CSC398 Autonomous Robots
- Introduction into ROS (3) -

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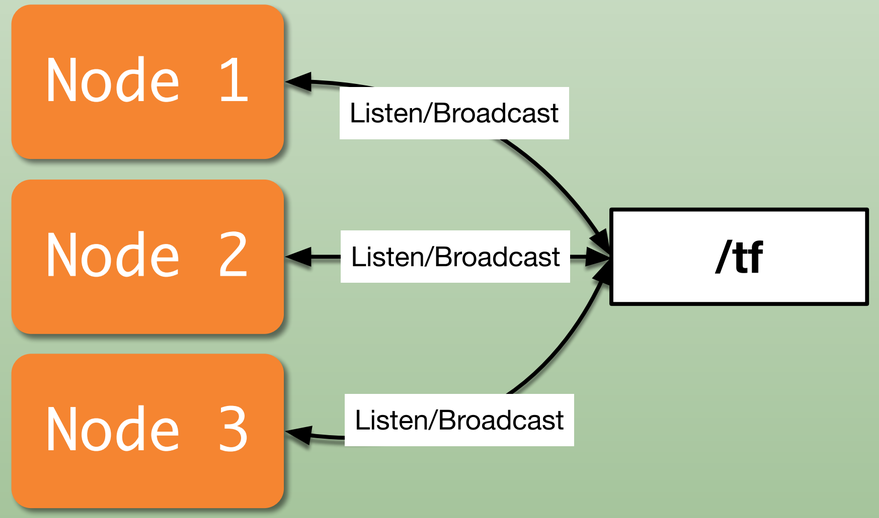
UNIVERSITY OF MIAMI
ROBOCANES

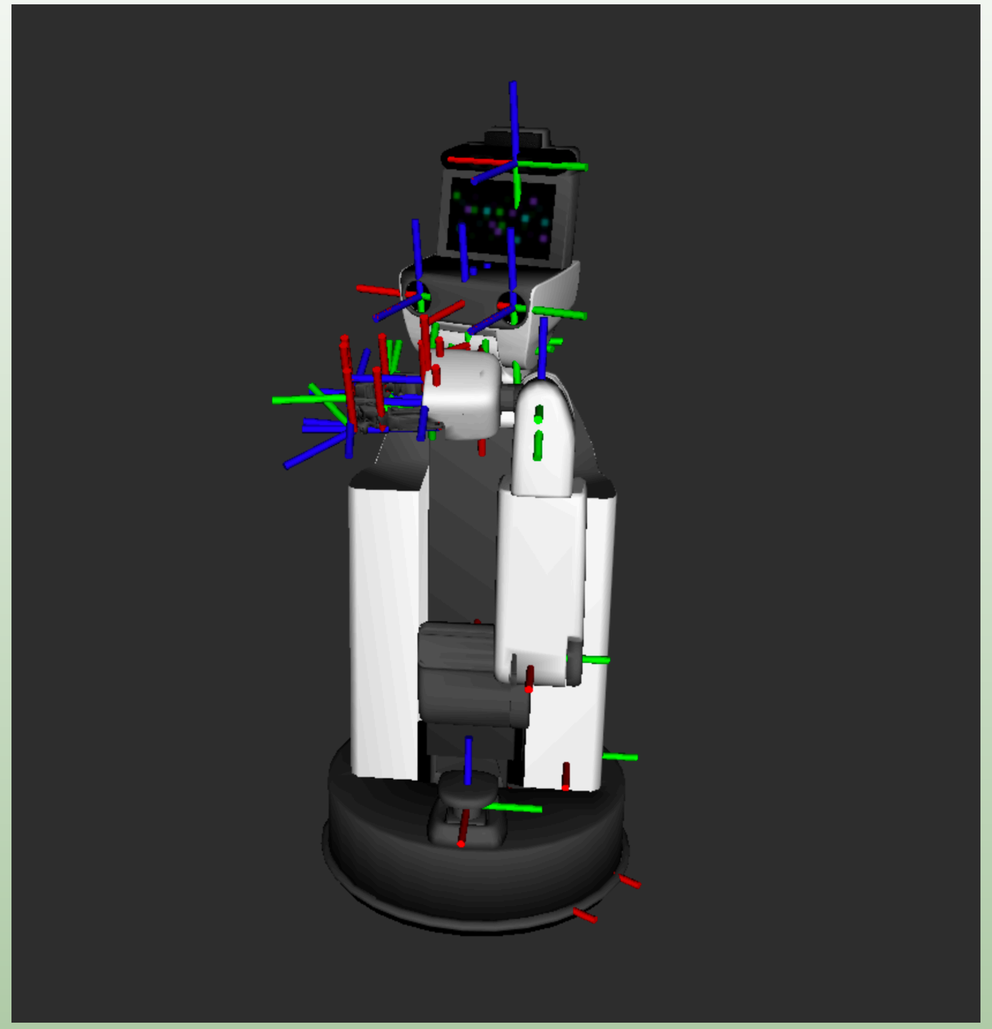
OVERVIEW

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

TF TRANSFORMATION SYSTEM

- Tool for keeping track of coordinate frames over time
- Maintains relationship between coordinate frames in a tree structure buffered in time
- Lets the user transform points, vectors, etc. between coordinate frames at desired time
- Implemented as publisher/subscriber model on the topics **/tf** and **/tf_static**





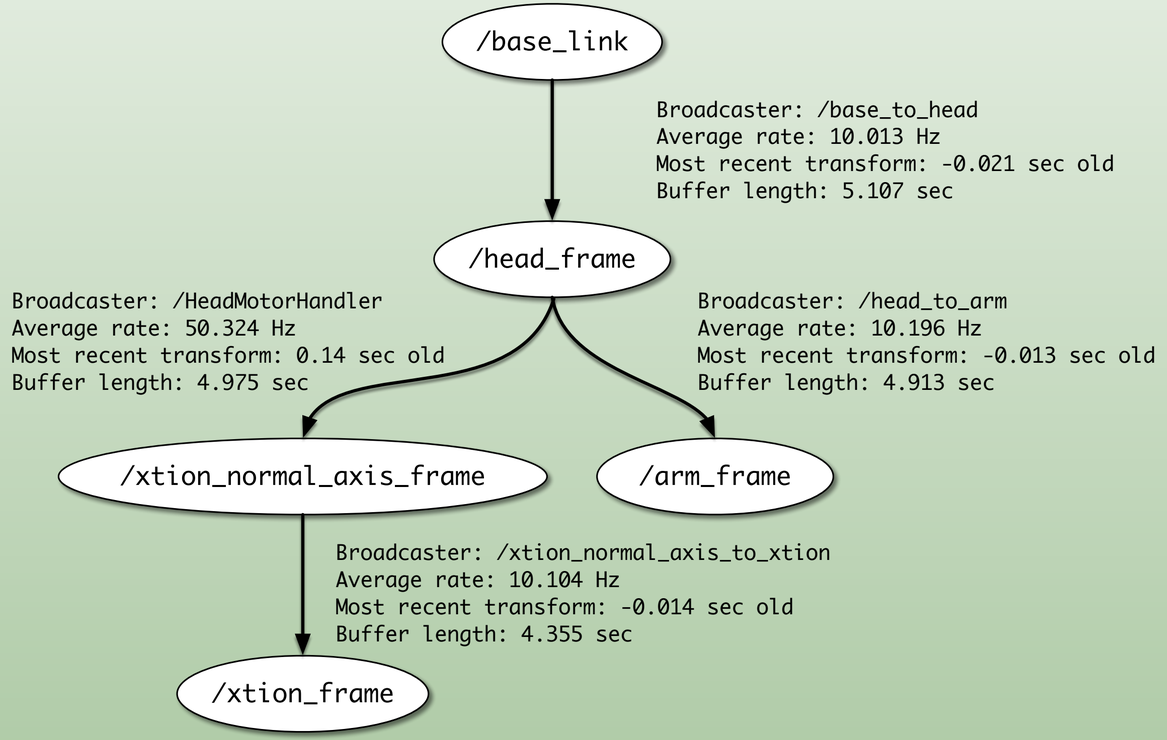
Details at: http://wiki.ros.org/tf2

TF TRANSFORMATION SYSTEM - TRANSFORM TREE

- TF listeners use a buffer to listen to all broadcasted transforms
- Query for specific transforms from the transform tree

tf2_msgs/TFMessage.msg

```
geometry_msgs/TransformStamped[] transforms
  std_msgs/Header header
    uint32 seqtime stamp
string frame_id
string child_frame_id
geometry_msgs/Transform transform
    geometry_msgs/Vector3 translation
    geometry_msgs/Quaternion rotation
```



