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You can download the sources of this presentation here:

github.com/severin-lemaignan/module-introduction-sensors-actuators

ROBOTICS WITH PLYMOUTH UNIVERSITY

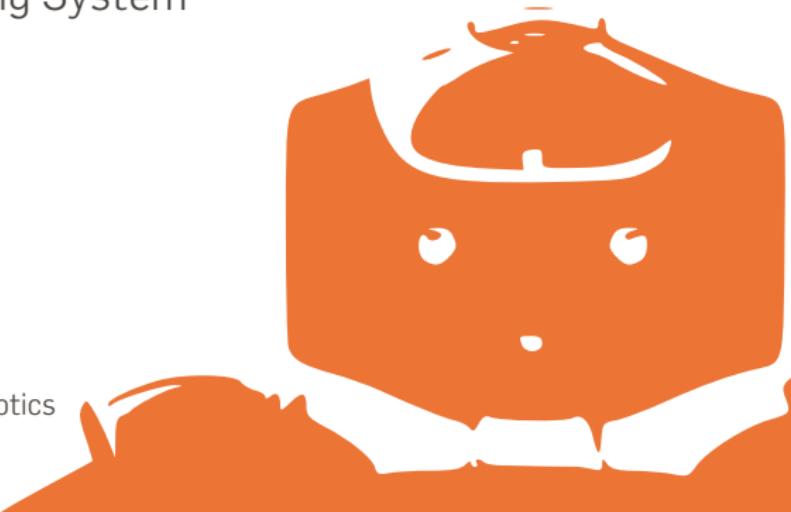
ROCO222

Intro to Sensors and Actuators

ROS, the Robot Operating System

Séverin Lemaignan

Centre for Neural Systems and Robotics
Plymouth University



ROS IS NOT AN OPERATING SYSTEM

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- A fairly simple peer-to-peer message passing system designed with robotics in mind

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 - **A middleware?**

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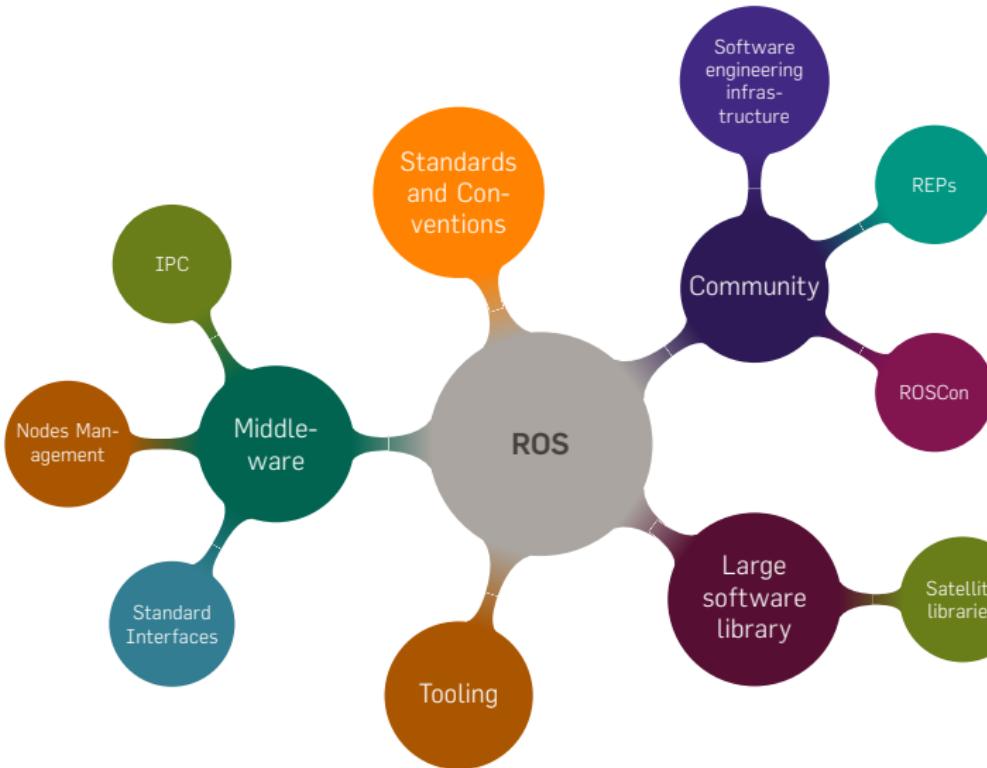
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 - A set of conventions to write and package robotic softwares
 - Deep integration of a few key open-source libraries (OpenCV, PCL, tf)
 - A set of tools to run and monitor the nodes
 - Engagement of a large academic community, leading to a library of thousands of nodes

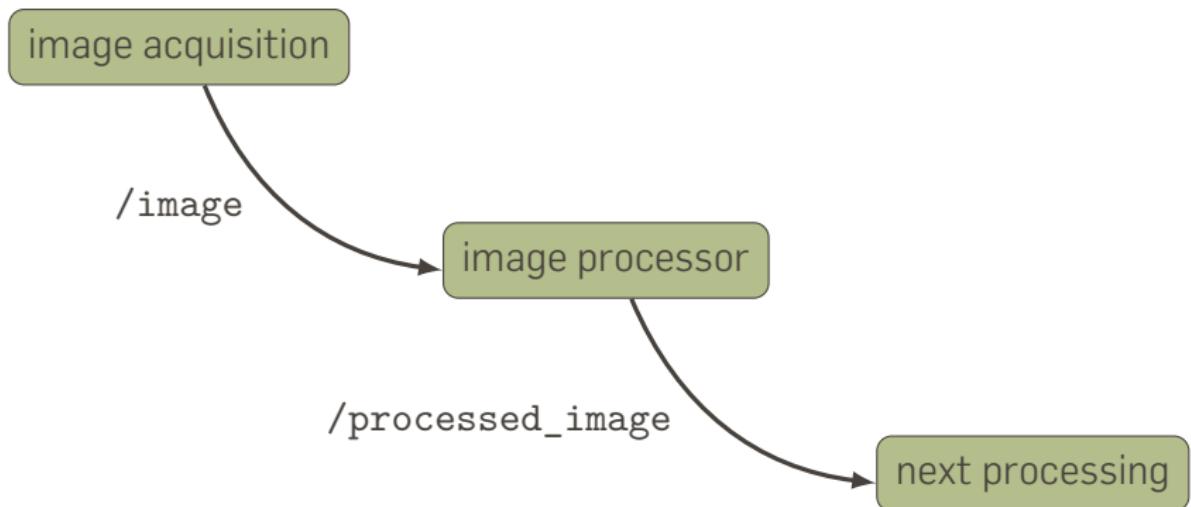
ROS ECOSYSTEM



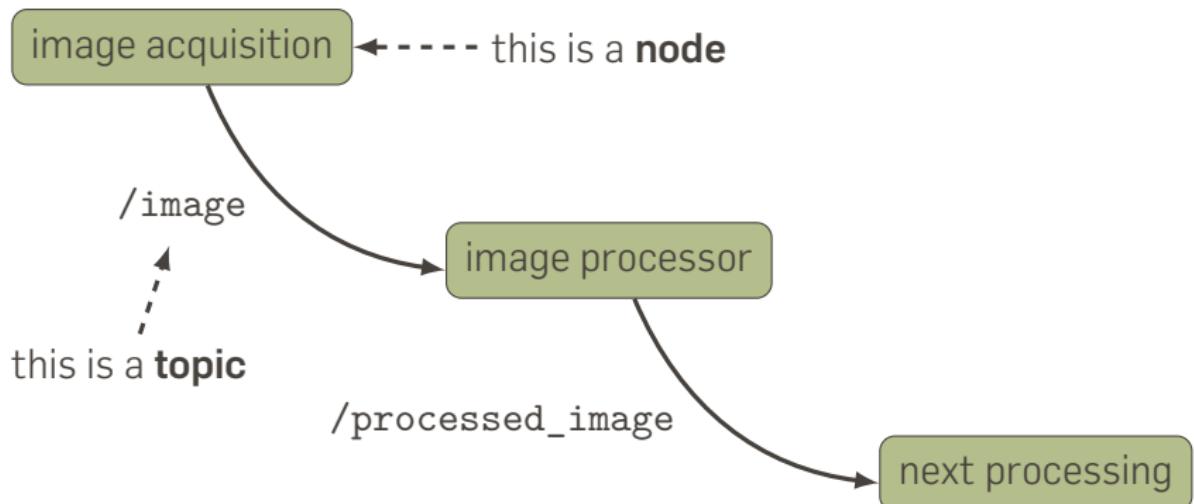
[we will revisit these slides at the end of the lecture]

A FIRST EXAMPLE

A SIMPLE IMAGE PROCESSING PIPELINE



A SIMPLE IMAGE PROCESSING PIPELINE



```
1 import sys, cv2, rospy
2 from sensor_msgs.msg import Image
3 from cv_bridge import CvBridge
4
5 def on_image(image):
6     cv_image = bridge.imgmsg_to_cv2(image, "bgr8")
7     rows, cols, channels = cv_image.shape
8     cv2.circle(cv_image, (cols/2, rows/2), 50, (0,0,255), -1)
9     image_pub.publish(bridge.cv2_to_imgmsg(cv_image, "bgr8"))
10
11 rospy.init_node('image_processor')
12 bridge = CvBridge()
13 image_sub = rospy.Subscriber("image",Image, on_image)
14 image_pub = rospy.Publisher("processed_image",Image)
15
16 while not rospy.is_shutdown():
17     rospy.spin()
```

HOW TO USE THIS CODE?

First, we need to write data onto the /image topic, for instance from a webcam:

```
> rosrun usb_cam usb_cam_node
```

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Then, we run our code:

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> python image_processor.py
```

HOW TO USE THIS CODE?

First, we need to write data onto the `/image` topic, for instance from a webcam:

```
> rosrun usb_cam usb_cam_node
```

Then, we run our code:

```
> python image_processor.py
```

Finally, we run a 3rd node to display the image:

```
> rosrun image_view image_view image:=/processed_image
```



THE KEY ROS CONCEPTS

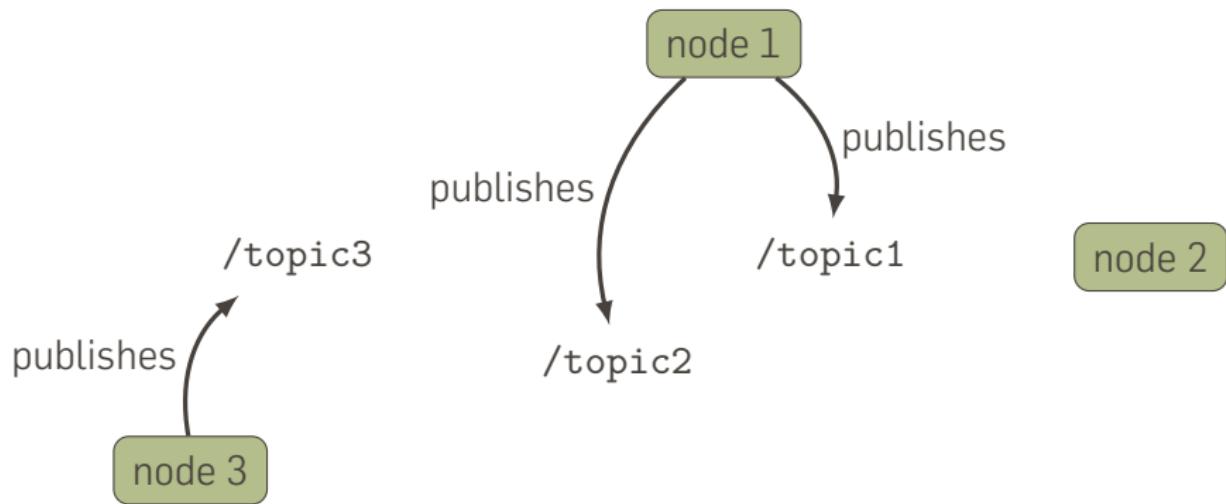
TALKING NODES

node 1

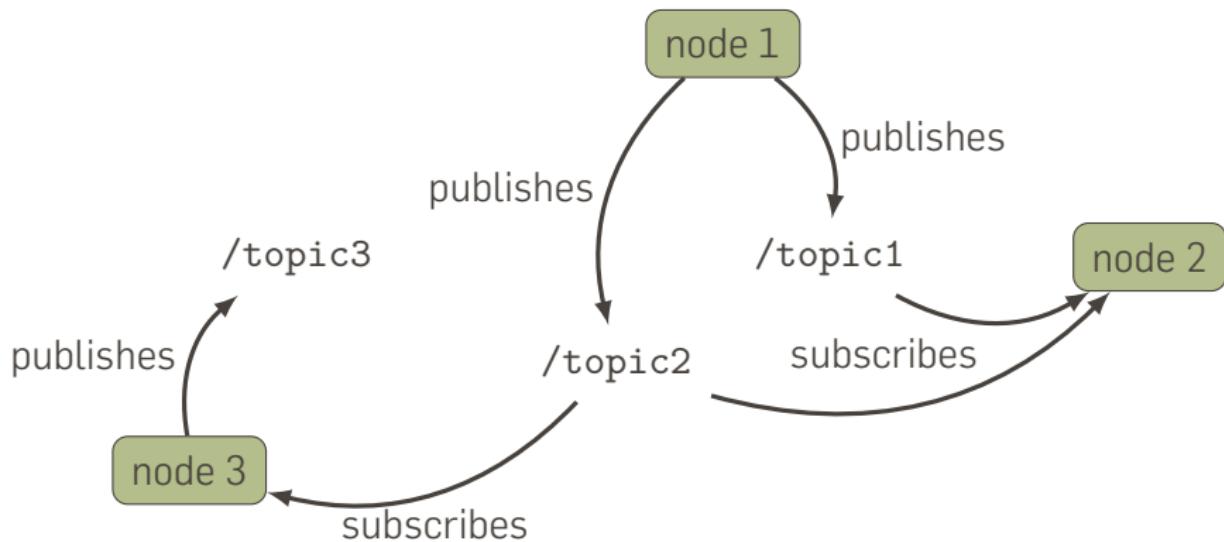
node 2

node 3

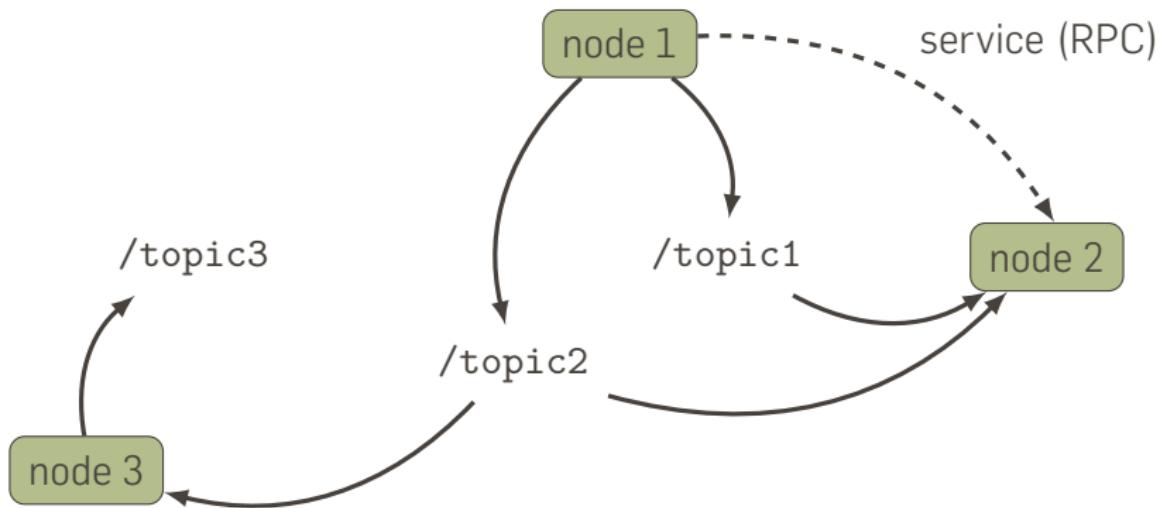
TALKING NODES



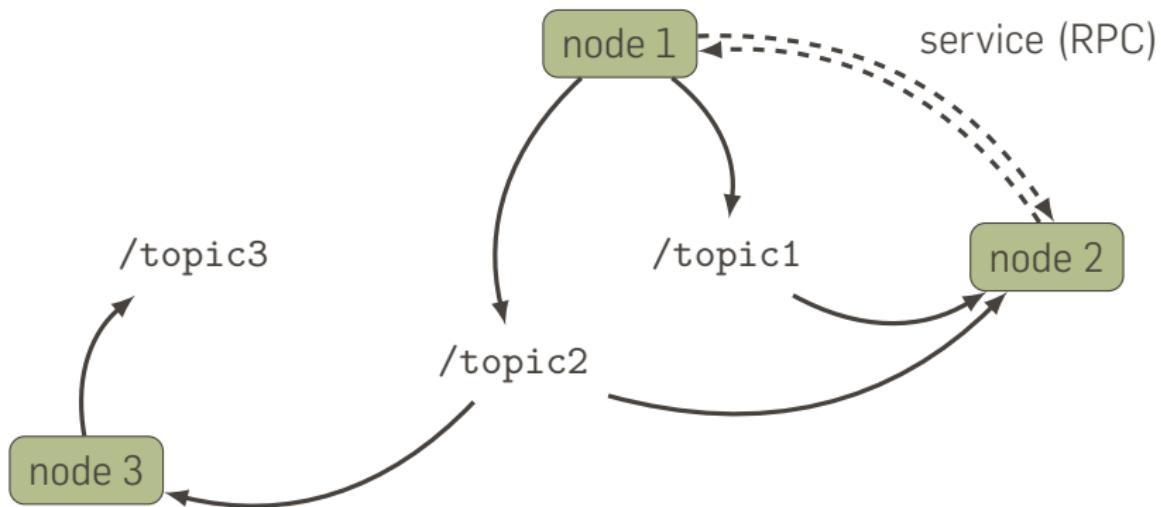
TALKING NODES



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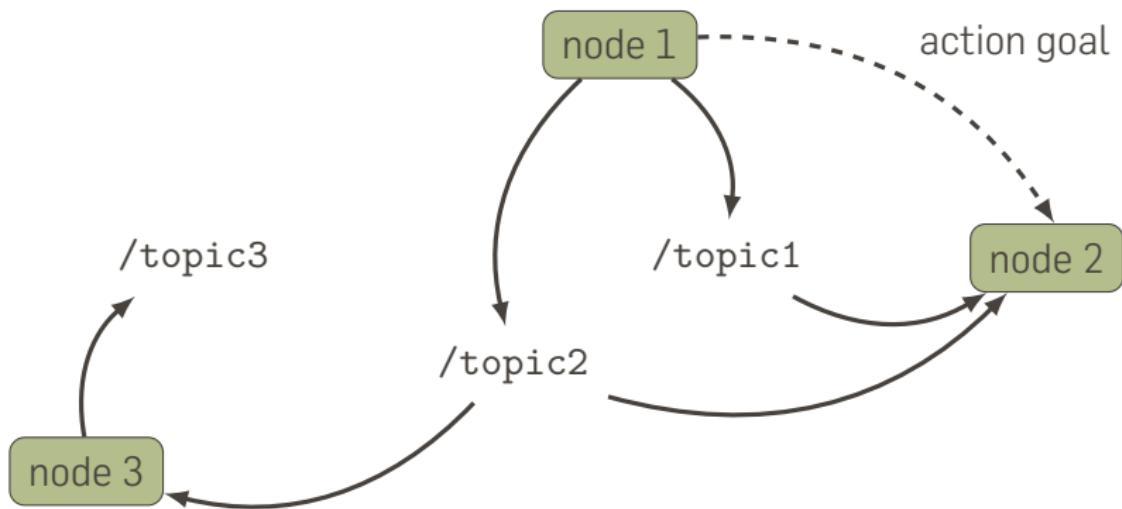


TALKING NODES

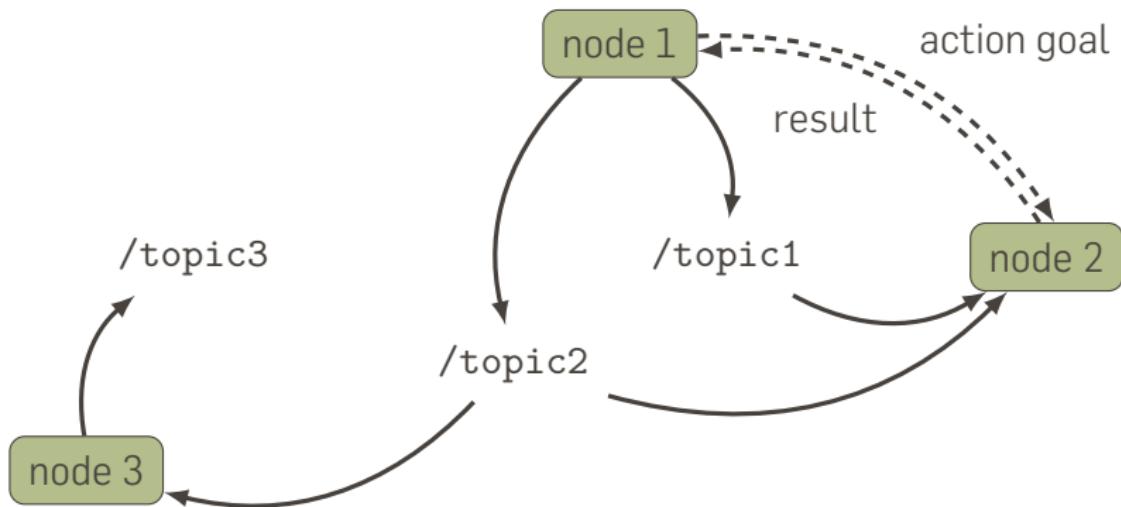


Services: **synchronous**: call is blocking, only suitable when very short processing (e.g. setting a parameter)

TALKING NODES

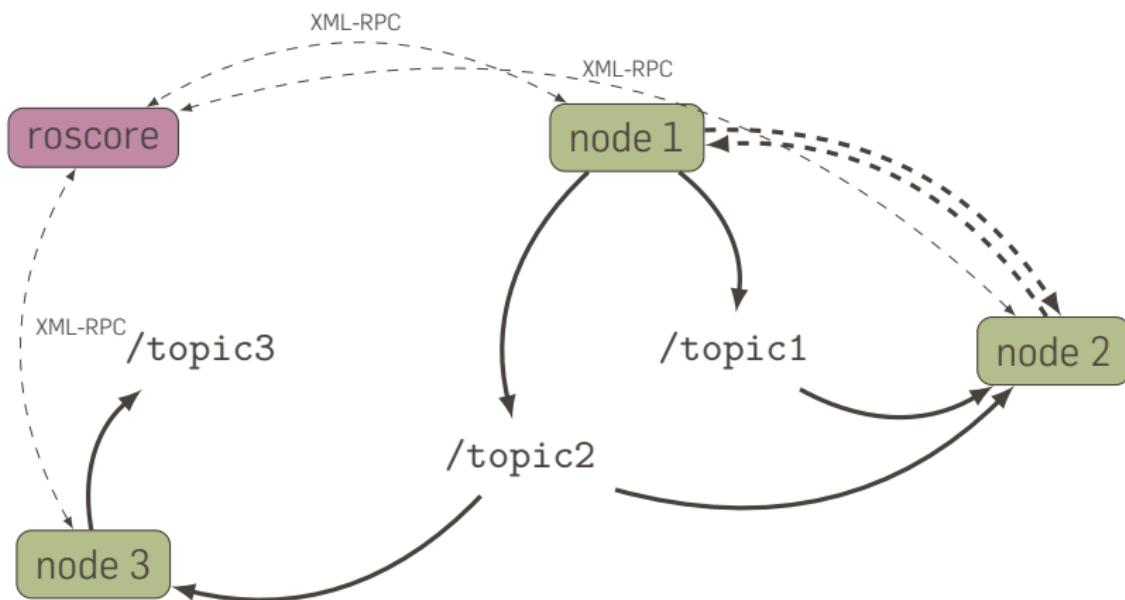


TALKING NODES



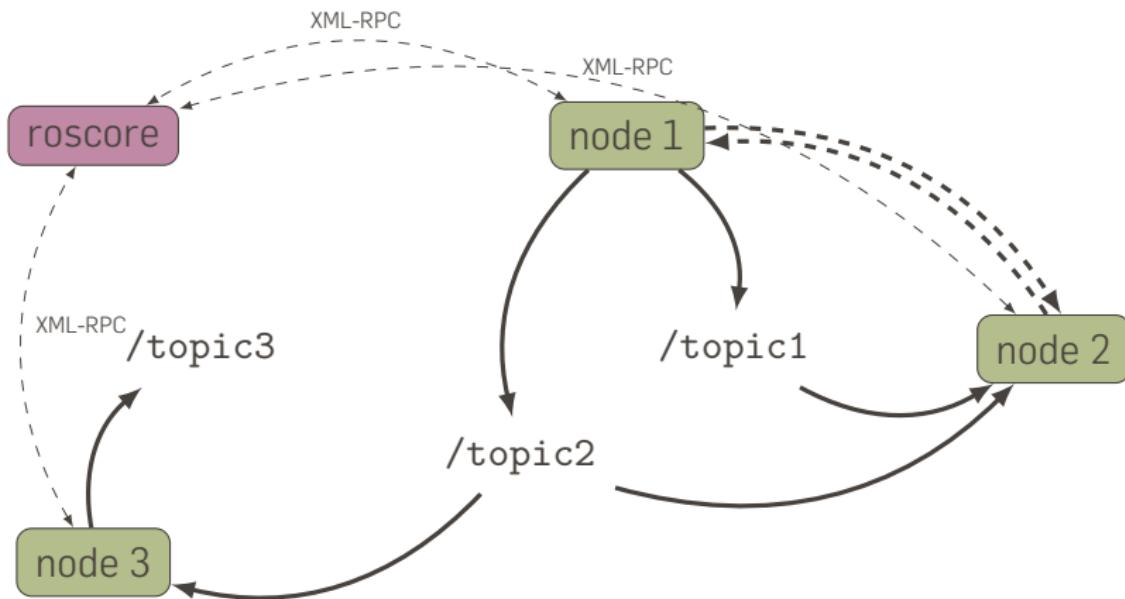
Actions: **asynchronous**: call is non-blocking, suitable for long processes (e.g. motion planning)

TALKING NODES



The `roscore` daemon act as yellow pages for the nodes to discover each others.

TALKING NODES



When nodes are distributed on different machines:

`ROS_MASTER_URI=http://<host>:<port>` to point to **roscore**

MESSAGES

Topics are TCP ports on which data is exchanged.

The data is **serialized** using a format specific to each type of data:
ROS defines its **data interface** with *messages*.

MESSAGES

Topics are TCP ports on which data is exchanged.

The data is **serialized** using a format specific to each type of data:
ROS defines its **data interface** with *messages*.

