Introduction to ROS

NTA3

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UNIVR - Altair Robotics Lab

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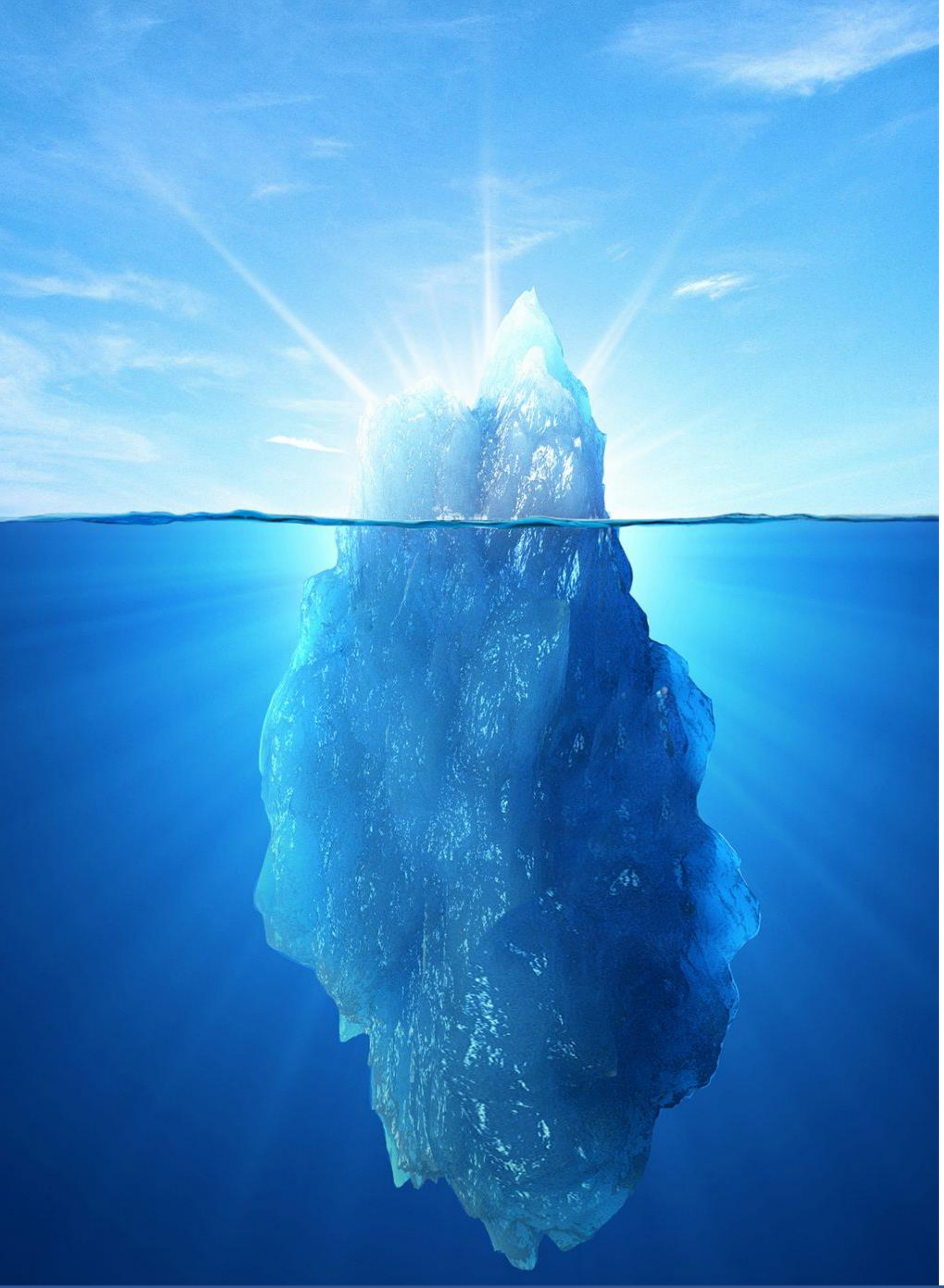


Overview

- ROS architecture & philosophy
- ROS master, nodes, and topics
- Catkin workspace and build system
- ROS package structure
- Console commands
- Launch-files
- ROS C++ client library (roscpp)
- ROS subscribers and publishers
- ROS parameter server
- ROS services
- ROS actions (actionlib)

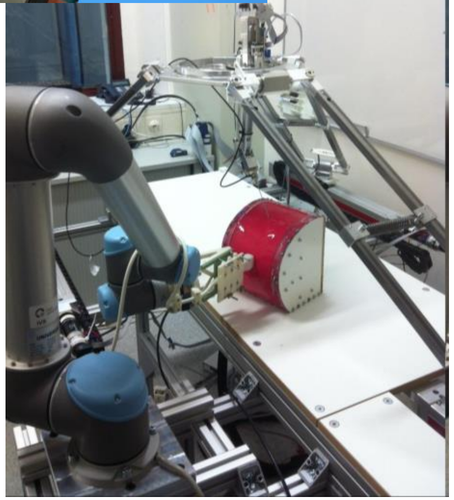
Personal Introduction: Diego Dall’Alba

I am currently an Assistant Professor in Altair robotics lab – Department of Computer Science @ University of Verona (Italy)

I have worked in 4 European project before ATLAS:

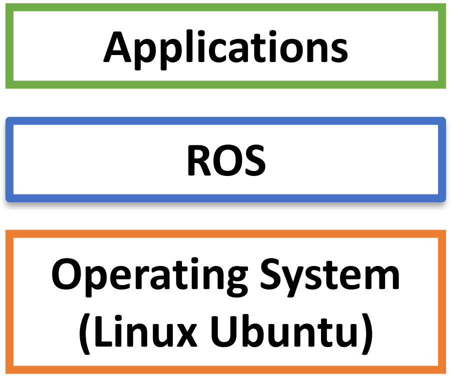
- AccuRobAs
- Safros
- I-Sur
- MURAB

Actually, I am actively inveolved in ARS and ATLAS



What is ROS (Robotic Operating System)?

- It is not a Operating System (OS)
- It is not an Application Programming Interface (API)
- It is not a «simple» framework



Applications

ROS

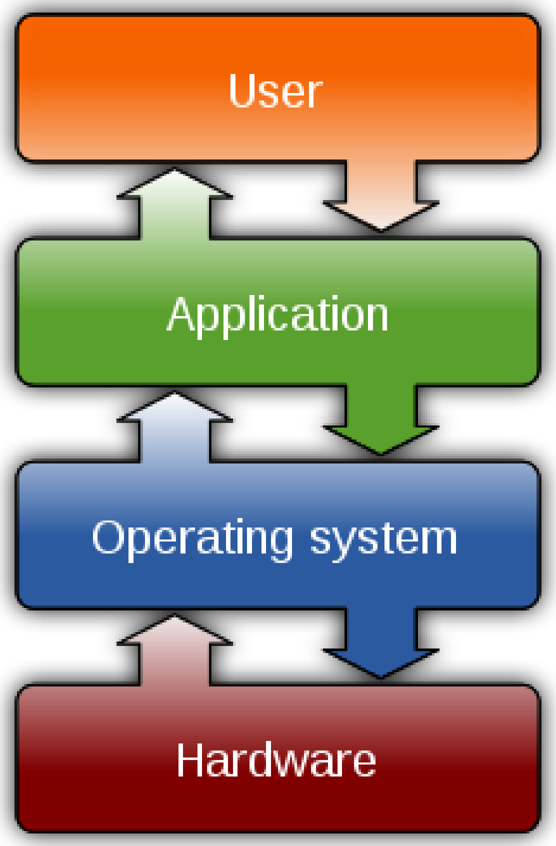
Operating System (Linux Ubuntu)

ROS is a middleware for robotic programming, specifically designed for complex applications

BTW, What are OS, API, Framework and Middleware? Which are the differences?

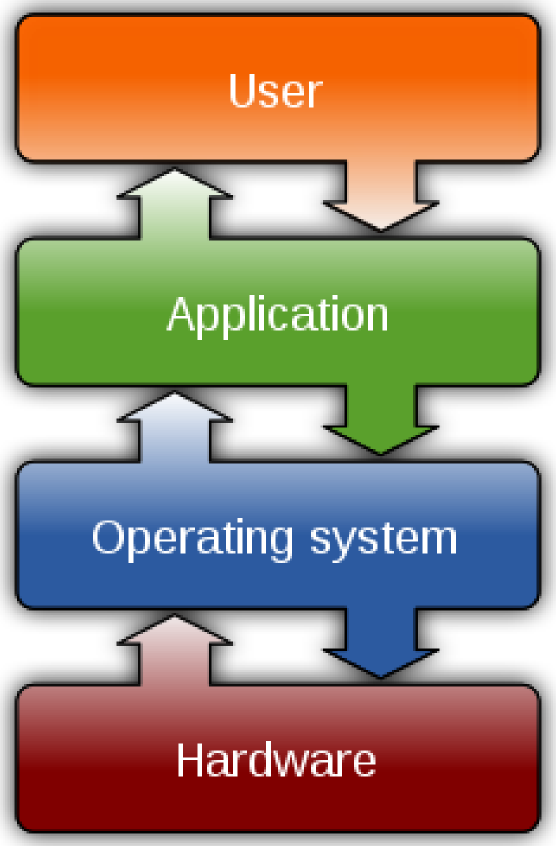
What are OS, API, Framework and Middleware?

- An application programming interface (API) is an interface (e.g. set of functions and methods, data types)intended to simplify the implementation and maintenance of software.
- An operating system (OS) is system software that manages computer hardware, software resources, and provides common services for computer programs.



What are OS, API, Framework and Middleware?

- Framework provide an infrastructure and a methodology for quickly developing and distributing complex software applications. Do not try to do things not supported by the framework!
- Middleware is a set of software tools (including APIs and Frameworks) that provides services to applications to enable easy communication and integration of different modules/functionalities. It can be described as "software glue".



Why a middleware for robotic programming?

- Simplify development process
- provide simple and transparent inter-processes communication
- Provide software functionalities that are frequently needed in robotic applications
- Abstract high complexity and heterogeneity of different hardware and software components
- Provide an automatic and efficient process for configuring and managing different resources and components
- Supporting embedded system and “low-resources devices”

Quick background about robotic middleware

Many robotic middleware have been proposed, for example:

- **Player/Stage**: based on client-server architecture
- **Miro - Middleware for Robots**: distributed inter-process communication(based on CORBA)
- **OROCOS**: designed for real-time applications
- **URBI:** focusing on component architecture and management
- **YARP**: Yet another robotic platform ☺

You could find a PARTIAL list of robotic middleware at: https://en.wikipedia.org/wiki/Robotics_middleware

NOTE: The European Union has fundend at least 2 big research projects (RoSta 1M and BRICS 10M). In the USA also DARPA invested a huge amount of resources in the development robotic middleware

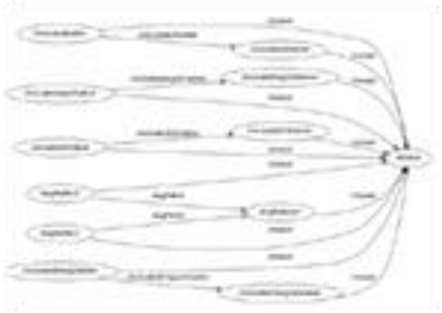
Quick background about ROS

- Video: https://vimeo.com/245826128
- Complete timeline/History: http://www.ros.org/history

- Originally developed, around 2007, from Stanford University, Artificial Intelligence Lab
- Then developed with the collaboration of other research groups, in particular Willow Garage
- Since 2013 developed and maintained by Open Source Robotic Foundation (OSRF)
- It is de-facto standard for high level robotic programming in research environment

- Recently the development of ROS2 has started but it is still in a early stage. There is also a consortium called ROS Industrial focused in transferring ROS modules in industrial applications

ROS Characteristics



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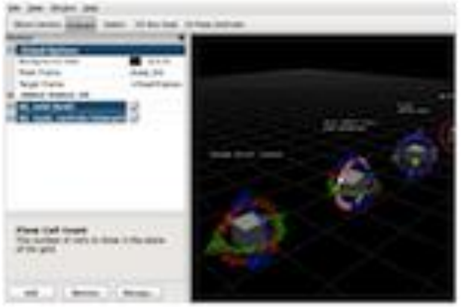

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Plumbing

- Process management
- Inter-process communication
- Device drivers

Tools

- Simulation
- Visualization
- Graphical user interface
- Data logging

Capabilities

- Control
- Planning
- Perception
- Mapping
- Manipulation

Ecosystem

- Package organization
- Software distribution
- Documentation
- Tutorials

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-language support:** ROS modules can be written in any programming language for which a client library exists (C++, Python, MATLAB, Java, etc.).
- **Light-weight:** 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.

ROS Distributions

- A ROS distribution is a versioned set of ROS packages.
- These are similar to Linux distributions (e.g. Ubuntu).
- The purpose of the ROS distributions is to let developers work against a relatively stable codebase

Release rules

- ROS release timing is based on need and available resources
- All future ROS 1 releases are LTS, supported for five years
- ROS releases will drop support for EOL Ubuntu distributions, even if the ROS release is still supported.

