ETH zürich

Programming for Robotics
Introduction to ROS

Course 1

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ROS

RSL Robotic Systems Lab

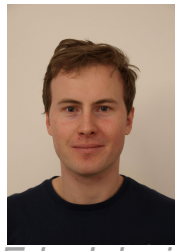
Overview

Edo Jelavic

- **Course 1**
  - ROS architecture & philosophy
  - ROS master, nodes, and topics
  - Console commands
  - Catkin workspace and build system
  - Launch-files
  - Gazebo simulator

Tom Lankhorst

- **Course 2**
  - ROS package structure
  - Integration and programming with Eclipse
  - ROS C++ client library (roscpp)
  - ROS subscribers and publishers
  - ROS parameter server
  - RViz visualization



Edo Jelavic

- **Course 3**
  - TF Transformation System
  - rqt User Interface
  - Robot models (URDF)
  - Simulation descriptions (SDF)

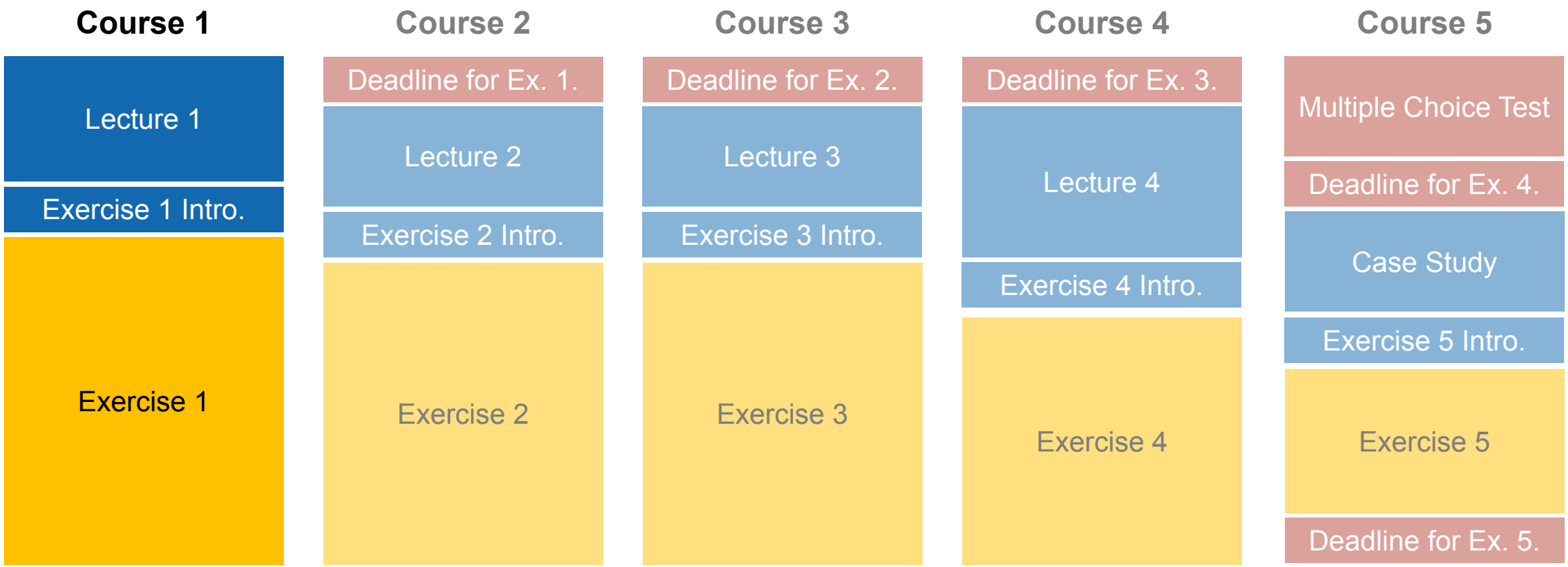
Tom Lankhorst

- **Course 4**
  - ROS services
  - ROS actions (actionlib)
  - ROS time
  - ROS bags
  - Intro to ROS2

Harmish & Max
ANYbotics AG

- **Course 5**
  - Case study

Course Structure



Course Logistics

- We have three sessions
  - Grading ~~(08:00 – 08:45)~~ (08:00-09:15)
  - Lectures ~~(08:45-10:00)~~ (09:15-10:00)
  - Exercises (10:00 – 12:00)
- **The lectures start at ~~08:45~~ 9:15**

Exercises

- Each exercise has several check questions
- Each exercise counts for 10% of the final grade (50 % in total)
- We encourage team work, but every student has to show the results on their own PC and is evaluated individually
- There are 7 TAs, each has a group of students assigned
- The TA will be in the zoom call with you (10:00 - 12:00)

