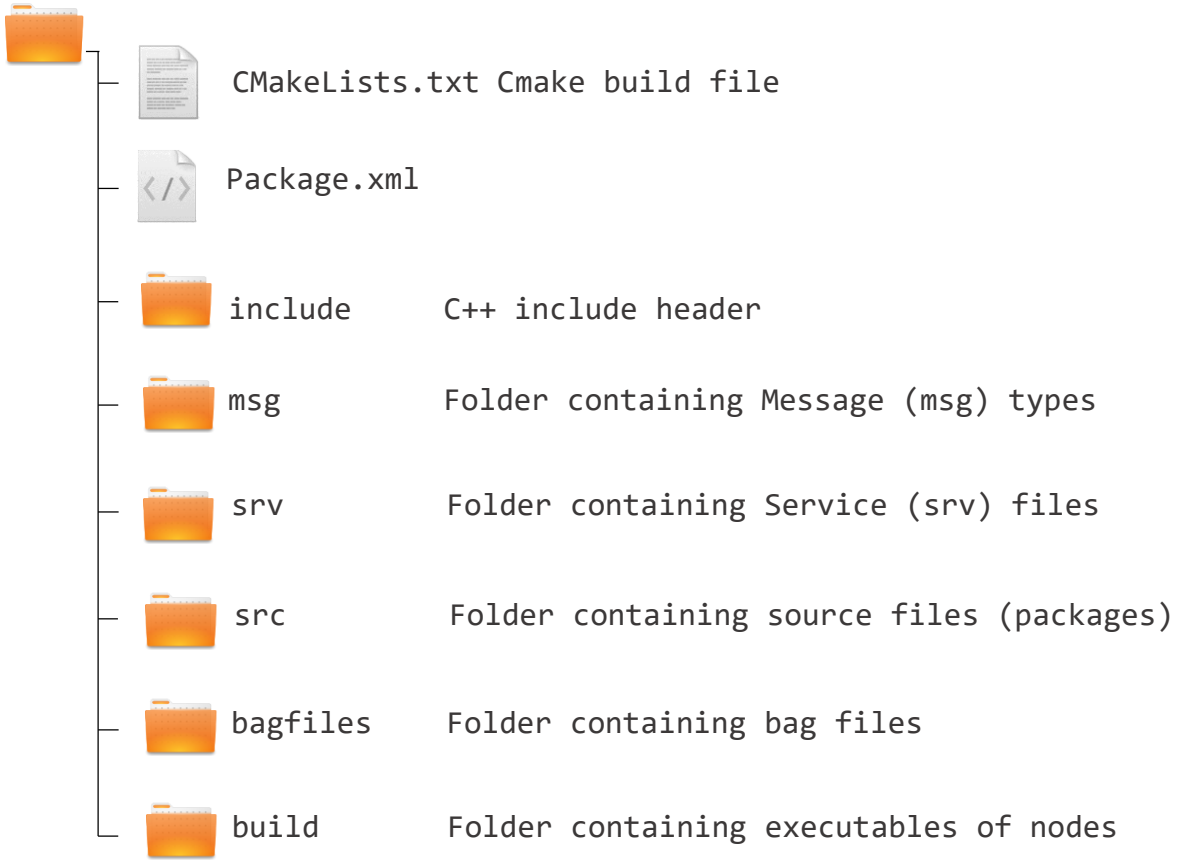
Overlay your catkin workspace with

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

Check your workspace with

```
> echo $ROS_PACKAGE_PATH
```

Workspace_folder



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

src

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

build

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

devel

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

(Recall: Linux Command *Source* Files)

- When a file is sourced, the lines of code in the file are executed as if they were printed at the command line.
- It updates functions and variables in the file for the curent shell
- Any changes in /home/user/.bashrc file will only be taken into acount after sourcing

