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Programming for Robotics
Introduction to ROS

Course 2

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Robotic Systems Lab

Course Structure

Course 1	Course 2	Course 3	Course 4	Course 5
Lecture 1	Deadline for Ex. 1.	Deadline for Ex. 2.	Deadline for Ex. 3.	Multiple Choice Test
Exercise 1 Intro.	Lecture 2	Lecture 3	Lecture 4	Deadline for Ex. 4.
Exercise 1	Exercise 2 Intro.	Exercise 3 Intro.	Exercise 4 Intro.	Case Study
	Exercise 2	Exercise 3	Exercise 4	Exercise 5 Intro.
				Exercise 5
				Deadline for Ex. 5.

Overview Course 2

- ROS package structure
- Integration and programming with Eclipse
- ROS C++ client library (roscpp)
- ROS subscribers and publishers
- ROS parameter server
- RViz visualization

ROS Packages

- 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*

To create a new package, use

```
> catkin_create_pkg package_name
    {dependencies}
```

Separate message definition packages from other packages!

package_name

- **config** Parameter files (YAML)
- **include/*package_name*** C++ include headers
- **launch** *.launch files
- **src** Source files
- **test** Unit/ROS tests
- **CMakeLists.txt** CMake build file
- **package.xml** Package information

package_name_msgs

- **action** Action definitions
- **msg** Message definitions
- **srv** Service definitions
- **CMakeLists.txt** Cmake build file
- **package.xml** Package information

More info
wiki.ros.org/Packages

ROS Packages
package.xml

- The `package.xml` file defines the properties of the package
  - Package name
  - Version number
  - Authors
  - **Dependencies on other packages**
  - …

package.xml

```xml
<?xml version="1.0"?>
<package format="2">
   <name>ros_package_template</name>
   <version>0.1.0</version>
   <description>A ROS package that...</description>
   <maintainer email="tlankhorst@ethz.ch">Tom Lankhorst</maintainer>
   <license>BSD</license>
   <url type="website">https://github.com/leggedrobotics/ros_…</url>
   <author email="tlankhorst@ethz.ch">Tom Lankhorst</author>

   <buildtool_depend>catkin</buildtool_depend>

   <depend>roscpp</depend>
   <depend>std_msgs</depend>

   <build_depend>message_generation</build_depend>
</package>
```

More info
wiki.ros.org/catkin/package.xml

ROS Packages
CMakeLists.xml

The `CMakeLists.txt` is input to the CMake build system

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

CMakeLists.txt

```
cmake_minimum_required (VERSION 3.10.2 )
project (ros_package_template )

## Use C++14, or 11…
set (CMAKE_CXX_STANDARD 14 )
set (CMAKE_CXX_STANDARD_REQUIRED TRUE )

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

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

ROS Packages
CMakeLists.xml Example

```
cmake_minimum_required(VERSION 3.10.2)
project(smb_highlevel_controller)

set(CMAKE_CXX_STANDARD 11)
set(CMAKE_CXX_STANDARD_REQUIRED TRUE)

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/SmbHighlevelController.cpp)

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

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

Use C++11 by default (or 14)

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 an executable, the node, with two src files

Specify libraries to link the executable against

Setup a Project in Eclipse

- Build the Eclipse project files with additional build flags

```
> catkin build package_name -G"Eclipse CDT4 - Unix Makefiles"
```

- To use flags by default in your catkin environment, use the `catkin config` command. E.g., to build in release mode:

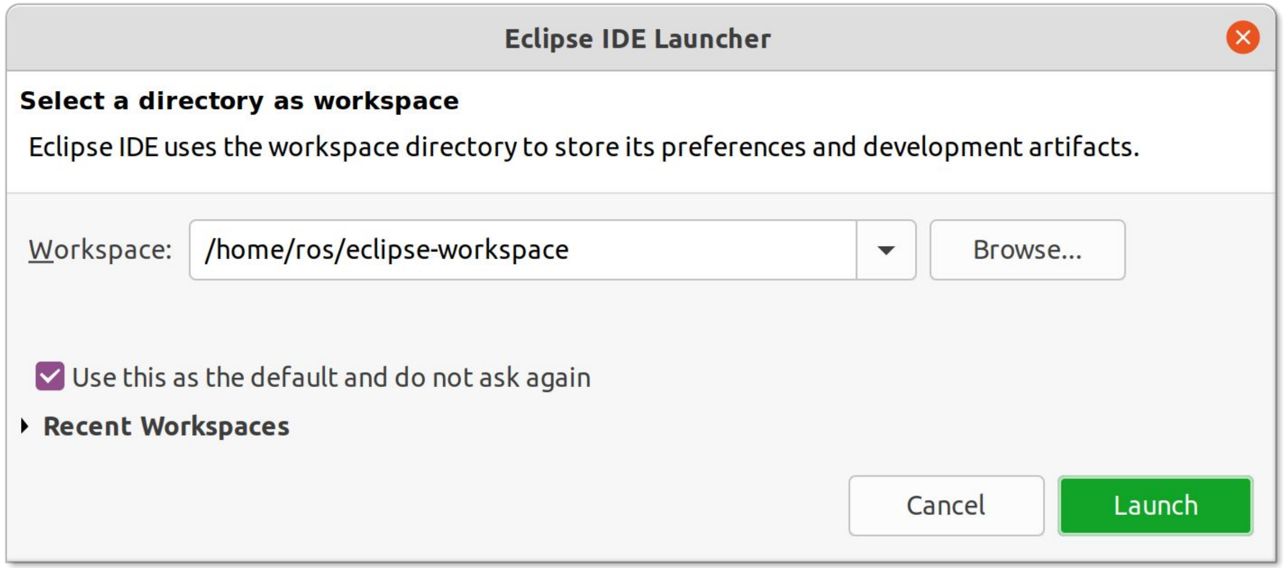
```
> catkin config -G"Eclipse CDT4 - Unix Makefiles"
```