Details at: http://docs.ros.org/jade/api/tf2_msgs/html/msg/TFMessage.html

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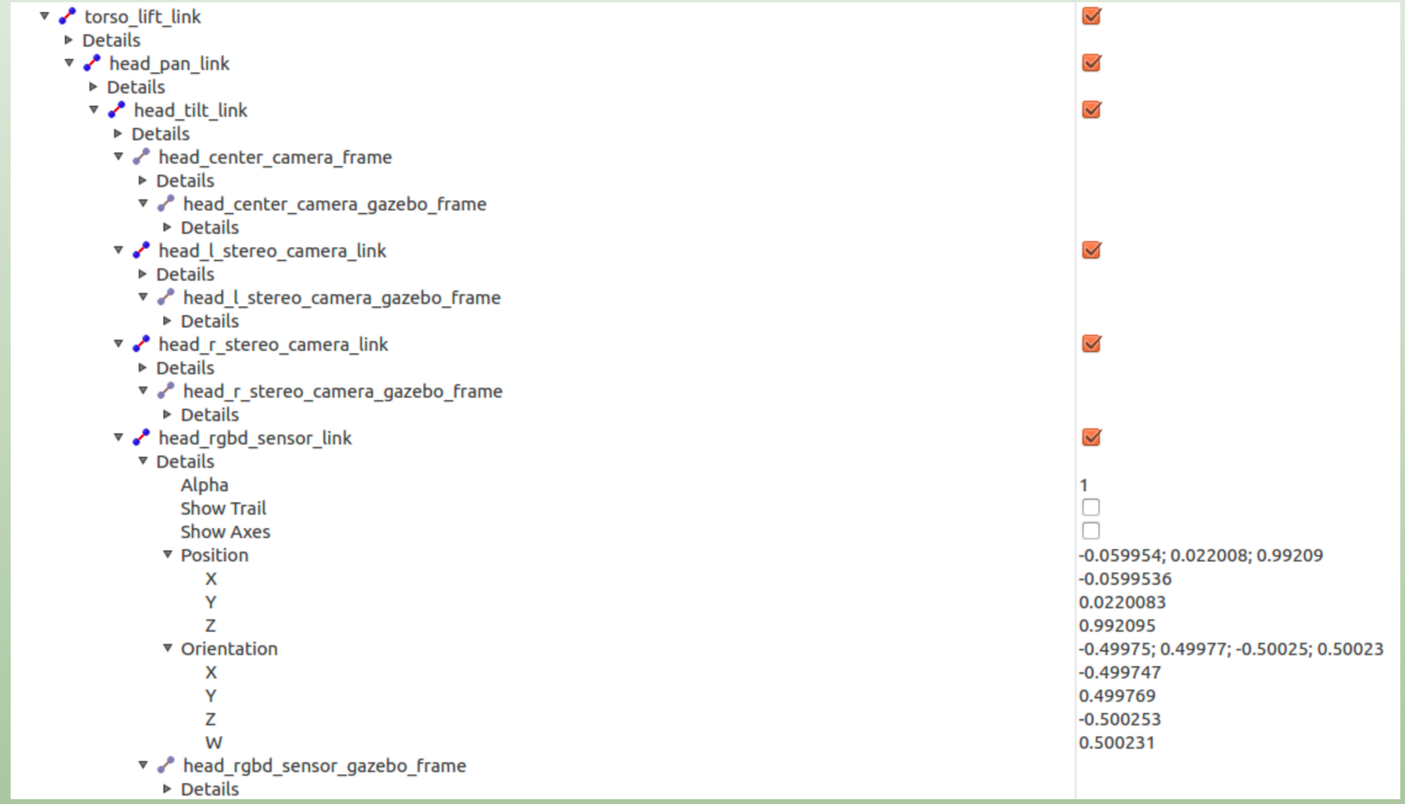
geometry_msgs/Transform transform
    geometry_msgs/Vector3 translation
    geometry_msgs/Quaternion rotation
```

Partial link tree from HSRB, torso



Details at: http://docs.ros.org/jade/api/tf2_msgs/html/msg/TFMessage.html

TF TRANSFORMATION SYSTEM - TOOLS

Terminal

Get information about the current transform tree

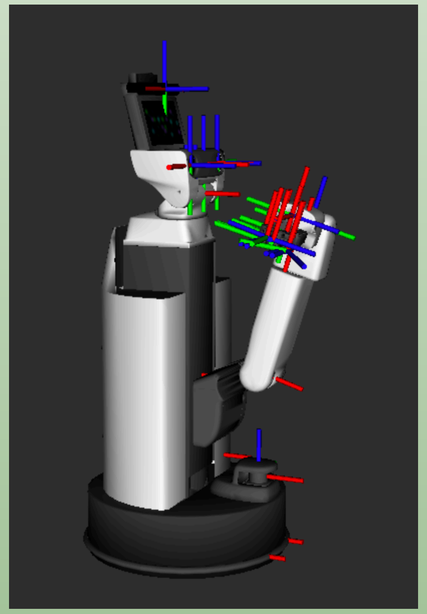
```
~$rosrun tf tf_monitor
```

Get information about the transform between two frames

```
~$rosrun tf tf_echo source_frame target_frame
```

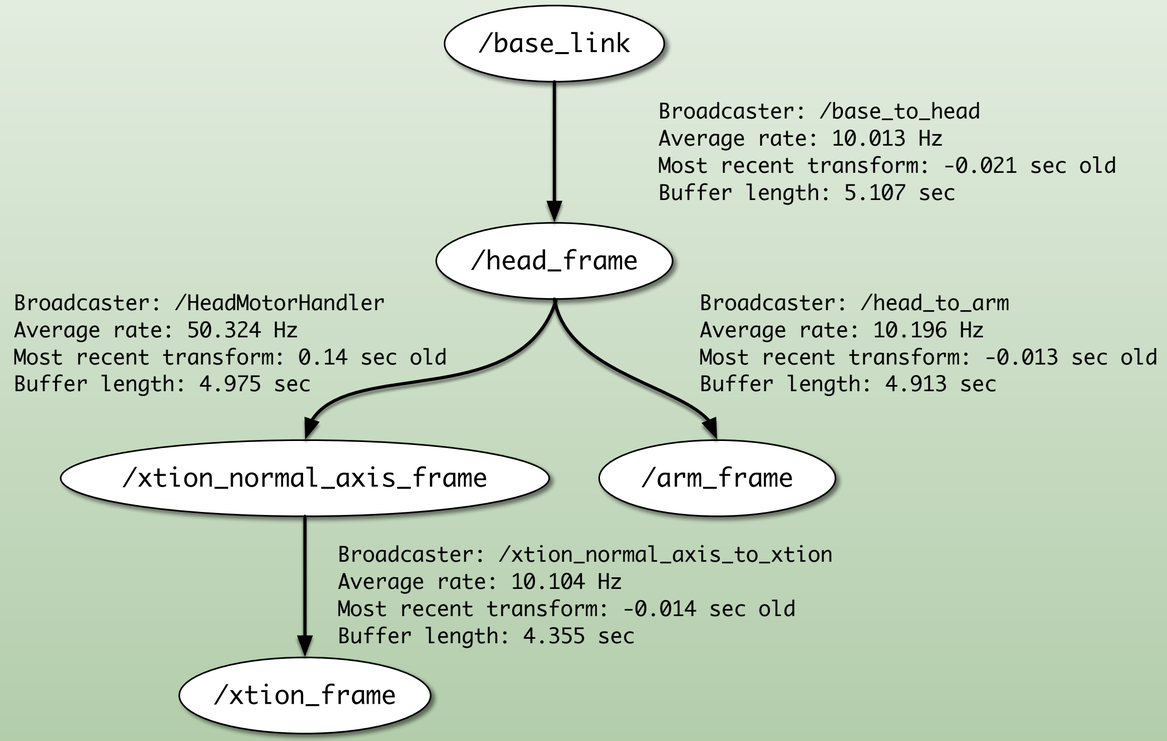
RViz

3D visualization of the transforms



View frames

Visual graph of the transform tree



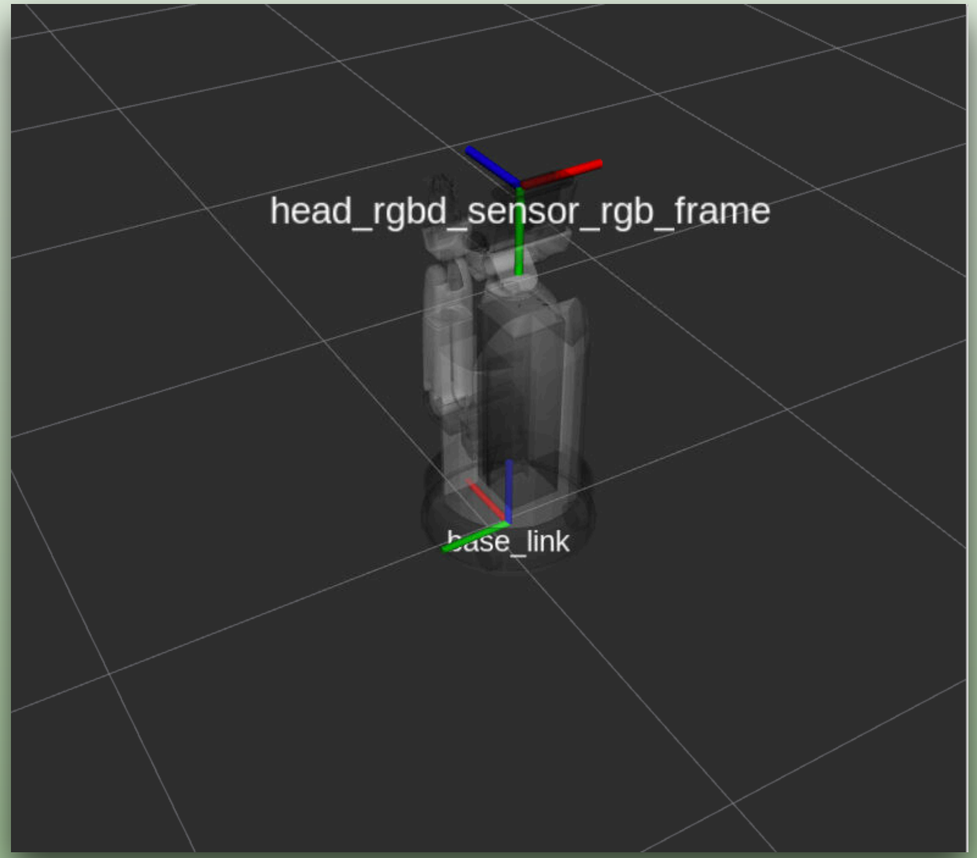
TF TRANSFORMATION SYSTEM - TOOLS

Terminal

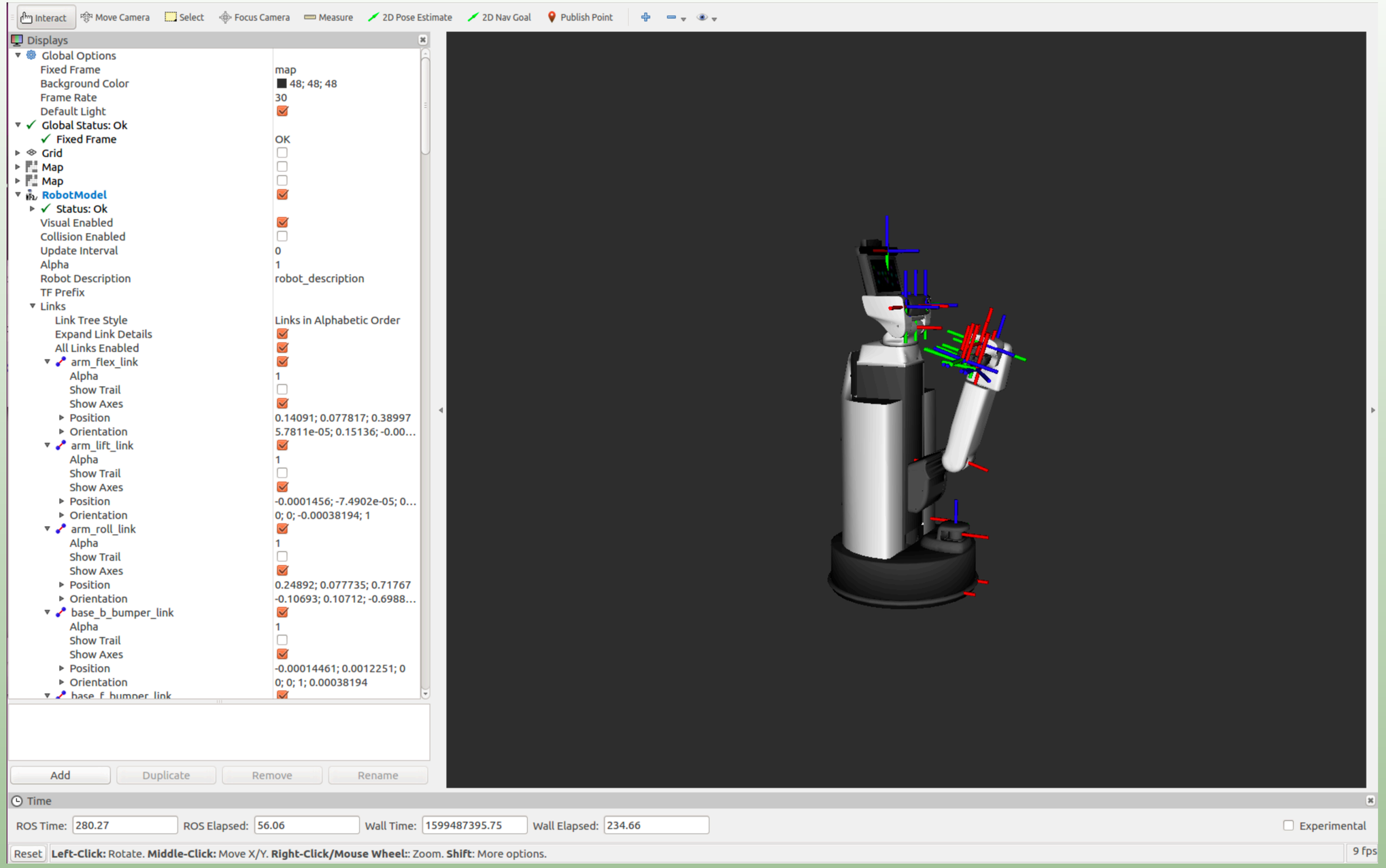
Example