ROS Kinetic Kame
Released May, 2016
LTS, supported until April, 2021

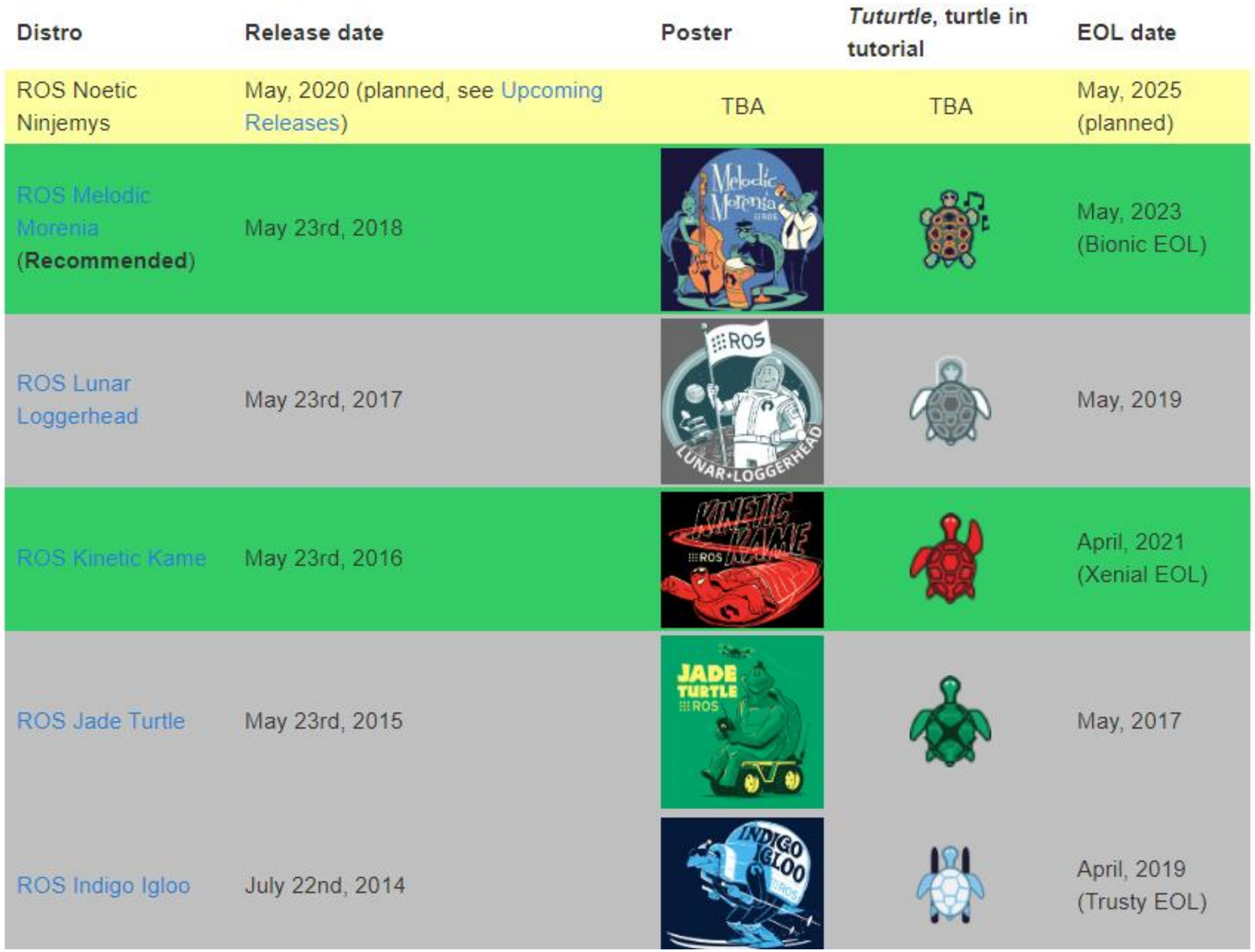
ROS Melodic Morenia
Released May, 2018
Latest LTS, supported until May, 2023

Partial List of ROS and Ubuntu Distributions

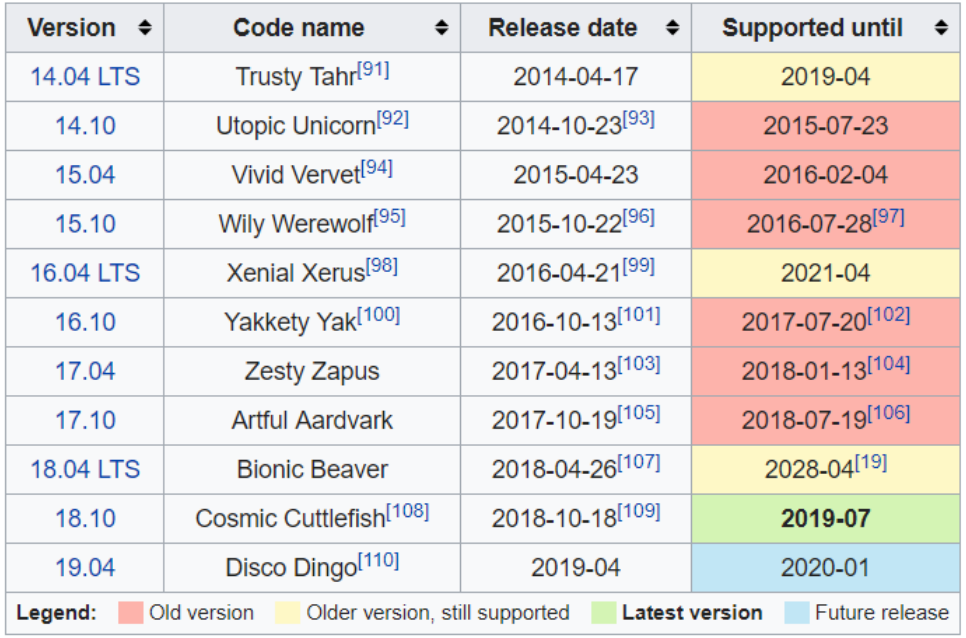
Applications

ROS

Operating System (Linux Ubuntu)



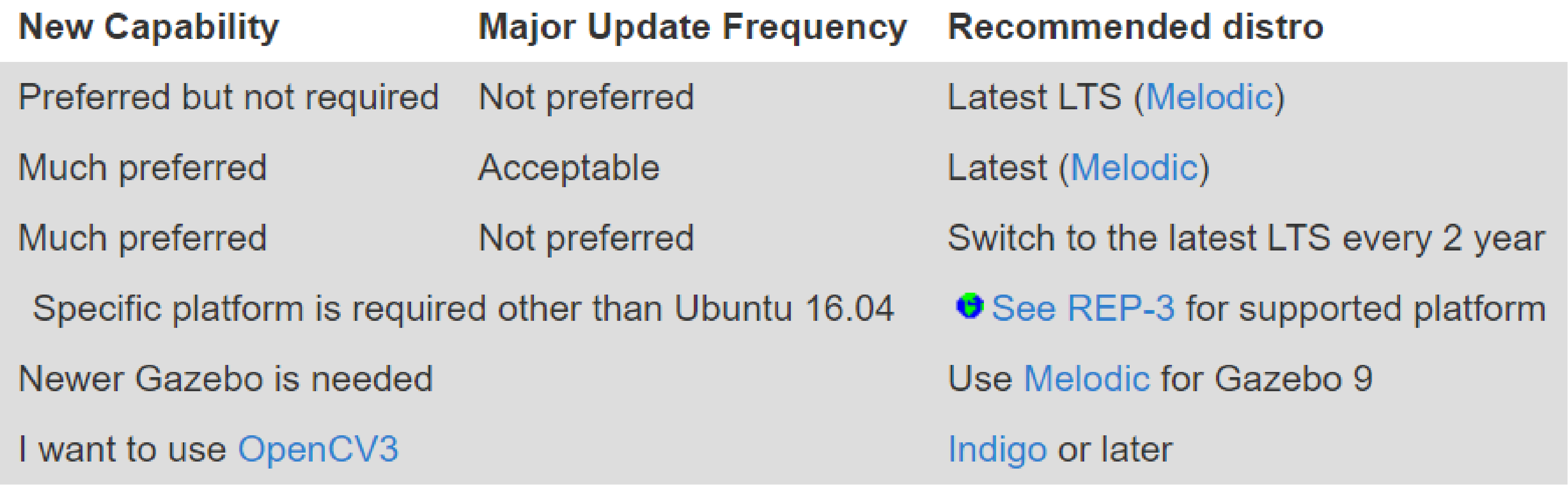
Distro	Release date	Poster	*Tuturtle*, turtle in tutorial	EOL date
ROS Noetic Ninjemys	May, 2020 (planned, see Upcoming Releases)	TBA	TBA	May, 2025 (planned)
ROS Melodic Morenia (**Recommended**)	May 23rd, 2018			May, 2023 (Bionic EOL)
ROS Lunar Loggerhead	May 23rd, 2017			May, 2019
ROS Kinetic Kame	May 23rd, 2016			April, 2021 (Xenial EOL)
ROS Jade Turtle	May 23rd, 2015			May, 2017
ROS Indigo Igloo	July 22nd, 2014			April, 2019 (Trusty EOL)



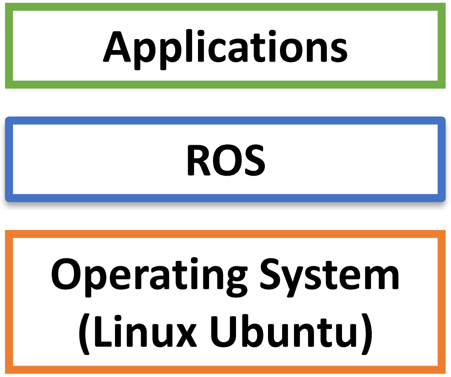
Version	Code name	Release date	Supported until
14.04 LTS	Trusty Tahr[91]	2014-04-17	2019-04
14.10	Utopic Unicorn[92]	2014-10-23[93]	2015-07-23
15.04	Vivid Vervet[94]	2015-04-23	2016-02-04
15.10	Wily Werewolf[95]	2015-10-22[96]	2016-07-28[97]
16.04 LTS	Xenial Xerus[98]	2016-04-21[99]	2021-04
16.10	Yakkety Yak[100]	2016-10-13[101]	2017-07-20[102]
17.04	Zesty Zapus	2017-04-13[103]	2018-01-13[104]
17.10	Artful Aardvark	2017-10-19[105]	2018-07-19[106]
18.04 LTS	Bionic Beaver	2018-04-26[107]	2028-04[19]
18.10	Cosmic Cuttlefish[108]	2018-10-18[109]	**2019-07**
19.04	Disco Dingo[110]	2019-04	2020-01

Legend: 🟥 Old version 🟨 Older version, still supported 🟩 **Latest version** 🟦 Future release

Choosing the right ROS distribution



New Capability	Major Update Frequency	Recommended distro
Preferred but not required	Not preferred	Latest LTS (Melodic)
Much preferred	Acceptable	Latest (Melodic)
Much preferred	Not preferred	Switch to the latest LTS every 2 year
Specific platform is required other than Ubuntu 16.04		See REP-3 for supported platform
Newer Gazebo is needed		Use Melodic for Gazebo 9
I want to use OpenCV3		Indigo or later



Applications

ROS

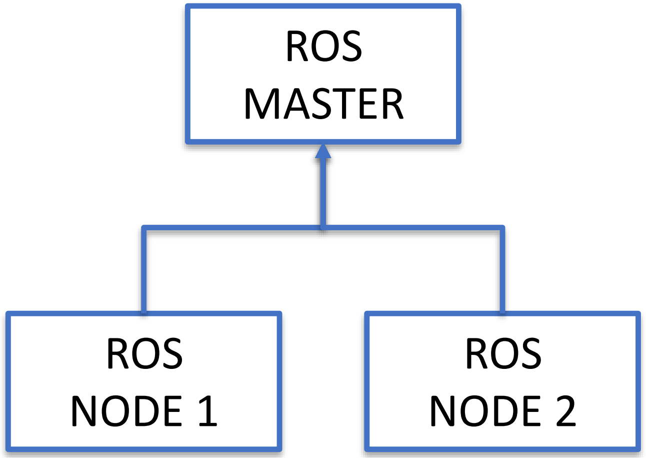
Operating System
(Linux Ubuntu)

- Changing ROS Distribution is usually quite complex, it depends on the specific application and development cycle
- Try to keep the same distribution in the same project
- Separate different distribution in different machine
- We will use Kinetic Kame on Linux 16.04 (Xenial Xerus)

ROS Architecture: Basics

ROS MASTER

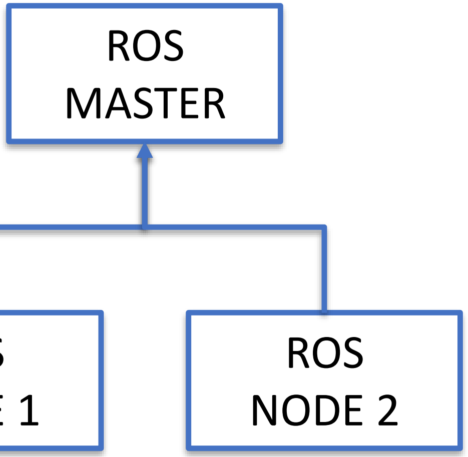
- Manages the communication between nodes (XML-RPC server + naming and communication services)
- Every node registers at start-up with the master
- Nodes can run on different workstation and communicate through network (transparent to user)



ROS NODE

- Single-purpose, executable program
- Individually compiled, executed, and managed
- Organized in *packages*

Configuring the ROS environment



ROS MASTER

I am assuming that you have intalled ROS following the offical guide available at:

http://wiki.ros.org/kinetic/Installation/Ubuntu

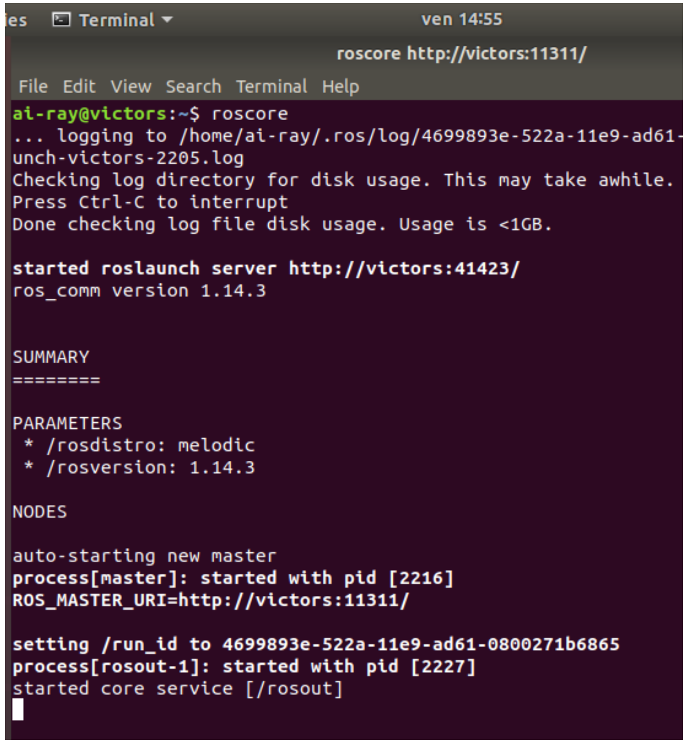
The first step is always configuring the Linux environment:

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

Then you will be able to run

```
roscore
```

It will run ROS master + other important services (logging and parameters server)


ies Terminal
ven 14:55
roscore http://victors:11311/
File Edit View Search Terminal Help

