Introduction to ROS

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What is ROS?

ROS (Robot Operating System) is an open-source, flexible framework for writing robot software.

Site: http://www.ros.org/

Blog: http://www.ros.org/news/

Documentation: http://wiki.ros.org/

Suggested OS: Ubuntu 14.04

Suggested release: Indigo

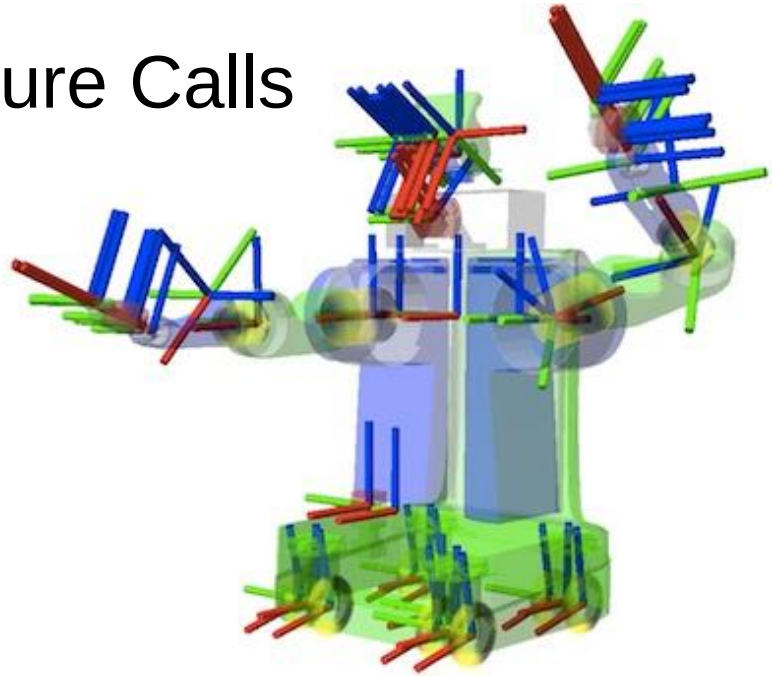
ROS Features

«Why ROS instead of OROCOS, Player, Robotics Studio, (…)?»

- Code reuse (exec. *nodes*, grouped in *packages*)
- Distributed, modular design (scalable)
- Language independent (C++, Python, Java, …)
- ROS-agnostic libraries (code is ROS indep.)
- Easy testing (ready-to-use)
- Vibrant community & collaborative environment

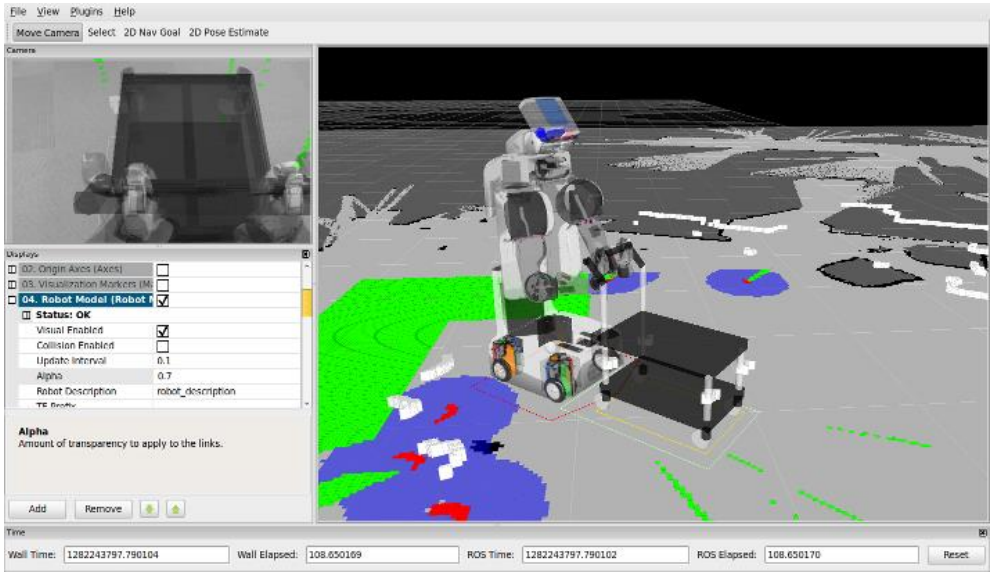
Robot Specific Features

- Standard Message Definitions for Robots
- Robot Geometry Library
- Robot Description Language
- Preemptable Remote Procedure Calls
- Diagnostics
- Pose Estimation
- Localization
- Mapping
- Navigation



ROS Tools

- Command-line tools
- Rviz
- rqt (e.g., rqt_plot, rqt_graph)



Integration with Libraries

ROS provides seamless integration of famous libraries and popular open-source projects.