```
~$rosrun tf tf_echo base_link head_rgbd_sensor_rgb_frame
```

```
At time 489.133
- Translation: [-0.060, 0.022, 0.967]
- Rotation: in Quaternion [0.500, -0.500, 0.500, -0.500]
            in RPY (radian) [-1.571, -0.000, -1.571]
            in RPY (degree) [-90.000, -0.000, -90.000]
At time 490.133
- Translation: [-0.060, 0.022, 0.967]
- Rotation: in Quaternion [0.500, -0.500, 0.500, -0.500]
            in RPY (radian) [-1.571, -0.000, -1.571]
            in RPY (degree) [-90.000, -0.000, -90.000]
At time 491.133
- Translation: [-0.060, 0.022, 0.967]
- Rotation: in Quaternion [0.500, -0.500, 0.500, -0.500]
            in RPY (radian) [-1.571, -0.000, -1.571]
            in RPY (degree) [-90.000, -0.000, -90.000]
At time 492.133
- Translation: [-0.060, 0.022, 0.967]
- Rotation: in Quaternion [0.500, -0.500, 0.500, -0.500]
            in RPY (radian) [-1.571, -0.000, -1.571]
            in RPY (degree) [-90.000, -0.000, -90.000]
```



TF TRANSFORMATION SYSTEM RVIZ PLUGIN



TF TRANSFORMATION SYSTEM - TRANSFORM LISTENER C++ API

```cpp
#include <ros/ros.h>
#include <tf2_ros/transform_listener.h>
#include <geometry_msgs/TransformStamped.h>

int main(int argc, char** argv)
{
  ros::init(argc, argv, "tf2_listener");
  ros::NodeHandle nodeHandle;

  tf2_ros::Buffer tfBuffer;
  tf2_ros::TransformListener tfListener(tfBuffer);

  ros::Rate rate(10.0);
  while (nodeHandle.ok())
  {
    geometry_msgs::TransformStamped transformStamped;
    try
    {
      transformStamped = ("base","odom", ros::Time(0));
    }
    catch (tf2::TransformException &exception)
    {
        ROS_WARN("%s", exception.what());
        os::Duration(1.0).sleep();
        continue;
    }
    rate.sleep();
  }
  return 0;
}
```

- Create a TF listener to fill up a buffer

```cpp
tf2_ros::Buffer tfBuffer;
tf2_ros::TransformListener tfListener(tfBuffer);
```

- Beware of scope!
- Lookup transformations use this:

```cpp
geometry_msgs::TransformStamped transformStamped =
    tfBuffer.lookupTransform(target_frame_id,
    source_frame_id, time);
```

- For time: use **ros::Time(0)** to get latest available transform

Details at:
http://wiki.ros.org/tf2/Tutorials/Writing%20a%20tf2%20listener%20(C++)

TF TRANSFORMATION SYSTEM - TRANSFORM LISTENER PYTHON API

```python
#!/usr/bin/env python

import rospy
import tf
from geometry_msgs.msg import TransformStamped

def get_transform():
    try:
        # Lookup the transformation from base_link to head_rgbd_sensor_rgb_frame
        (trans, rot) = listener.lookupTransform('base_link', 'head_rgbd_sensor_rgb_frame', rospy.Time(0))
        rospy.loginfo("Translation: %s" % str(trans))
        rospy.loginfo("Rotation: %s" % str(rot))
    except (tf.LookupException, tf.ConnectivityException, tf.ExtrapolationException):
        rospy.logwarn("Could not get transform from base_link to head_rgbd_sensor_rgb_frame")

# Initialize the ROS node
rospy.init_node('tf_listener')

# Create a tf listener
listener = tf.TransformListener()

# Set up the timer to call 'get_transform' every second
rospy.Timer(rospy.Duration(1), lambda event: get_transform())

# Keeps the node running until it is manually shut down
rospy.spin()
```

- Create a TF listener to fill up a buffer

```
listener = tf.TransformListener()
```

- Lookup transformations, rospy.Time(0) for latest frame