- The Eclipse project files will be generated in the build folder, in e.g.: `~/Workspaces/smb_ws/build`

More info
catkin-tools.readthedocs.io/en/latest/verbs/catkin_config.html
github.com/leggedrobotics/ros_best_practices/wiki#catkin-build-flags

Setup a Project in Eclipse

- Start Eclipse and set the workspace folder



Eclipse IDE Launcher

Select a directory as workspace

Eclipse IDE uses the workspace directory to store its preferences and development artifacts.

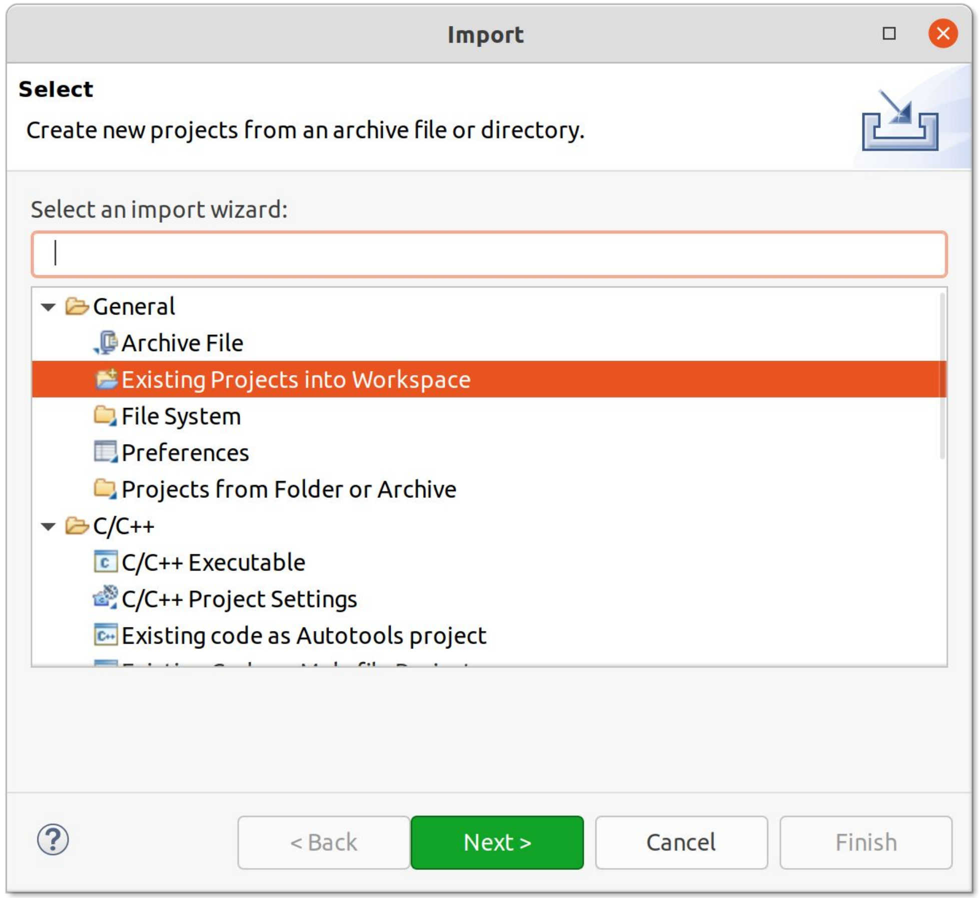
Workspace: /home/ros/eclipse-workspace

[✓] Use this as the default and do not ask again

Setup a Project in Eclipse

- Import your project to Eclipse

  File > Import > General
  > Existing Projects into Workspace