Installation

3 possibilities for installing ROS:

- Install ROS from source (not recommended):
  - http://wiki.ros.org/indigo/Installation/Source
- Install ROS from Debian packages:
  - http://wiki.ros.org/indigo/Installation/Ubuntu
- Install virtual machine (Ubuntu 14.04 + ROS):
  - https://drive.google.com/file/d/0B6Nvp-r2hOVvWE1BSlBPbGl3XzA/edit?usp=sharing
  - Virtualbox instructions: http://www.virtualbox.org/manual/ch01.html#ovf
  - Login: user **indigo** password **indigo**

Post Installation

You must initialize the rosdep system in your system:

```
sudo rosdep init
rosdep update
```

rosdep is a tool for checking and installing package dependencies in an OS-independent way.

Note: do not use sudo for `rosdep_update`

ROS Filesystem

- **Packages:** unit for organizing software in ROS. Each package can contain libraries, executables, scripts, or other artifacts.
- **Manifest (package.xml):** meta-information about a package (e.g., version, maintainer, license, etc.) and description of its dependencies (other ROS packages, messages, services, etc.). http://wiki.ros.org/catkin/package.xml

package.xml (1)

```
<?xml version="1.0"?>
<package>
<name>my_package</name>
<version>1.0</version>
<description>My package description</description>
<!-- One maintainer tag required, multiple allowed, one
person per tag -->
<maintainer email="my@mail.com">Roberto
Capobianco</maintainer>
<!-- One license tag required, multiple allowed, one
license per tag. Commonly used license strings: BSD, MIT,
Boost Software License, GPLv2, GPLv3, LGPLv2.1, LGPLv3 -->
<license>BSD</license>
```

package.xml (2)

```
<!-- Url tags are optional, but mutiple are allowed, one
per tag. Optional attribute type can be: website,
bugtracker, or repository -->
<url type="website">http://wiki.ros.org/my_package</url>
<!-- Author tags are optional, mutiple are allowed, one per
tag. Authors do not have to be maintianers, but could be --
>
<author email="my@mail.com">Roberto Capobianco</author>
<!-- The *_depend tags are used to specify dependencies.
Dependencies can be catkin packages or system dependencies.
Use build_depend for packages you need at compile time. Use
buildtool_depend for build tool packages. Use run_depend
for packages you need at runtime. Use test_depend for
packages you need only for testing. -->
```

package.xml (3)

```
<buildtool_depend>catkin</buildtool_depend>
<build_depend>message_generation</build_depend>
<build_depend>roscpp</build_depend>
<build_depend>roslib</build_depend>
<run_depend>message_runtime</run_depend>
<run_depend>roscpp</run_depend>
<run_depend>roslib</run_depend>
<!-- The export tag contains other, unspecified, tags -->
<export>
<!-- You can specify that this package is a metapackage
here: --><!-- <metapackage/> -->
<!-- Other tools can request additional information be
placed here -->
</export>
</package>
```

Catkin vs Rosbuild

ROS build systems: catkin, rosbuild (**old, do not use rosbuild if not needed**).

«So, why are you talking about rosbuild?»

Some packages are still developed for rosbuild.