Sourcing a file

```
> source file_name.sh
```

Or

```
> . file_name.sh
```

ROS Installation

Source workspace setup.bash

ROS Environment

Source workspace setup.bash

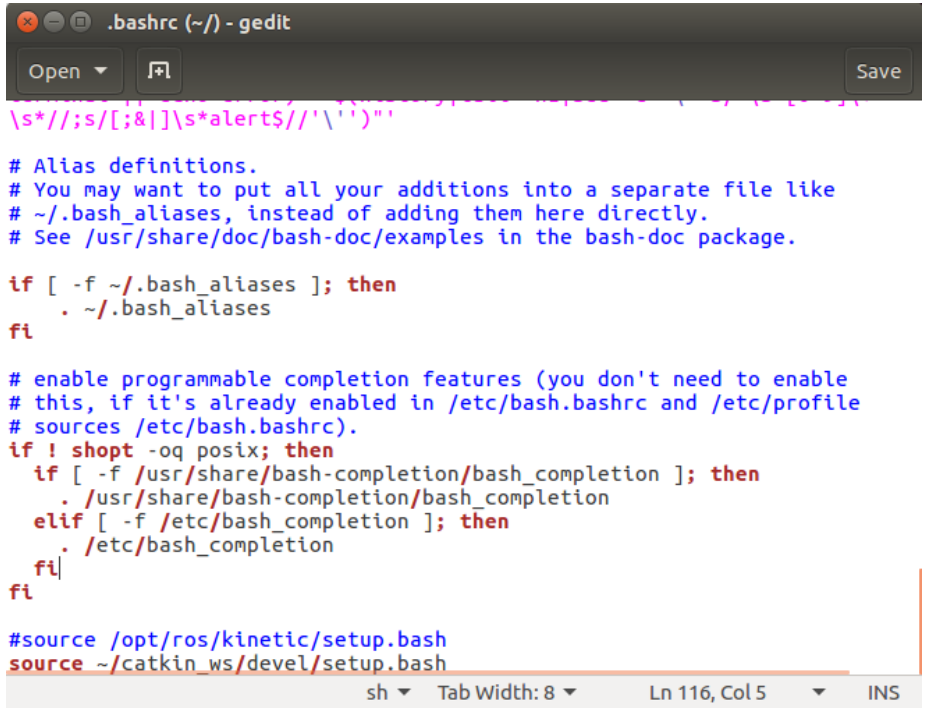
- You will need to run source /opt/ros/kinetic/setup.bash on every new shell you open to have access to the ROS commands, unless you add this line to your bash startup file (~/.bashrc)
- This will allow you to run roscore from any directory in your terminal window. To do so, we will modify the .bashrc.