Evaluation – Exercises

- Exercises are checked by the teaching assistants when you are ready, but latest the following course day in the grading sessions
- Grading sessions (~~08:00 – 08:45~~, 08:00-09:15 except for exercise 5)
- The TA will take you in a separate breakout room
- After that you leave the grading session
- Let the teaching assistant know once you are ready to present your results

Evaluation – Multiple Choice Test

- The test counts for 50 % of the final grade
- Duration: 45min
- The test will be in person
- The multiple choice test takes place at the last course day:

05.03.2021 at 08:00

Overview Course 1

- ROS architecture & philosophy
- ROS master, nodes, and topics
- Console commands
- Catkin workspace and build system
- Launch-files
- Gazebo simulator

What is ROS?

ROS = Robot Operating System

History of ROS

- Originally developed in 2007 at the Stanford Artificial Intelligence Laboratory
- Since 2013 managed by OSRF
- Today used by many robots, universities and companies
- De facto standard for robot programming

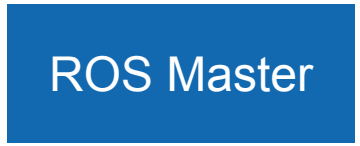
ros.org

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, 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 Master

- Manages the communication between nodes (processes)
- Every node registers at startup with the master



Start a master with

```
> roscore
```

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

ROS Nodes

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

Run a node with

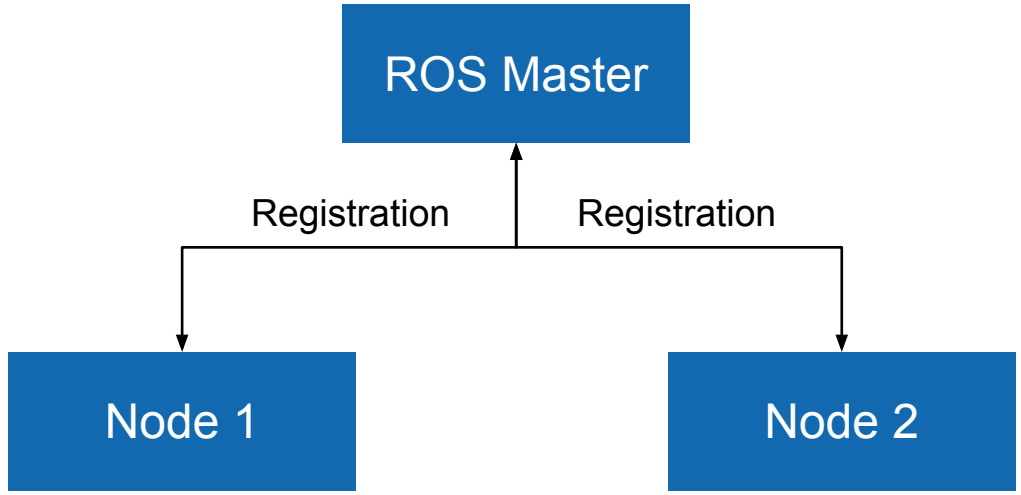
```
> rosrun package_name node_name
```

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

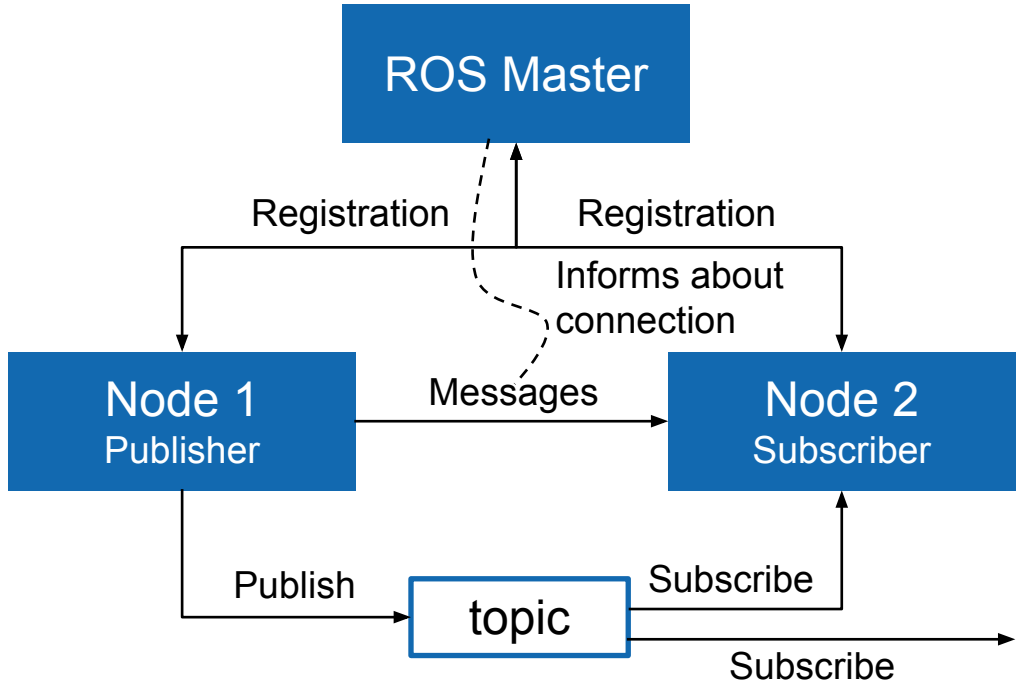
```
> rostopic list
```

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

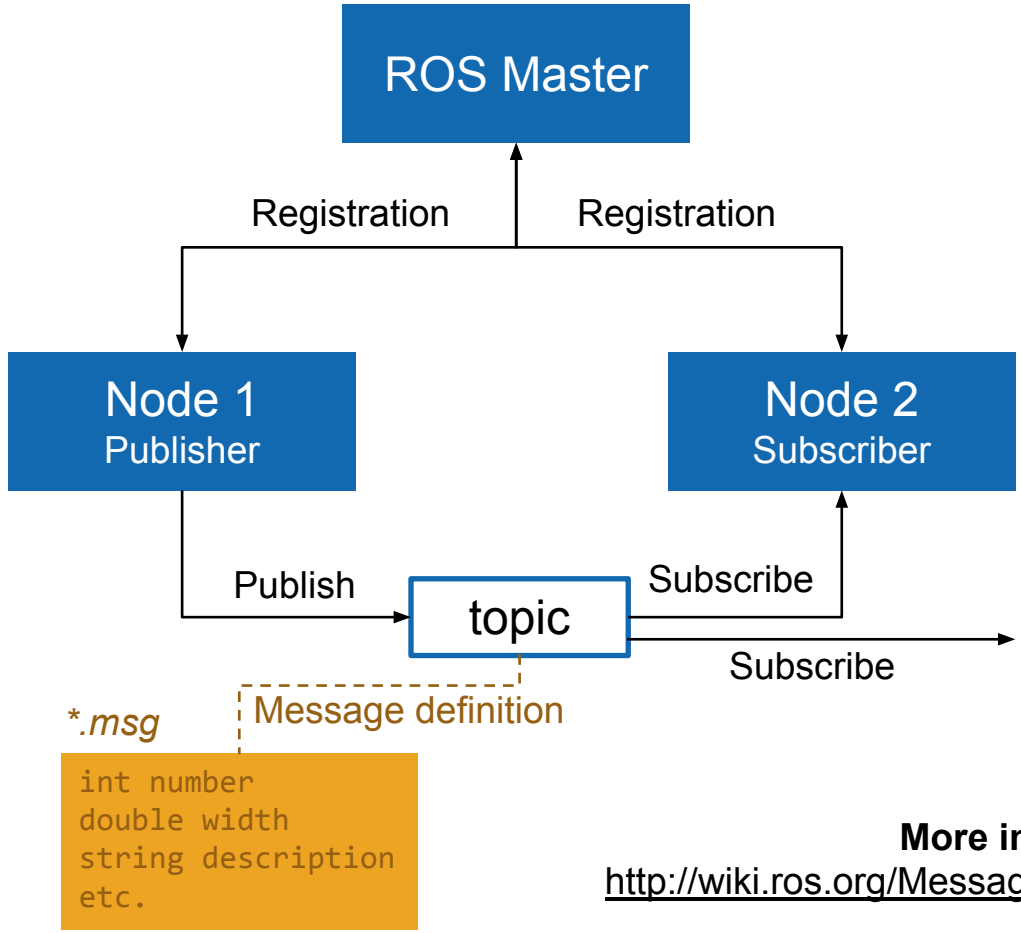
- Data structure defining the *type* of a topic
- Comprised of a nested structure of integers, floats, booleans, strings etc. and arrays of objects
- Defined in **.msg* files