Main differences between catkin and rosbuild:

http://wiki.ros.org/catkin_or_rosbuild

Catkin Workspace Configuration

```
$ source /opt/ros/indigo/setup.bash
$ mkdir -p ~/catkin_ws/src
$ cd ~/catkin_ws/src
$ catkin_init_workspace
$ cd ~/catkin_ws/
$ catkin_make
```

Open ~/.bashrc and add the following lines:

```
# ROS
source ~/catkin_ws/devel/setup.bash
```

Catkin Workspace (1)

```
workspace_folder/        -- WORKSPACE
   src/                  -- SOURCE SPACE
      CMakeLists.txt     -- The 'toplevel' Cmake file
         package_1/
            CMakeLists.txt
            package.xml
            ...
         package_n/
            CMakeLists.txt
            package.xml
            ...
```

Catkin Workspace (2)

```
build/                  -- BUILD SPACE
   CATKIN_IGNORE        -- Keeps catkin from walking
                           this directory
devel/                  -- DEVELOPMENT SPACE (set by
                           CATKIN_DEVEL_PREFIX)
   setup.bash           \
   setup.zsh            |-- Environment setup files
   setup.sh             /
   env.bash
   etc/                 -- Generated configuration
                           files
   include/             -- Generated header files
```

Catkin Workspace (3)

```
    lib/                    -- Generated libraries and
                               other artifacts (bin included)
    share/                  -- Generated architecture
                               independent artifacts
    ...
install/                    -- INSTALL SPACE (set by
    bin/                       CMAKE_INSTALL_PREFIX)
    etc/
    include/
    lib/
    share/
    env.bash
```

Catkin Workspace (4)

```
setup.bash
setup.sh
...
```

Rosbuild Workspace Configuration

Catkin and rosbuild workspaces can coexist (**if needed**).

Add to ~/.bashrc also:

```
export
ROS_PACKAGE_PATH=~/path/to/your/rosbuild/wor
kspace/:$ROS_PACKAGE_PATH
```

Additional info:

http://wiki.ros.org/rosbuild

http://wiki.ros.org/rosmake

catkin_make

- `catkin_make` is a **convenience** tool for building code in a catkin workspace
- Execute `catkin_make` in the root of your catkin workspace
- Running the command is equivalent to:

```
$ mkdir build
$ cd build
$ cmake ../src -DCMAKE_INSTALL_PREFIX=../install -
DCATKIN_DEVEL_PREFIX=../devel
$ make
```

Building Specific Packages

- If you want to build specific packages in the workspace, invoke (**always in the root of the worskspace**):

```
$ catkin_make -DCATKIN_WHITELIST_PACKAGES="pack-
age1;package2"
```

For reverting back:

```
$ catkin_make -DCATKIN_WHITELIST_PACKAGES=""
```

- If you want to build a single package, invoke:

```
$ catkin_make --pkg my_package
```

Installing Packages

- You can pass to `catkin_make` arguments that you would normally pass to `make` and `cmake`. For example, you can invoke the install target:

```
$ catkin_make install
```

Which is equivalent to:

```
$ cd ~/catkin_ws/build
# If cmake hasn't already been called
$ cmake ../src -DCMAKE_INSTALL_PREFIX=../install -DCATKIN_DEVEL_PREFIX=../devel
$ make
$ make install
```

Listing and Locating Packages

`rospack` allows to get information about packages:

- Listing all ROS packages:

  ```
  rospack list
  ```

- Find the directory of a single package:

  ```
  rospack find package-name
  ```

- When you don't know (remember) the complete name of the package, you can simply use **tab completion** for package names.

Hands on: find the *roscpp* package

Inspecting Packages

- To view the files in a package directory:
  `rosls` *`package-name`*
- To go to a package directory:
  `roscd` *`package-name`* (also without package name)
- These tools will *only* find ROS packages that are within the directories listed in your ROS_PACKAGE_PATH. To see what is in this variable, type: `echo $ROS_PACKAGE_PATH`

Hands on: list all the images in the *turtlesim* package; try roscd without a package name

Creating Packages

- A package must contain:
  - A catkin compliant package.xml
  - A CMakeLists.txt which uses catkin
- No nested packages are allowed (one per folder)
- You can create metapackages

```
# You should have created this!
$ cd ~/catkin_ws/src
# catkin_create_pkg <package_name> [depend1] [depend2] [depend3]
$ catkin_create_pkg my_first_pkg std_msgs rospy roscpp
```

Checking Dependencies

- Packages can have direct or indirect dependencies
- Direct dependencies can be checked with:
  `rospack depends1 package-name`
- A full list of dependencies is available with:
  `rospack depends package-name`
- System dependencies for a package *package-name* can be solved: `rosdep install package-name`