Edit *.bashrc* file

```
> gedit ~/.bashrc
```

add the the line at the bottom

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

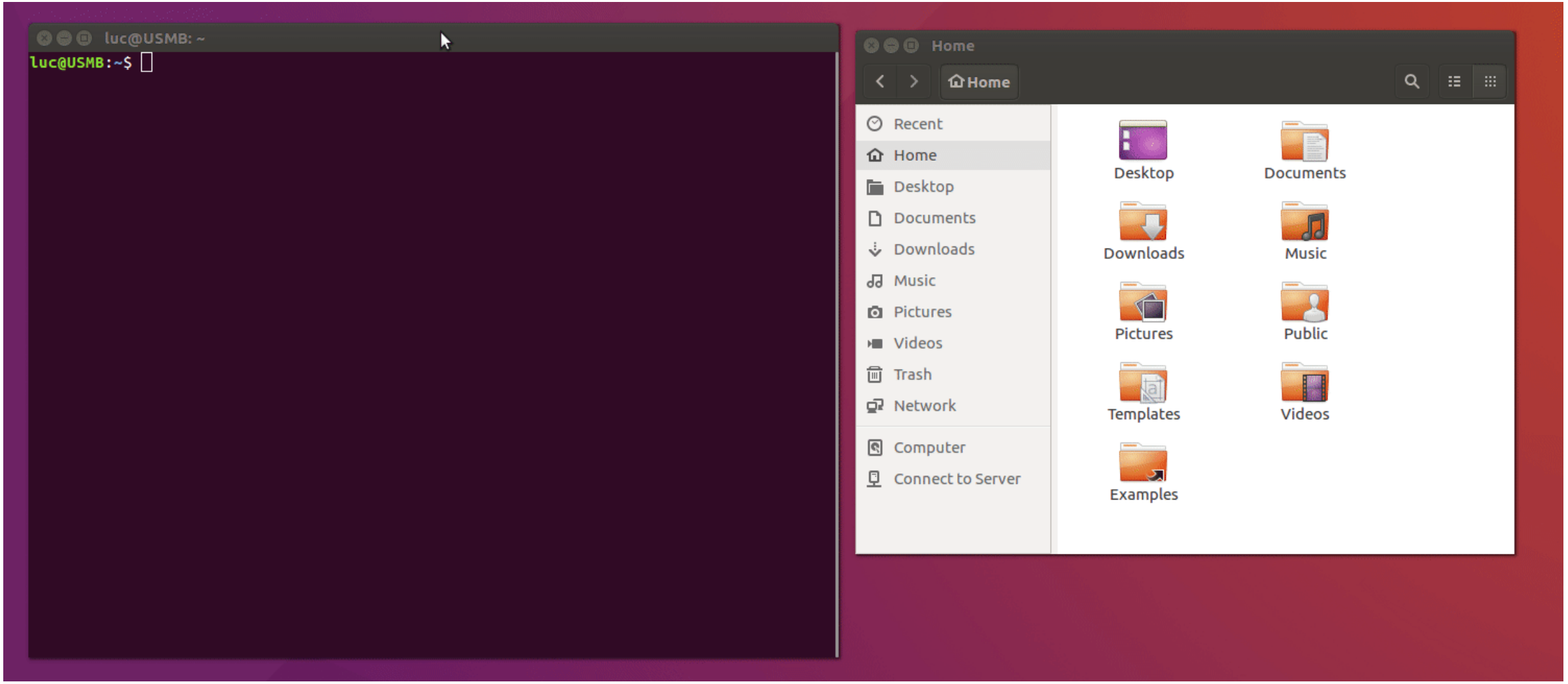


Creating a Catkin Workspace

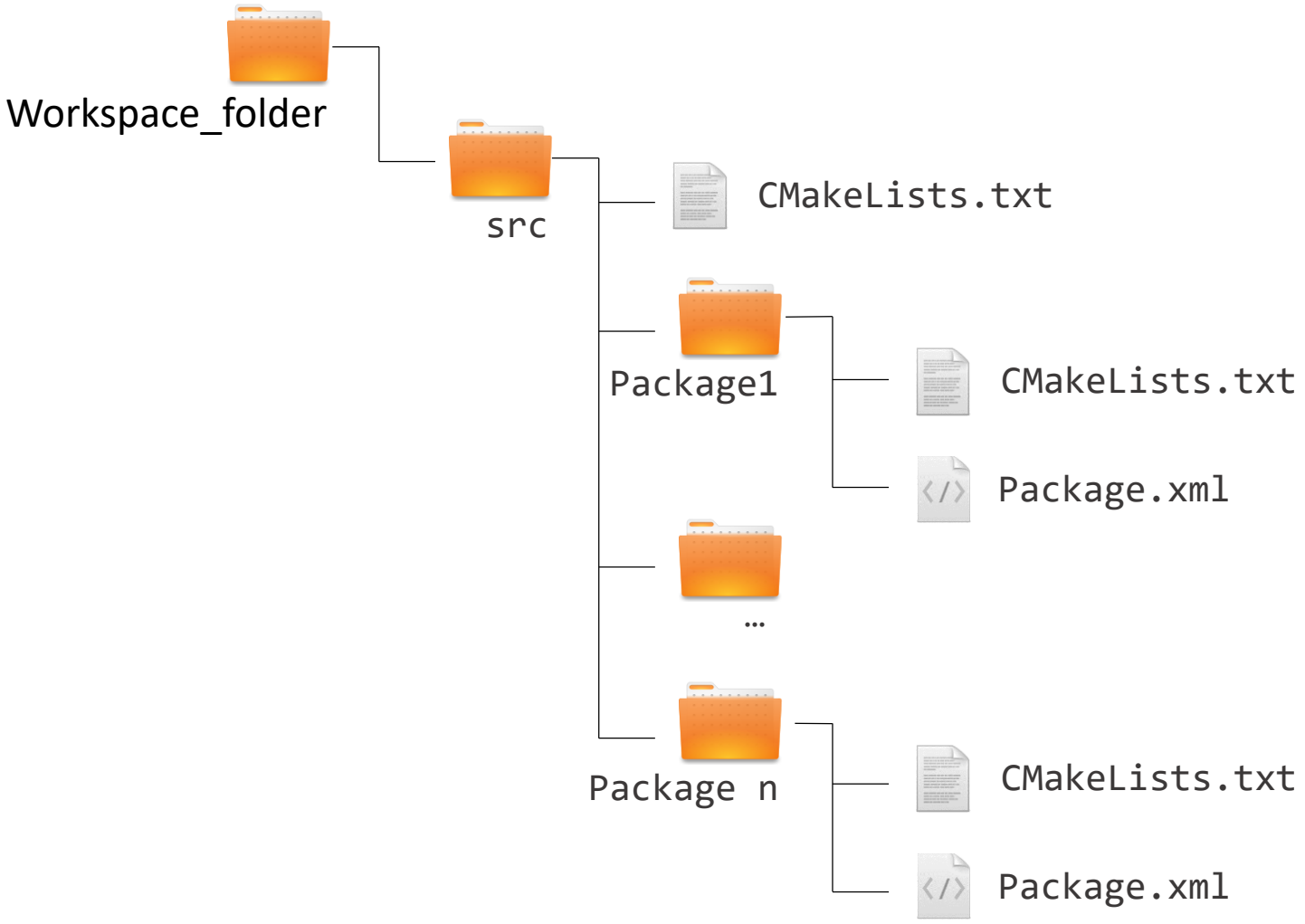
- Catkin_make

```
 mkdir -p ~/catkin_ws/src
> cd ~/catkin_ws/src
> catkin_init_workspace
> cd ~/catkin_ws
> catkin_make
> source devel/setup.bash
```