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

ROS Messages
Pose Stamped Example

geometry_msgs/Point.msg

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

sensor_msgs/Image.msg

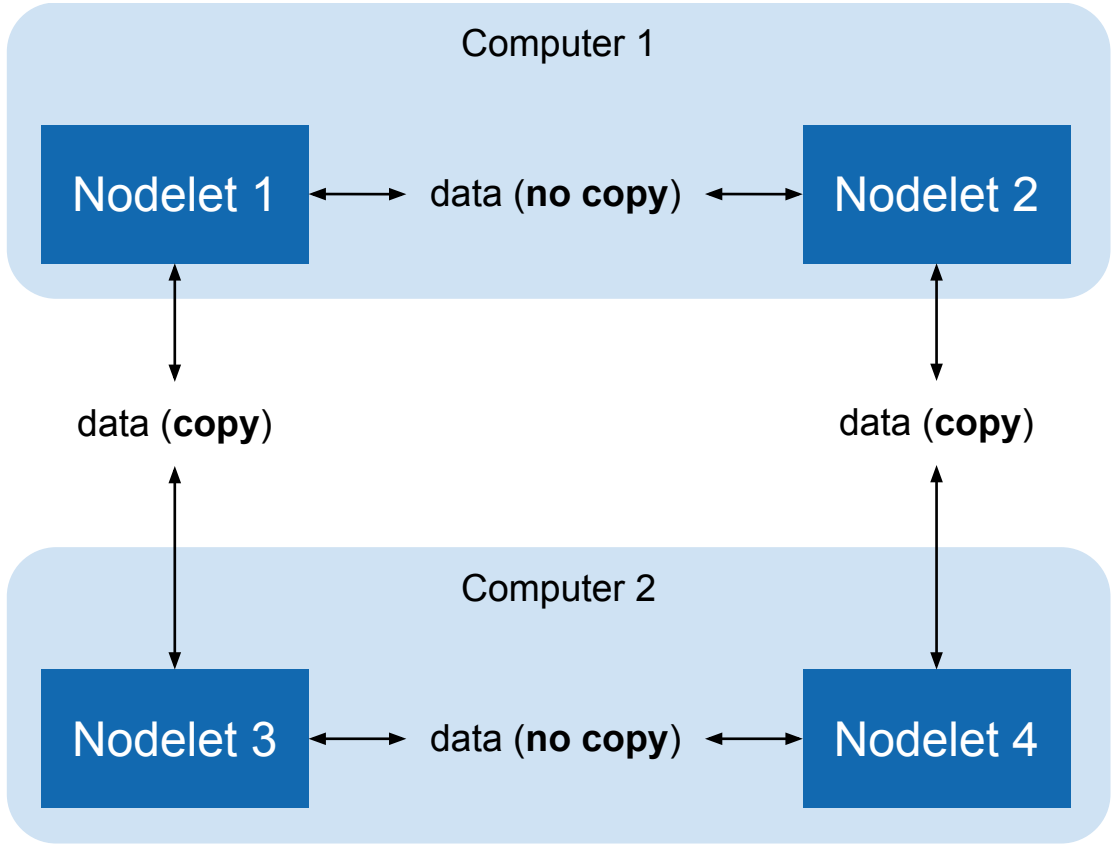
```
std_msgs/Header header
  uint32 seq
  time stamp
  string frame_id
uint32 height
uint32 width
string encoding
uint8 is_bigendian
uint32 step
uint8[] data
```

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 Nodelets

- Same concept as ROS nodes
- Reduce communication overhead when running on same machine
- Try to use ROS nodes first
- Nodeletes are more complicated to implement



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

Example

Console Tab Nr. 1 – Starting a *roscore*

Start a roscore with

```
> roscore
```

```
student@ubuntu:~/catkin_ws$ roscore
... logging to /home/student/.ros/log/6c1852aa-e961-11e6-8543-000c297bd368/ros
launch-ubuntu-6696.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://ubuntu:34089/
ros_comm version 1.11.20


SUMMARY
========

PARAMETERS
 * /rosdistro: indigo
 * /rosversion: 1.11.20

NODES

auto-starting new master
process[master]: started with pid [6708]
ROS_MASTER_URI=http://ubuntu:11311/

setting /run_id to 6c1852aa-e961-11e6-8543-000c297bd368
process[rosout-1]: started with pid [6721]
started core service [/rosout]
```

Example

Console Tab Nr. 2 – Starting a *talker* node

Run a talker demo node with

```
> rosrun roscpp_tutorials talker
```

```
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
```

Example

Console Tab Nr. 3 – Analyze *talker* node

See the list of active nodes

```
> rosnode list
```

```
student@ubuntu:~/catkin_ws$ rosnode list
/rosout
/talker
```