Hands on: list all the dependencies in *my_first_pkg*

CMakeLists.txt (1)

- CMake version 2.8.3 or higher
- Your CMakeLists.txt file **MUST** follow this format otherwise your packages will not build correctly:
  - Required CMake Version (`cmake_minimum_required`)
  - Package Name (`project()`)
  - Find other CMake/Catkin packages needed for build (`find_package()`)
  - Message/Service/Action Generators (`add_message_files()`, `add_service_files()`, `add_action_files()`)
  - Invoke message/service/action generation (`generate_messages()`)

CMakeLists.txt (2)

- Specify package build info export (`catkin_package()`)
- Libraries/Executables to build (`add_library()` / `add_executable()` / `target_link_libraries()`)
- Tests to build (`catkin_add_gtest()`)
- Install rules (`install()`)

- If you have self-defined messages / services / actions, remember:
  - You must follow the order presented here (in particular before the `catkin_package()` macro) in order for generate stuff correctly
  - Your `catkin_package()` macro must have a `CATKIN_DEPENDS` dependency on `message_runtime`
  - You must use `find_package()` for the package `message_generation`, either alone or as a component of catkin

CMakeLists.txt (3)

- Your package.xml file must contain a build dependency on `message_generation` and a runtime dependency on `message_runtime`. This is not necessary if the dependencies are pulled in transitively from other packages.
- If you have a package which builds messages and/or services as well as executables that use them, you need to create an explicit dependency on the automatically-generated message target so that they are built in the correct order, e.g.:

```
add_dependencies(some_target
${PROJECT_NAME}_generate_messages_cpp)
```

Metapackages (1)

- Useful for grouping multiple packages in a single logical package
- Conceptually similar to rosbuild stacks, but no strict hierarchy in directory structure
- Normal package with the following tag in the package.xml:

```
<export>
    <metapackage />
</export>
```

Metapackages (2)

- Required buildtool_depends dependency on catkin
- Can only have run dependencies on packages of which they group
- Required CMakeLists.txt:

```
cmake_minimum_required(VERSION 2.8.3)
project(<PACKAGE_NAME>)
find_package(catkin REQUIRED)
catkin_metapackage()
```

- Other packages should not depend on metapackages

The master (1)

(One of) The goal(s) of ROS is to enable the use of small and mostly independent programs (*nodes*), all running at the same time. For doing this, *communication* is needed. By providing *naming* and *registration* services, the **ROS master**, enables the nodes to locate each other and, therefore, to communicate.

- To execute it, launch this command: `roscore`
- The master MUST be always running while using ROS.

The master (2)

What the master **does**:

- Naming
- Registration
- Publisher and Subscriber tracking (both for services and messages)
- Parameter server

What the master **does not**:

- Nodes do not communicate through the master

Nodes (1)

- *Running instance of* a ROS program
- Starting a node:

```
rosrun package-name executable-name
```

Hands on: run an instance of `turtlesim_node` and `turtle_teleop_key` (hint: you need 3 terminals); focus on the terminal with `turtle_teleop_key` and press the Up, Down, Left, Right keys to move the turtle

Nodes (2)

- Listing running nodes:

  `rosnode list`

  - `/rosout` is a node started by roscore (similar to std output)
  - `/` indicates the global namespace
  - Node names are not necessarily the same as the names of their executables. You can explicitly set the name of a node using `rosrun`:

    `rosrun` *`package-name executable-name __name:=node-name`*

Hands on: list nodes in the previous exercise

Nodes (3)

- Inspecting a node (list of topics published and subscribed, services, PID and summary of connections with other nodes):

  `rosnode info` *`node-name`*

- Kill a node (also CTRL+C, but unregistration may not happen)

  `rosnode kill` *`node-name`*

- Remove dead nodes:

  `rosnode cleanup`

Topics and Messages

- Communication in ROS through *messages*
- Messages are organized in *topics*
- A node that wants to share information will *publish* messages on a topic(s)
- A node that wants to receive information will *subscribe* to the topic(s)
- ROS master takes care of ensuring that publishers and subscribers can find each other
- Use of namespaces