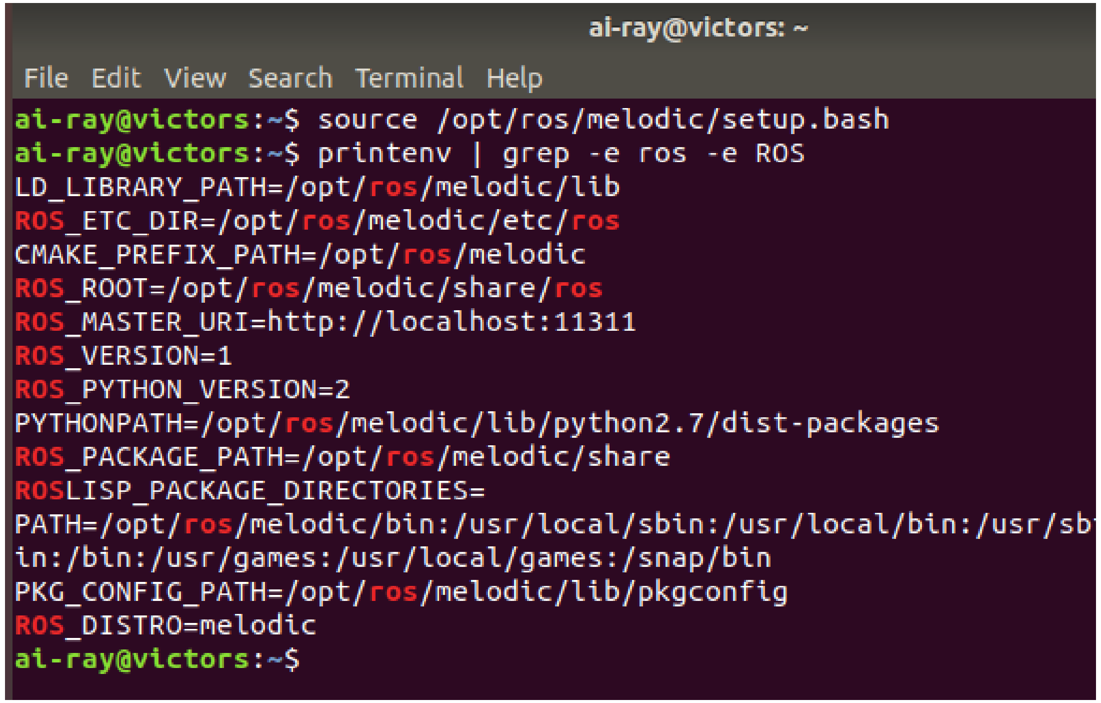
```
ai-ray@victors:~$ roscore
... logging to /home/ai-ray/.ros/log/4699893e-522a-11e9-ad61-
unch-victors-2205.log
Checking log directory for disk usage. This may take awhile.
Press Ctrl-C to interrupt
Done checking log file disk usage. Usage is <1GB.

started roslaunch server http://victors:41423/
ros_comm version 1.14.3


SUMMARY
========

PARAMETERS
 * /rosdistro: melodic
 * /rosversion: 1.14.3

NODES

auto-starting new master
process[master]: started with pid [2216]
ROS_MASTER_URI=http://victors:11311/

setting /run_id to 4699893e-522a-11e9-ad61-0800271b6865
process[rosout-1]: started with pid [2227]
started core service [/rosout]
```

Configuring the ROS environment

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

This command is fundamental for correctly configuring all environment variables required for:

- Finding packages
- Effecting a Node runtime
- Modifying the build system



```
ai-ray@victors:~$ source /opt/ros/melodic/setup.bash
ai-ray@victors:~$ printenv | grep -e ros -e ROS
LD_LIBRARY_PATH=/opt/ros/melodic/lib
ROS_ETC_DIR=/opt/ros/melodic/etc/ros
CMAKE_PREFIX_PATH=/opt/ros/melodic
ROS_ROOT=/opt/ros/melodic/share/ros
ROS_MASTER_URI=http://localhost:11311
ROS_VERSION=1
ROS_PYTHON_VERSION=2
PYTHONPATH=/opt/ros/melodic/lib/python2.7/dist-packages
ROS_PACKAGE_PATH=/opt/ros/melodic/share
ROSLISP_PACKAGE_DIRECTORIES=
PATH=/opt/ros/melodic/bin:/usr/local/sbin:/usr/local/bin:/usr/sb
in:/bin:/usr/games:/usr/local/games:/snap/bin
PKG_CONFIG_PATH=/opt/ros/melodic/lib/pkgconfig
ROS_DISTRO=melodic
ai-ray@victors:~$
```

Essential variables are:

- ROS_ROOT sets the location where the ROS core packages are installed.
- ROS_MASTER_URI is a required setting that tells nodes where they can locate the master.
- ROS requires that your PYTHONPATH be updated, even if you don't program in Python! Many ROS infrastructure tools rely on Python

ROS Build System (1)

CATKIN
BUILD SYSTEM
CMake
python™

catkin is the official build system of ROS starting from ROS Groovy and the successor to the original ROS build system, rosbuild.

catkin combines CMake macros and Python scripts to provide some functionality on top of CMake's normal workflow (improved automatic dependencies management and compilation of large project)

The name catkin comes from the tail-shaped flower cluster found on willow trees -- a reference to Willow Garage where catkin was created.

It is essential to know catkin build process for proficiently use ROS build system, having a good knowledge of CMake is also helping a lot in solving many problem when working in ROS

ROS Build System (2)

catkin build system is organized in a workspace containing different spaces and packages, this feature is very useful for having a common files/directory structure and for building multiple packages with complex dependencies.

A typical catkin workspace contains 4 (5) spaces:

- Source Space
- Build Space
- Devel space
- Install space
- (Log Space)

Result Space

Please keep separate catkin workspace when you use catkin_make and where you use catkin command line tools (e.g. catkin init ; catkin build).

Many tutorial available online use catkin_make, even if I strongly suggest using catkin build

NEVER MIX THE TWO COMMANDS IN THE SAME WS

ROS Build System (3)

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).

Example of creating of a new catkin workspace using command line tools

CATKIN
BUILDSYSTEM

```
source /opt/ros/kinetic/setup.bash
mkdir -p /tmp/quickstart_ws/src          # Make a new workspace
cd /tmp/quickstart_ws                    # Navigate to the workspace root
catkin init                              # Initialize it
cd /tmp/quickstart_ws/src                # Navigate to the source space
catkin create pkg pkg_a                  # Populate the source space
catkin create pkg pkg_b
catkin create pkg pkg_c --catkin-deps pkg_a
catkin create pkg pkg_d --catkin-deps pkg_a pkg_b
catkin list                              # List the packages in the workspace
catkin build                             # Build all packages in the workspace
source /tmp/quickstart_ws/devel/setup.bash
```

Typical structure of Catkin Source Space

```
workspace_folder/           --  CATKIN WORKSPACE
 └src/                         -- SOURCE SPACE
    ├package_1/
    │     CMakeLists.txt   -- CMakeLists.txt file for package_1
    │     package.xml      -- Package manifest for package_1
    │ …
    └package_n/
          CMakeLists.txt   -- CMakeLists.txt file for package_n
          package.xml      -- Package manifest for package_n
```

The *source space* contains the source code.

Organized in different *packages*

CMakeLists.txt is the configuration file for CMake → see Cmake docs for more details

Package.xml is a supporting file providing additiona package info and dependencies for catkin build system.

Typical structure of a package.xml

```
<package>
  <name>foo_core</name>
  <version>1.2.4</version>
  <description>
    This package provides foo capability.
  </description>
  <maintainer email="ivana@willowgarage.com">Ivana
Bildbotz</maintainer>
  <license>BSD</license>

 <buildtool_depend>catkin</buildtool_depend>
</package>
```

Typical structure of a package.xml

```
<package>
  <name>foo_core</name>
  <version>1.2.4</version>
  <description> This package provides foo capability. </description>
  <maintainer email="ivana@willowgarage.com">Ivana Bildbotz</maintainer>
  <license>BSD</license>

  <url>http://ros.org/wiki/foo_core</url>
  <author>Ivana Bildbotz</author>
  <buildtool_depend>catkin</buildtool_depend>

  <build_depend>message_generation</build_depend>
  <build_depend>roscpp</build_depend>
  <build_depend>std_msgs</build_depend>

  <run_depend>message_runtime</run_depend>
  <run_depend>roscpp</run_depend>
  <run_depend>rospy</run_depend>
  <run_depend>std_msgs</run_depend>

  <test_depend>python-mock</test_depend>
</package>
```

See previous slide

For more details please check:

http://wiki.ros.org/catkin/conceptual_overview#Dependency_Management

<build_depend>

Build Dependencies

<run_depend> Run Dependencies

<test_depend>Test Dependencies

<buildtool_depend>

Build Tool Dependencies

Typical structure of a CMakeLists.txt

```
cmake_minimum_required(VERSION 2.8)
project(app_project)
add_executable(myapp main.c)
install(TARGETS myapp DESTINATION bin)
```

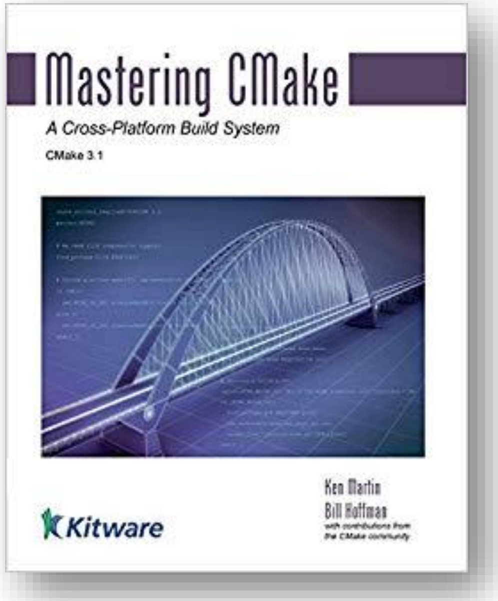
```
cmake_minimum_required(VERSION 2.8)
project(libtest_project)
add_library(test STATIC test.c)
install(TARGETS test DESTINATION lib)
install(FILES test.h DESTINATION include)
```

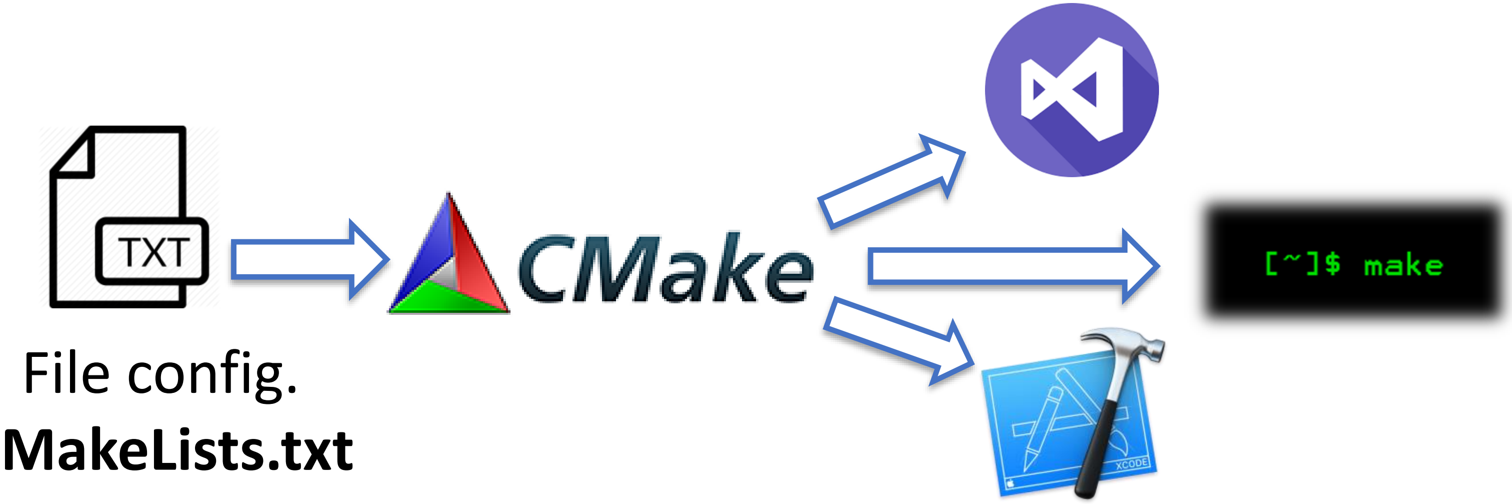
```
cmake_minimum_required(VERSION 2.8)
project(myapp)
add_subdirectory(libtest_project)
add_executable(myapp main.c)
target_link_libraries(myapp test)
install(TARGETS myapp DESTINATION bin)
```

CMake could be considered as a "meta build system"

CMake support a specific scripting language for the creation of its configuration files

More than 300 pages!





```
[~]$ make
```

File config.

CMakeLists.txt

A more realistic CMakeLists.txt

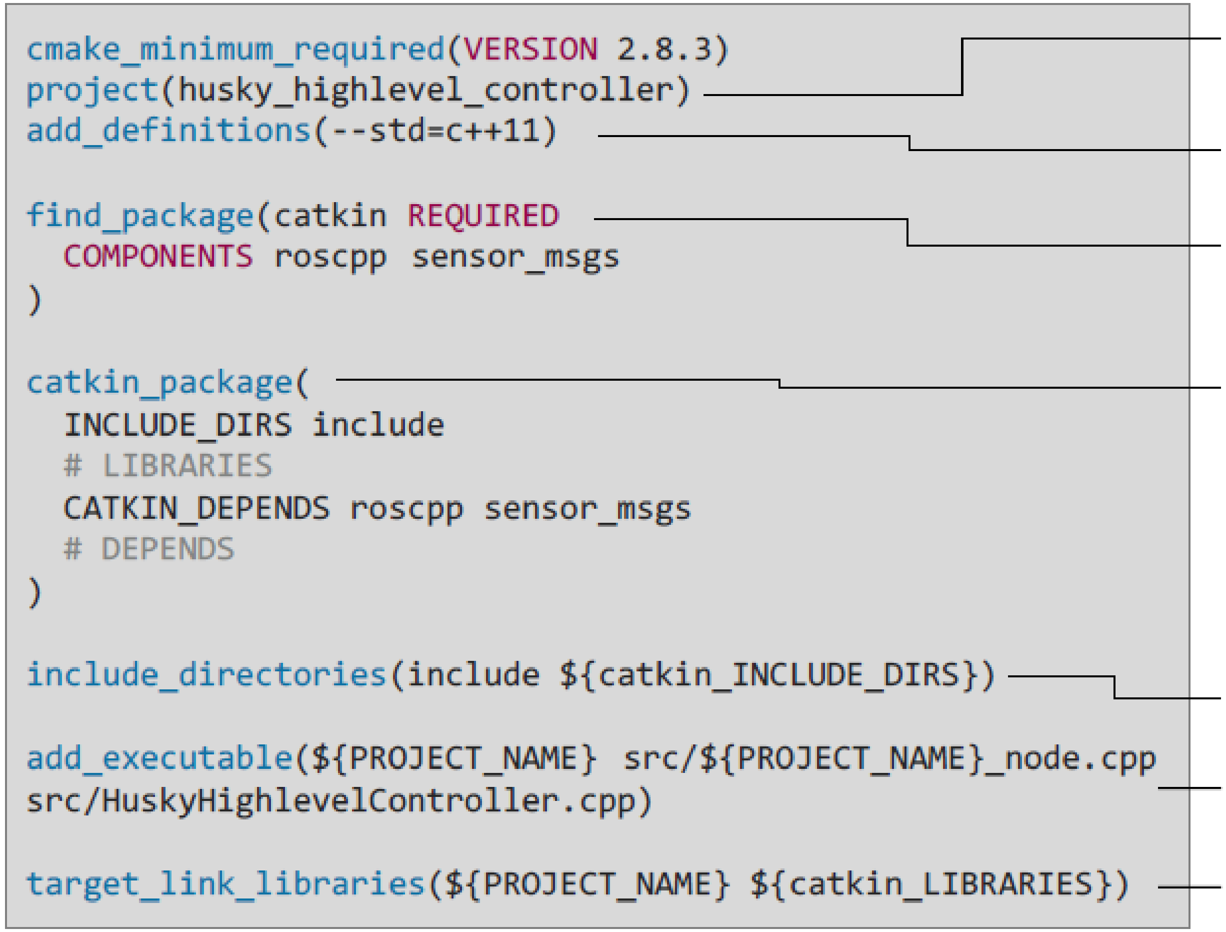
```
ExternalProject_Add(project_luajit
  URL http://luajit.org/download/LuaJIT-2.0.1.tar.gz
  PREFIX ${CMAKE_CURRENT_BINARY_DIR}/luajit-2.0.1
  CONFIGURE_COMMAND ""
  BUILD_COMMAND make
  INSTALL_COMMAND make install
  PREFIX=${CMAKE_CURRENT_BINARY_DIR}/luajit-2.0.1
)
ExternalProject_Get_Property(project_luajit install_dir)
add_library(luajit STATIC IMPORTED)
set_property(TARGET luajit PROPERTY IMPORTED_LOCATION
${install_dir}/lib/libluajit-5.1.a)
add_dependencies(luajit project_luajit)
add_executable(myapp main.c)
include_directories(${install_dir}/include/luajit-2.0)
target_link_libraries(myapp luajit)
```

When working in ROS (using C++ API) you need to modify CMakeLists.txt file prepared by catkin.