Creating a Catkin Workspace: *Catkin_ws*



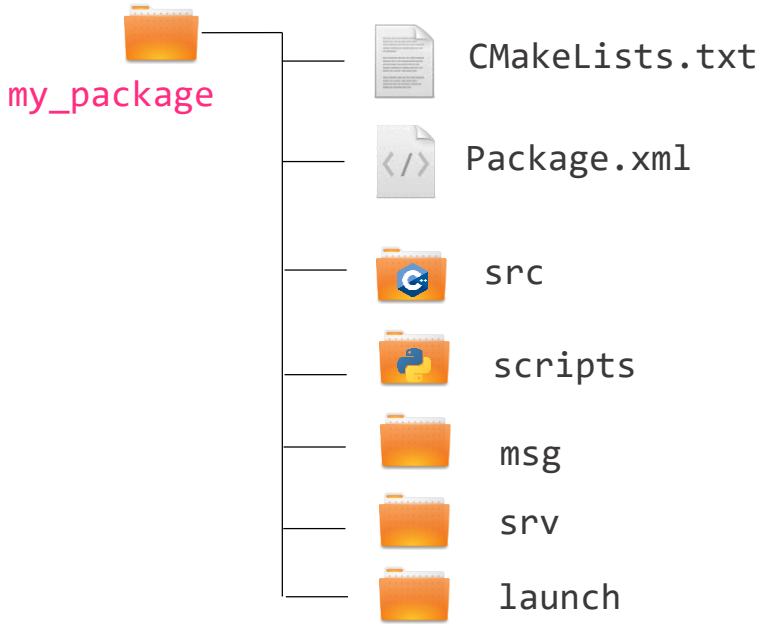
ROS Workspace Environment



ROS Package

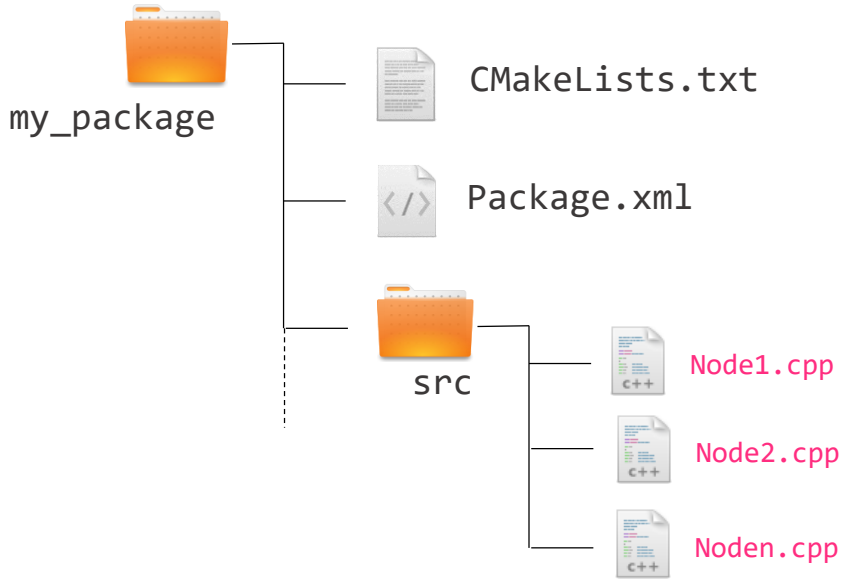
- Software in ROS is organized in *packages*.
- A package contains one or more nodes and provides a ROS interface
- A ROS package is simply a directory inside a catkin workspace that has a package.xml file in it