```
> rosmsg show geometry_msgs/Pose
geometry_msgs/Point position
    float64 x
    float64 y
    float64 z
geometry_msgs/Quaternion orientation
    float64 x
    float64 y
    float64 z
    float64 w
```

Source: *geometry_msgs::Pose definition*

MESSAGE EXAMPLE: JOINT STATE

```
> rosmsg show sensor_msgs/JointState
std_msgs/Header header
    uint32 seq
    time stamp
    string frame_id
    string[] name
    float64[] position
    float64[] velocity
    float64[] effort
```

Source: [sensor_msgs::JointState definition](#)

MESSAGE EXAMPLE: IMAGE

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

Source: *sensor_msgs::Image definition*

MESSAGES CONTENT

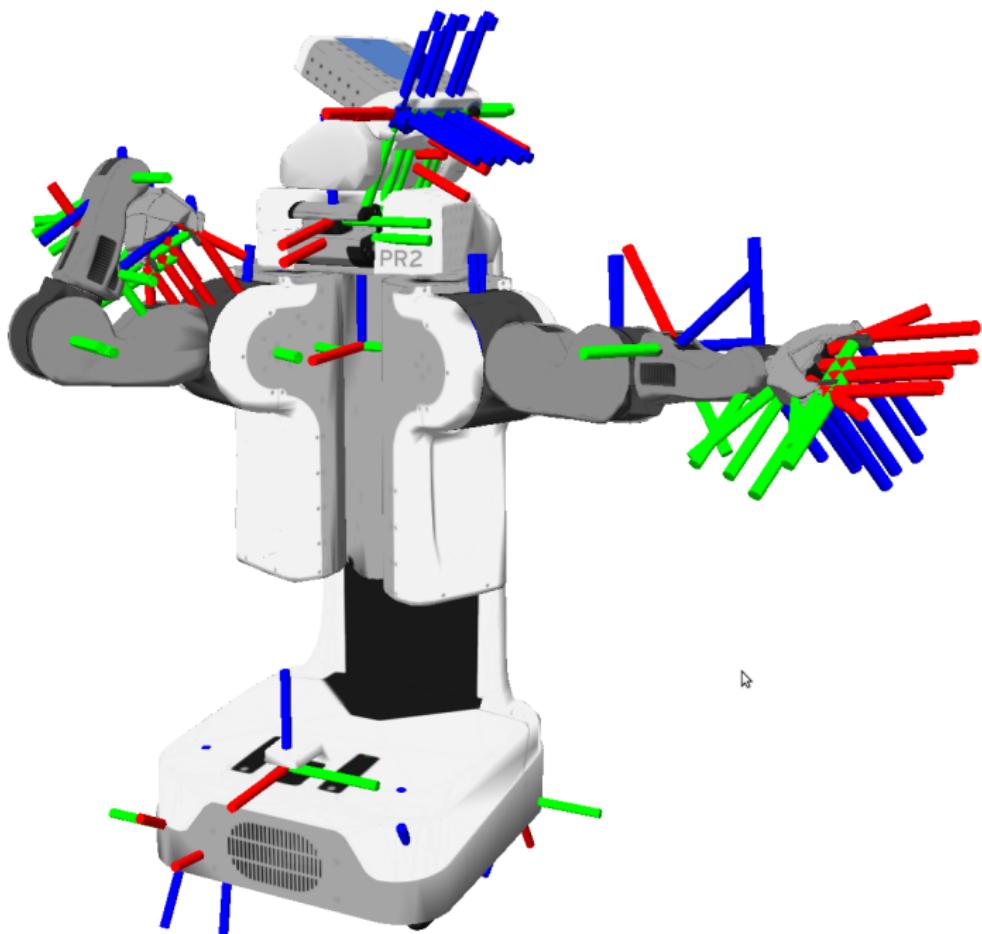
```
> rostopic echo /camera/image_raw
header:
  seq: 56
  stamp:
    secs: 1449243166
    nsecs: 415330019
  frame_id: /camera_frame
height: 720
width: 1280
encoding: rgb8
is_bigendian: 0
step: 3840
data: [32, 57, 51, 36, 61, 55, 41, 63, 60, ...]
```

What are these *frames*?

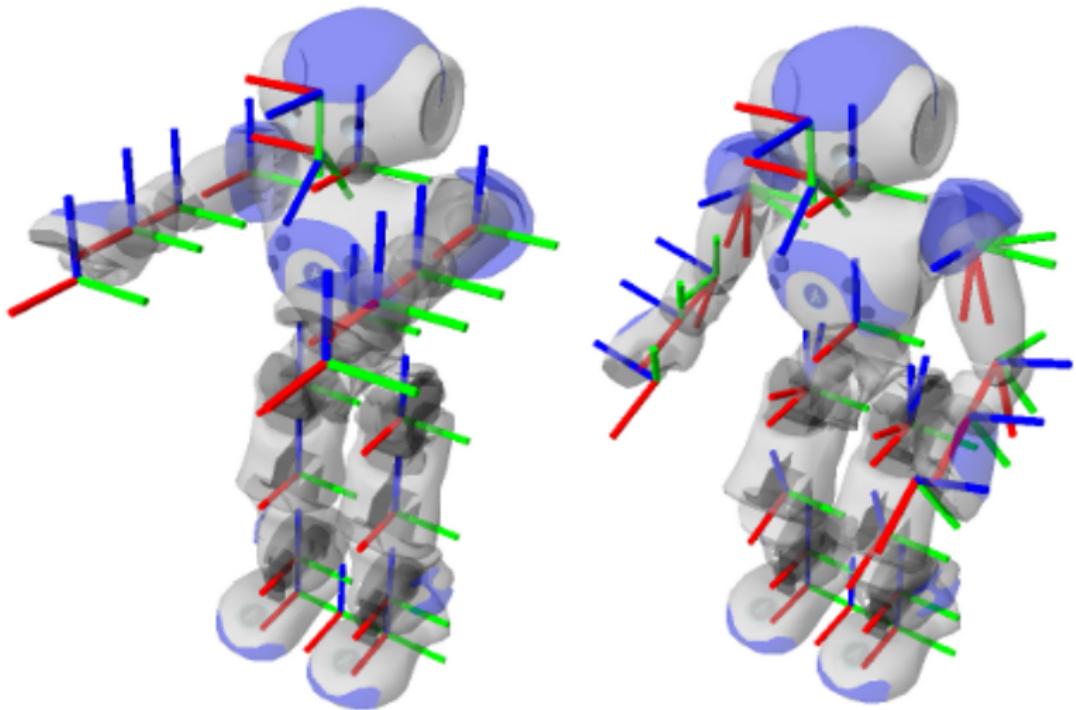
What are these *frames*?

A **frame** is a labelled orthogonal basis with a convenient (6D) origin.

Each part of the robot has usually its own frame, sensors have their frames, objects in the environment have their frames, etc.



4



Intro
oooo

Example
ooooo

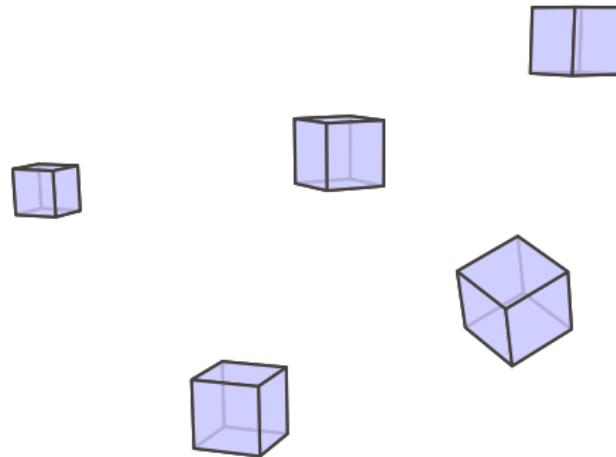
Key concepts
oooooooo●oooo

Robot arm
oooooooooooooooo

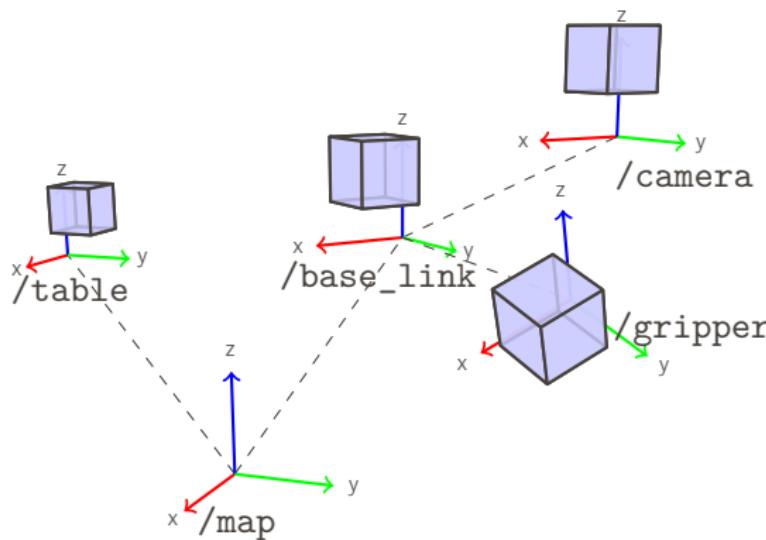
Deeper into ROS
oooooooooooooooooooo

So, what is ROS?
ooo

FRAMES

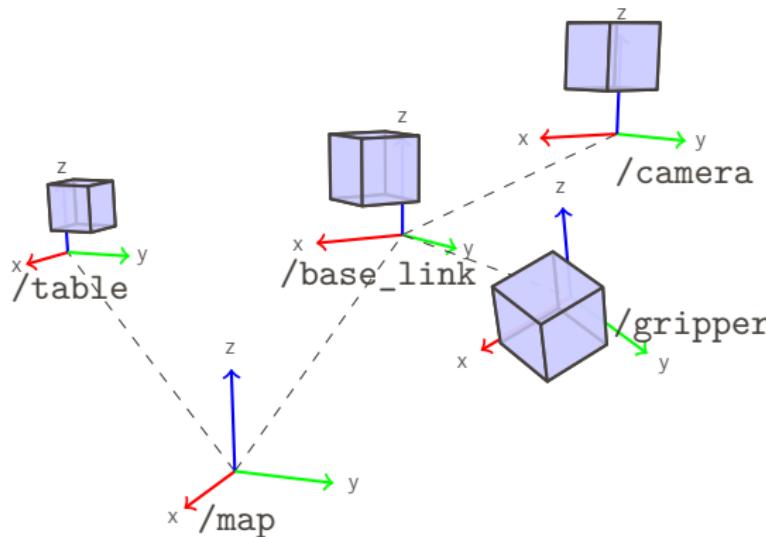


FRAMES



The **TF** library is responsible for maintaining the full transformation tree, and calculating the transformation between any two frames.

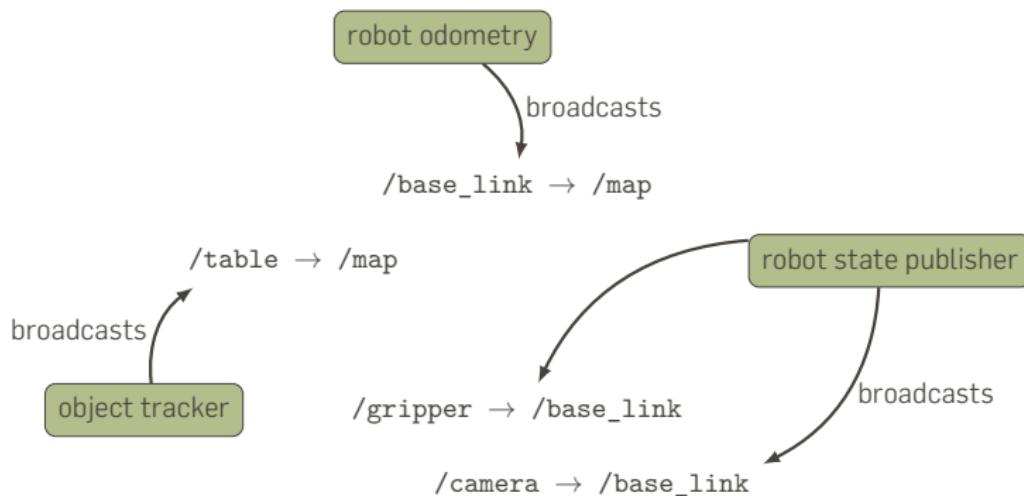
FRAMES



Attention: even though they look similar, frames and topics are unrelated.

"CREATING" FRAMES

Frames come to existence as soon as someone (a node) broadcast them.



HOW TO WRITE A TF BROADCASTER?

C++