<u>If you correctly use catkin the modification of the CMakeLists.txt are (almost ☺) straightforward</u>

Many problems (i.e., errors) when working with ROS are related to wrong configuration of CMake build process → useful for searching the right solution ☺

Example of ROS Cmakelists.txt



```
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 of header files

Declare a C++ executable

Specify libraries to link the executable against

ROS Nodes

Single-purpose, executable program

Individually compiled, executed, and managed

Organized in *packages*

Run a node with

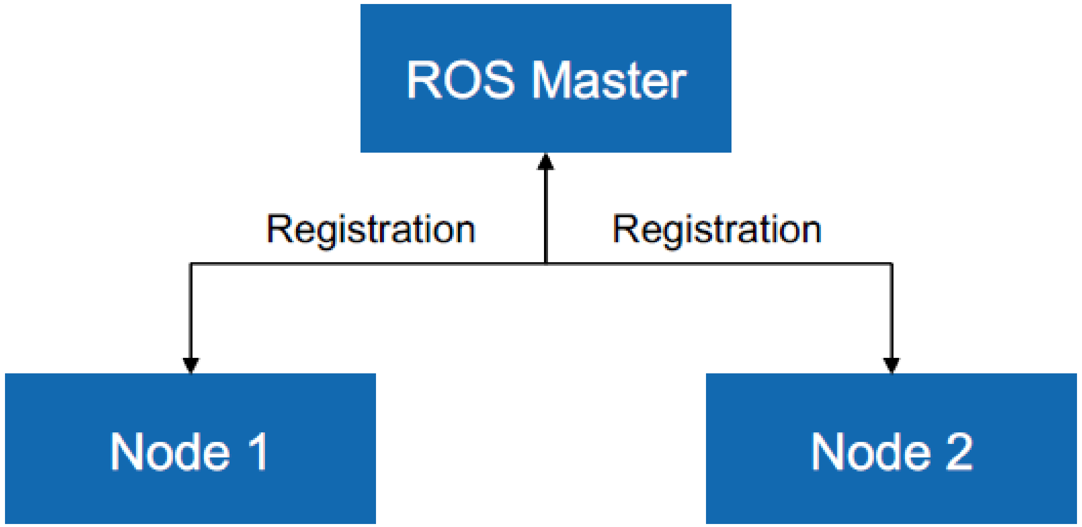
```
> rosrun package_name node_name
```

See active nodes 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

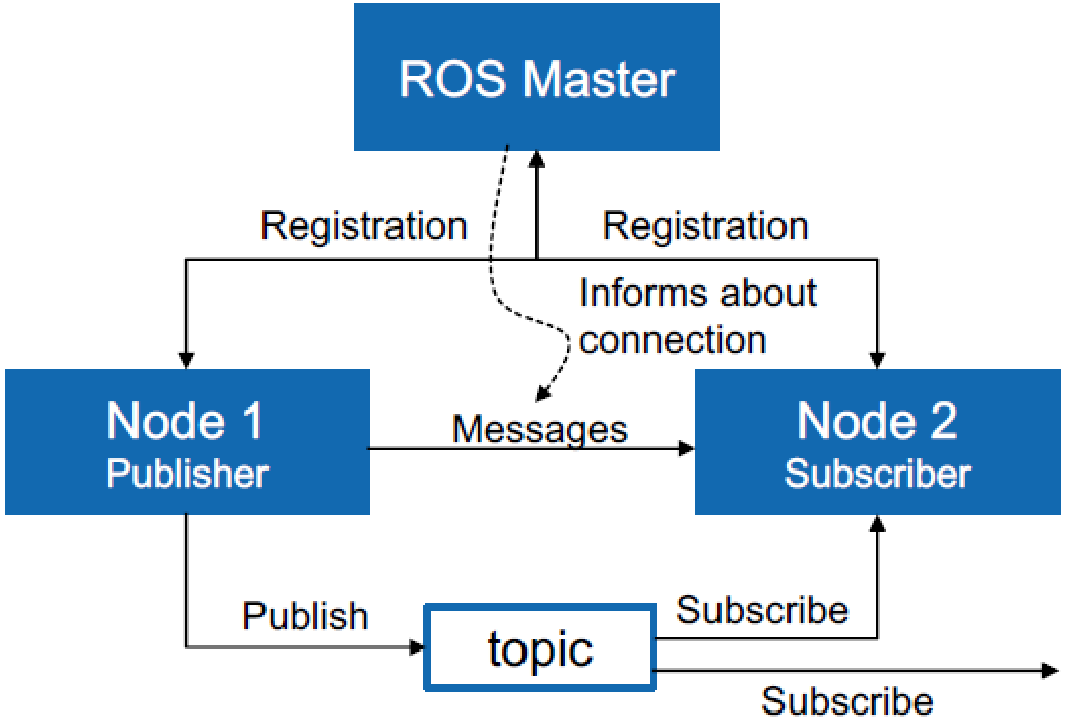
```
> rostopic list
```

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

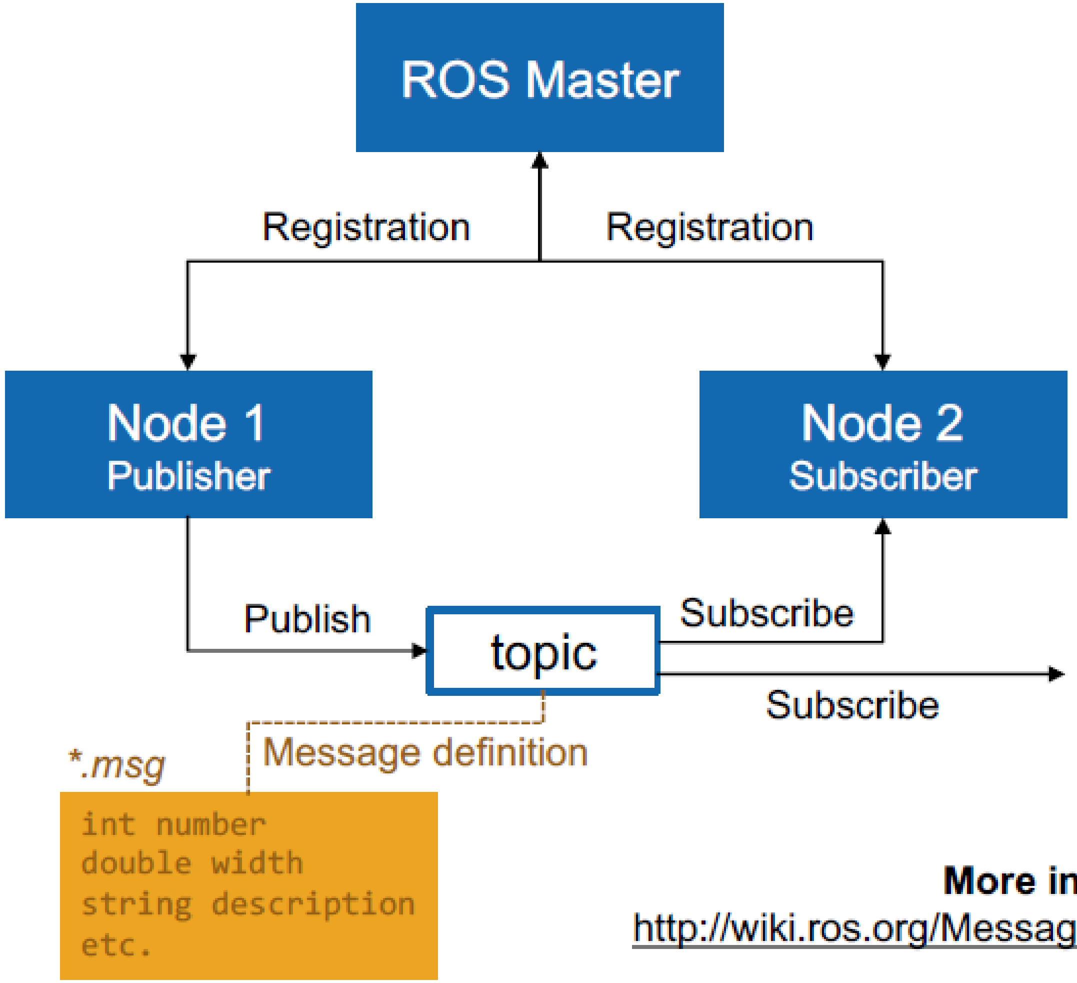
- Data structure defining the *type* of a topic
- Compromised of a nested structure of integers, floats, booleans, strings etc. and arrays of objects
- Defined in **.msg* files

See the type of a topic

```
> rostopic type /topic
```

Publish a message to a topic

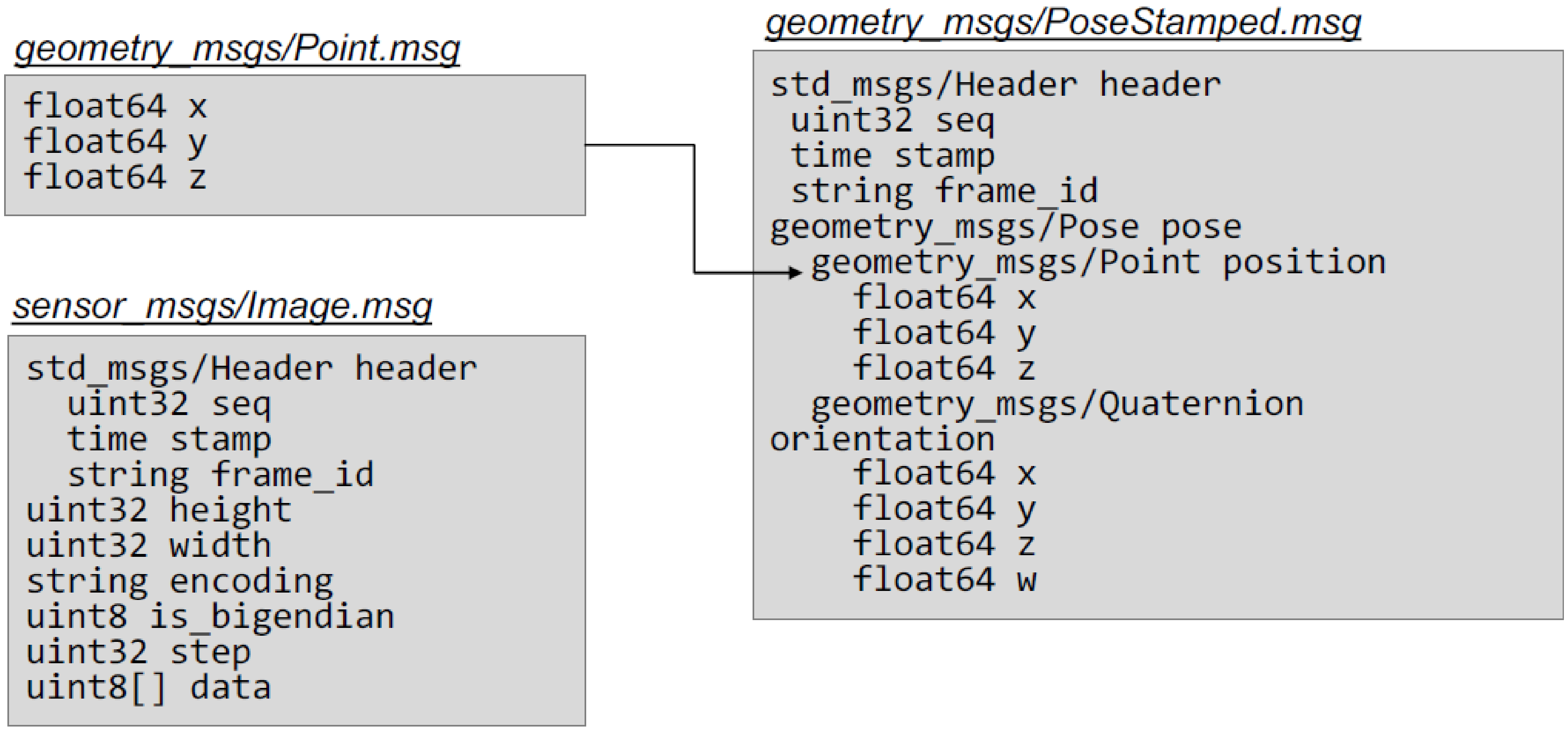
```
> rostopic pub /topic type args
```



```
int number
double width
string description
etc.
```

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

ROS Message Example: PoseStamped



geometry_msgs/Point.msg

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

sensor_msgs/Image.msg

```
std_msgs/Header header
  uint32 seq
  time stamp
  string frame_id
uint32 height
uint32 width
string encoding
uint8 is_bigendian
uint32 step
uint8[] data
```

geometry_msgs/PoseStamped.msg

```
std_msgs/Header header
 uint32 seq
 time stamp
 string frame_id
geometry_msgs/Pose pose
  geometry_msgs/Point position
    float64 x
    float64 y
    float64 z
  geometry_msgs/Quaternion
orientation
    float64 x
    float64 y
    float64 z
    float64 w
```

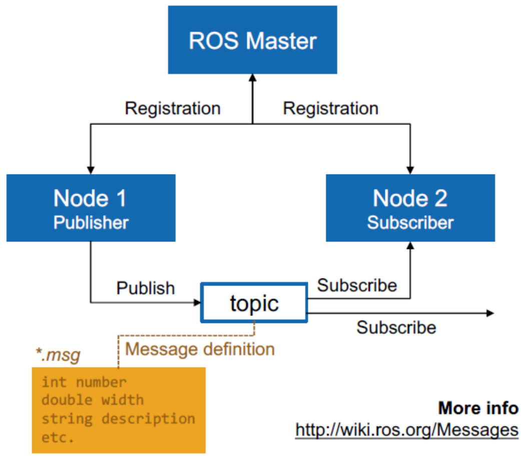
ROS Client Library (1)

A ROS client library is a collection of code that eases the job of the ROS programmer.

It takes many of the ROS concepts and makes them accessible via code.

In general, these libraries let you to:

- write ROS nodes,
- publish and subscribe to topics,
- write and call services,
- use the Parameter Server.