```
(trans, rot) = listener.lookupTransform('base_link', 'head_rgbd_sensor_rgb_frame', rospy.Time(0))
```

Details at:
http://wiki.ros.org/tf2/Tutorials/Writing%20a%20tf2%20listener%20%28Python%29

RQT USER INTERFACE

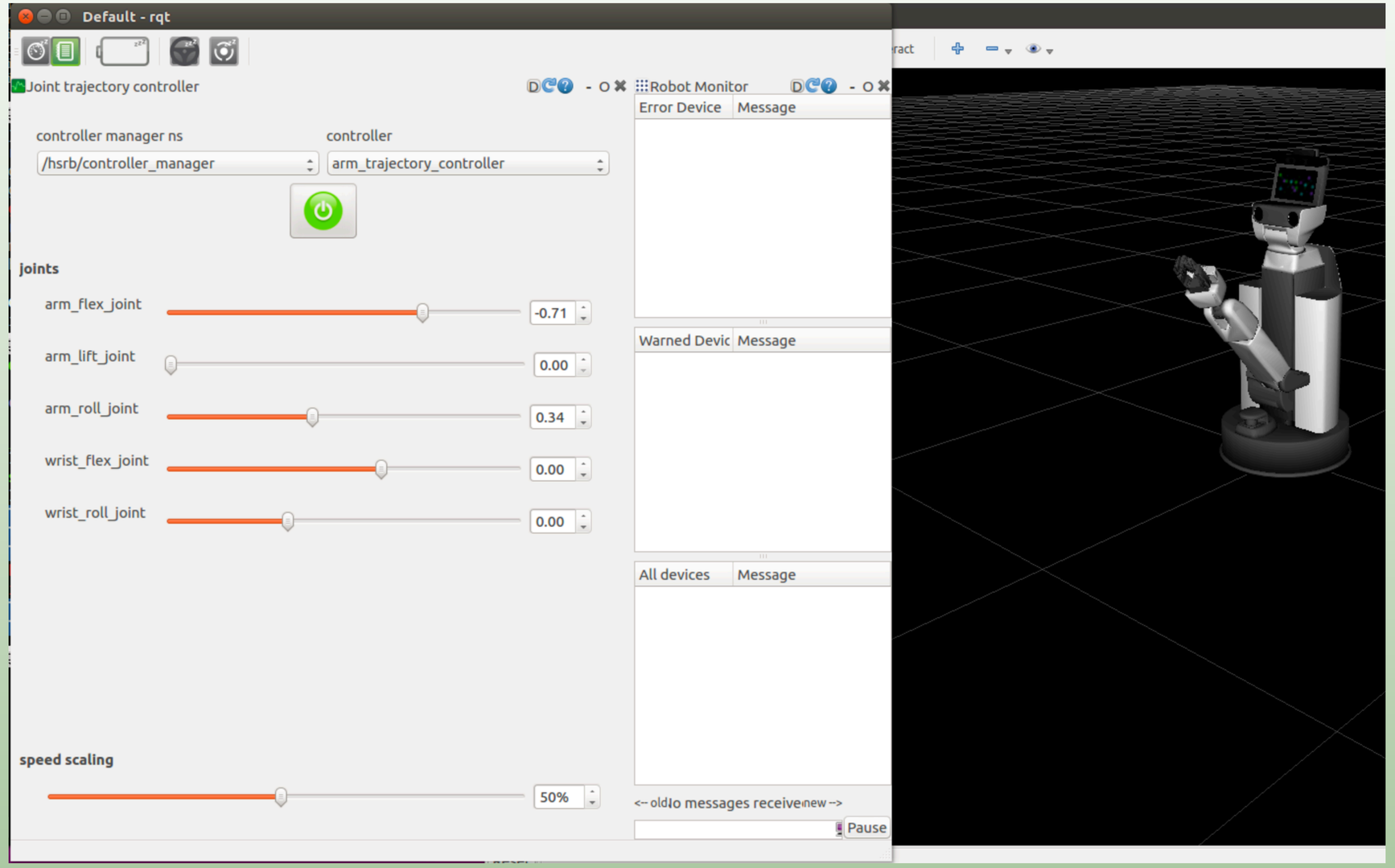
- User interface based on Qt
- Custom interfaces possible
- Use existing plugins
- Create your own plugins

Run RQT

```
~$rosrun rqt_gui rqt_gui
```

Alternative

```
~$rqt
```



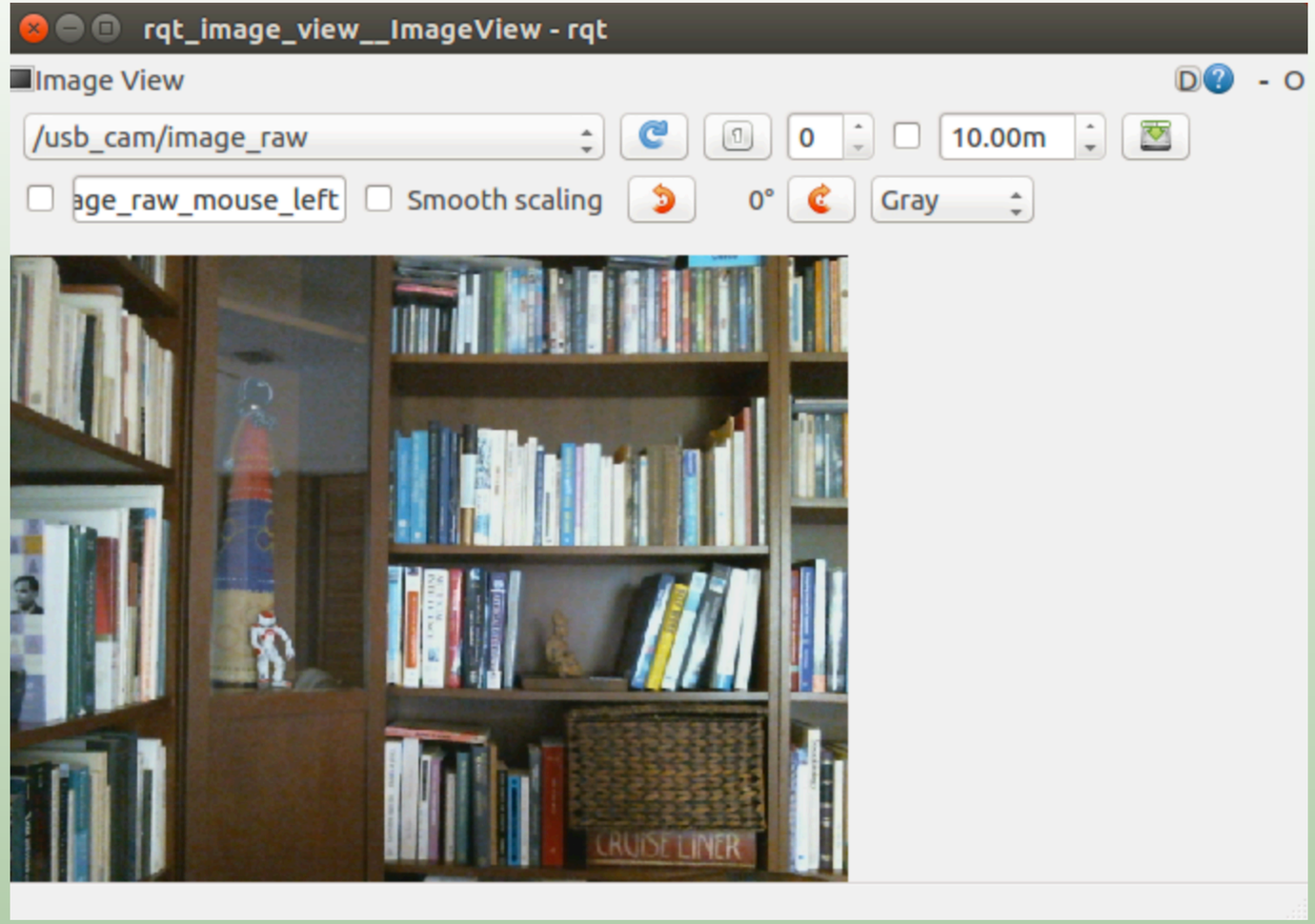
Details at: http://wiki.ros.org/rqt/Plugins

RQT USER INTERFACE IMAGE VIEW

- Visualizing images

Run rqt_image_view