Import

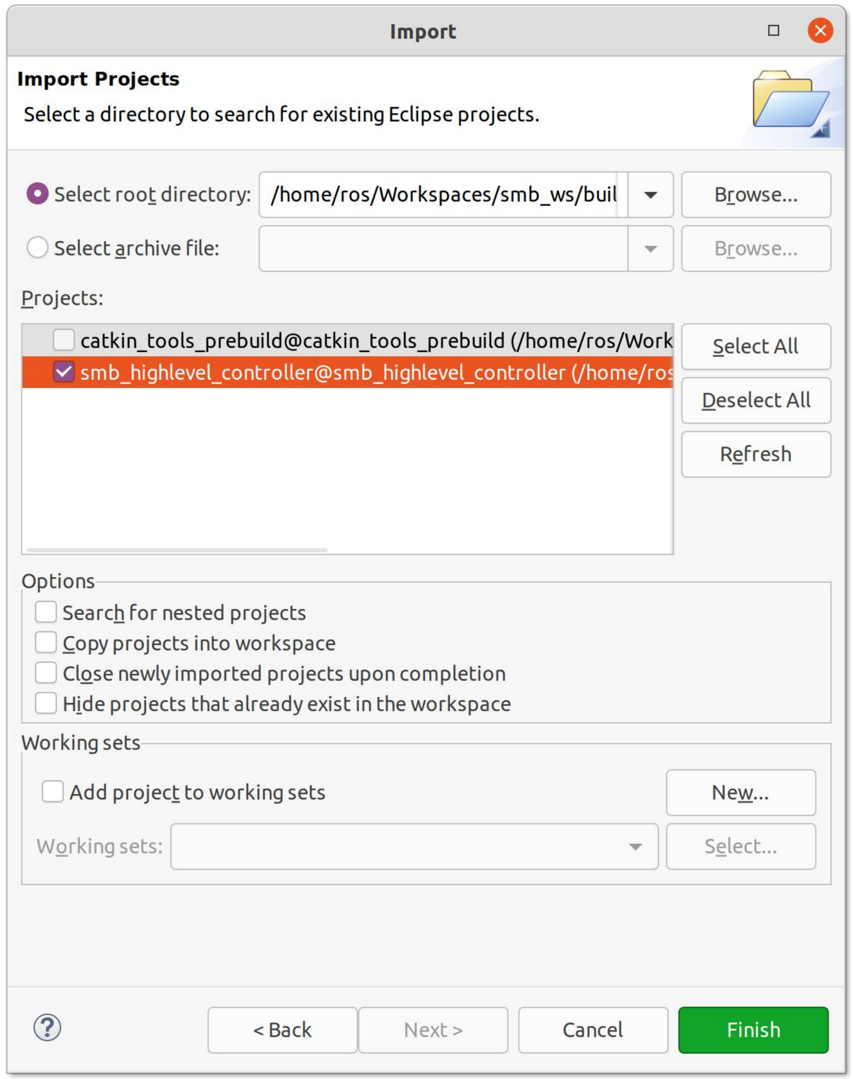
Select

Create new projects from an archive file or directory.

Select an import wizard:

Setup a Project in Eclipse

- The project files can be imported from the ROS workspace folder



Import

Import Projects

Select a directory to search for existing Eclipse projects.

[✓ Select root directory:] /home/ros/Workspaces/smb_ws/buil

Select archive file:

Projects:

- [ ] catkin_tools_prebuild@catkin_tools_prebuild (/home/ros/Work
- [✓] smb_highlevel_controller@smb_highlevel_controller (/home/ros

Options

- [ ] Search for nested projects
- [ ] Copy projects into workspace
- [ ] Close newly imported projects upon completion
- [ ] Hide projects that already exist in the workspace