```
int number
double width
string description
etc.
```

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

Such a library can be implemented in any programming language

Main Client Libraries

- **roscpp :** roscpp is a C++ client library for ROS. It is the most widely used ROS client library and is designed to be the high performance library for ROS.
- **rospy:** rospy is the pure Python client library for ROS and is designed to provide the advantages of an object-oriented scripting language to ROS. The design of rospy favors implementation speed (i.e. developer time) over runtime performance.

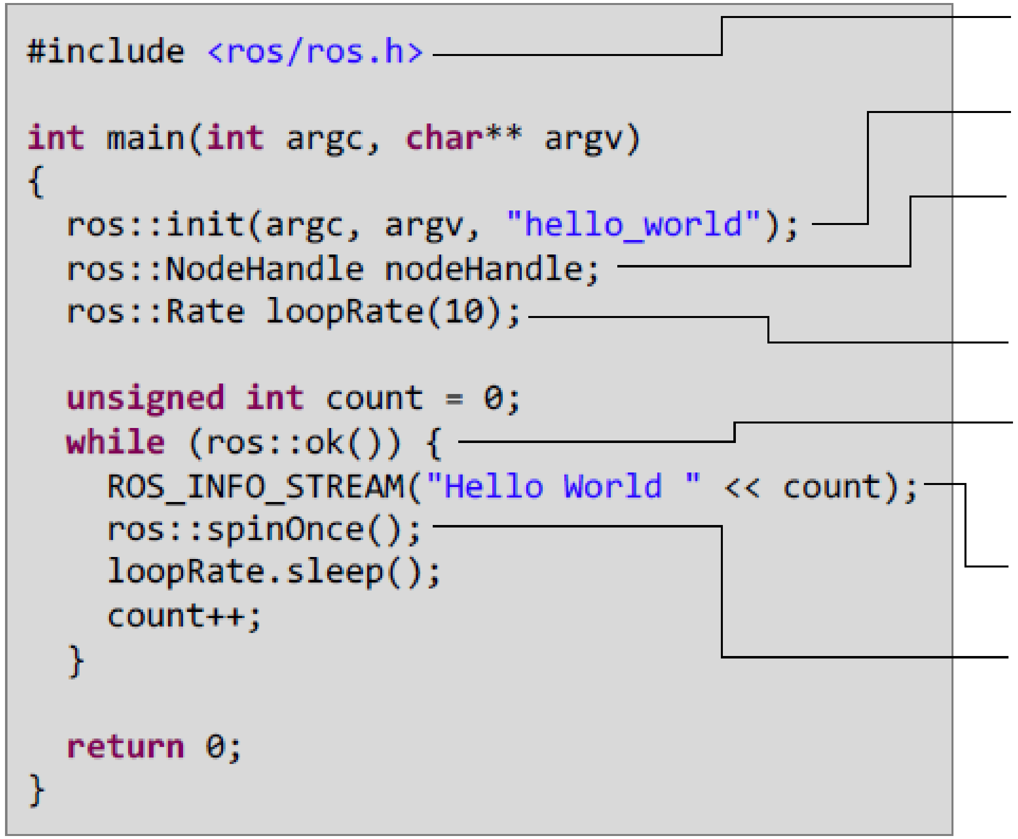
The ROS Master, roslaunch, and other ros tools are developed in rospy, so Python is a core dependency of ROS.

Basic tutorial

- Roscpp tutorial: http://wiki.ros.org/roscpp_tutorials/Tutorials/WritingPublisherSubscriber
- Rospy tutorial: http://wiki.ros.org/ROS/Tutorials/WritingPublisherSubscriber%28python%29

ROSCPP Basic Source code

hello_world.cpp



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

int main(int argc, char** argv)
{
  ros::init(argc, argv, "hello_world");
  ros::NodeHandle nodeHandle;
  ros::Rate loopRate(10);

  unsigned int count = 0;
  while (ros::ok()) {
    ROS_INFO_STREAM("Hello World " << count);
    ros::spinOnce();
    loopRate.sleep();
    count++;
  }

  return 0;
}
```

ROS main header file include

`ros::init(…)` has to be called before calling other ROS functions

The node handle is the access point for communications with the ROS system (topics, services, parameters)

`ros::Rate` is a helper class to run loops at a desired frequency

`ros::ok()` checks if a node should continue running
Returns `false` if `SIGINT` is received (`Ctrl + C`) or `ros::shutdown()` has been called

`ROS_INFO()` logs messages to the filesystem

`ros::spinOnce()` processes incoming messages via callbacks

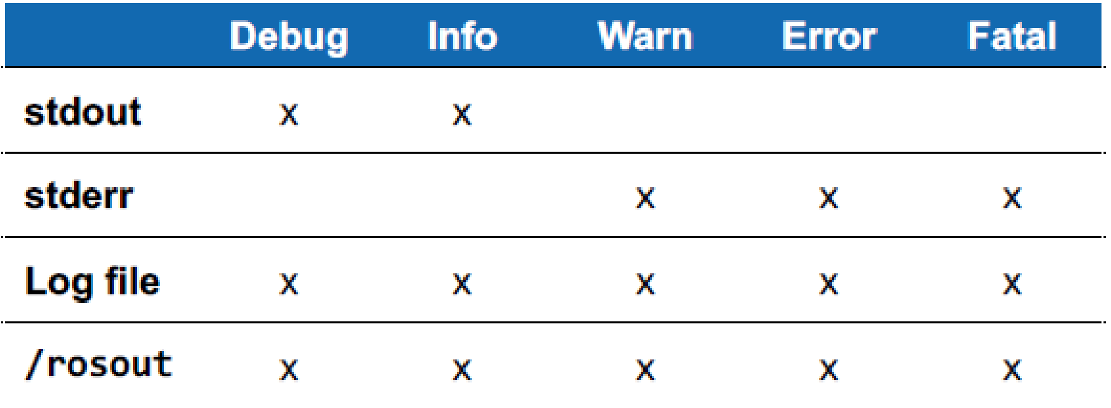
More info
http://wiki.ros.org/roscpp
http://wiki.ros.org/roscpp/Overview

ROSCPP Logging

- Mechanism for logging human readable text from nodes in the console and to log files
- Instead of `std::cout`, use e.g. `ROS_INFO`
- Automatic logging to console, log file, and `/rosout` topic
- Different severity levels (Info, Warn, Error etc.)
- Supports both printf- and stream-style formatting

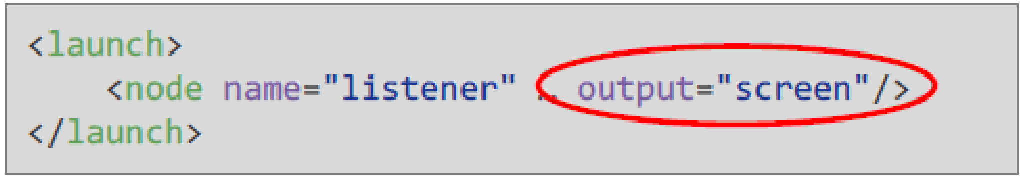
```
ROS_INFO("Result: %d", result);
ROS_INFO_STREAM("Result: " << result);
```

- Further features such as conditional, throttled, delayed logging etc.



	Debug	Info	Warn	Error	Fatal
stdout	x	x			
stderr			x	x	x
Log file	x	x	x	x	x
/rosout	x	x	x	x	x

! To see the output in the console, set the output configuration to `screen` in the launch file



```
<launch>
    <node name="listener" ... output="screen"/>
</launch>
```

More info
http://wiki.ros.org/rosconsole
http://wiki.ros.org/roscpp/Overview/Logging

ROSCPP Subscriber

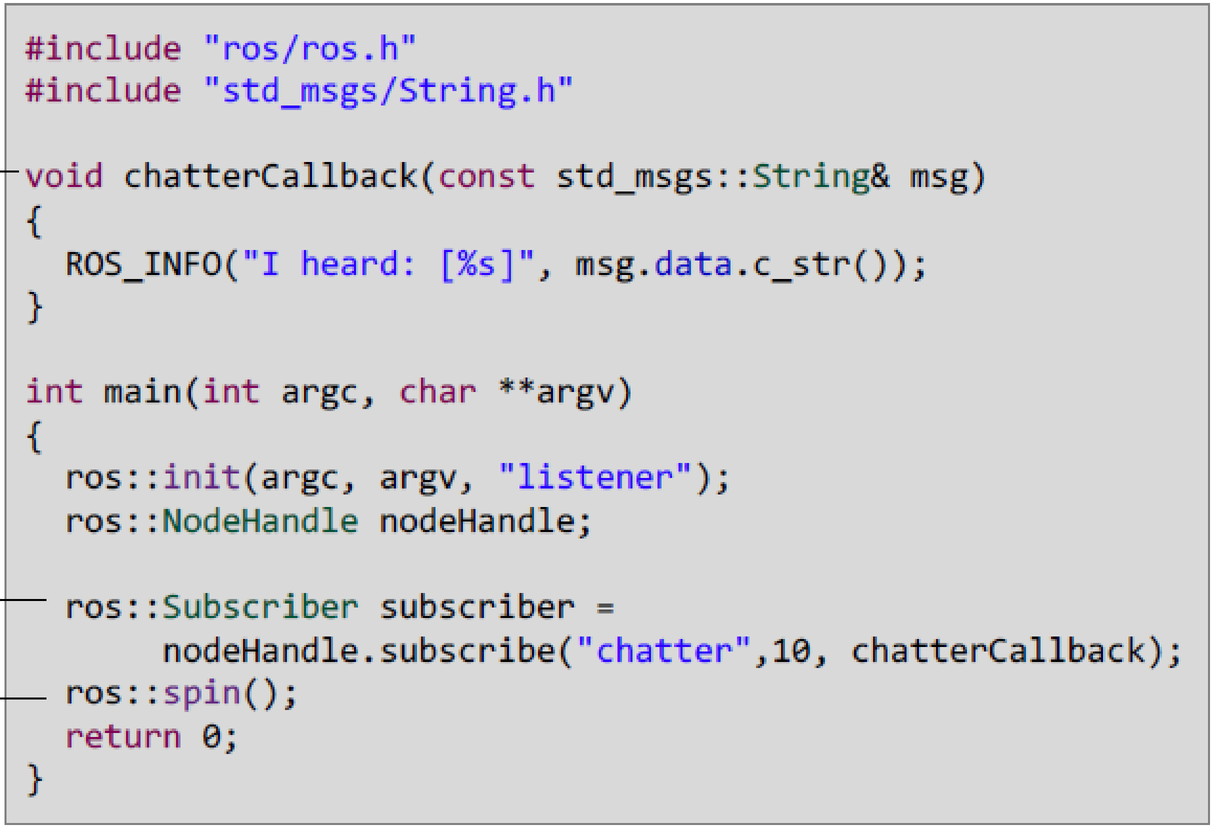
- Start listening to a topic by calling the method `subscribe()` of the node handle

```
ros::Subscriber subscriber =
nodeHandle.subscribe(topic, queue_size,
                     callback_function);
```

- When a message is received, callback function is called with the contents of the message as argument
- Hold on to the subscriber object until you want to unsubscribe

`ros::spin()` processes callbacks and will not return until the node has been shutdown

listener.cpp



```
#include "ros/ros.h"
#include "std_msgs/String.h"

void chatterCallback(const std_msgs::String& msg)
{
  ROS_INFO("I heard: [%s]", msg.data.c_str());
}

int main(int argc, char **argv)
{
  ros::init(argc, argv, "listener");
  ros::NodeHandle nodeHandle;

  ros::Subscriber subscriber =
       nodeHandle.subscribe("chatter",10, chatterCallback);
  ros::spin();
  return 0;
}
```

More info
http://wiki.ros.org/roscpp/Overview/Publishers%20and%20Subscribers

ROSCPP Publisher

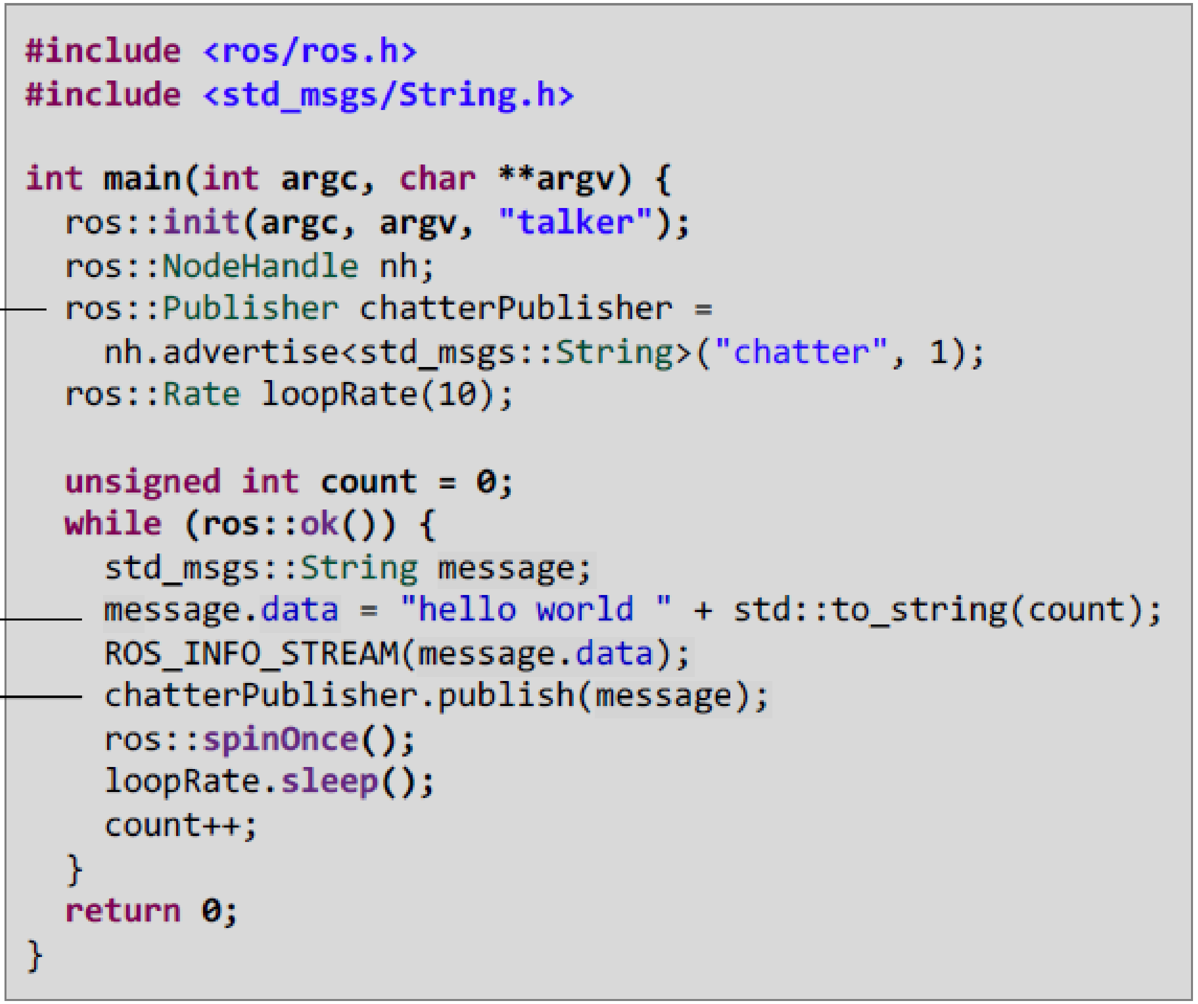
- Create a publisher with help of the node handle

```
ros::Publisher publisher =
nodeHandle.advertise<message_type>(topic,
queue_size);
```