- 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



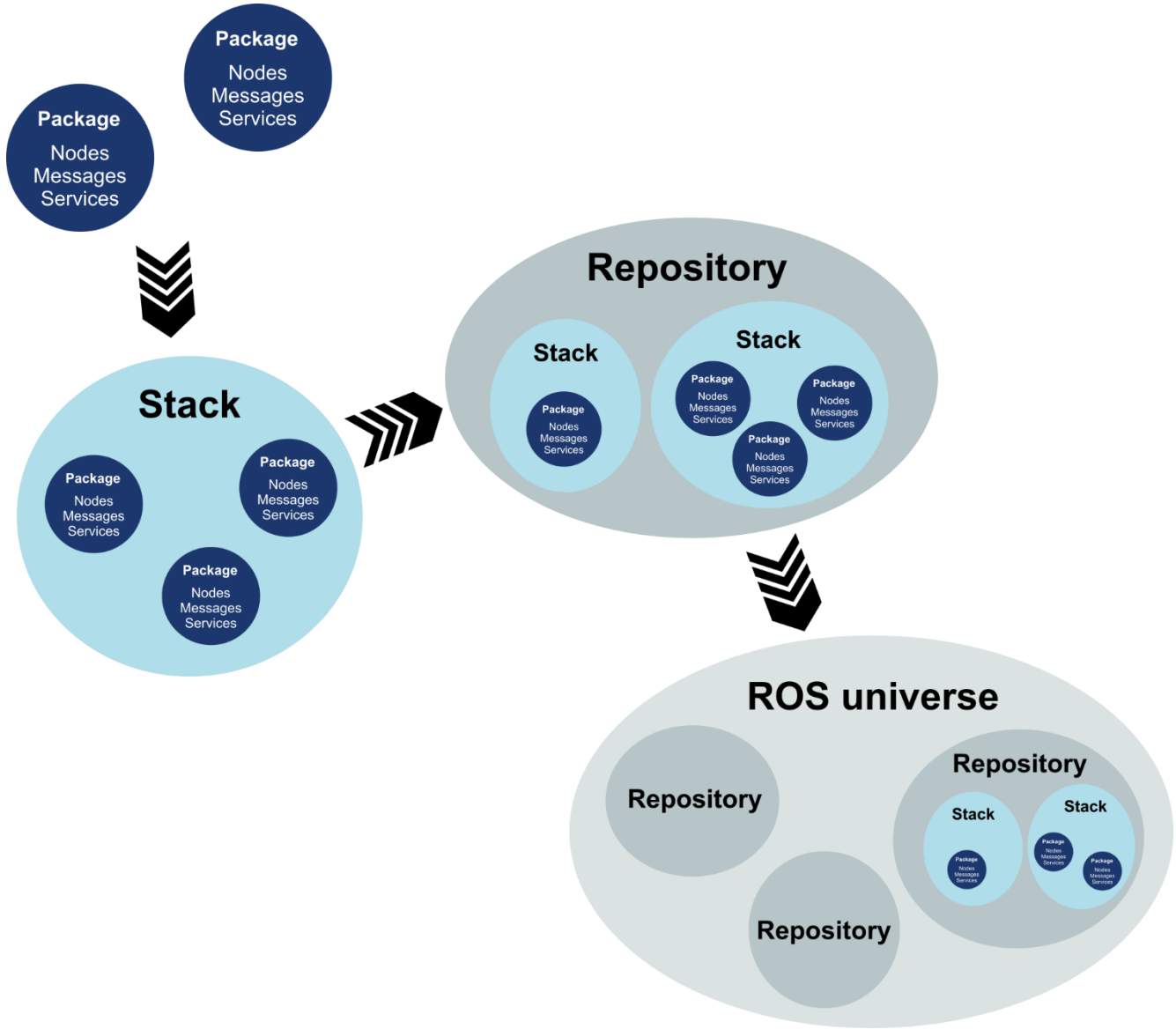
ROS Node

- File located in the source folder *src* of the package
- The file contains the code of the executable



ROS universe

- Most of ROS packages are hosted in GitHub



ROS System File

Commands

Get information on packages

```
> rospack find [package_name]
```

Change directory (cd) directly to a package or a stack

```
> roscd [location_name[/subdir]]
```

ls directly in a package by name rather than by absolute path

```
> rosls [location_name[/subdir]]
```