Show information about the *talker* node

```
> rosnode info /talker
```

```
student@ubuntu:~/catkin_ws$ rosnode info /talker
--------------------------------------------------------------------------------
Node [/talker]
Publications:
 * /chatter [std_msgs/String]
 * /rosout [rosgraph_msgs/Log]

Subscriptions: None

Services:
 * /talker/get_loggers
 * /talker/set_logger_level
```

See information about the *chatter* topic

```
> rostopic info /chatter
```

```
student@ubuntu:~/catkin_ws$ rostopic info /chatter
Type: std_msgs/String

Publishers:
 * /talker (http://ubuntu:39173/)

Subscribers: None
```

Example

Console Tab Nr. 3 – Analyze *chatter* topic

Check the type of the *chatter* topic

```
> rostopic type /chatter
```

```
student@ubuntu:~/catkin_ws$ rostopic type /chatter
std_msgs/String
```

Show the message contents of the topic

```
> rostopic echo /chatter
```

```
student@ubuntu:~/catkin_ws$ rostopic echo /chatter
data: hello world 11874
---
data: hello world 11875
---
data: hello world 11876
```

Analyze the frequency

```
> rostopic hz /chatter
```

```
student@ubuntu:~/catkin_ws$ rostopic hz /chatter
subscribed to [/chatter]
average rate: 9.991
        min: 0.099s max: 0.101s std dev: 0.00076s window: 10
average rate: 9.996
        min: 0.099s max: 0.101s std dev: 0.00069s window: 20
```

Example

Console Tab Nr. 4 – Starting a *listener* node

Run a listener demo node with

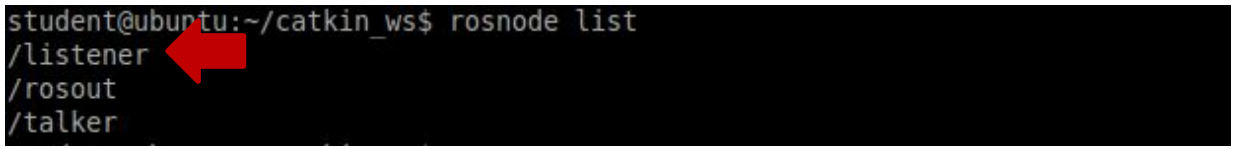
```
> rosrun roscpp_tutorials listener
```

```
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]
```

Example
Console Tab Nr. 3 – Analyze

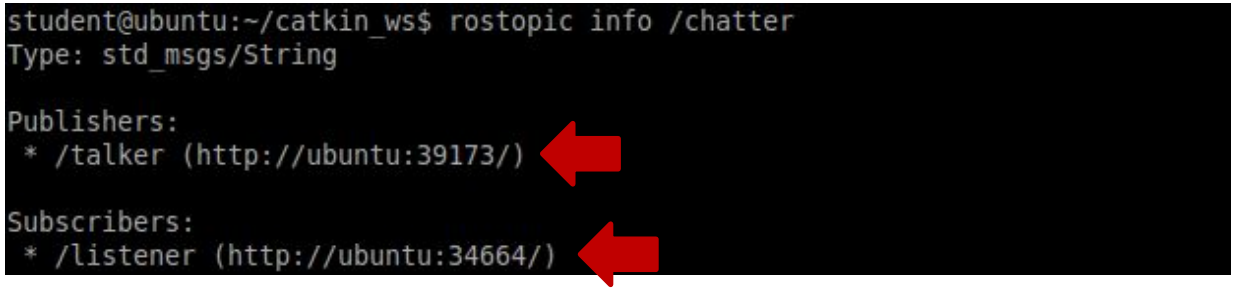
See the new *listener* node with

```
> rosnode list
```



Show the connection of the nodes over the chatter topic with

```
> rostopic info /chatter
```



Example
Console Tab Nr. 3 – Publish Message from Console

Close the *talker* node in console nr. 2 with `Ctrl + C`

Publish your own message with

```
> rostopic pub /chatter std_msgs/String
  "data: 'ETH Zurich ROS Course'"
```

```
student@ubuntu:~/catkin_ws$ rostopic pub /chatter std_msgs/String "data: 'ETH
Zurich ROS Course'"
publishing and latching message. Press ctrl-C to terminate
```

Check the output of the *listener* in console nr. 4

```
[ INFO] [1486054667.604322265]: I heard: [hello world 28202]
[ INFO] [1486054667.704264199]: I heard: [hello world 28203]
[ INFO] [1486054667.804389058]: I heard: [hello world 28204]
[ INFO] [1486054707.646404558]: I heard: [ETH Zurich ROS Course]
```

ROS Workspace Environment

- Defines context for the current workspace
- Default workspace loaded with

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

Overlay your *catkin workspace* with

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

Check your workspace with

```
> echo $ROS_PACKAGE_PATH
```

This is already setup in the provided installation.