Working sets

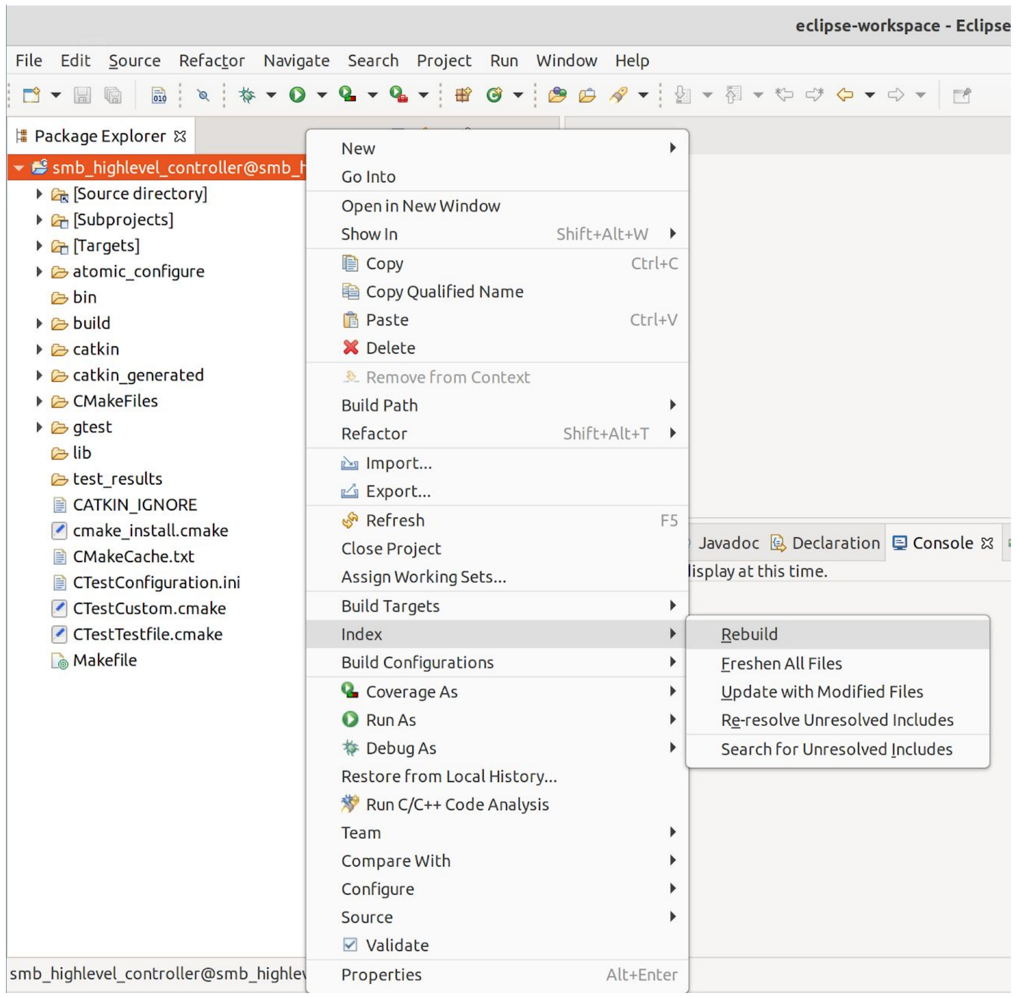
- [ ] Add project to working sets

Working sets:

Setup a Project in Eclipse

- Rebuild the C/C++ index of your project by Right click on Project □ Index □ Rebuild

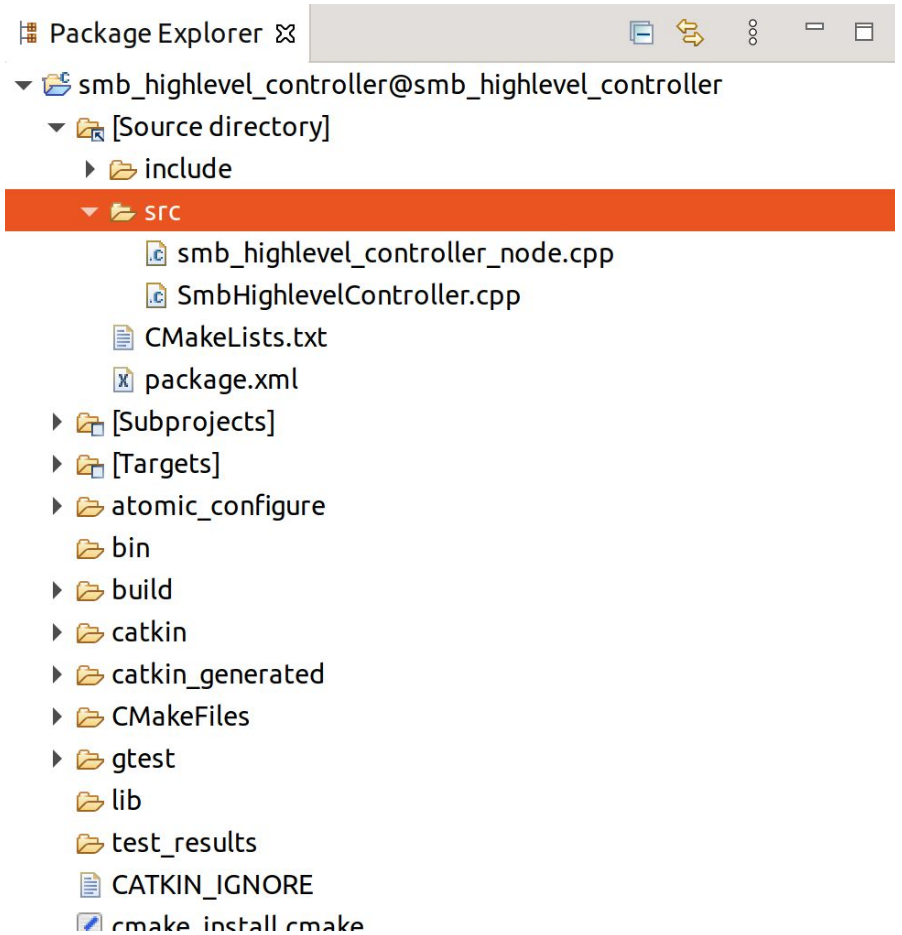
- Resolving the includes enables
  - Fast navigation through links (`Ctrl` + click)
  - Auto-completion (`Ctrl` + `Space`)
  - Building (`Ctrl` + `B`) and debugging your code in Eclipse