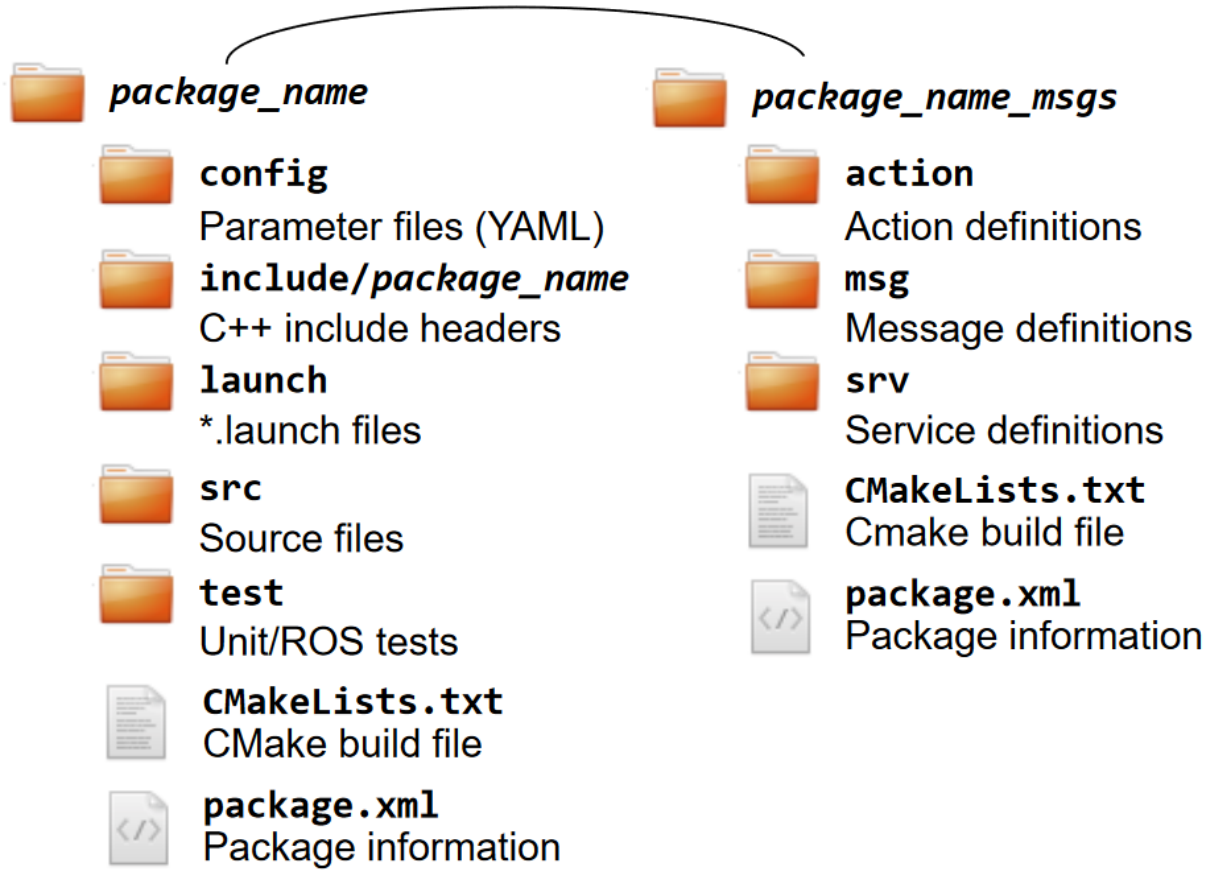
More info

http://wiki.ros.org/ROS/Tutorials/NavigatingTheFilesystem

ROS Package

- ROS software is organized into packages, which can contain source code, launch files, configuration files, message definitions, data, and documentation
- A package that builds up on/requires other packages (e.g. message definitions), declares these as dependencies

Separate message definition packages from other packages!



To create a new package, use

```
> cd ~/catkin_ws/src
> catkin_create_pkg package_name {dependencies}
```

More info

http://wiki.ros.org/Packages

ROS Package

package.xml

- The package.xml defines properties of the package
  - <name> Package name
  - <version> Version numbers
  - <description> Description of the content
  - <maintainer> Person maintaning the package
  - <licence> Type of licence (usualy BSD)
  - **Dependencies on other catkin packages**

  The dependencies are split into :
  build_depend, buildtool_depend, exec_depend, test_depend

  - and more

```
<?xml version="1.0"?>
<package format="2">
<name>ros_package_template</name>
<version>0.1.0</version>
<description>A template for ROS packages.</description>
<maintainer email="luc.marechal@univ-smb.fr">Luc</maintainer>
<license>BSD</license>

<url type="website">https://github.com/my_project/ros_…</url>
<author email="luc.marechal@univ-smb.fr">Luc Mare</author>

<buildtool_depend>catkin</buildtool_depend>
<build_depend>roscpp</build_depend>

<build_depend>rospy</build_depend>
<build_depend>std_msgs</build_depend>

<run_depend>roscpp</run_depend>
<run_depend>rospy</run_depend>
<run_depend>std_msgs</run_depend>
</package>
```

ROS Package

CMakeLists.txt

The `CMakeLists.txt` is the input to the CMakebuild system

1. Required CMake Version (`cmake_minimum_required`)
2. Package Name (`project()`)
3. Find other CMake/Catkin packages needed for build (`find_package()`)
4. Message/Service/Action Generators (`add_message_files()`, `add_service_files()`, `add_action_files()`)
5. Invoke message/service/action generation (`generate_messages()`)
6. Specify package build info export (`catkin_package()`)
7. Libraries/Executables to build (`add_library()`/`add_executable()`/`target_link_libraries()`)
8. Tests to build (`catkin_add_gtest()`)
9. Install rules (`install()`)

CMakeLists.txt

```
cmake_minimum_required(VERSION 2.8.3)
project(ros_package_template)

## Use C++11
add_definitions(--std=c++11)

## Find catkin macros and libraries
find_package(catkin REQUIRED
  COMPONENTS
    roscpp
    sensor_msgs
)

…
```

More info
http://wiki.ros.org/catkin/CMakeLists.txt

ROS Package

CMakeLists.txt Example

```
cmake_minimum_required(VERSION 2.8.3)
project(husky_highlevel_controller)
add_definitions(--std=c++11)

find_package(catkin REQUIRED
  COMPONENTS roscpp sensor_msgs
)

catkin_package(
  INCLUDE_DIRS include
  # LIBRARIES
  CATKIN_DEPENDS roscpp sensor_msgs
  # DEPENDS
)

include_directories(include ${catkin_INCLUDE_DIRS})

add_executable(${PROJECT_NAME} src/${PROJECT_NAME}_node.cpp
src/HuskyHighlevelController.cpp)

target_link_libraries(${PROJECT_NAME} ${catkin_LIBRARIES})
```