- Create the message contents
- Publish the contents with

```
publisher.publish(message);
```

talker.cpp



```
#include <ros/ros.h>
#include <std_msgs/String.h>

int main(int argc, char **argv) {
  ros::init(argc, argv, "talker");
  ros::NodeHandle nh;
  ros::Publisher chatterPublisher =
    nh.advertise<std_msgs::String>("chatter", 1);
  ros::Rate loopRate(10);

  unsigned int count = 0;
  while (ros::ok()) {
    std_msgs::String message;
    message.data = "hello world " + std::to_string(count);
    ROS_INFO_STREAM(message.data);
    chatterPublisher.publish(message);
    ros::spinOnce();
    loopRate.sleep();
    count++;
  }
  return 0;
}
```

More info
http://wiki.ros.org/roscpp/Overview/Publishers%20and%20Subscribers

ROSCPP Publisher

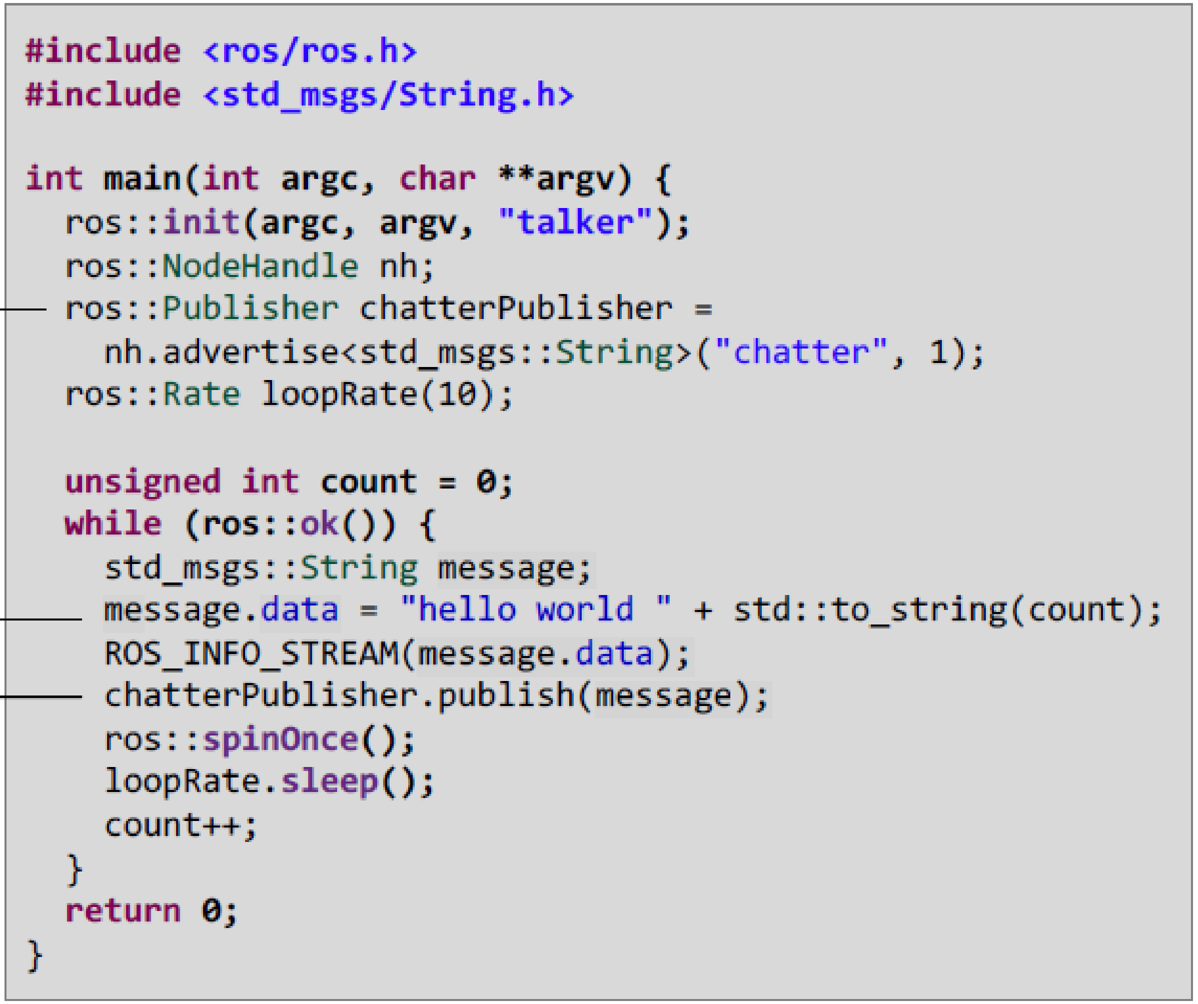
- Create a publisher with help of the node handle

```
ros::Publisher publisher =
nodeHandle.advertise<message_type>(topic,
queue_size);
```

- Create the message contents
- Publish the contents with

```
publisher.publish(message);
```

talker.cpp



```
#include <ros/ros.h>
#include <std_msgs/String.h>

int main(int argc, char **argv) {
  ros::init(argc, argv, "talker");
  ros::NodeHandle nh;
  ros::Publisher chatterPublisher =
    nh.advertise<std_msgs::String>("chatter", 1);
  ros::Rate loopRate(10);

  unsigned int count = 0;
  while (ros::ok()) {
    std_msgs::String message;
    message.data = "hello world " + std::to_string(count);
    ROS_INFO_STREAM(message.data);
    chatterPublisher.publish(message);
    ros::spinOnce();
    loopRate.sleep();
    count++;
  }
  return 0;
}
```

More info
http://wiki.ros.org/roscpp/Overview/Publishers%20and%20Subscribers

ROS Launch

- *launch* is a tool for launching multiple nodes (as well as setting parameters)
- Are written in XML as **.launch* files
- If not yet running, launch automatically starts a roscore

Browse to the folder and start a launch file with

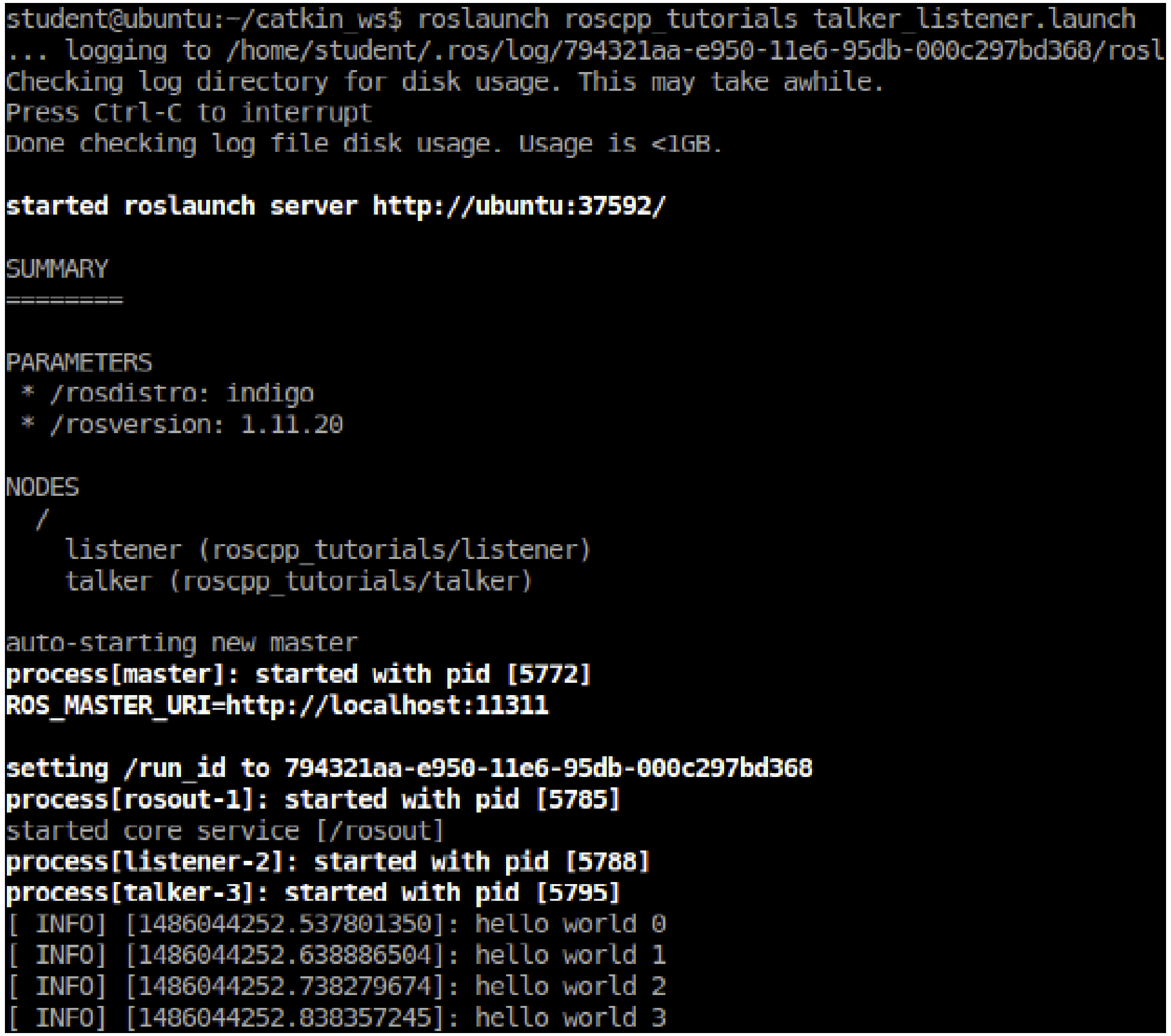
```
> roslaunch file_name.launch
```

Start a launch file from a package with

```
> roslaunch package_name file_name.launch
```

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

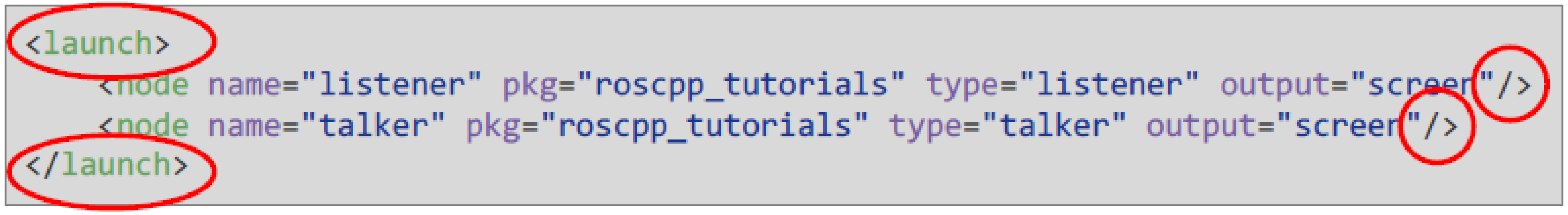
Example console output for
`roslaunch roscpp_tutorials talker_listener.launch`



```
student@ubuntu:~/catkin_ws$ roslaunch roscpp_tutorials talker_listener.launch
... logging to /home/student/.ros/log/794321aa-e950-11e6-95db-000c297bd368/rosl
Checking log directory for disk usage. This may take awhile.
Press Ctrl-C to interrupt
Done checking log file disk usage. Usage is <1GB.

started roslaunch server http://ubuntu:37592/

SUMMARY
========

PARAMETERS
 * /rosdistro: indigo
 * /rosversion: 1.11.20

NODES
  /
    listener (roscpp_tutorials/listener)
    talker (roscpp_tutorials/talker)

auto-starting new master
process[master]: started with pid [5772]
ROS_MASTER_URI=http://localhost:11311

setting /run_id to 794321aa-e950-11e6-95db-000c297bd368
process[rosout-1]: started with pid [5785]
started core service [/rosout]
process[listener-2]: started with pid [5788]
process[talker-3]: started with pid [5795]
[ INFO] [1486044252.537801350]: hello world 0
[ INFO] [1486044252.638886504]: hello world 1
[ INFO] [1486044252.738279674]: hello world 2
[ INFO] [1486044252.838357245]: hello world 3
```

ROS Launch: File format

talker_listener.launch



```
<launch>
    <node name="listener" pkg="roscpp_tutorials" type="listener" output="screen"/>
    <node name="talker" pkg="roscpp_tutorials" type="talker" output="screen"/>
</launch>
```

! Notice the syntax difference for self-closing tags: `<tag></tag>` and `<tag/>`

- **`launch`**: Root element of the launch file
- **node**: Each *<node>* tag specifies a node to be launched
- **name**: Name of the node (free to choose)
- **pkg**: Package containing the node
- **type**: Type of the node, there must be a corresponding executable with the same name
- **`output`**: Specifies where to output log messages (`screen`: console, `log`: log file)

More info
http://wiki.ros.org/roslaunch/XML
http://wiki.ros.org/roslaunch/Tutorials/Roslaunch%20tips%20for%20larger%20projects

ROS Launch: Arguments

- Create re-usable launch files with <arg> tag, which works like a parameter (default optional)

```
<arg name="arg_name" default="default_value"/>
```