```
~$rosrun rqt_image_view rqt_image_view
```



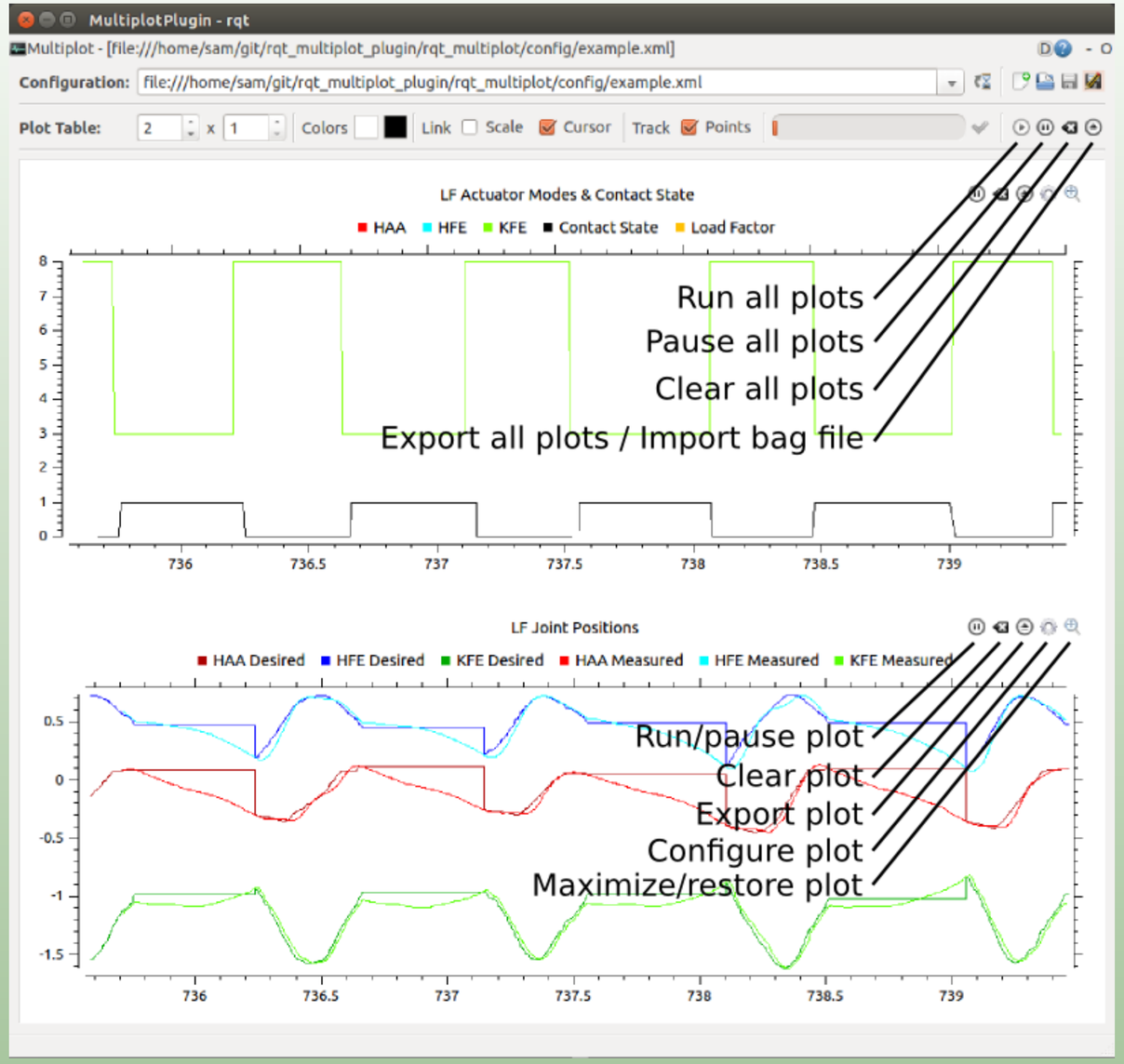
Details at: http://wiki.ros.org/rqt_image_view

RQT USER INTERFACE RQT_MULTIPLOT

- Visualizing numeric values in 2D plots

Run rqt_multiplot

```
~$rosrun rqt_multiplot rqt_multiplot
```



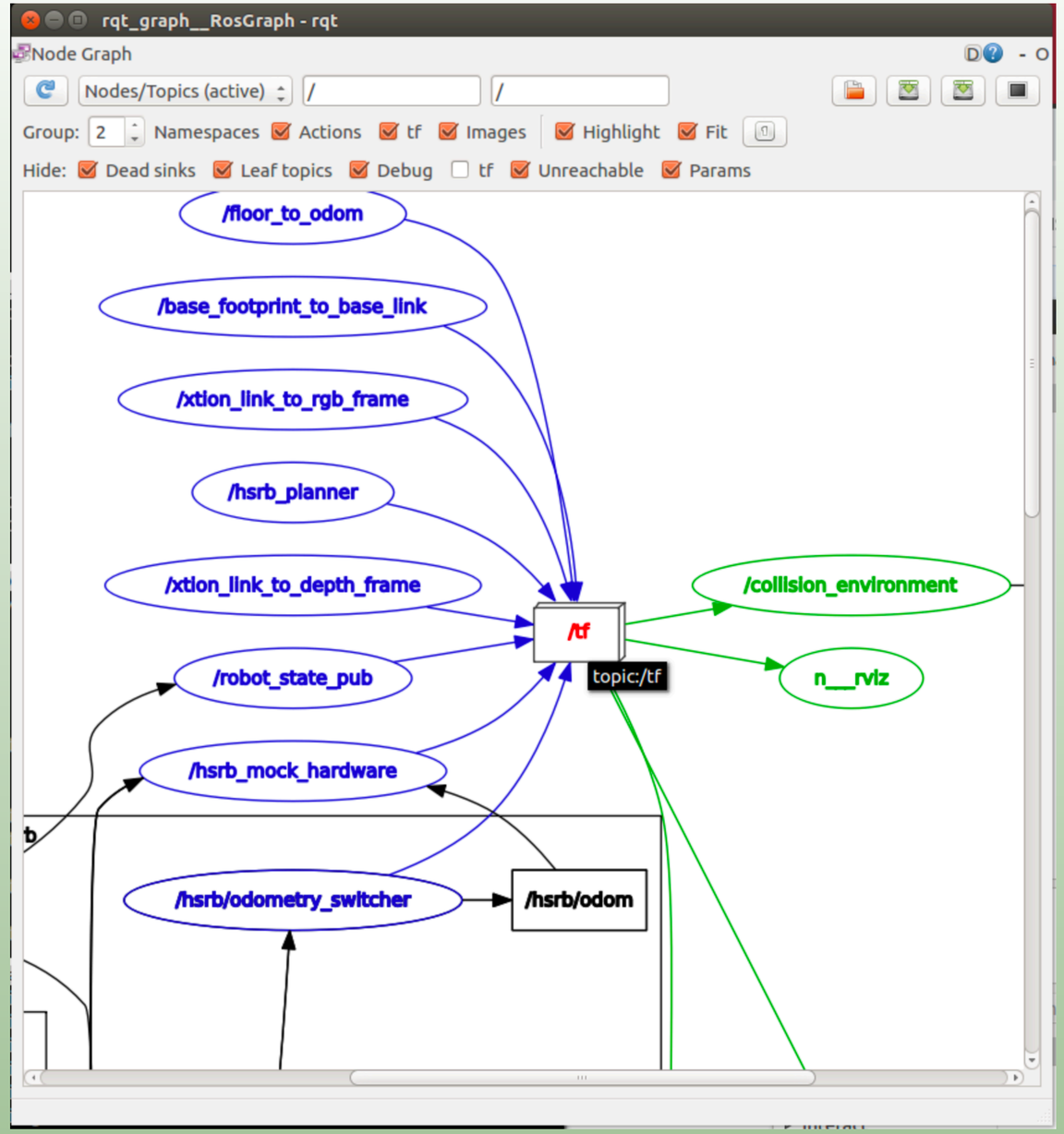
Details at: http://wiki.ros.org/rqt_multiplot

RQT USER INTERFACE RQT_GRAPH

- Visualizing the ROS computation graph

Run rqt_graph

```
~$rosrun rqt_graph rqt_graph
```



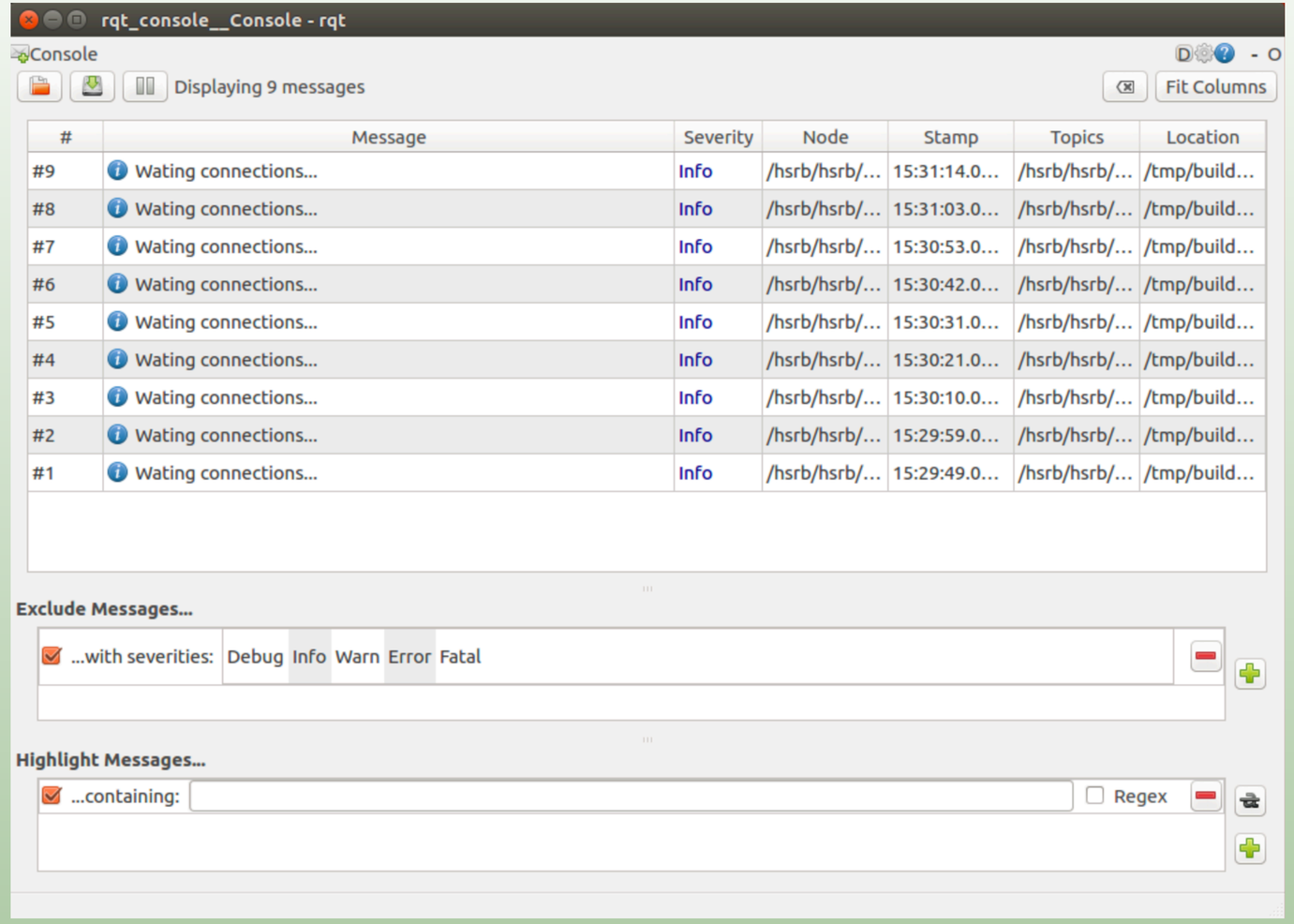
Details at: http://wiki.ros.org/rqt_graph

RQT USER INTERFACE RQT_CONSOLE

- Displaying and filtering ROS messages

Run rqt_console