```
1 #include <ros/ros.h>
2 #include <tf/transform_broadcaster.h>
3
4
5 int main(int argc, char** argv){
6
7     float x=0.f,y=0.f,theta=0.f;
8
9     ros::init(argc, argv, "my_tf_broadcaster");
10    tf::TransformBroadcaster br;
11    ros::Rate rate(10); // 10 hz
12
13    while (ros::ok()) {
14        tf::Transform transform(
15                    tf::Quaternion(0, 0, theta),
16                    tf::Vector3(x, y, 0.0));
17
18        br.sendTransform(
19            tf::StampedTransform(transform,
20                                ros::Time::now(),
21                                "my_robot", "map"));
22
23        x++;
24        rate.sleep();
25    }
26    return 0;
27 }
```

Python

```
1 import rospy
2 import tf
3 from tf.transformations import quaternion_from_euler
4
5 if __name__ == '__main__':
6     x = 0.; y = 0.; theta = 0.
7
8     rospy.init_node('my_tf_broadcaster')
9     br = tf.TransformBroadcaster()
10    rate = rospy.Rate(10) # 10hz
11
12    while not rospy.is_shutdown():
13        br.sendTransform(
14            (x, y, 0),
15            quaternion_from_euler(0, 0, theta),
16            rospy.Time.now(),
17            "my_robot", "map")
18
19        x += 1
20        rate.sleep()
```

```
> rostopic echo tf
transforms:
-
  header:
    seq: 0
    stamp:
      secs: 1449488936
      nsecs: 480597909
    frame_id: map
  child_frame_id: my_robot
  transform:
    translation:
      x: 239.0
      y: 0.0
      z: 0.0
    rotation:
      x: 0.0
      y: 0.0
      z: 0.0
      w: 1.0
```

TO SUMMARIZE: KEY CONCEPTS

- Node
- Master
- Messages
- Topics
- Services
- Actions
- Transformations/frames

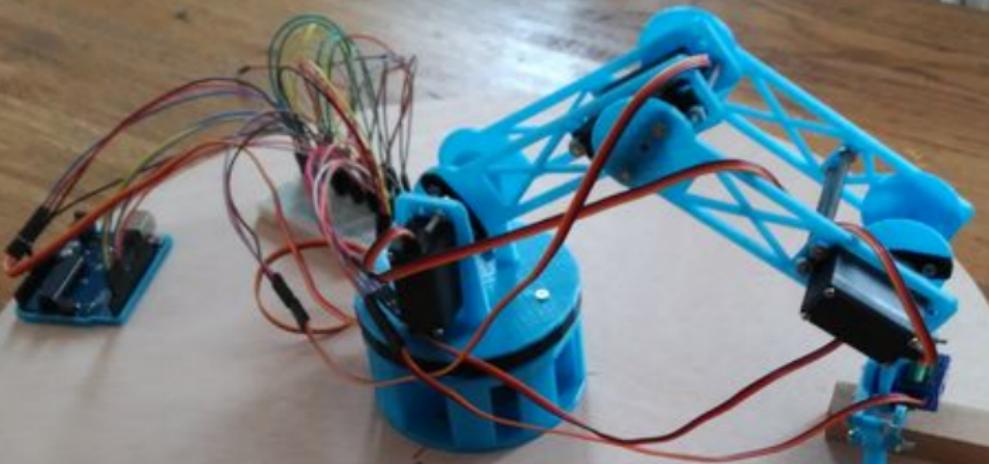
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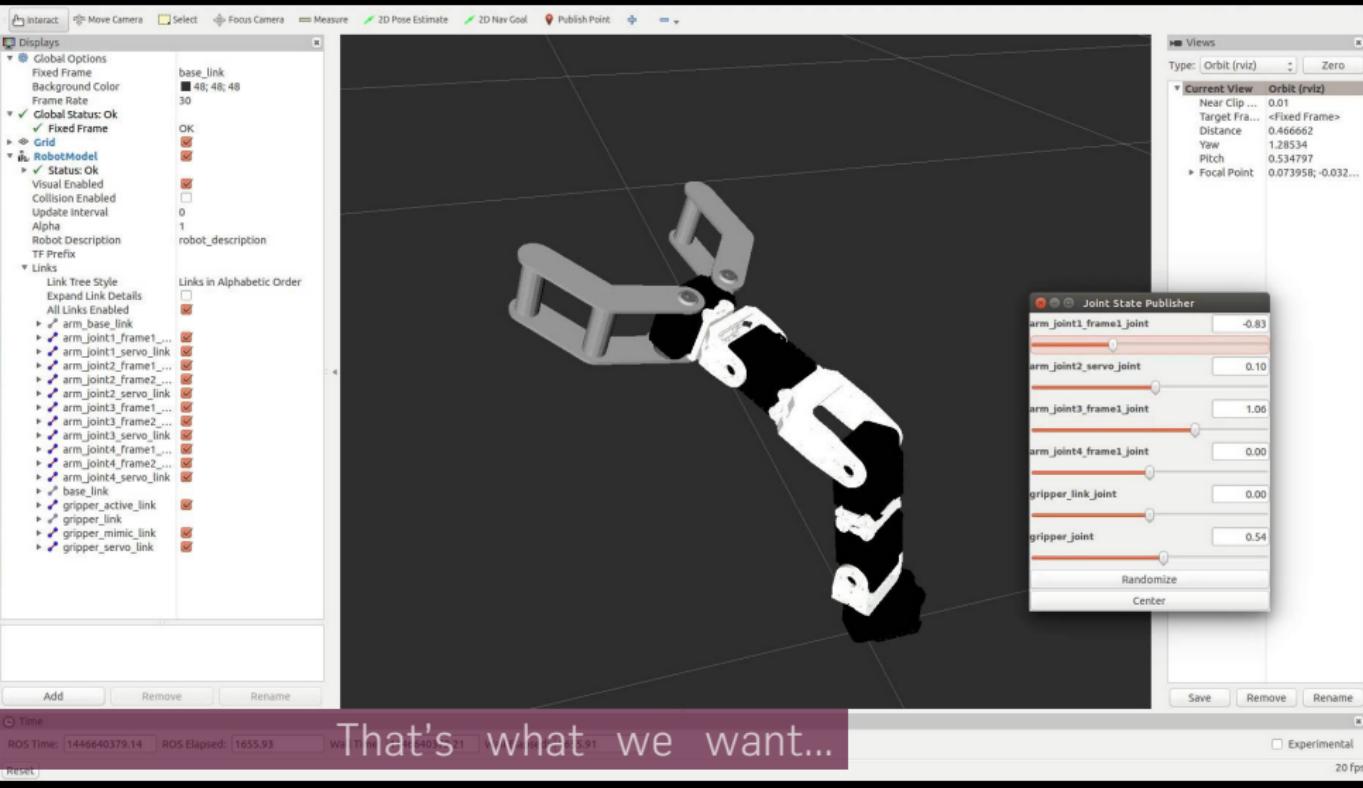
Some additional concepts that we will discuss later on:

- Package
- Launch file

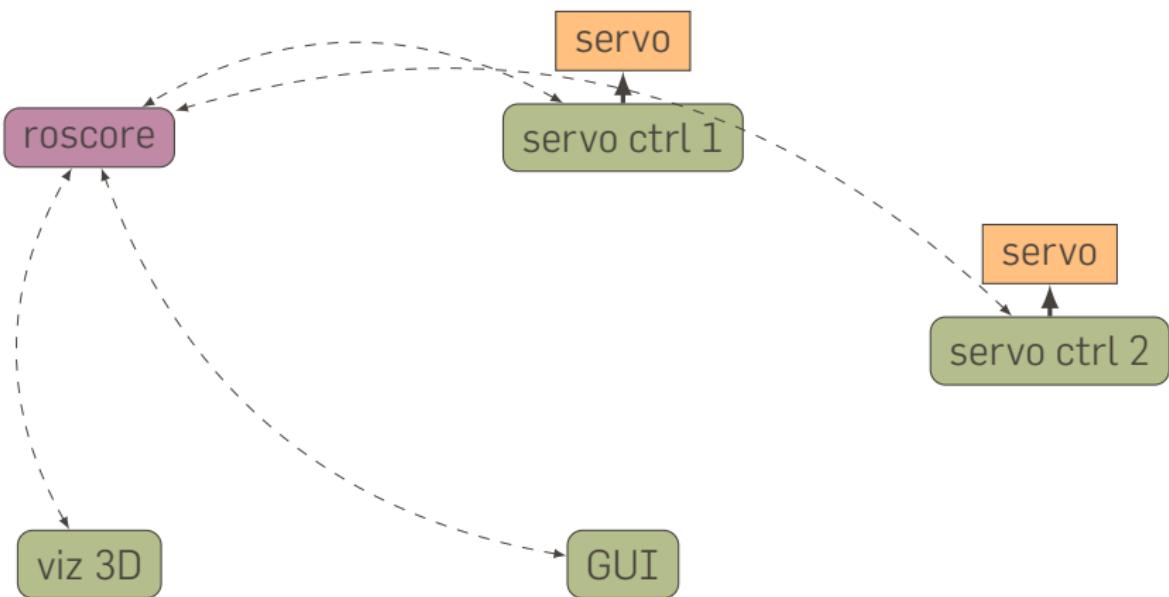
A ROBOTIC ARM WITH ROS



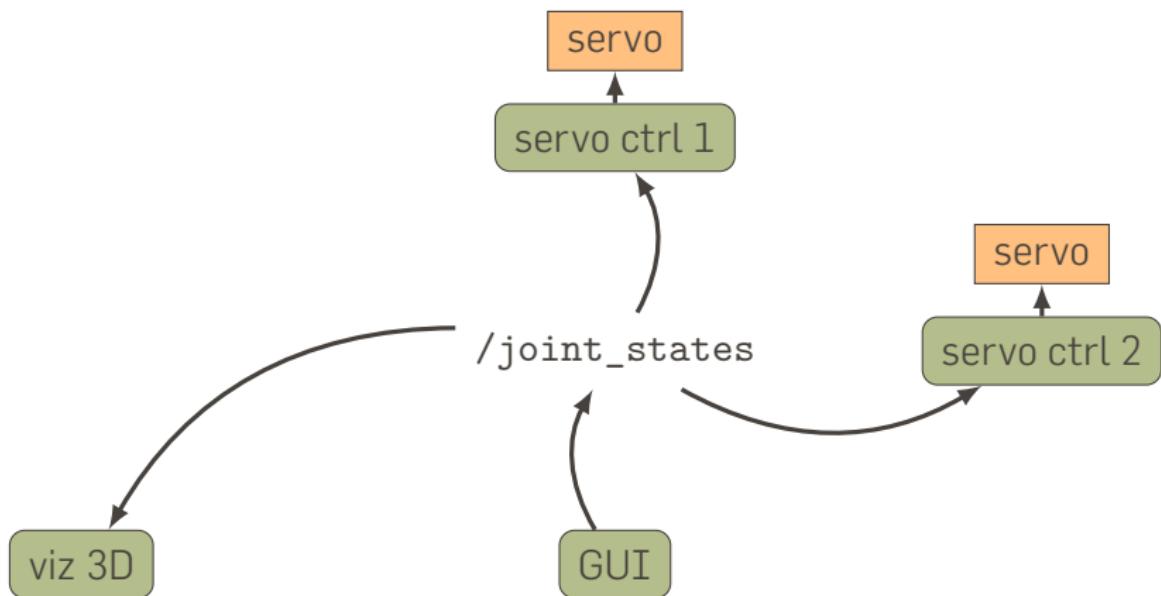
That's our hardware...



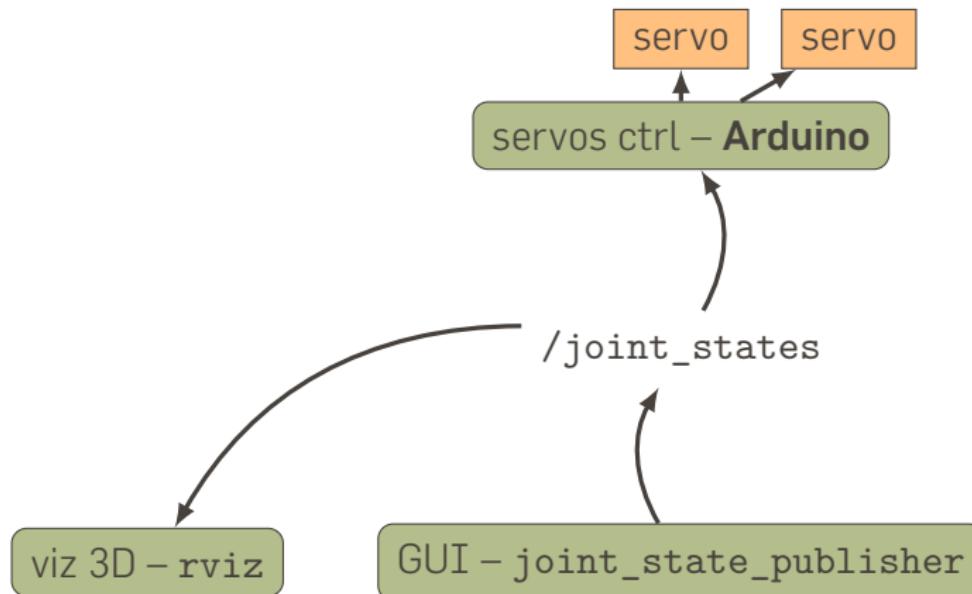
NODES



NODES



NODES



ROS WITH THE ARDUINO

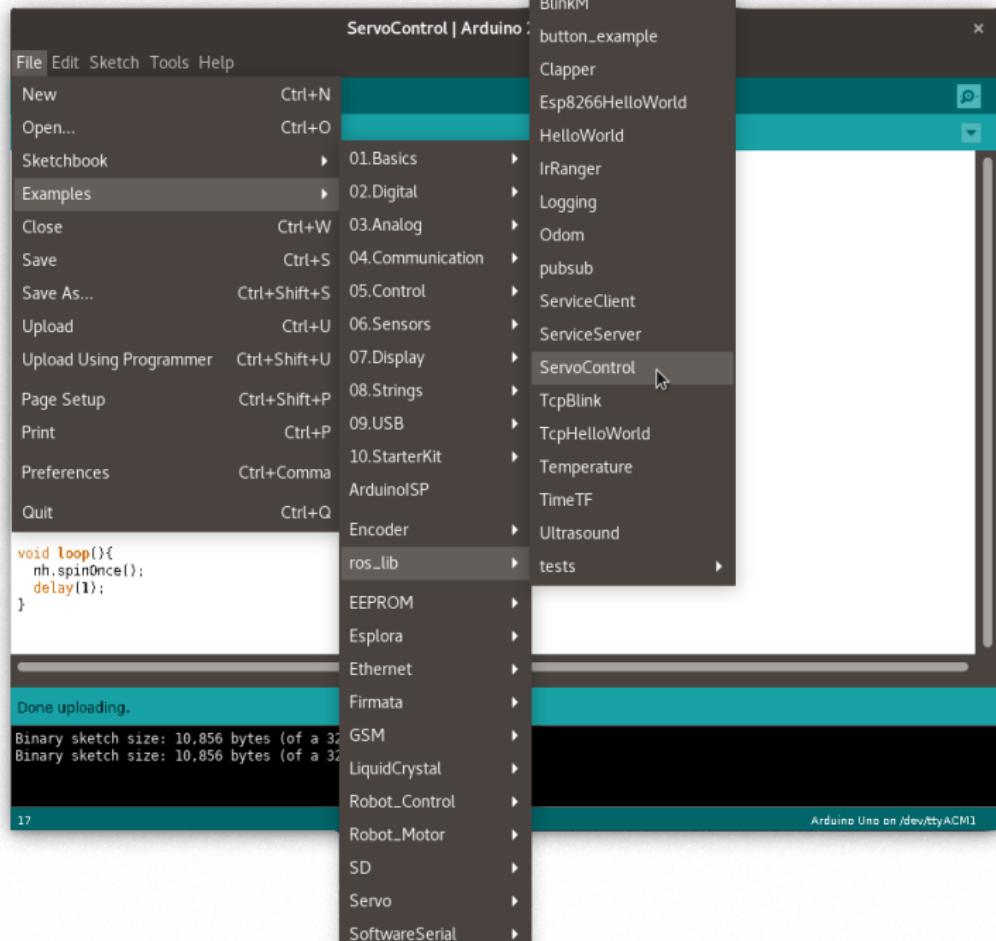
`rosserial` is a ROS *bridge* that transparently transport ROS messages over a serial connection.

`rosserial_arduino` is a `rosserial` *client* for the Arduino. You can install it easily:

```
apt install ros-kinetic-rosserial ros-kinetic-rosserial-arduino
```

To make it transparently available in the Arduino IDE, you need to also install it as an Arduino library:

```
> cd $HOME/sketchbook/libraries  
> rosrun rosserial_arduino make_libraries.py .
```



ARDUINO CODE TO CONTROL A SERVO WITH ROS

```
1 #include <ros.h>
2 #include <std_msgs/UInt16.h>
3 #include <Servo.h>
4
5 using namespace ros;
6
7 NodeHandle nh;
8 Servo servo;
9
10 void cb( const std_msgs::UInt16& msg){
11     servo.write(msg.data); // 0-180
12 }
13
14 Subscriber<std_msgs::UInt16> sub("servo", cb);
15
16 void setup(){
17     nh.initNode();
18     nh.subscribe(sub);
19
20     servo.attach(9); //attach it to pin 9
21 }
22
23 void loop(){
24     nh.spinOnce();
25     delay(1);
26 }
```

Python ≈equivalent:

```
1 import rospy
2 from std_msgs.msg import UInt16
3
4 def cb(msg):
5     # servo.write(msg.data)
6     print(msg.data)
7
8 rospy.init_node('listener')
9 rospy.Subscriber("servo", UInt16, cb)
10 # servo.attach(9)
11 rospy.spin()
```

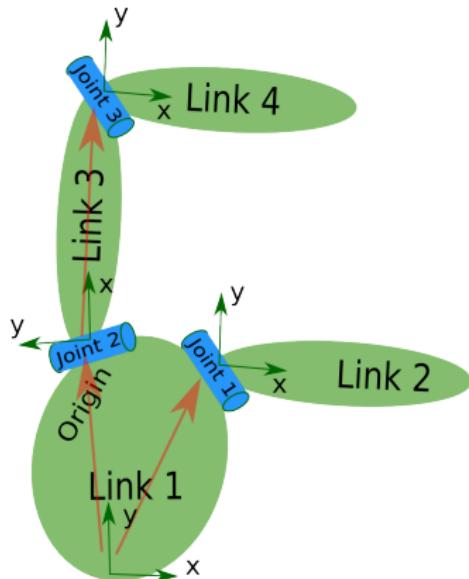
RUNNING THE CODE

To use the code, from your 'master' ROS computer:

```
> roscore
> rosrun rosserial_python serial_node.py /dev/ttyACM0
> rostopic pub --once servo std_msgs/UInt16 110
```

URDF

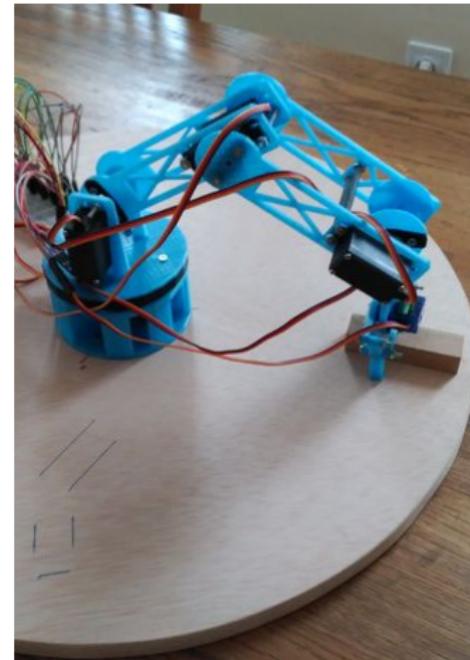
URDF (*Unified Robot Description Format*) is an XML-based language to describe a robot.



- Primitives (cylinders, cubes, spheres) to describe the geometry
- For complex geometries, any STL or Collada meshes can be used
- Only *tree structures* can be represented: no parallel robots
- Only *rigid links* can be represented: no soft robots

URDF: DESCRIBING THE KINEMATICS OF OUR ROBOT

```
<?xml version="1.0"?>
<robot name="roco_arm">
  <link name="base_link">
    <visual>
      <geometry>
        <cylinder length="0.06" radius="0.1"/>
      </geometry>
    </visual>
  </link>
</robot>
```

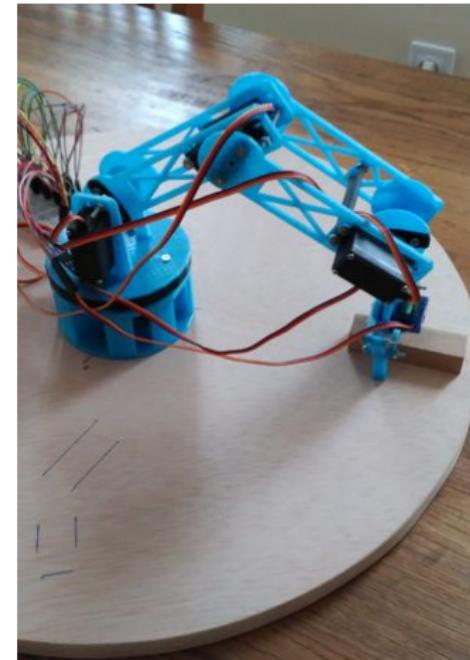


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      </geometry>
    </visual>
  </link>

  <link name="first_segment">
    <visual>
      <geometry>
        <box size="0.6 0.05 0.1"/>
      </geometry>
      <origin rpy="0 0 0" xyz="-0.3 0 0" />
    </visual>
  </link>

</robot>
```

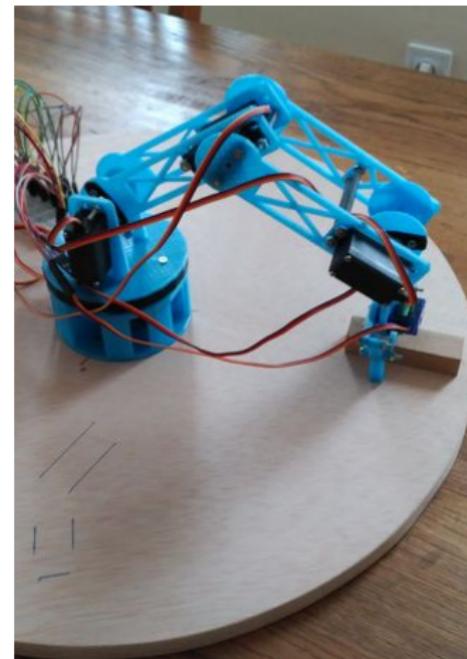


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      </geometry>
      <origin rpy="0 0 0" xyz="-0.3 0 0" />
    </visual>
  </link>