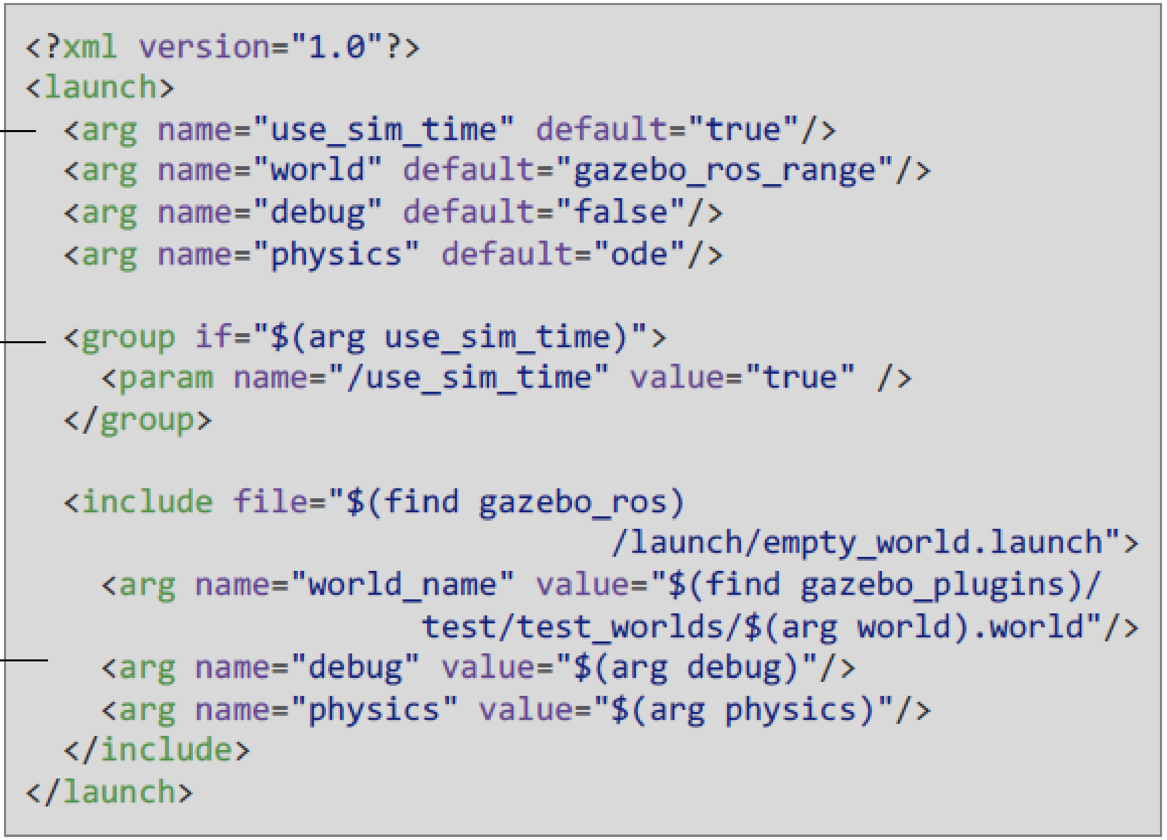
- Use arguments in launch file with

```
$(arg arg_name)
```

- When launching, arguments can be set with

```
> roslaunch launch_file.launch arg_name:=value
```

range_world.launch (simplified)



```
<?xml version="1.0"?>
<launch>
  <arg name="use_sim_time" default="true"/>
  <arg name="world" default="gazebo_ros_range"/>
  <arg name="debug" default="false"/>
  <arg name="physics" default="ode"/>

  <group if="$(arg use_sim_time)">
    <param name="/use_sim_time" value="true" />
  </group>

  <include file="$(find gazebo_ros)
                              /launch/empty_world.launch">
    <arg name="world_name" value="$(find gazebo_plugins)/
                    test/test_worlds/$(arg world).world"/>
    <arg name="debug" value="$(arg debug)"/>
    <arg name="physics" value="$(arg physics)"/>
  </include>
</launch>
```

More info
http://wiki.ros.org/roslaunch/XML/arg

ROS Launch:
Parameter server and YAML format

- Nodes use the *parameter server* to store and retrieve parameters at runtime
- Best used for static data such as configuration parameters
- Parameters can be defined in launch files or separate *YAML* files

List all parameters with

```
> rosparam list
```

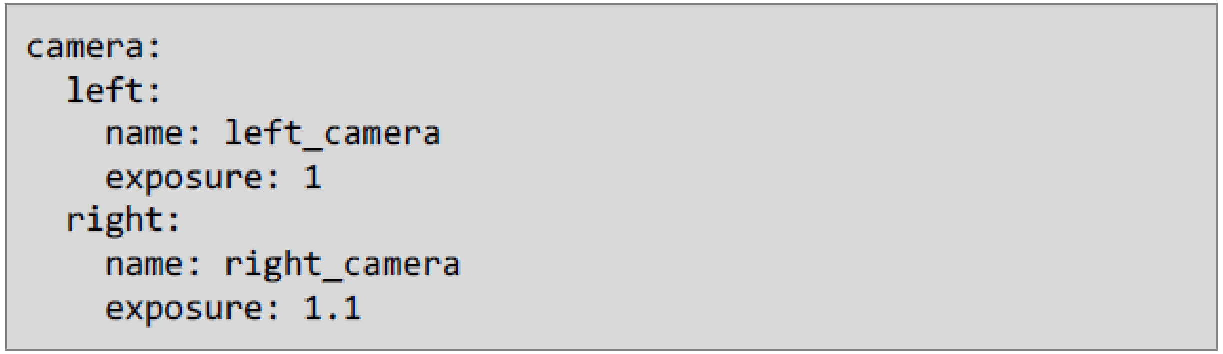
Get the value of a parameter with

```
> rosparam get parameter_name
```

Set the value of a parameter with

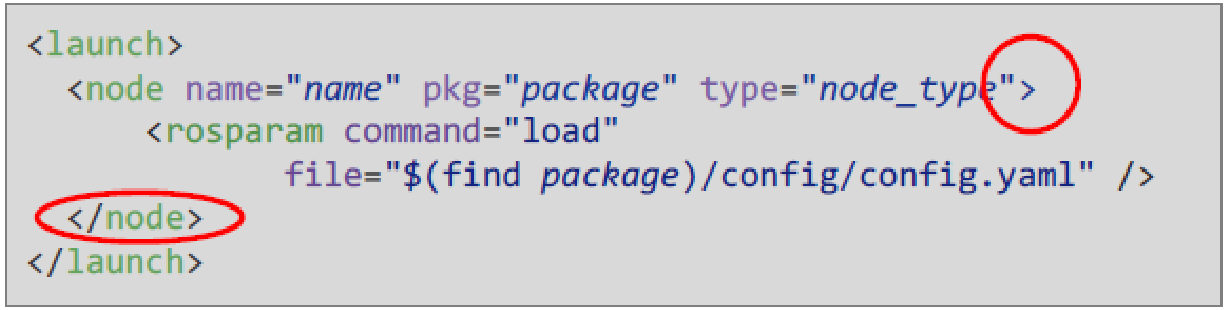
```
> rosparam set parameter_name value
```

config.yaml



```
camera:
  left:
    name: left_camera
    exposure: 1
  right:
    name: right_camera
    exposure: 1.1
```

package.launch



```
<launch>
  <node name="name" pkg="package" type="node_type">
      <rosparam command="load"
              file="$(find package)/config/config.yaml" />
  </node>
</launch>
```

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

ROSCPP: Parameter server

- Get a parameter in C++ with

```
nodeHandle.getParam(parameter_name, variable)
```

- Method returns `true` if parameter was found, `false` otherwise
- Global and relative parameter access:
  - Global parameter name with preceding /

  ```
  nodeHandle.getParam("/package/camera/left/exposure", variable)
  ```

  - Relative parameter name (relative to the node handle)

  ```
  nodeHandle.getParam("camera/left/exposure", variable)
  ```

- For parameters, typically use the private node handle `ros::NodeHandle("~")`

```
ros::NodeHandle nodeHandle("~");
std::string topic;
if (!nodeHandle.getParam("topic", topic)) {
  ROS_ERROR("Could not find topic
             parameter!");
}
```

More info
http://wiki.ros.org/roscpp/Overview/Parameter%20Server

ROSCPP: Node handle Types

- There are four main types of node handles

1. Default (public) node handle:
   `nh_ = ros::NodeHandle();`
2. Private node handle:
   `nh_private_ = ros::NodeHandle("~");`
3. Namespaced node handle:
   `nh_eth_ = ros::NodeHandle("eth");`
4. Global node handle:
   `nh_global_ = ros::NodeHandle("/");`

Recommended

Not recommended

For a ***node*** in ***namespace*** looking up ***topic***, these will resolve to:

```
/namespace/topic

/namespace/node/topic

/namespace/eth/topic

/topic
```

More info
http://wiki.ros.org/roscpp/Overview/NodeHandles

ROS Services

- Request/response communication between nodes is realized with *services*
  - The *service server* advertises the service
  - The *service client* accesses this service
- Similar in structure to messages, services are defined in **.srv* files

List available services with

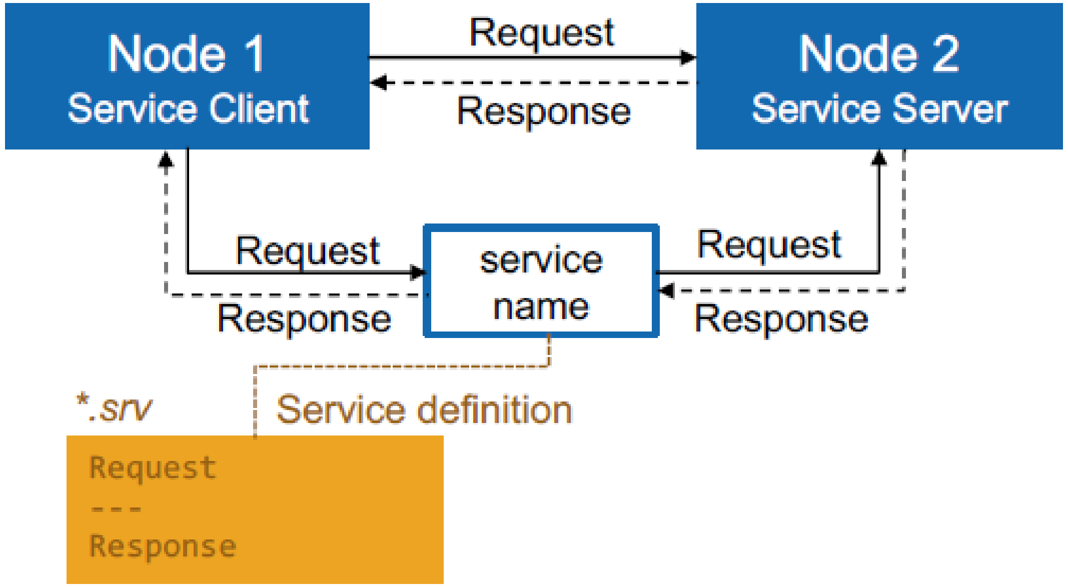
```
> rosservice list
```

Show the type of a service

```
> rosservice type /service_name
```

Call a service with the request contents

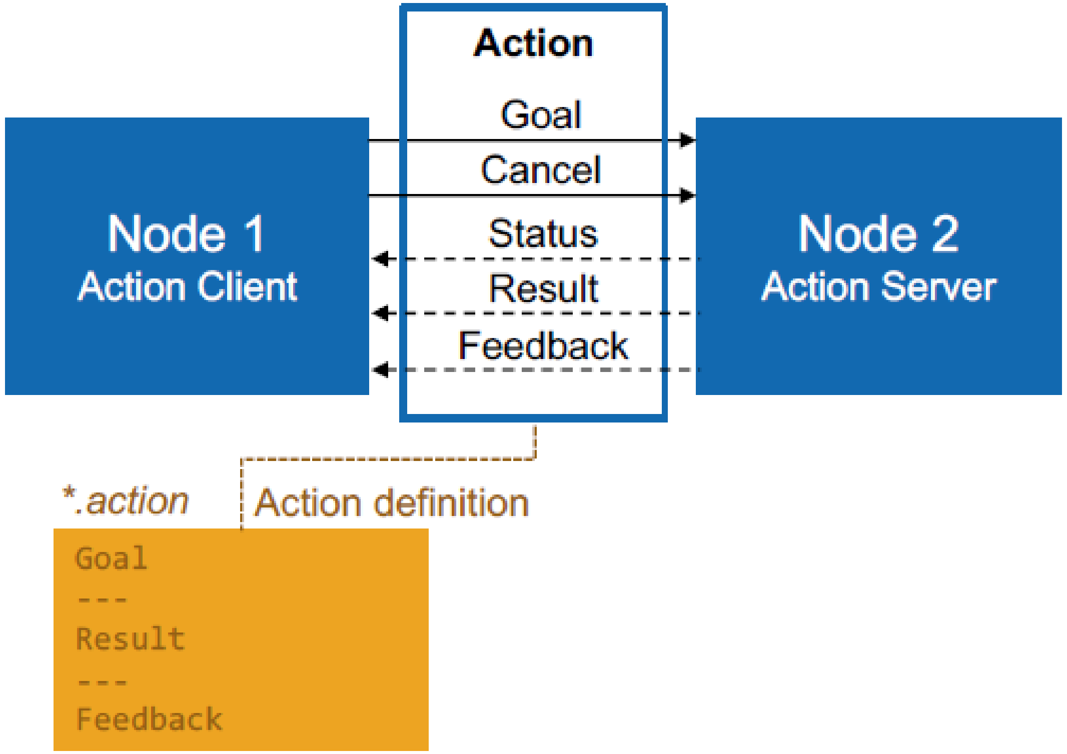
```
> rosservice call /service_name args
```



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

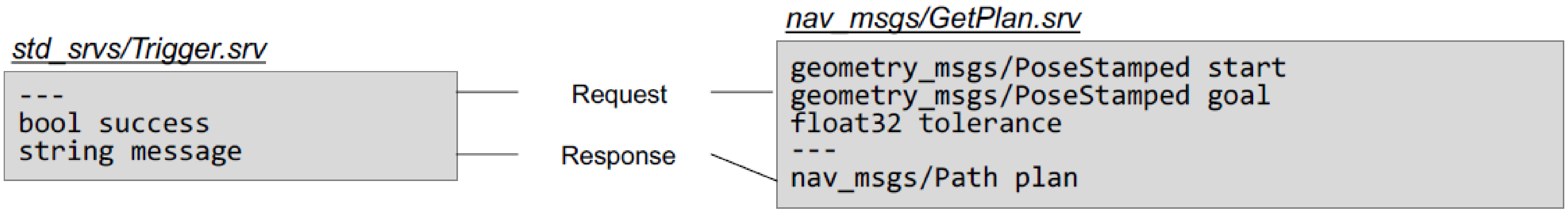
ROS Actions (actionlib)

- Similar to service calls, but provide possibility to
  - Cancel the task (preempt)
  - Receive feedback on the progress
- Best way to implement interfaces to time-extended, goal-oriented behaviors
- Similar in structure to services, action are defined in **.action* files
- Internally, actions are implemented with a set of topics



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

ROS Services and Actions Definition example

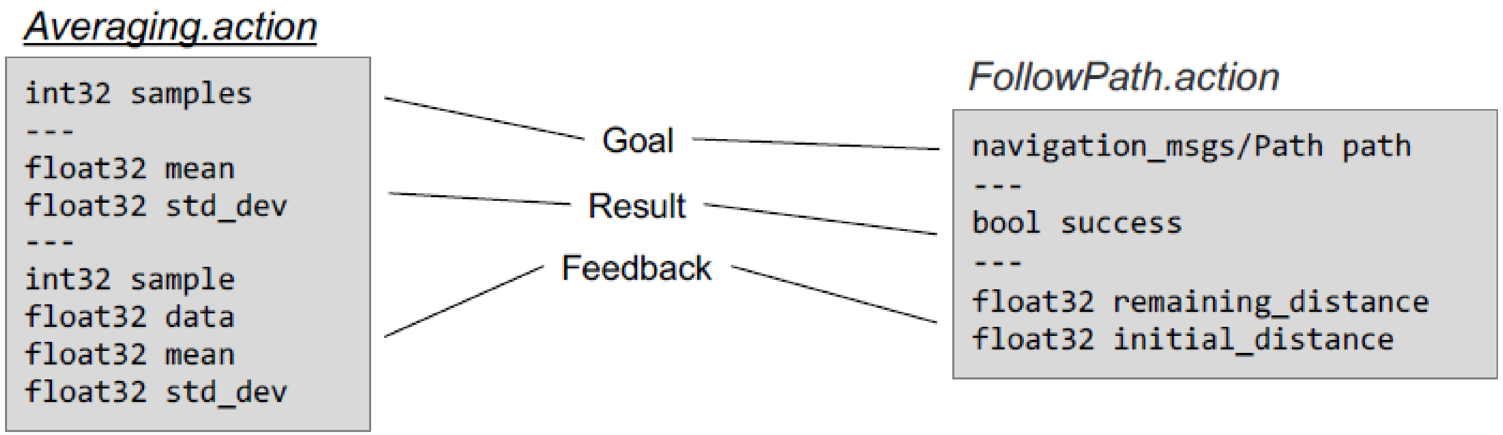


std_srvs/Trigger.srv

```
---
bool success
string message
```

nav_msgs/GetPlan.srv

```
geometry_msgs/PoseStamped start
geometry_msgs/PoseStamped goal
float32 tolerance
---
nav_msgs/Path plan
```