Use the same name as in the `package.xml`

We use C++11 by default

List the packages that your package requires to build (have to be listed in `package.xml`)

Specify build export information

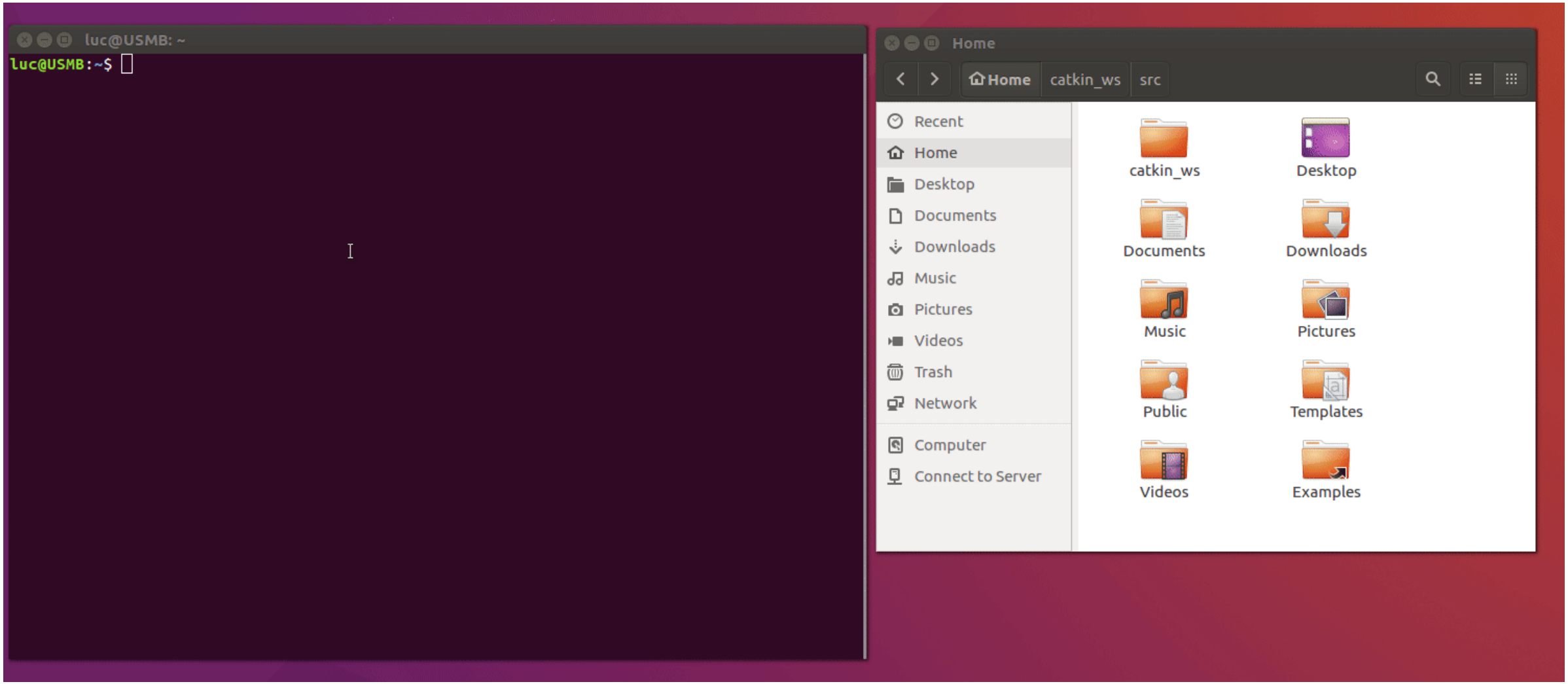
- `INCLUDE_DIRS`: Directories with header files
- `LIBRARIES`: Libraries created in this project
- `CATKIN_DEPENDS`: Packages dependent projects also need
- `DEPENDS`: System dependencies dependent projects also need (have to be listed in `package.xml`)