Setup a Project in Eclipse

- Within the project a link `[Source directory]` is provided such that you can edit your project

- Useful Eclipse shortcuts
  - `Ctrl` + `Space`: Auto-complete
  - `Ctrl` + `/`: Comment / uncomment line or section
  - `Ctrl` + `Shift` + `F`: Auto-format code using code formatter
  - `Alt` + `Arrow Up / Arrow Down`: Move line or selection up or down
  - `Ctrl` + `D`: Delete line



```
Package Explorer
smb_highlevel_controller@smb_highlevel_controller
  [Source directory]
    include
    src
      smb_highlevel_controller_node.cpp
      SmbHighlevelController.cpp
    CMakeLists.txt
    package.xml
  [Subprojects]
  [Targets]
  atomic_configure
  bin
  build
  catkin
  catkin_generated
  CMakeFiles
  gtest
  lib
  test_results
  CATKIN_IGNORE
  cmake_install.cmake
```

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Other IDEs

- Underlying CMake build-systems provides flexibility

wiki.ros.org/IDEs

- E.g.:
  - CLion
  - Vim
  - VSCode

Not supported during the course

Robotic Systems Lab

ROS C++ Client Library (roscpp)

Essential components of the client library

- Initialization and spinning
- Node handle
- Logging
- Subscriber / Publisher
- Parameters

Discussed in lecture 4

- Services
- Actions
- Time

ROS C++ Client Library (*roscpp*)

Initialization and spinning

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 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
wiki.ros.org/roscpp
wiki.ros.org/roscpp/Overview

ROS C++ Client Library (*roscpp*)
Node Handle

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

- There are four main types of node handles

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

Recommended (1, 2)

Not recommended (4)

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

ROS C++ Client Library (*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, etc.)
- Supports both printf- and stream-style formatting

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

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

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

! 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
wiki.ros.org/rosconsole
wiki.ros.org/roscpp/Overview/Logging

ROS C++ Client Library (*roscpp*)
Subscriber

- When a message is received, callback function is called with the contents of the message as argument
- Start listening to a topic by calling the method `subscribe()` of the node handle

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

- 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
wiki.ros.org/roscpp/Overview/Publishers%20and%20Subscribers

ROS C++ Client Library (*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);
```

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

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;
}
```

ROS C++ Client Library (*roscpp*)
Object Oriented Programming

my_package_node.cpp

```
#include <ros/ros.h>
#include "my_package/MyPackage.hpp"
int main(int argc, char* argv[])
{
  ros::init(argc, argv, "my_package");
  ros::NodeHandle nodeHandle("~");

  my_package::MyPackage myPackage(nodeHandle);

  ros::spin();
  return 0;
}
```

MyPackage.hpp

MyPackage.cpp

Algorithm.hpp

Algorithm.cpp

class MyPackage

Main node class providing ROS interface (subscribers, parameters, timers etc.)

class Algorithm

Class implementing the algorithmic part of the node

Note: The algorithmic part of the code could be separated in a (ROS-independent) library

! Specify a function handler to a method from within the class as

```
subscriber_ = nodeHandle_.subscribe(topic, queue_size,
&ClassName::methodName, this);
```