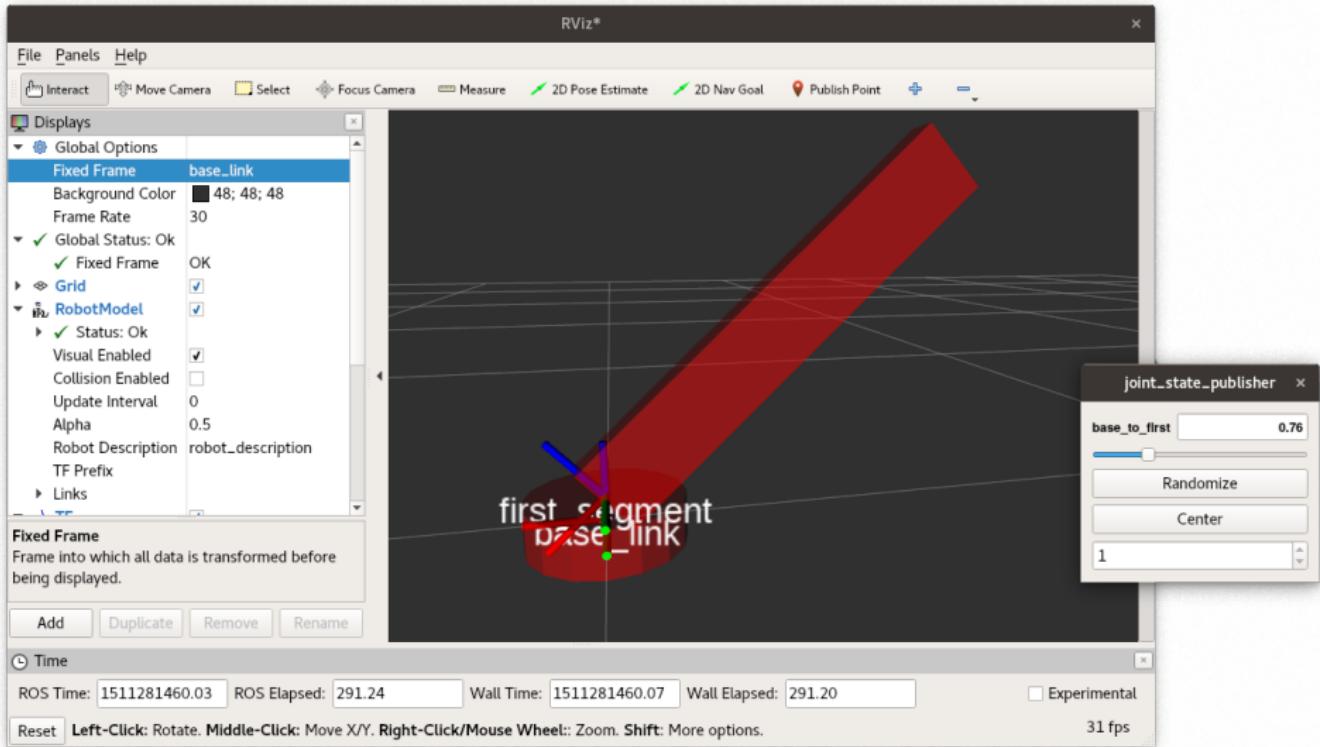
  <joint name="base_to_first" type="revolute">
    <axis xyz="0 1 0" />
    <limit effort="1000" lower="0"
          upper="3.14" velocity="0.5" />
    <parent link="base_link"/>
    <child link="first_segment"/>
    <origin xyz="0 0 0.03" />
  </joint>
</robot>
```

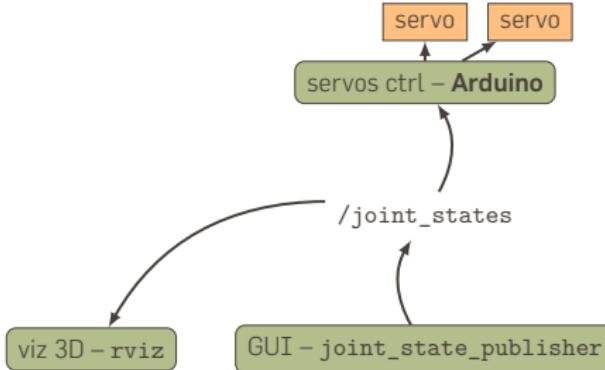


DISPLAY THE MODEL

To display and interact with the URDF model:

```
> rosparam set robot_description -t code/robot-arm.urdf
> rosrun robot_state_publisher robot_state_publisher
> rosrun joint_state_publisher joint_state_publisher _use_gui:=true
> rosrun rviz rviz
```

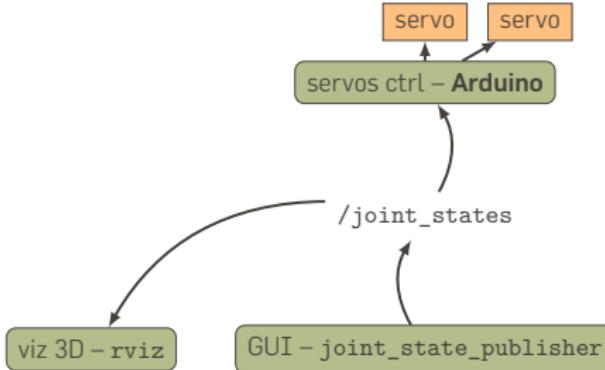




Why do we need `robot_state_publisher`?

`rviz` needs the transformations between each geometry. Going from a **joint state** (i.e. the angles for each joint) to transformations (i.e. **frames**) requires **forward kinematics**.

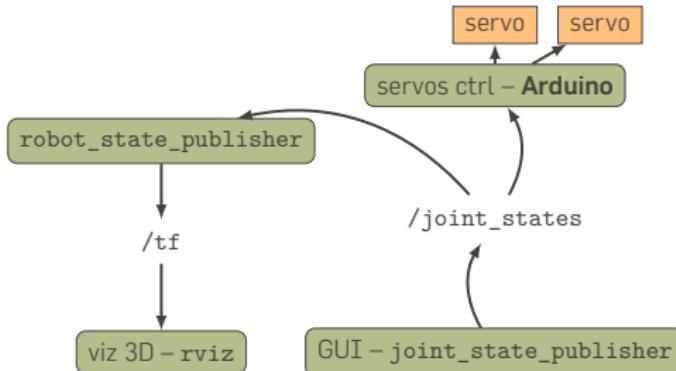
`robot_state_publisher` *subscribes* to the joint state topic `/joint_states` and *broadcasts* the corresponding TF frames.



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`robot_state_publisher` *subscribes* to the joint state topic `/joint_states` and *broadcasts* the corresponding TF frames.

JOINT STATE

```
> rosmsg show sensor_msgs/JointState
std_msgs/Header header
    uint32 seq
    time stamp
    string frame_id
    string[] name
    float64[] position
    float64[] velocity
    float64[] effort
```

Source: [sensor_msgs::JointState definition](#)

READING THE JOINT STATE ON THE ARDUINO

Original: reading an integer

```
1 #include <ros.h>
2 #include <std_msgs/UInt16.h>
3 #include <Servo.h>
4
5 using namespace ros;
6
7 NodeHandle nh;
8 Servo servo;
9
10 void cb( const std_msgs::UInt16& msg){
11     servo.write(msg.data); // 0-180
12 }
13
14
15 Subscriber<std_msgs::UInt16>
16                 sub("servo", cb);
17
18 void setup(){
19     nh.initNode();
20     nh.subscribe(sub);
21
22     servo.attach(9); //attach it to pin 9
23 }
24
25 void loop(){
26     nh.spinOnce();
27     delay(1);
28 }
```

Updated: reading the joint state

```
1 #include <Servo.h>
2 #include <ros.h>
3 #include <sensor_msgs/JointState.h>
4
5 using namespace ros;
6
7 NodeHandle nh;
8 Servo servo;
9
10 void cb( const sensor_msgs::JointState& msg){
11     int angle = (int) (msg.position[0] * 180/3.14);
12     servo.write(angle); // 0-180
13 }
14
15 Subscriber<sensor_msgs::JointState>
16                 sub("joint_states", cb);
17
18 void setup(){
19     nh.initNode();
20     nh.subscribe(sub);
21
22     servo.attach(9); //attach it to pin 9
23 }
24
25 void loop(){
26     nh.spinOnce();
27     delay(1);
28 }
```

DEEPER INTO ROS

PACKAGES

The source code of ROS nodes is usually organised into a *package*.

```
> cd my_package
> ls
CMakeLists.txt
cfg/
include/
launch/
msgs/
nodes/
package.xml
src/
> rosrun my_package my_node
```

One package often contains more than one node.

Besides the source code, packages may contain as well specific messages, configuration files, launch files, etc.

PACKAGES

The source code of ROS nodes is usually organised into a *package*.

```
> cd my_package
> ls
CMakeLists.txt
cfg/
include/
launch/
msgs/
nodes/
package.xml
src/
> rosrun my_package my_node
```

Packages must contain a *manifest*, `package.xml`. It contains the package name, version, authors, as well as the dependencies.

PACKAGES

The source code of ROS nodes is usually organised into a *package*.

```
> cd my_package
> ls
CMakeLists.txt
cfg/
include/
launch/
msgs/
nodes/
package.xml
src/
> rosrun my_package my_node
```

A new package template can be created easily:

```
> catkin_create_pkg my_package <ROS dependencies>
```

LAUNCH FILES

Launch files allow to group together nodes and their configuration.

```
<launch>
  <arg name="model" />
  <arg name="gui" default="true" />

  <param name="robot_description" textfile="$(arg model)" />
  <param name="use_gui" value="$(arg gui)"/>

  <node name="joint_state_publisher" pkg="joint_state_publisher"
        type="joint_state_publisher" />
  <node name="robot_state_publisher" pkg="robot_state_publisher"
        type="state_publisher" />
  <node name="rviz" pkg="rviz" type="rviz" required="true" />

</launch>
```

LAUNCH FILES

```
<launch>
  <arg name="model" />
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  <param name="robot_description" textfile="$(arg model)" />
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  <node name="joint_state_publisher" pkg="joint_state_publisher"
        type="joint_state_publisher" />
  <node name="robot_state_publisher" pkg="robot_state_publisher"
        type="state_publisher" />
  <node name="rviz" pkg="rviz" type="rviz" required="true" />

</launch>
```

To use the launch file, call `roslaunch` instead of `rosrun`:

```
> roslaunch my_package interactive_arm.launch
```

LAUNCH FILES

```
<launch>
  <arg name="model" />
  <arg name="gui" default="true" />

  <param name="robot_description" textfile="$(arg model)" />
  <param name="use_gui" value="$(arg gui)"/>

  <node name="joint_state_publisher" pkg="joint_state_publisher"
        type="joint_state_publisher" />
  <node name="robot_state_publisher" pkg="robot_state_publisher"
        type="state_publisher" />
  <node name="rviz" pkg="rviz" type="rviz" required="true" />

</launch>
```

Arguments (`<arg>`) can be provided from the command-line:

```
> roslaunch my_package interactive_arm.launch
model:=my_arm.urdf
```

LAUNCH FILES

```
<launch>
  <arg name="model" />
  <arg name="gui" default="true" />

  <param name="robot_description" textfile="$(arg model)" />
  <param name="use_gui" value="$(arg gui)"/>

  <node name="joint_state_publisher" pkg="joint_state_publisher"
        type="joint_state_publisher" />
  <node name="robot_state_publisher" pkg="robot_state_publisher"
        type="state_publisher" />
  <node name="rviz" pkg="rviz" type="rviz" required="true" />

</launch>
```

Parameters (`<param>`) are loaded to the ROS *parameter server* and shared with all the ROS nodes.

LAUNCH FILES

```
<launch>
  <arg name="model" />
  <arg name="gui" default="true" />

  <param name="robot_description" textfile="$(arg model)" />
  <param name="use_gui" value="$(arg gui)"/>

  <node name="joint_state_publisher" pkg="joint_state_publisher"
        type="joint_state_publisher" />
  <node name="robot_state_publisher" pkg="robot_state_publisher"
        type="state_publisher" />
  <node name="rviz" pkg="rviz" type="rviz" required="true" />

</launch>
```

Some nodes may be marked as `required`: if they die (closed or crashed), all the other nodes in the launch file are killed as well.

LAUNCH FILES

```
<launch>
  <arg name="model" />
  <arg name="gui" default="true" />

  <param name="robot_description" textfile="$(arg model)" />
  <param name="use_gui" value="$(arg gui)"/>