See setup with

```
> cat ~/.bashrc
```

More info

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

catkin Build System

- *catkin* is the ROS build system to generate executables, libraries, and interfaces
- We suggest to use the *Catkin Command Line Tools*

→ Use **`catkin build`** instead of `catkin_make`

Navigate to your catkin workspace with

```
> cd ~/catkin_ws
```

Build a package with

```
> catkin build package_name
```

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

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

The catkin command line tools are pre-installed in the provided installation.

More info
http://wiki.ros.org/catkin/Tutorials
https://catkin-tools.readthedocs.io/

catkin Build System

The catkin workspace contains the following spaces

Work here

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

Don't touch

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

Don't touch

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

If necessary, clean the entire build and devel space with

```
> catkin clean
```

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

catkin Build System

The catkin workspace setup can be checked with

```
> catkin config
```

For example, to set the *CMake build type* to Release (or Debug etc.), use

```
> catkin build --cmake-args
      -DCMAKE_BUILD_TYPE=Release
```

```
student@ubuntu:~/catkin_ws$ catkin config
--------------------------------------------------------------------------------
Profile:                     default
Extending:             [env] /opt/ros/indigo:/home/student/catkin_ws/devel
Workspace:                   /home/student/catkin_ws
--------------------------------------------------------------------------------
Source Space:       [exists] /home/student/catkin_ws/src
Log Space:          [exists] /home/student/catkin_ws/logs
Build Space:        [exists] /home/student/catkin_ws/build
Devel Space:        [exists] /home/student/catkin_ws/devel
Install Space:      [unused] /home/student/catkin_ws/install
DESTDIR:            [unused] None
--------------------------------------------------------------------------------
Devel Space Layout:          linked
Install Space Layout:        None
--------------------------------------------------------------------------------
Additional CMake Args:       -GEclipse CDT4 - Unix Makefiles -DCMAKE_CXX_COMP
ILER_ARG1=-std=c++11 -DCMAKE_BUILD_TYPE=Release
Additional Make Args:        None
Additional catkin Make Args: None
Internal Make Job Server:    True
Cache Job Environments:      False
--------------------------------------------------------------------------------
Whitelisted Packages:        None
Blacklisted Packages:        None
--------------------------------------------------------------------------------
Workspace configuration appears valid.
--------------------------------------------------------------------------------
```

Already setup in the provided installation.

More info
http://catkin-tools.readthedocs.io/en/latest/verbs/catkin_config.html
http://catkin-tools.readthedocs.io/en/latest/cheat_sheet.html

Example

Open a terminal and browse to your `git` folder

```
> cd ~/git
```

Clone the Git repository with

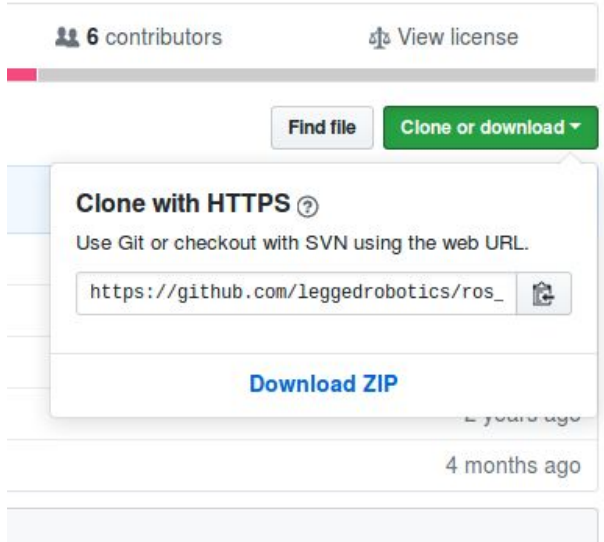
```
> git clone https://github.com/leggedrobotics/
ros_best_practices.git
```

Symlink the new package to your catkin workspace

```
> ln -s ~/git/ros_best_practices/
 ~/catkin_ws/src/
```

Note: You could also directly clone to your catkin workspace, but using a common `git` folder is convenient if you have multiple catkin workspaces.