```
~$rosrun rqt_console rqt_console
```



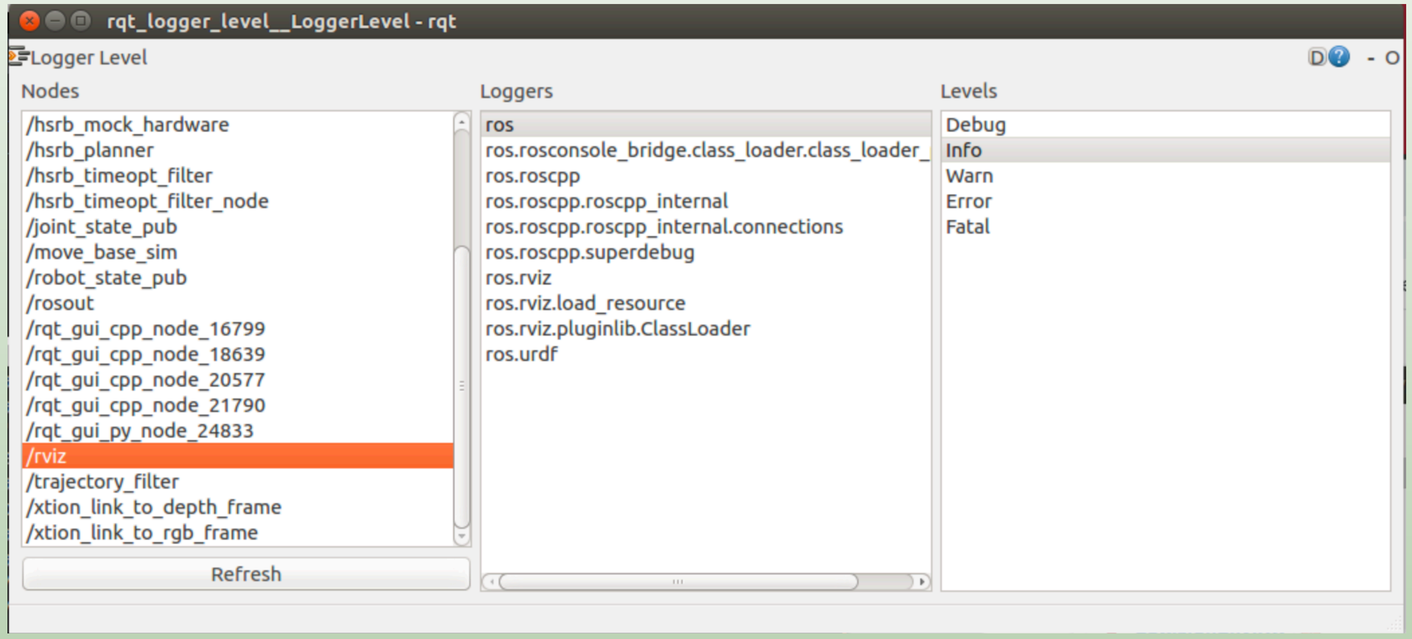
Details at: http://wiki.ros.org/rqt_console

RQT USER INTERFACE RQT_LOGGER_LEVEL

- Configuring the logger level of ROS nodes

Run rqt_logger_level

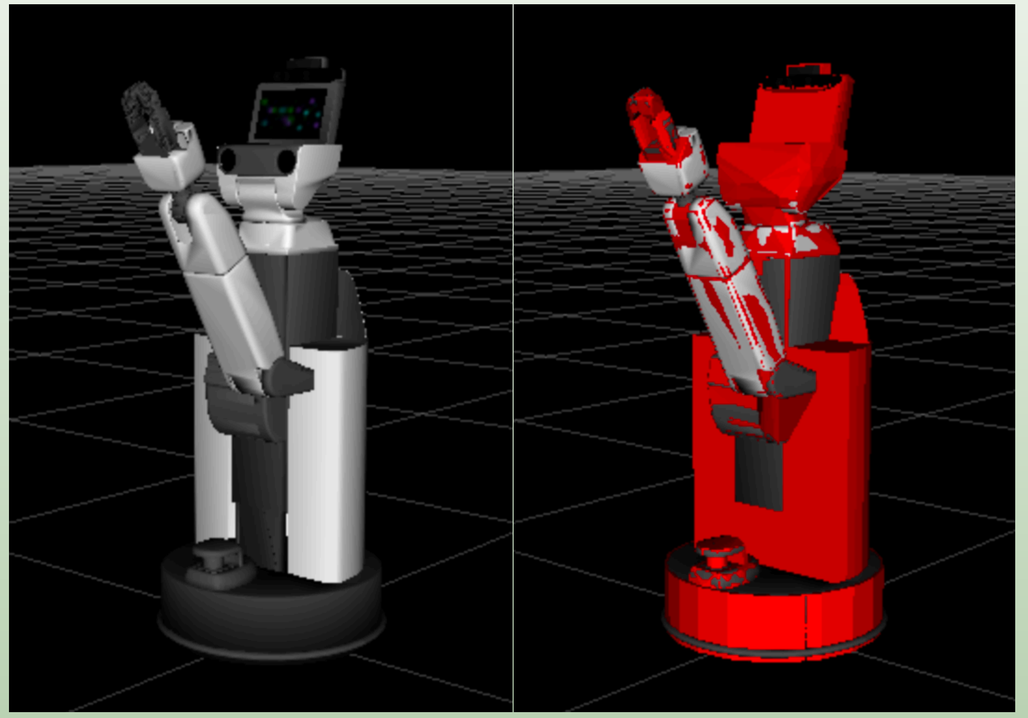
```
~$rosrun rqt_logger_level rqt_logger_level
```



Details at: http://wiki.ros.org/rqt_logger_level

ROBOT MODELS - URDF

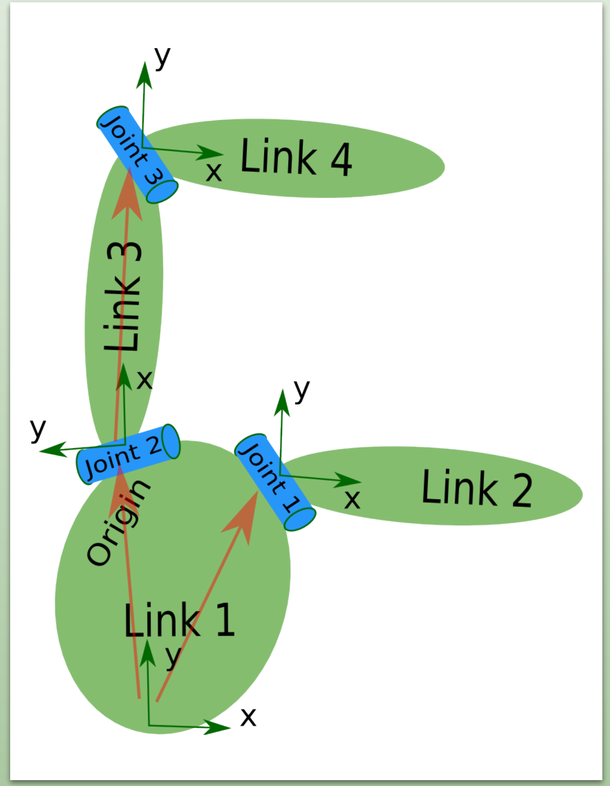
- Unified Robot Description Format (URDF)
- Defines robot model in XML format
  - Kinematic description
  - Dynamic description
  - Visual representation (left figure of HSR)
  - Collision model (right figure of HSR)
- URDF generation can be scripted using XACRO



Details at:
http://wiki.ros.org/urdf, http://wiki.ros.org/xacro

ROBOT MODELS - URDF

- Description consists of a set of **link** elements and a set of **joint** elements
- Joints connect the link elements together




```
<robot name="hsr">
  <link> ... </link>
  <link> ... </link>
  <link> ... </link>

  <joint>  ....  </joint>
  <joint>  ....  </joint>
  <joint>  ....  </joint>
</robot>
```