More info
wiki.ros.org/roscpp_tutorials/Tutorials/UsingClassMethodsAsCallbacks

ROS Parameter Server

- 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
wiki.ros.org/rosparam

ROS C++ Client Library (*roscpp*)
Parameters

- 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!");
}
ROS_INFO_STREAM("Read topic: " << topic);
```

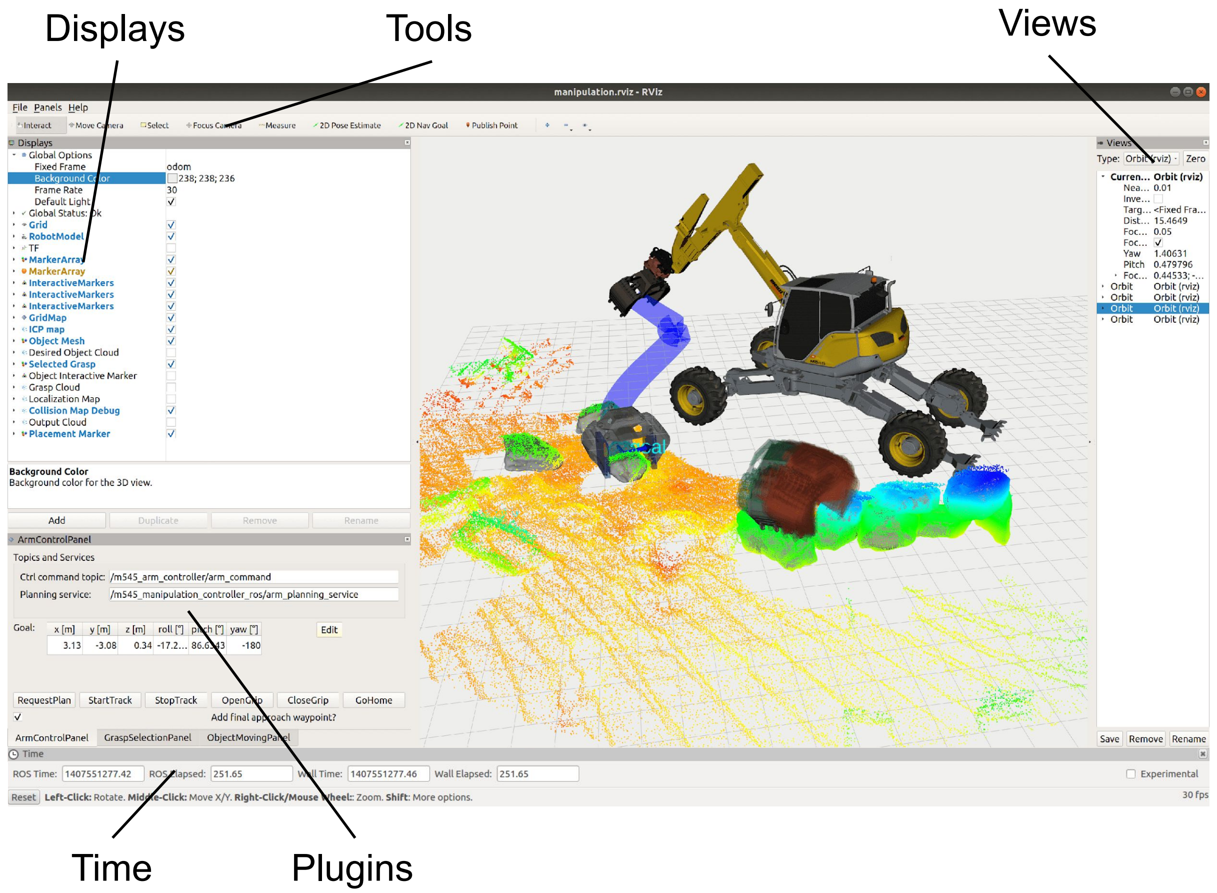
More info
wiki.ros.org/roscpp/Overview/Parameter%20Server

RViz

- 3D visualization tool for ROS
- Subscribes to topics and visualizes the message contents
- Different camera views (orthographic, top-down, etc.)
- Interactive tools to publish user information
- Save and load setup as RViz configuration
- Extensible with plugins

Run RViz with