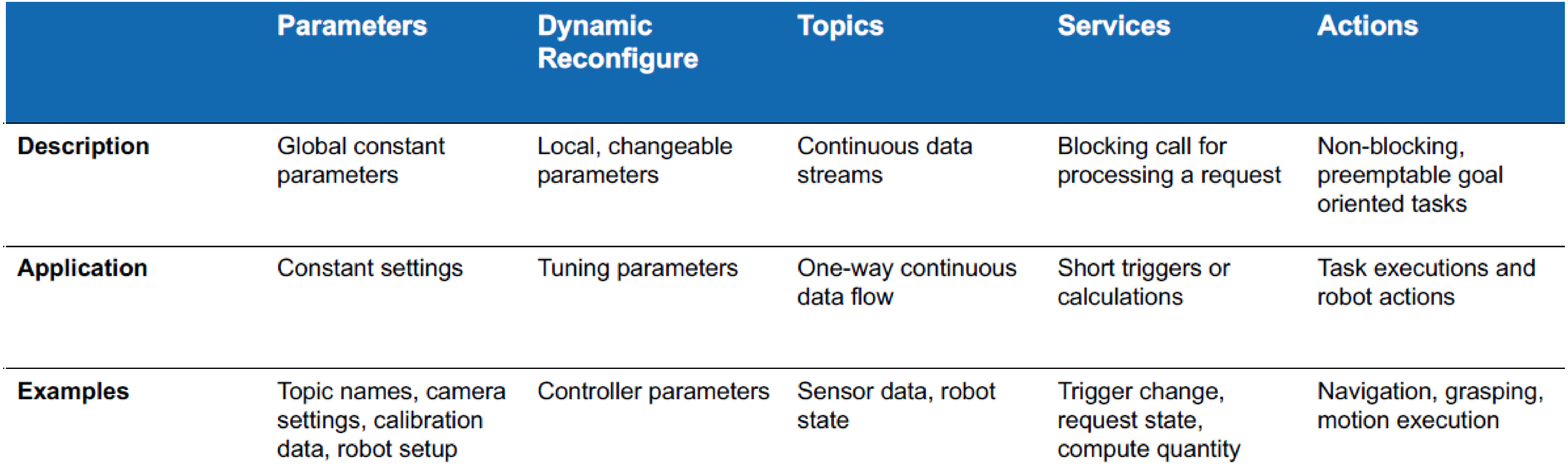
Averaging.action

```
int32 samples
---
float32 mean
float32 std_dev
---
int32 sample
float32 data
float32 mean
float32 std_dev
```

FollowPath.action

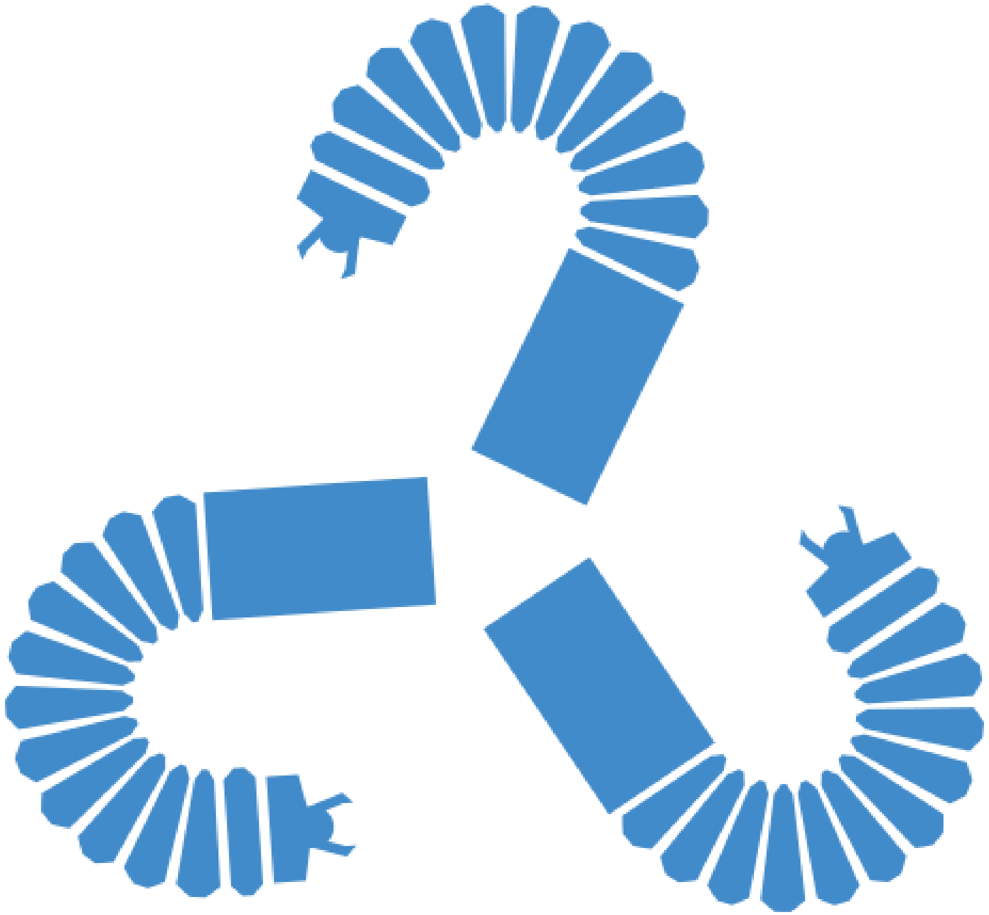
```
navigation_msgs/Path path
---
bool success
---
float32 remaining_distance
float32 initial_distance
```

ROS Parameters, Dynamic Reconfigure, Topics, Services, and Actions Comparison



	Parameters	Dynamic Reconfigure	Topics	Services	Actions
Description	Global constant parameters	Local, changeable parameters	Continuous data streams	Blocking call for processing a request	Non-blocking, preemptable goal oriented tasks
Application	Constant settings	Tuning parameters	One-way continuous data flow	Short triggers or calculations	Task executions and robot actions
Examples	Topic names, camera settings, calibration data, robot setup	Controller parameters	Sensor data, robot state	Trigger change, request state, compute quantity	Navigation, grasping, motion execution

Questions?

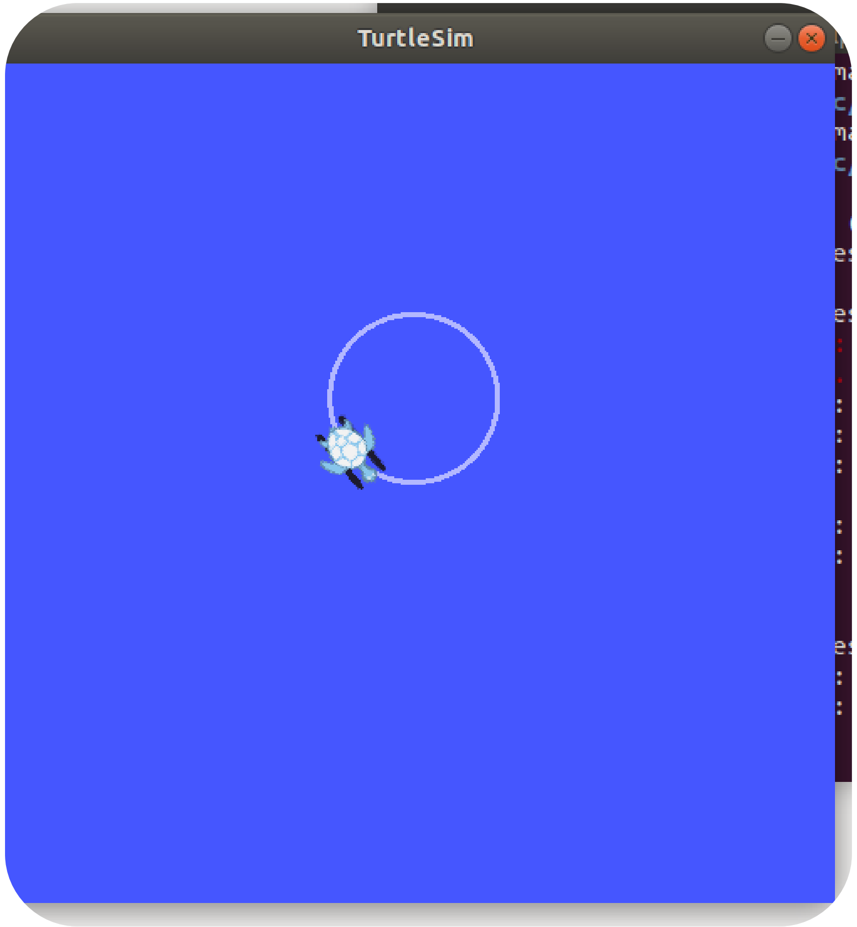


Exercises A

- Install the following Ubuntu package:
  ros-kinetic-ros-tutorials
- Understand *«turtlesim»* package
  - navigate package contents
  - run different nodes
  - understand the communication architecture
- Create a separate package in your catkin workspace able to move the turtle on a circular trajectory
- Use roslauch to set parameters (radius and speed)

turtlesim_node

turtle_teleop_key



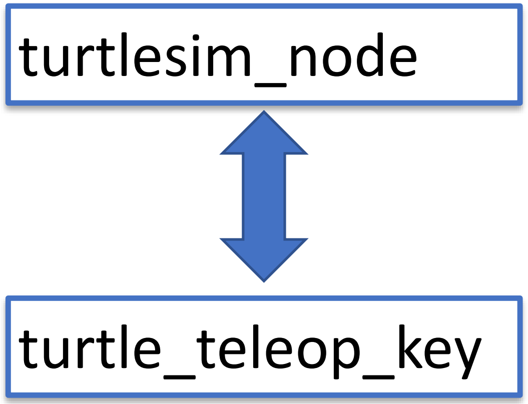
Exercises B

Remote teleoperation of turtle_bot:

- Following tutorial here:
  http://wiki.ros.org/ROS/Tutorials/MultipleMachines

- Run the turtlesim_node and the turtle_teleop_key on two different machine

- Introduce a node publishing a status message able to change the spinning direction of the node previously implemented (modification requred)



turtlesim_node

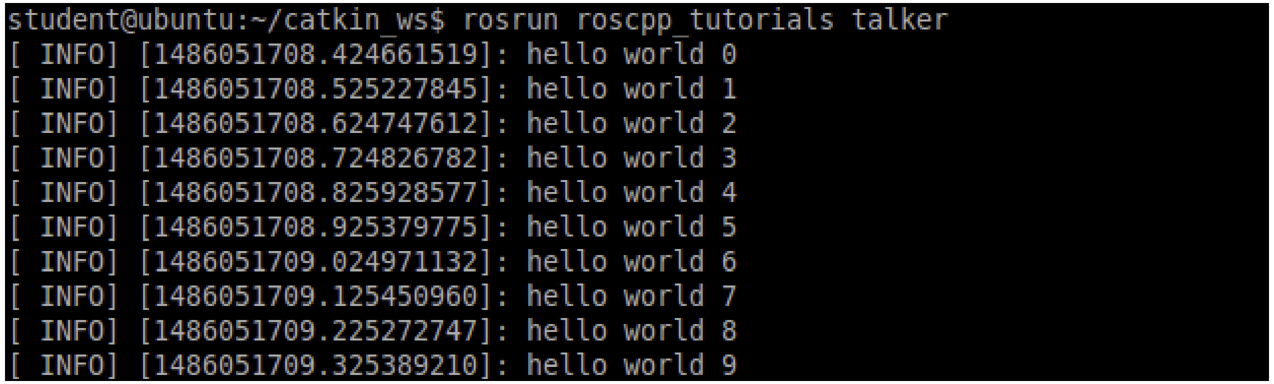
turtle_teleop_key

Exercises B

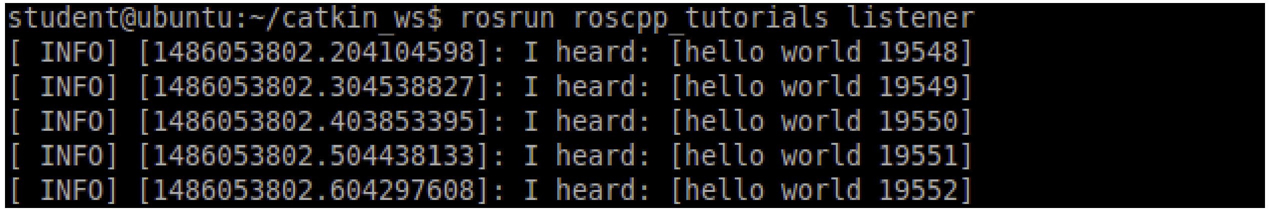
Implement the talker → listener example (following C++ or python tutorial)

Modify the code for printing the following string «Hello world from ESRxx counter»

Run a single listener for all the talker implemented



```
student@ubuntu:~/catkin_ws$ rosrun roscpp_tutorials talker
[ INFO] [1486051708.424661519]: hello world 0
[ INFO] [1486051708.525227845]: hello world 1
[ INFO] [1486051708.624747612]: hello world 2
[ INFO] [1486051708.724826782]: hello world 3
[ INFO] [1486051708.825928577]: hello world 4
[ INFO] [1486051708.925379775]: hello world 5
[ INFO] [1486051709.024971132]: hello world 6
[ INFO] [1486051709.125450960]: hello world 7
[ INFO] [1486051709.225272747]: hello world 8
[ INFO] [1486051709.325389210]: hello world 9
```



```
student@ubuntu:~/catkin_ws$ rosrun roscpp_tutorials listener
[ INFO] [1486053802.204104598]: I heard: [hello world 19548]
[ INFO] [1486053802.304538827]: I heard: [hello world 19549]
[ INFO] [1486053802.403853395]: I heard: [hello world 19550]
[ INFO] [1486053802.504438133]: I heard: [hello world 19551]
[ INFO] [1486053802.604297608]: I heard: [hello world 19552]
```