```
<link name="my_link">
  <inertial>
    <origin xyz="0 0 0.5" rpy="0 0 0"/>
    <mass value="1"/>
    <inertia ixx="100"  ixy="0"  ixz="0" iyy="100"
    iyz="0" izz="100" />
  </inertial>

  <visual>
    <origin xyz="0 0 0" rpy="0 0 0" />
    <geometry>
      <box size="1 1 1" />
    </geometry>
    <material name="Cyan">
      <color rgba="0 1.0 1.0 1.0"/>
    </material>
  </visual>

  <collision>
    <origin xyz="0 0 0" rpy="0 0 0"/>
    <geometry>
      <cylinder radius="1" length="0.5"/>
    </geometry>
  </collision>
</link>
```

Details at:
http://wiki.ros.org/urdf/XML/model

ROBOT MODELS - USAGE IN ROS

- The robot description (URDF) is stored on the parameter server (typically) under **/robot_description**
- You can visualize the robot model in RViz with the RobotModel plugin

husky.urdf.xacro

```
<robot name="husky" xmlns:xacro="http://ros.org/wiki/xacro">

  <xacro:arg name="laser_enabled" default="false" />
  <xacro:arg name="laser_xyz" default="$(optenv HUSKY_LMS1XX_XYZ 0.2206 0.0 0.00635)" />
  <xacro:arg name="laser_rpy" default="$(optenv HUSKY_LMS1XX_RPY 0.0 0.0 0.0)" />

  <xacro:arg name="kinect_enabled" default="false" />
  <xacro:arg name="kinect_xyz" default="$(optenv HUSKY_KINECT_XYZ 0 0 0)" />
  <xacro:arg name="kinect_rpy" default="$(optenv HUSKY_KINECT_RPY 0 0.18 3.14)" />

  <xacro:arg name="realsense_enabled" default="false" />
  <xacro:arg name="realsense_xyz" default="$(optenv HUSKY_REALSENSE_XYZ 0 0 0)" />
  <xacro:arg name="realsense_rpy" default="$(optenv HUSKY_REALSENSE_RPY 0 0 0)" />
  <xacro:arg name="realsense_mount" default="$(optenv HUSKY_REALSENSE_MOUNT_FRAME
  sensor_arch_mount_link)" />

  <xacro:property name="husky_front_bumper_extend" value="$(optenv
  HUSKY_FRONT_BUMPER_EXTEND 0)" />
  <xacro:property name="husky_rear_bumper_extend" value="$(optenv HUSKY_REAR_BUMPER_EXTEND
  0)" />

  <xacro:arg name="robot_namespace" default="/" />
  <xacro:arg name="urdf_extras" default="empty.urdf" />
```

spawn_husky.launch

```
<launch>

  <arg name="multimaster" default="false"/>

  <arg name="robot_namespace" default="/"/>

  <arg name="x" default="0.0"/>
  <arg name="y" default="0.0"/>
  <arg name="z" default="0.0"/>
  <arg name="yaw" default="0.0"/>

  <arg name="laser_enabled" default="$(optenv HUSKY_LMS1XX_ENABLED false)"/>
  <arg name="kinect_enabled" default="$(optenv HUSKY_KINECT_ENABLED false)"/>
  <arg name="realsense_enabled" default="$(optenv HUSKY_REALSENSE_ENABLED false)"/>
  <arg name="urdf_extras" default="$(optenv HUSKY_URDF_EXTRAS)"/>

  <group ns="$(arg robot_namespace)">

    <group if="$(arg multimaster)">
      <include file="$(find husky_description)/launch/description.launch" >
        <arg name="robot_namespace" value="$(arg robot_namespace)"/>
        <arg name="laser_enabled" default="$(arg laser_enabled)"/>
        <arg name="kinect_enabled" default="$(arg kinect_enabled)"/>
        <arg name="realsense_enabled" default="$(arg realsense_enabled)"/>
        <arg name="urdf_extras" default="$(arg urdf_extras)"/>
      </include>

      <include file="$(find multimaster_launch)/launch/multimaster_gazebo_robot.launch">
        <arg name="gazebo_interface" value="$(find husky_control)/config/
        gazebo_interface.yaml" />
        <arg name="robot_namespace" value="$(arg robot_namespace)"/>
      </include>

      <!-- For multimaster bringup, need to load the controller config -->
      <rosparam command="load" file="$(find husky_control)/config/control.yaml" />
    </group>
```

ROBOT MODELS - USAGE IN ROS

- The robot description (URDF) is stored on the parameter server (typically) under **/robot_description**
- You can visualize the robot model in RViz with the RobotModel plugin

hsrb4s.urdf.xacro

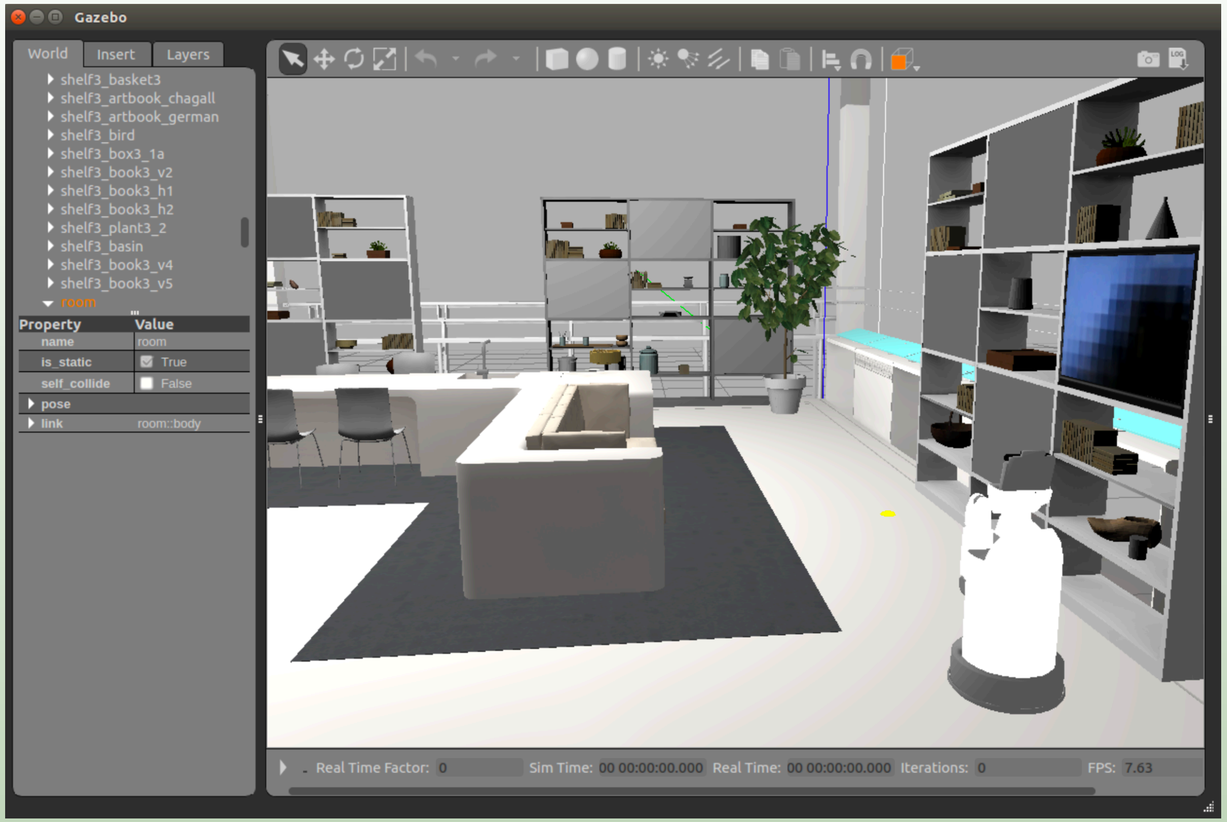
```
<robot name="hsrb"
       xmlns:controller="http://playerstage.sourceforge.net/gazebo/xmlschema/#controller"
       xmlns:interface="http://playerstage.sourceforge.net/gazebo/xmlschema/#interface"
       xmlns:sensor="http://playerstage.sourceforge.net/gazebo/xmlschema/#sensor"
       xmlns:xacro="http://ros.org/wiki/xacro">

    <!-- common xacro -->
    <xacro:include filename="$(find hsrb_description)/urdf/common.xacro" />
    <xacro:include filename="$(find hsrb_description)/urdf/materials.urdf.xacro" />

    <!-- links and joints -->
    <xacro:include filename="$(find hsrb_description)/urdf/base_v2/base.urdf.xacro" />
    <xacro:include filename="$(find hsrb_description)/urdf/torso_v0/torso.urdf.xacro" />
    <xacro:include filename="$(find hsrb_description)/urdf/head_v2/head.urdf.xacro" />
    <xacro:include filename="$(find hsrb_description)/urdf/arm_v0/arm.urdf.xacro" />
    <xacro:include filename="$(find hsrb_description)/urdf/wrist_v0/wrist.urdf.xacro" />
    <xacro:include filename="$(find hsrb_description)/urdf/hand_v0/hand.urdf.xacro" />

    <xacro:arg name="personal_name" default=""/>
    <xacro:arg name="loopback_hardware" default="false" />