https://github.com/leggedrobotics/ros_best_practices



Example

Go to your catkin workspace

```
> cd ~/catkin_ws
```

Build the package with

```
> catkin build ros_package_template
```

Re-source your workspace setup

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

Launch the node with

```
> roslaunch ros_package_template
  ros_package_template.launch
```

```
NOTE: Forcing CMake to run for each package.
--------------------------------------------------------------------------------
[build] Found '1' packages in 0.0 seconds.
[build] Updating package table.
Starting  >>> catkin_tools_prebuild
Finished  <<< catkin_tools_prebuild                [ 1.0 seconds ]
Starting  >>> ros_package_template
Finished  <<< ros_package_template                 [ 4.1 seconds ]
[build] Summary: All 2 packages succeeded!
[build]   Ignored:   None.
[build]   Warnings:  None.
[build]   Abandoned: None.
[build]   Failed:    None.
[build] Runtime: 5.2 seconds total.
[build] Note: Workspace packages have changed, please re-source setup files to u
se them.
student@ubuntu:~/catkin_ws$
```

```
 * /rosdistro: indigo
 * /rosversion: 1.11.20

NODES
  /
    ros_package_template (ros_package_template/ros_package_template)

auto-starting new master
process[master]: started with pid [27185]
ROS_MASTER_URI=http://localhost:11311

setting /run_id to e43f937a-ed52-11e6-9789-000c297bd368
process[rosout-1]: started with pid [27198]
started core service [/rosout]
process[ros_package_template-2]: started with pid [27201]
[ INFO] [1486485095.843512614]: Successfully launched node.
```

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 Structure

! Attention when copy & pasting code from the internet

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
Including Other Launch Files

- Include other launch files with <include> tag to organize large projects

```
<include file="package_name"/>
```

- Find the system path to other packages with

```
$(find package_name)
```

- Pass arguments to the included file

```
<arg name="arg_name" value="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>
```

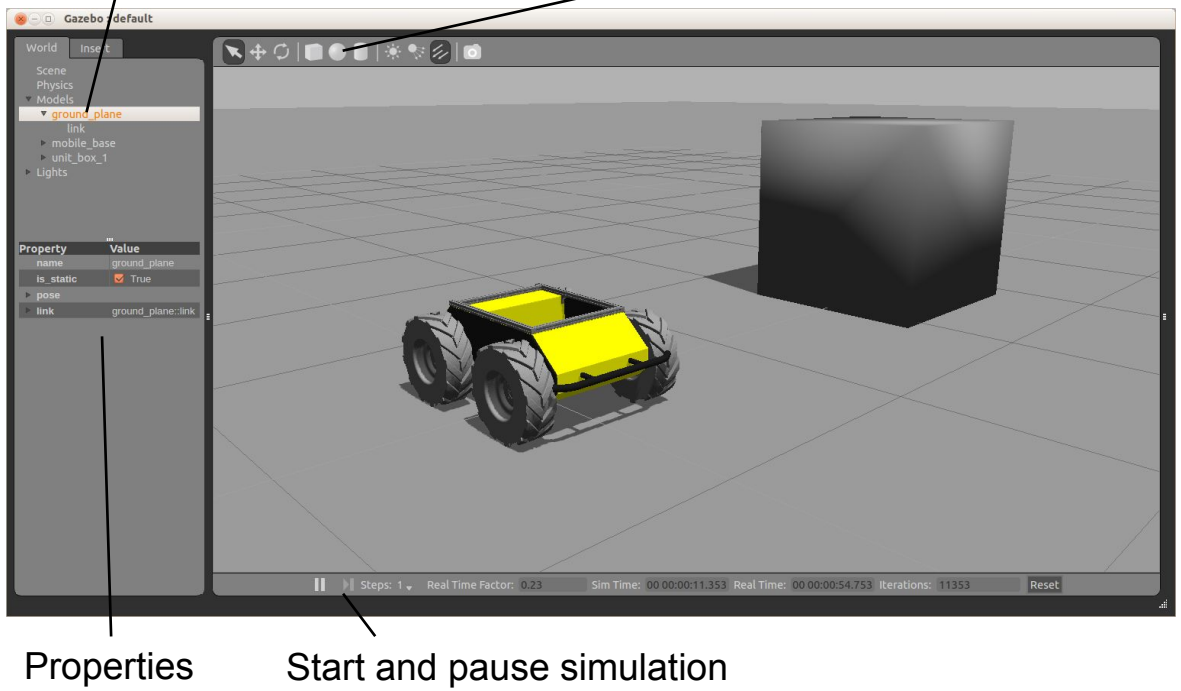
More info
http://wiki.ros.org/roslaunch/XML/include

Gazebo Simulator

- Simulate 3d rigid-body dynamics
- Simulate a variety of sensors including noise
- 3d visualization and user interaction
- Includes a database of many robots and environments (*Gazebo worlds*)
- Provides a ROS interface
- Extensible with plugins