Specify locations of header files

Declare a C++ executable

Specify libraries to link the executable against

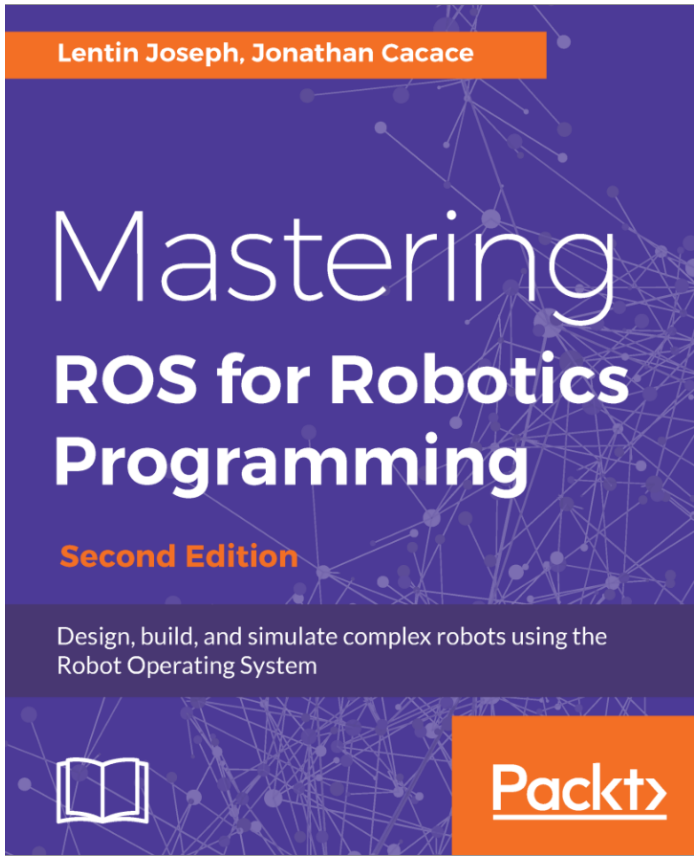
Creating a ROS package : *beginner_tutorials*

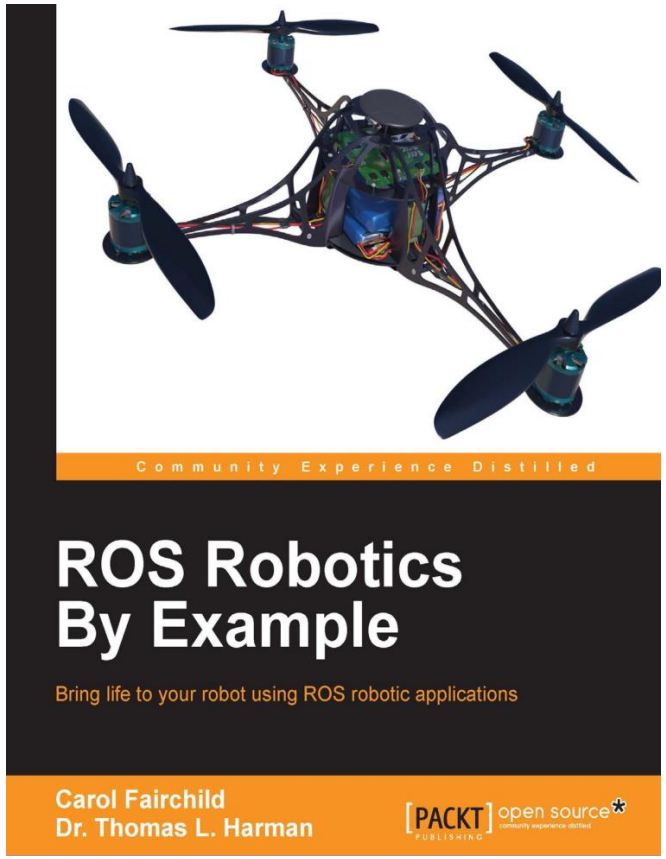


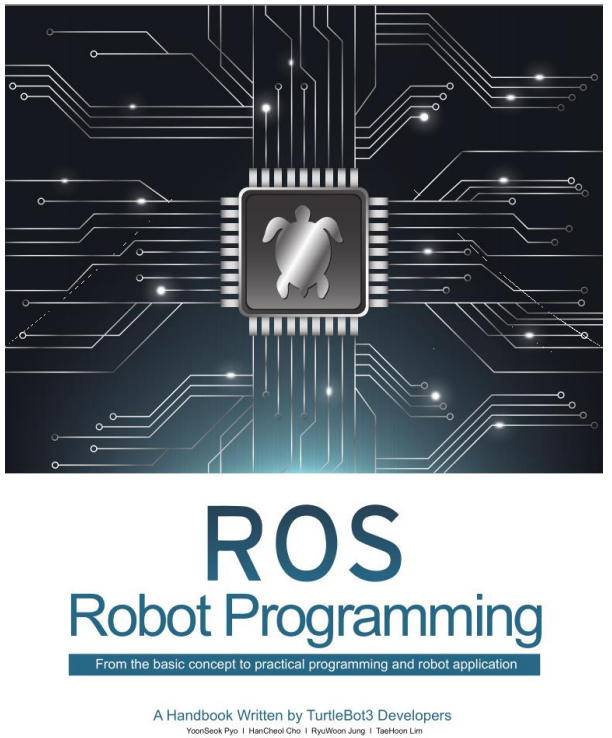
Further References

- 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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