  <node name="joint_state_publisher" pkg="joint_state_publisher"
        type="joint_state_publisher" />
  <node name="robot_state_publisher" pkg="robot_state_publisher"
        type="state_publisher" />
  <node name="rviz" pkg="rviz" type="rviz" required="true" />

</launch>
```

Many more possibilities, see roslaunch documentation.

RViz*

File Panels Help

Interact Move Camera Select Focus Camera Measure 2D Pose Estimate 2D Nav Goal Publish Point + -

Displays

Global Options

Fixed Frame base_link
Background Color 48; 48; 48
Frame Rate 30

Global Status: Ok

✓ Fixed Frame

Grid



Grid

Displays a grid along the ground plane, centered at the origin of the target frame of reference.

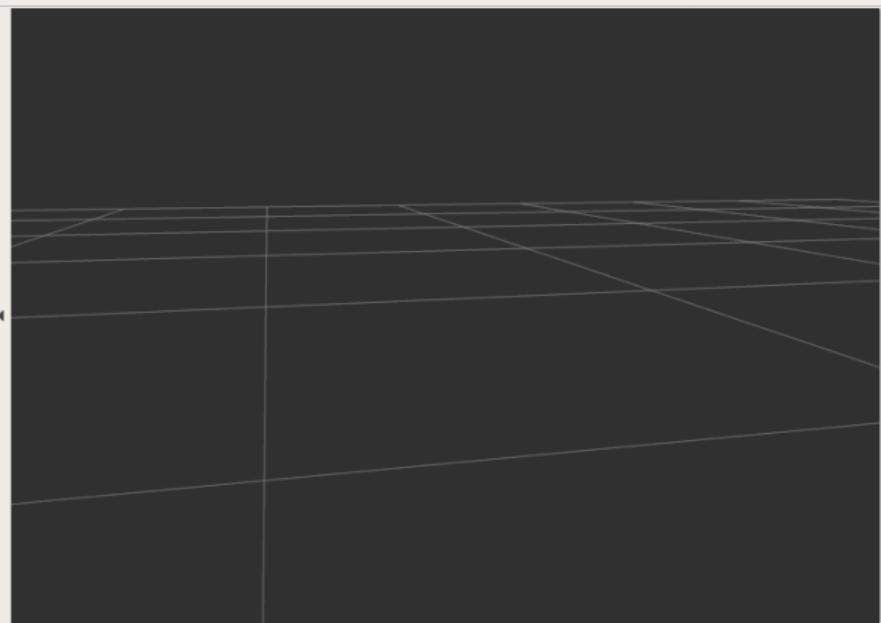
[More Information](#)

Add

Duplicate

Remove

Rename



Time

ROS Time: 1511281694.55

ROS Elapsed: 525.75

Wall Time: 1511281694.58

Wall Elapsed: 525.75

Experimental

Reset

31 fps

RViz*

File Panels Help

Interact

Move Camera

Select

Focus Camera

Measure

2D Pose Estimate

2D Nav Goal

Publish Point

+

-

Displays

Global Options

Fixed Frame base_link
 Background Color [48; 48; 48]
 Frame Rate 30

Global Status: Ok

Fixed Frame OK

Grid

Grid

Displays a grid along the ground plane, centered at the origin of the target frame of reference.

[More Information](#)

Add

Duplicate

Remove

Rename

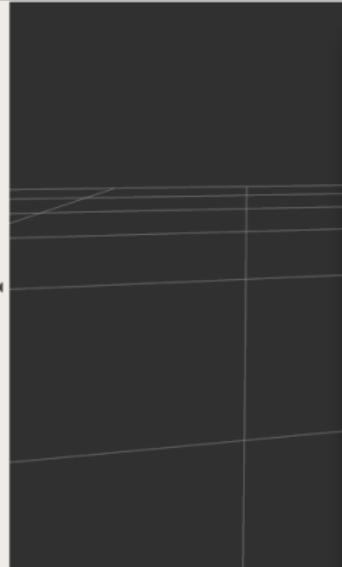
Time

ROS Time: 1511281588.67

ROS Elapsed: 419.88

Wall Time: 1511281588.71

Reset Left-Click: Rotate. Middle-Click: Move X/Y. Right-Click/Mouse Wheel: Zoom. Shift: More



rviz

Create visualization

By display type By topic

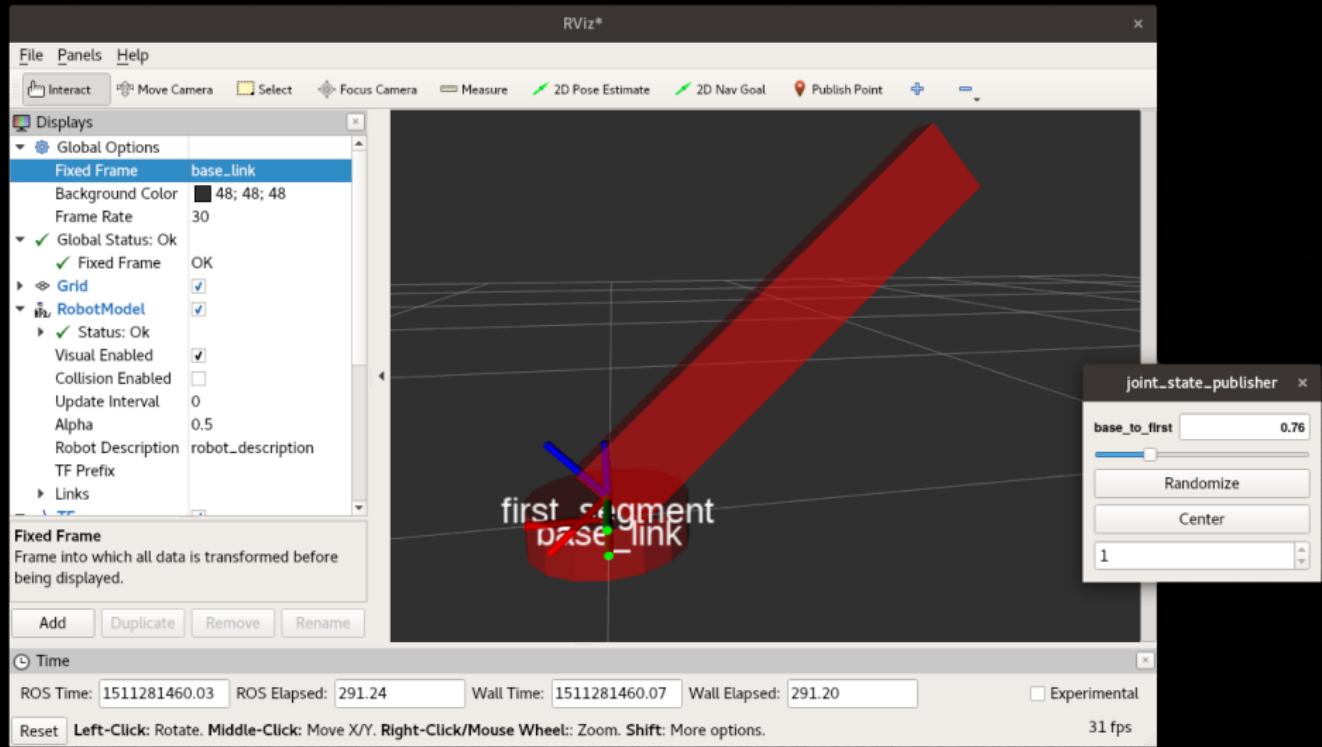
- Odometry
- Path
- PointCloud
- PointCloud2
- PointStamped
- Polygon
- Pose
- PoseArray
- Range
- RelativeHumidity
- RobotModel
- TF
- Temperature
- WrenchStamped

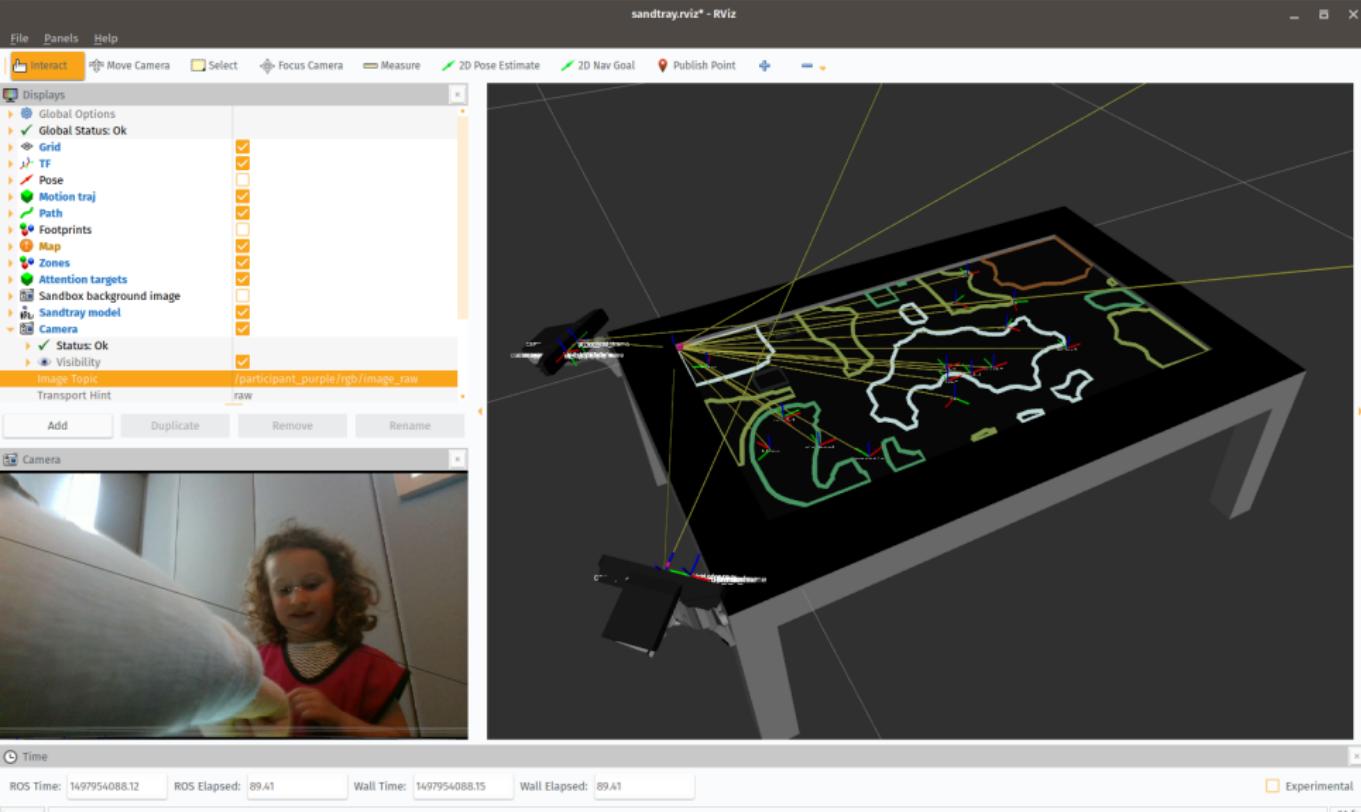
Description:

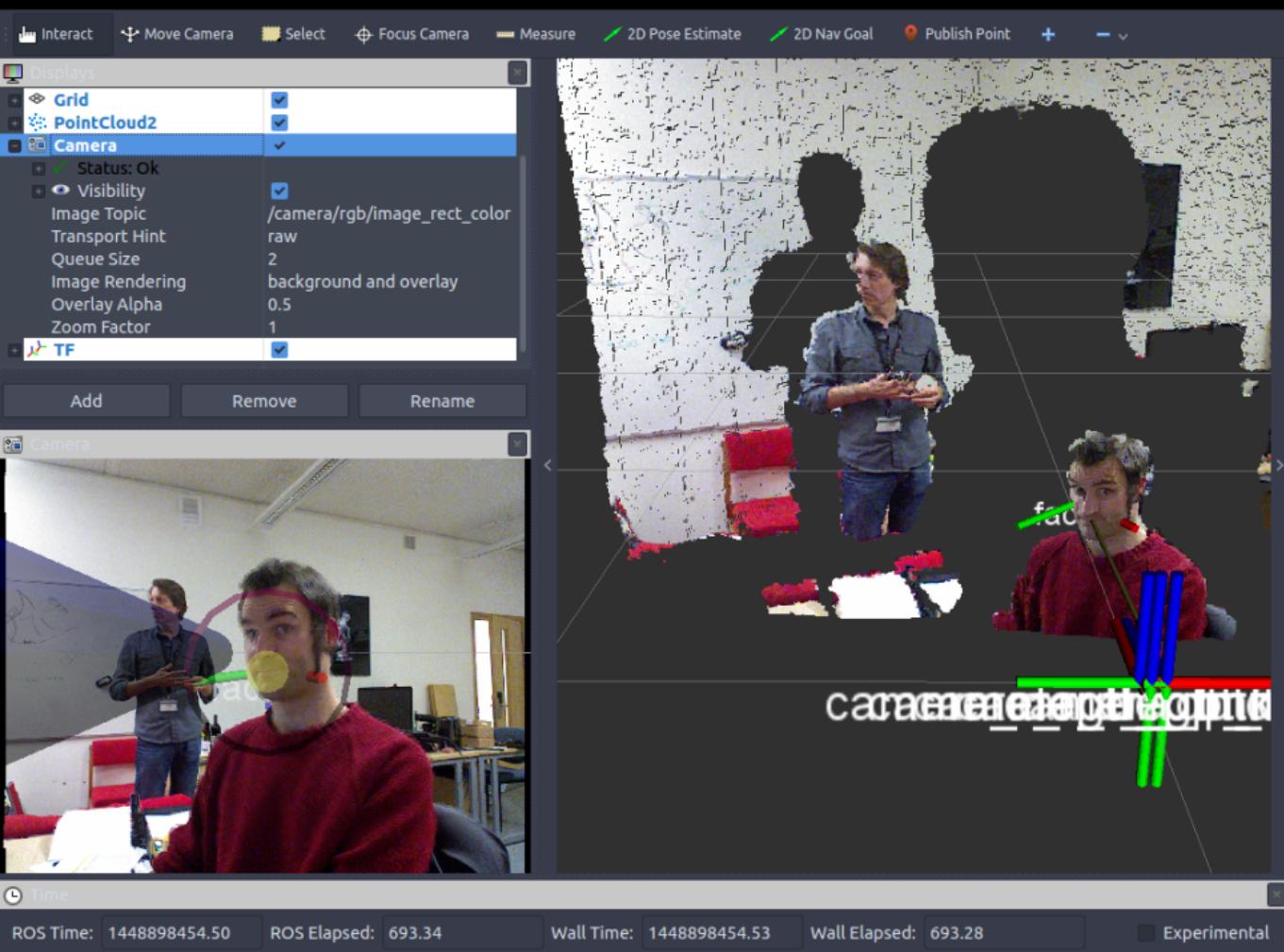
Displays a visual representation of a robot in the correct pose (as defined by the current TF transforms). [More Information](#).

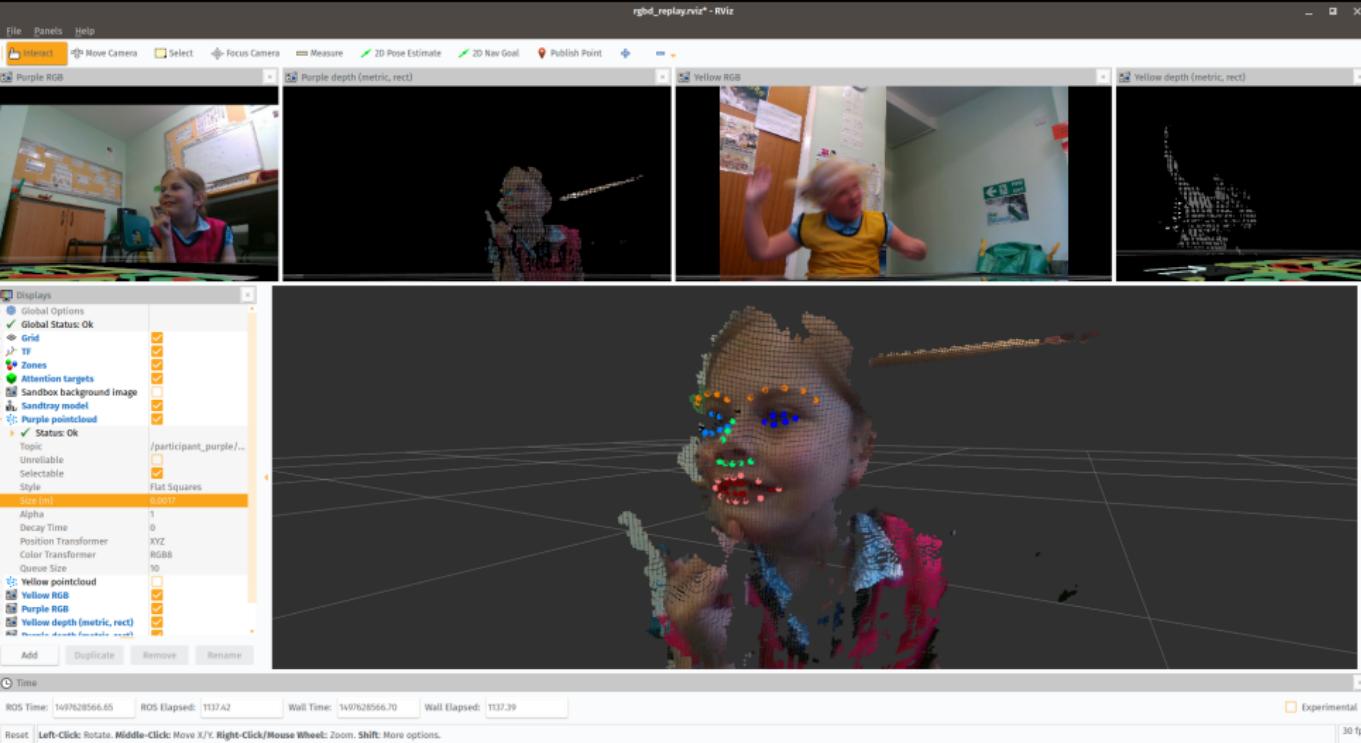
Display Name

Cancel OK









OTHER TOOLS

<code>rosnode</code> , <code>rostopic</code> , ...	Print out/publish/call messages, services, nodes
<code>rosconsole</code>	Centralized logging
<code>rosbag</code>	Record and replay messages
<code>rqt_reconfigure</code>	Live configuration of nodes
<code>rqt_diagnostics</code>	Standardized diagnostics
<code>rosgraph</code>	plots the node network