```
> rviz
```



Displays

Global Options	
Fixed Frame	odom
Background Color	238; 238; 236
Frame Rate	30
Default Light	✓
Global Status: Ok	
Grid	✓
RobotModel	✓
TF	
MarkerArray	✓
MarkerArray	✓
InteractiveMarkers	✓
InteractiveMarkers	✓
InteractiveMarkers	✓
GridMap	✓
ICP map	✓
Object Mesh	✓
Desired Object Cloud	
Selected Grasp	✓
Object Interactive Marker	
Grasp Cloud	
Localization Map	
Collision Map Debug	✓
Output Cloud	
Placement Marker	✓

Background Color
Background color for the 3D view.

ArmControlPanel

Topics and Services

Ctrl command topic: /m545_arm_controller/arm_command
Planning service: /m545_manipulation_controller_ros/arm_planning_service

Goal:

x [m]	y [m]	z [m]	roll [°]	pitch [°]	yaw [°]
3.13	-3.08	0.34	-17.2…	86.6343	-180

✓ Add final approach waypoint?

Views

Type: Orbit (rviz) Zero

Curren…	Orbit (rviz)
Nea…	0.01
Inve…	
Targ…	<Fixed Fra…
Dist…	15.4649
Foc…	0.05
Foc…	✓
Yaw	1.40631
Pitch	0.479796
Foc…	0.44533; -…
Orbit	Orbit (rviz)
Orbit	Orbit (rviz)
Orbit	Orbit (rviz)
Orbit	Orbit (rviz)

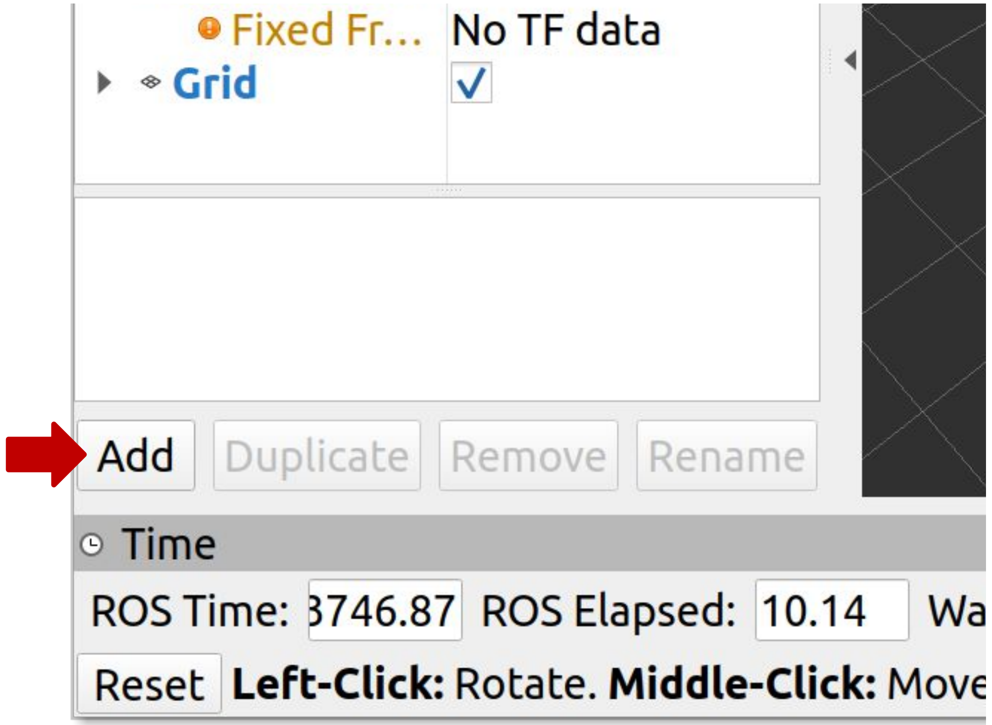
Time

ROS Time: 1407551277.42 ROS Elapsed: 251.65 Wall Time: 1407551277.46 Wall Elapsed: 251.65 ☐ Experimental

Left-Click: Rotate. **Middle-Click:** Move X/Y. **Right-Click/Mouse Wheel:**: Zoom. **Shift:** More options. 30 fps

More info
wiki.ros.org/rviz

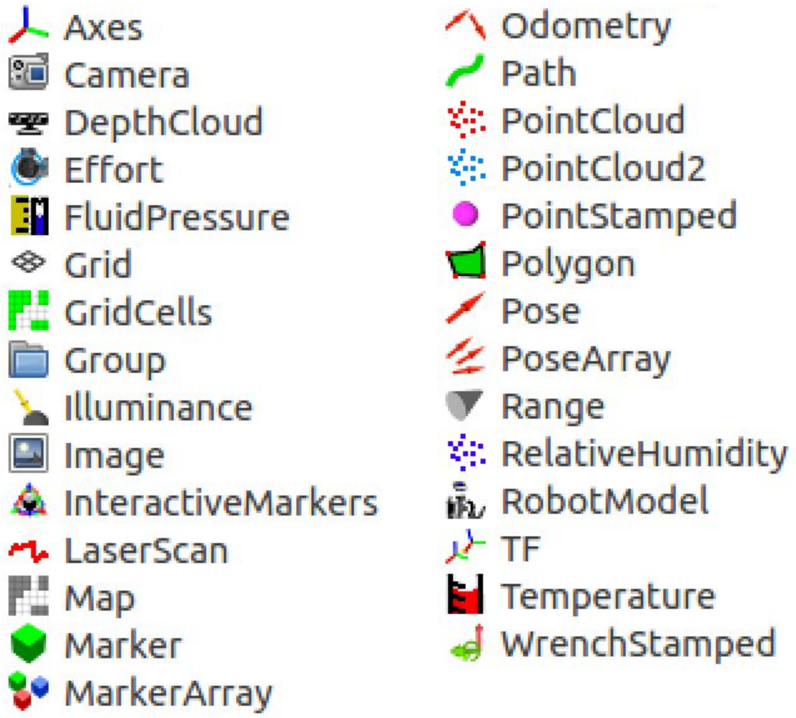
RViz
Display Plugins



ROS Time: 3746.87 ROS Elapsed: 10.14 Wa