Run Gazebo with

```
> rosrun gazebo_ros gazebo
```



More info
http://gazebosim.org/
http://gazebosim.org/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/Contents/Resources/Documents/index
- **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

ETH Robotics Summer School

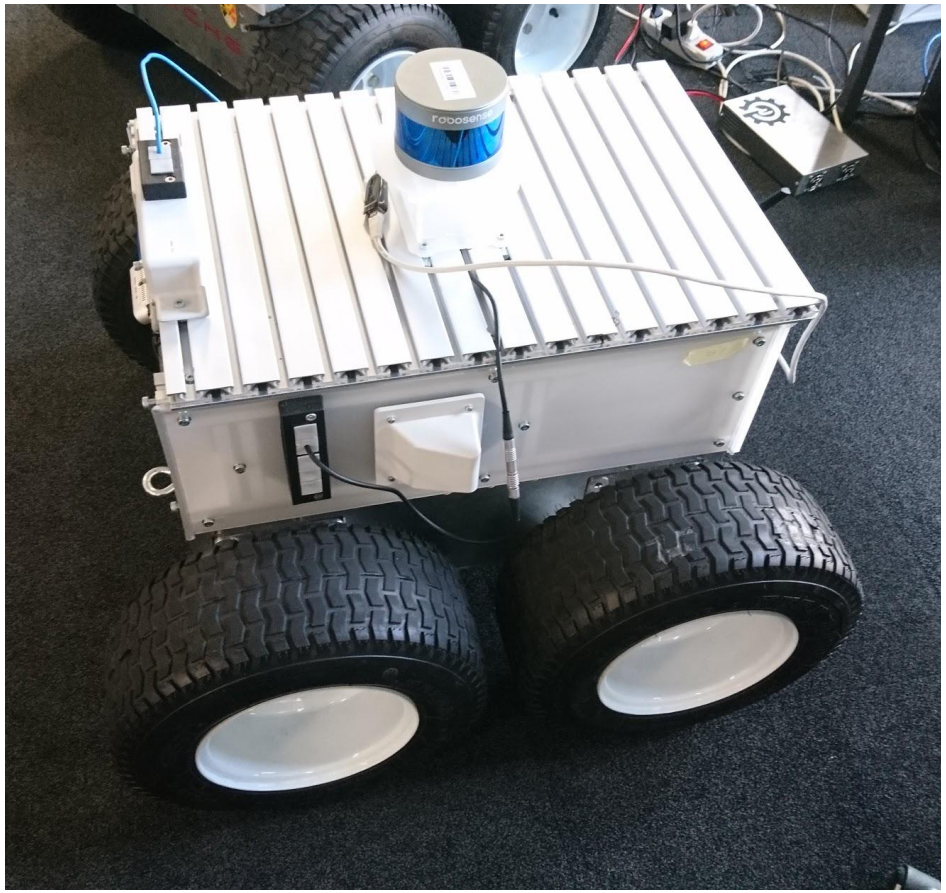
- A full week (July 5-9) with lectures, tutorials and hands-on focus, ending with a robotic challenge.
- Students are invited to attend the ETH Robotic Symposium (tentative date: July 2).
- Takes place in Wangen an der Aare
- Application window Feb. 15 to Mar. 26.
  - Acceptance notification April 15.

More info:
https://robotics-summerschool.ethz.ch/

RobotX - Robotic Platforms

4 all terrain robots “Super Mega Bot” (SMB)

- Base (skid steer drive, driving battery, E-Stop, remote control)
- Payload
  - Intel NUC (option for GPU and 2nd NUC)
  - Connectivity (WiFi, 4G Modem)
  - Sensors:
    - RGB-D - RealSense D435
    - 3D LiDAR - RoboSense RS-16
    - Tracking Cam - RealSense T265
    - VIO-System - VersaVis / RGB / IMU



Tentative Program

	Su 04	Mo 05	Tu 06	We 07	Th 08	Fr 09
9:00		Intro to RSS	**Localization & Mapping**	**Visual Recognition**	Robot time	Robot time
10:00		Intro to Robots	Tutorial	Tutorial		
11:00			Robot time	Robot time		
12:00		Lunch			Lunch	Lunch
13:00		**State Estimation**	Lunch	Lunch	Robot time	Challenge
14:00	Transfer to WadA	Tutorial	**Path Planning**	Robot time		
15:00		Break	Tutorial		Break	
16:00		**Trajectory Optimization**	Break	Social Activity	Robot time	Awards
17:00	Social Activity	Tutorial	Robot time			Transfer to ZH
18:00		Robot time				
19:00						

Preview

Contact Information

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