```
> rosnode list
/camera_base_link
/camera_base_link1
/camera_base_link2
/camera_base_link3
/ros_attention_tracker
/rosout
/camera/camera_nodelet_manager
/camera/debayer
/camera/depth_metric
/camera/depth_metric_rect
/camera/depth_points
/camera/depth_rectify_depth
/camera/depth_registered_hw_metric_rect
/camera/depth_registered_metric
/camera/depth_registered_rectify_depth
/camera/depth_registered_sw_metric_rect
/camera/disparity_depth
/camera/disparity_registered_hw
/camera/disparity_registered_sw
```

```
> rostopic list
/camera_info
/image
/nb_detected_faces
/rosout
/rosout_agg
/tf
/camera/depth/image_rect_raw
/camera/depth/image_rect_raw/compressed
/camera/depth/image_rect_raw/compressed/parameter_descriptions
/camera/depth/image_rect_raw/compressed/parameter_updates
/camera/depth/image_rect_raw/compressedDepth
/camera/depth/image_rect_raw/compressedDepth/parameter_descript
/camera/depth/image_rect_raw/compressedDepth/parameter_updates
/camera/depth/image_rect_raw/theora
/camera/depth/image_rect_raw/theora/parameter_descriptions
/camera/depth/image_rect_raw/theora/parameter_updates
/camera/depth_rectify_depth/parameter_descriptions
/camera/depth_rectify_depth/parameter_updates
```

```
> rostopic echo tf
transforms:
-
  header:
    seq: 0
    stamp:
      secs: 1449222890
      nsecs: 396561780
      frame_id: /camera_link
    child_frame_id: /camera_rgb_frame
    transform:
      translation:
        x: 0.0
        y: -0.045
        z: 0.0
      rotation:
        x: 0.0
        y: 0.0
        z: 0.0
        w: 1.0
```

rqt_console__Console - rqt

Console

D ? - O

Displaying 10 messages



Fit Columns

#	Message	Severity	Node	Stamp	Topics	Location
#8	Connection::drop(0)	Debug	/ros_attention_tracker	16:17:21.98...	/attention_...	/home/sl...
#7	TCP socket [18] closed	Debug	/ros_attention_tracker	16:17:21.98...	/attention_...	/home/sl...
#6	Connection::drop(2)	Debug	/ros_attention_tracker	16:17:21.98...	/attention_...	/home/sl...
#5	head_pose_estimator is r...	Info	/ros_attention_tracker	16:17:02.54...	/attention_...	/home/sl...
#4	Initializing the face detec...	Info	/ros_attention_tracker	16:17:01.48...	/rosout	/home/sl...
#3	Started stream.	Info	/v4l/gscam_driver_v4l	16:16:46.65...	/rosout, /v4...	/home/sl...
#2	Publishing stream...	Info	/v4l/gscam_driver_v4l	16:16:46.65...	/rosout, /v4...	/home/sl...
#1	Time offset: 1448897724....	Info	/v4l/gscam_driver_v4l	16:16:45.45...	/rosout	/home/sl...

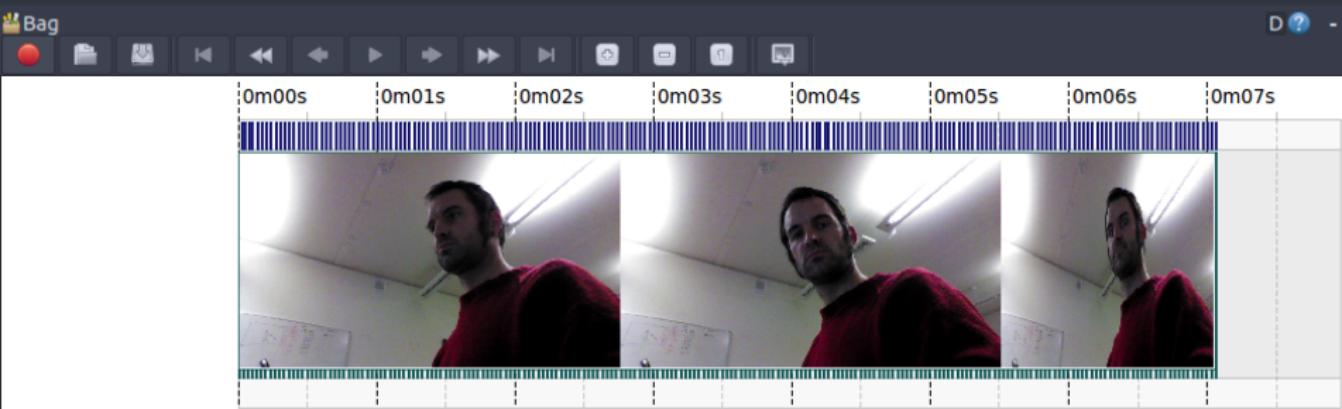
Exclude Messages...

 ...with severities: Debug Info Warn Error Fatal

Highlight Messages...

 ...containing: face
 Regex

rqt_bag_Bag - rqt



1449246342.413s Dec 04 2015 16:25:42.413 0.000s

rqt_reconfigure_Param - rqt

Dynamic Reconfigure

Filter key:

Collapse all

Expand all

+ attention_tracker

- camera
debayer

+ depth
depth_rectify_depth

+ depth_registered
depth_registered_rectify_depth
driver

+ ir
rectify_color
rectify_ir
rectify_mono

+ rgb

Refresh

/camera driver

image_mode	SXGA_15Hz (1)	▼
depth_mode	VGA_30Hz (2)	▼
depth_registration	<input checked="" type="checkbox"/>	
data_skip	0	1000 0
depth_time_offset	-1.0	1.0 0.0
image_time_offset	-1.0	1.0 0.0
depth_ir_offset_x	-10.0	10.0 5.0
depth_ir_offset_y	-10.0	10.0 4.0
z_offset_mm	-200	200 0
z_scaling	0.5	1.5 1.0

SO, WHAT IS ROS?

ROS IS...

- A fairly simple peer-to-peer message passing system designed with robotics in mind

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- Deep integration of a few key open-source libraries (OpenCV, PCL, tf)

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- A set of standard message types that facilitate interoperability between modules
- A set of conventions to write and package robotic softwares
- Deep integration of a few key open-source libraries (OpenCV, PCL, tf)
- A set of tools to run and monitor the nodes

That's all, folks!

Questions:

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Slides:

github.com/severin-lemaignan/module-introduction-sensors-actuators