Reset **Left-Click:** Rotate. **Middle-Click:** Move

Save configuration with `Ctrl + S`



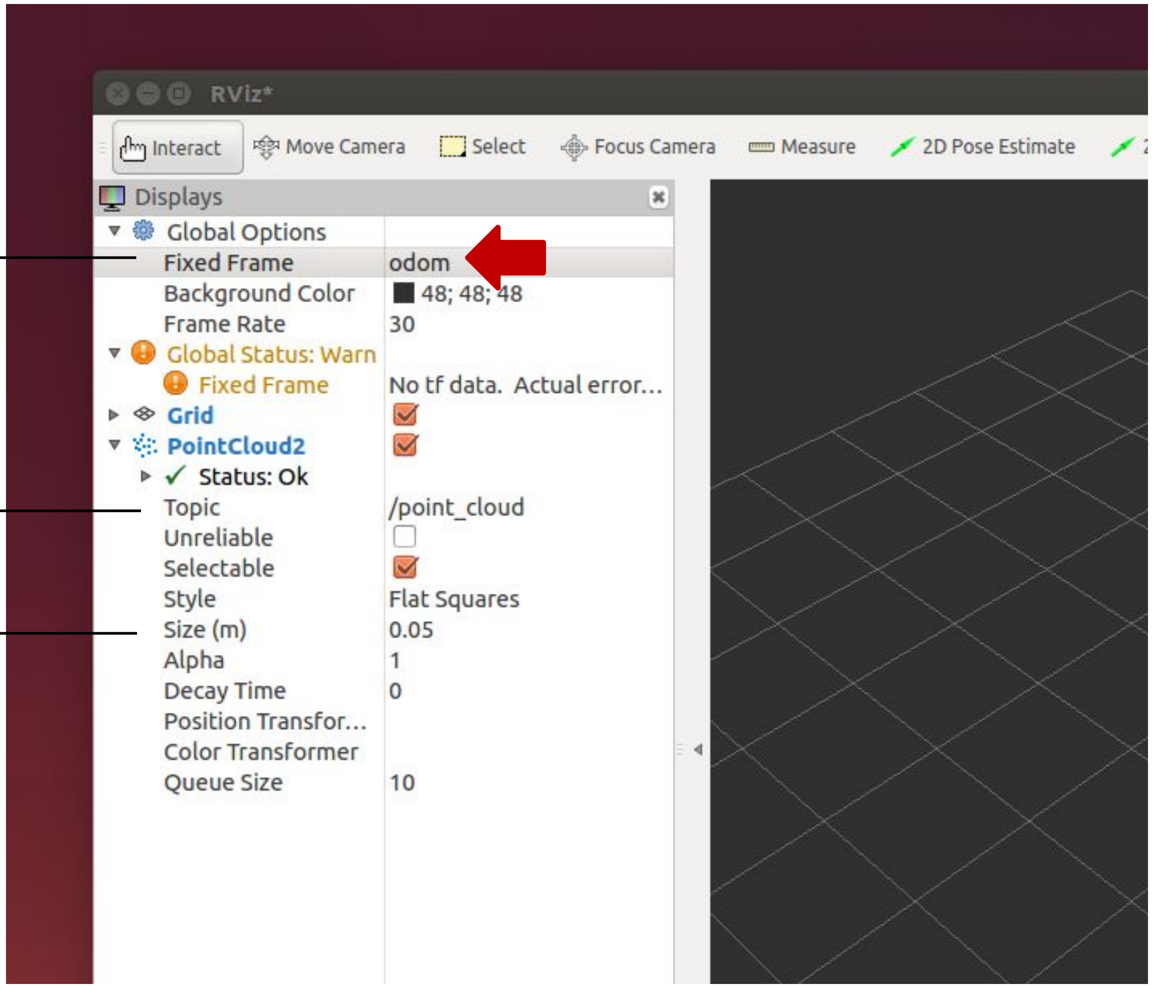
Axes
Camera
DepthCloud
Effort
FluidPressure
Grid
GridCells
Group
Illuminance
Image
InteractiveMarkers
LaserScan
Map
Marker
MarkerArray
Odometry
Path
PointCloud
PointCloud2
PointStamped
Polygon
Pose
PoseArray
Range
RelativeHumidity
RobotModel
TF
Temperature
WrenchStamped

RViz
Visualizing Point Clouds Example

! Frame in which the data is displayed (has to exist!)

Choose the topic for the display

Change the display options (e.g. size)



Global Options	
Fixed Frame	odom
Background Color	■ 48; 48; 48
Frame Rate	30
Global Status: Warn	
Fixed Frame	No tf data. Actual error...
Grid	✓
PointCloud2	✓
✓ Status: Ok	
Topic	/point_cloud
Unreliable	☐
Selectable	✓
Style	Flat Squares
Size (m)	0.05
Alpha	1
Decay Time	0
Position Transfor...	
Color Transformer	
Queue Size	10

Further References

- **ROS Wiki**
  - https://wiki.ros.org/
- **Installation**
  - https://wiki.ros.org/ROS/Installation
- **Tutorials**
  - https://wiki.ros.org/ROS/Tutorials
- **Available packages**
  - https://www.ros.org/browse/
- **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
- **ROS Cheat Sheet**
  - https://kapeli.com/cheat_sheets/ROS.docset/Contents/Resources/Documents/index

Contact Information

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Course website:
rsl.ethz.ch/education-students/lectures/ros.html