    <!-- constant -->
    <xacro:property name="personal_name" value="$(arg personal_name)"/>
    <xacro:property name="robot_name" value="hsrb"/>

    <!-- create robot -->
    <xacro:hsrb_base prefix="base" personal_name="${personal_name}" robot_namespace="${robot_name}" robot_name="${robot_name}"/>

    <xacro:hsrb_torso prefix="torso" parent="base_link" mimic_joint="arm_lift_joint">
        <origin xyz="0.0 0.0 0.752" rpy="0.0 0.0 0.0"/>
    </xacro:hsrb_torso>

    <xacro:hsrb_head prefix="head" parent="torso_lift_link">
        <origin xyz="0.0 0.0 0.0" rpy="0.0 0.0 0.0"/>
    </xacro:hsrb_head>

    <xacro:hsrb_arm prefix="arm" parent="base_link">
        <origin xyz="0.0 0.0 0.340" rpy="0.0 0.0 0.0"/>      cduarte, 4 weeks ago • src add
    </xacro:hsrb_arm>

    <xacro:hsrb_wrist prefix="wrist" parent="arm_roll_link" robot_namespace="${robot_name}">
        <origin xyz="0.0 0.0 0.0" rpy="0.0 0.0 0.0"/>
    </xacro:hsrb_wrist>

    <xacro:hsrb_hand prefix="hand" parent="wrist_roll_link">
        <origin xyz="0.012 0.0 0.1405" rpy="0.0 0.0 ${pi}"/>
    </xacro:hsrb_hand>
```

hsrb4s.urdf

```
<robot name="hsrb" xmlns:controller="http://playerstage.sourceforge.net/gazebo/xmlschema/#controller" xmlns:interface="http://playerstage.sourceforge.net
  <material name="body_main">
    <color rgba="1.0 0.0 0.0 1.0"/>
  </material>
  <material name="body_sub">
    <color rgba="0.33 0.33 0.33 1.0"/>
  </material>
  <material name="wheel">
    <color rgba="0.2 0.2 0.2 1.0"/>
  </material>
  <material name="black">
    <color rgba="0.1 0.1 0.1 1.0"/>
  </material>
  <material name="tablet">
    <color rgba="0.1 0.1 0.2 1.0"/>
  </material>
  <!--
    ASUS Xtion PRO LIVE
    Specs from:
    http://www.asus.com/Multimedia/Xtion_PRO_LIVE/#specifications
    -->
  <link name="base_footprint">
      </link>
  <joint name="base_footprint_joint" type="fixed">
    <parent link="base_footprint"/>
    <child link="base_link"/>
  </joint>
  <link name="base_link">
    <inertial>
      <mass value="50.00"/>
      <!-- use dummy weight to stabilize gazebo move base (real value: 11.017971)-->
      <origin xyz="-0.025978 -0.005498 0.17633"/>
      <inertia ixx="0.3742" ixy="0.000434172172" ixz="0.03088" iyy="0.3436" iyz="0.01775" izz="0.1509"/>
    </inertial>
    <visual>
      <geometry>
        <mesh filename="package://hsrb_meshes/meshes/base_v2/base_light.dae"/>
      </geometry>
    </visual>
    <visual>
      <geometry>
        <mesh filename="package://hsrb_meshes/meshes/base_v2/body_light.dae"/>
      </geometry>
    </visual>
```

UNIVERSAL SCENE DESCRIPTION (USD)

- For large-scale, physically accurate digital twins
- OpenUSD is foundational to NVIDIA Omniverse
- Alliance for OpenUSD (AOUSD)—including Pixar, Adobe, Apple, and Autodesk—to evolve OpenUSD as it becomes one of the building blocks in the era of AI and industrial digitalization
  - Environments (incl. gravity, lights etc)
  - Objects (both static and dynamic)
  - Sensors
  - Robots
- USD is standard for Isaac Sim

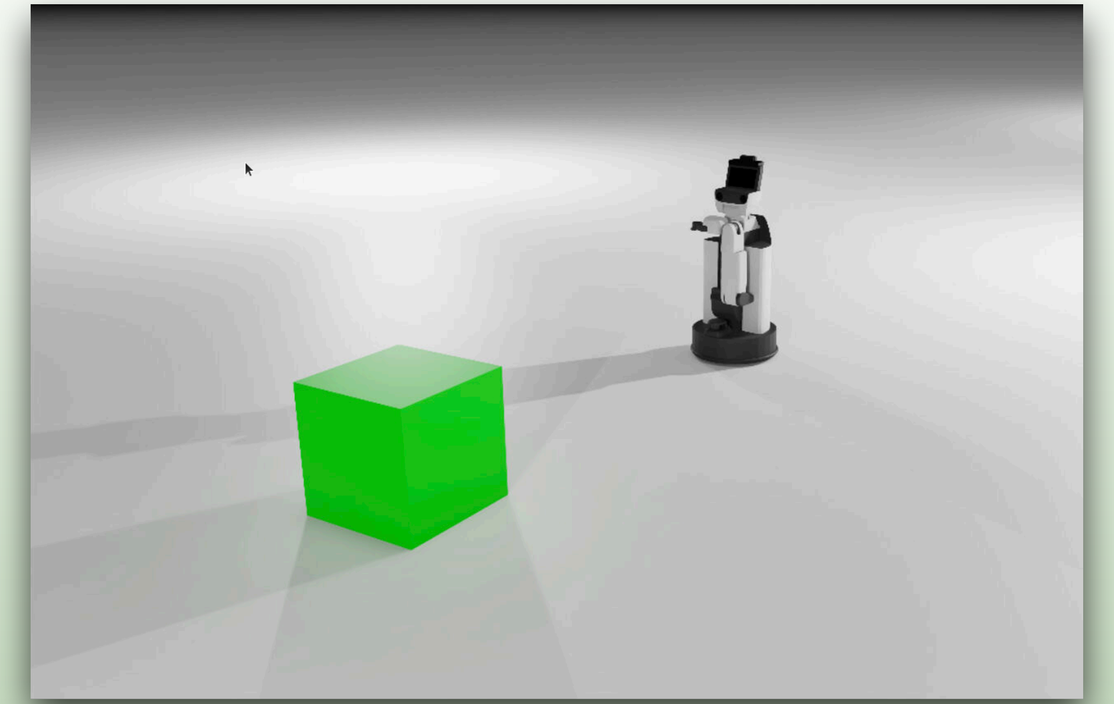



```xml
<?xml version="1.0" ?>
<sdf version="1.4">
  <model name="shelf3_book3_v4">
    <link name="body">
      <pose>0 0 0 0 0 0</pose>
      <inertial>
        <pose>   0.001798   0.085315   0.005927 0 0 0</pose>
        <mass>0.5</mass>
        <inertia>
          <ixx>0.01</ixx>
          <ixy>0</ixy>
          <ixz>0</ixz>
          <iyy>0.01</iyy>
          <iyz>0</iyz>
          <izz>0.01</izz>
        </inertia>
      </inertial>
      <collision name="collision">
```

Details at:
http://sdformat.org/

UNIVERSAL SCENE DESCRIPTION (USD)

- Encoding scalable, hierarchically organized, static and time-sampled data
- Rich, extensible language
  - Environments (incl. gravity, lights etc)
  - Objects (both static and dynamic)
  - Sensors
  - Robots
- USD is standard for Isaac Sim
- Converters to USD available



```python
from pxr import Usd, UsdGeom

stage = Usd.Stage.CreateNew('/path/to/HelloWorld.usda')
xformPrim = UsdGeom.Xform.Define(stage, '/hello')
spherePrim = UsdGeom.Sphere.Define(stage, '/hello/world')
# generic_spherePrim = stage.DefinePrim('/hello/world_generic', 'Sphere')
stage.GetRootLayer().Save()
```

```
#usda 1.0

def Xform "hello"
{
    def Sphere "world"
    {
    }
}
```

```
#usda 1.0
(
    defaultPrim = "bookshelf"
    upAxis = "Y"
)

    def Xform "bookshelf"
    {
        token ui:displayGroup = "Material Graphs"
        token ui:displayName = "bookshelf"
        int ui:order = 1024
        float3 xformOp:rotateXYZ = (0, -0, 0)
        float3 xformOp:scale = (1, 1, 1)
        double3 xformOp:translate = (0, 0, 0)
        uniform token[] xformOpOrder = ["xformOp:translate", "xformOp:rotateXYZ", "xformOp:scale"]

        def Xform "bookshelf" (
            apiSchemas = ["SemanticsAPI:Semantics_rmOw", "SemanticsAPI:Semantics_zY6Z",
            "SemanticsAPI:Semantics_Ql3t", "SemanticsAPI:QWQQ", "SemanticsAPI:QWQL",
            "SemanticsAPI:QWQC", "PhysicsRigidBodyAPI", "PhysicsMassAPI"]
```

Details at:
https://docs.omniverse.nvidia.com/isaacsim/latest/open_usd.html

FURTHER REFERENCES

- ROS Wiki
  - http://wiki.ros.org/
- Installation
  - http://wiki.ros.org/ROS/Installation
- Tutorials
  - http://wiki.ros.org/ROS/Tutorials
- Packages
  - https://www.ros.org/browse/list.php

- 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 Templates
  - https://github.com/leggedrobotics/ros_best_practices/tree/master/ros_package_template

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