Viewing the Graph

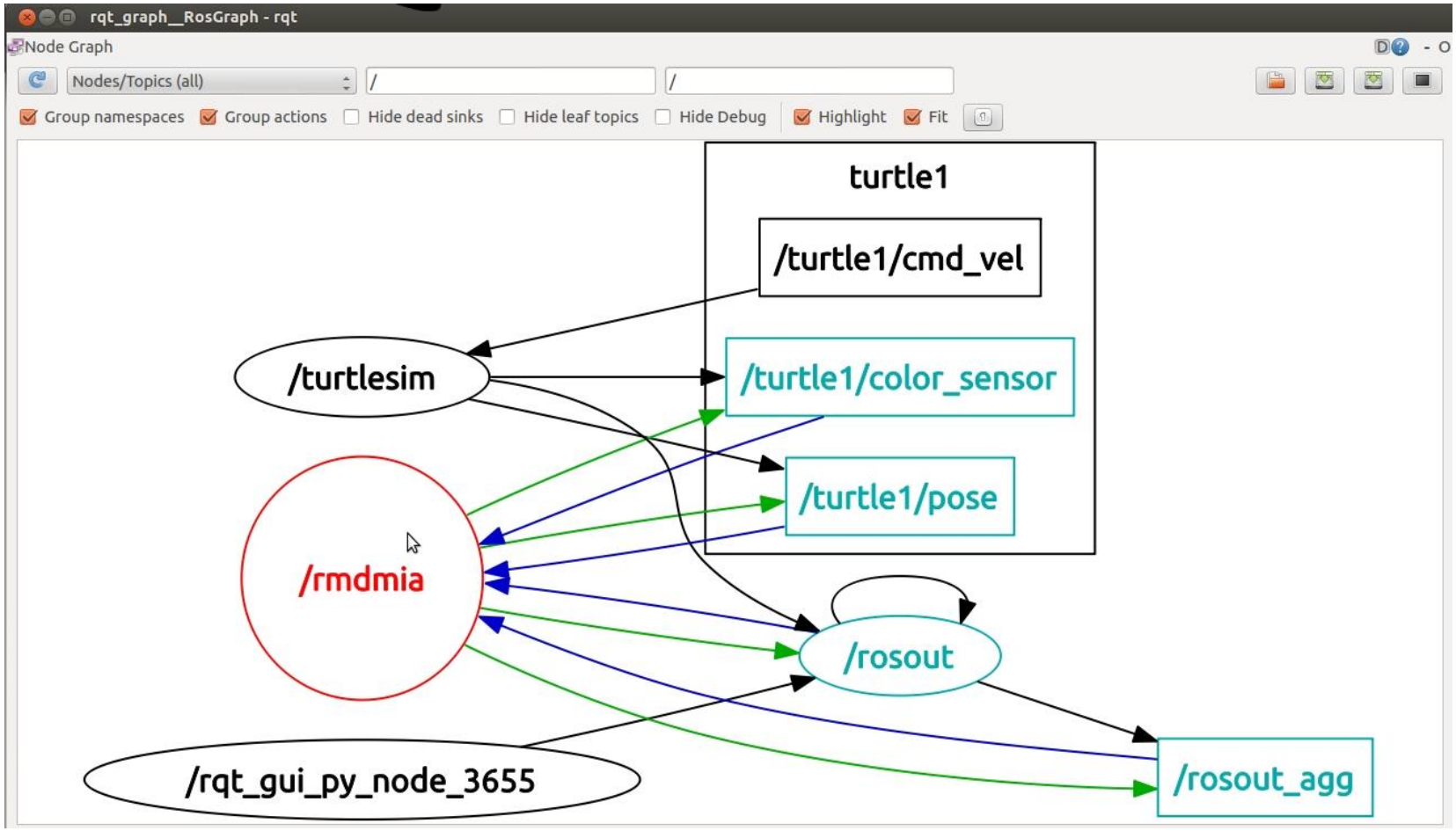
- Graphically intuitive, easy to visualize the publish-subscribe relationships between nodes:

  `rqt_graph`

- `rqt_graph` itself appears as a node
- All nodes publish on the topic `/rosout` (not the node!) subsribed by the node `/rosout`
- Topics without a subscriber (or a publisher) are possible (not both)

Hands on: analyze the graph of the previous exercise

rqt_graph


rqt_graph__RosGraph - rqt
Node Graph
Nodes/Topics (all)
/
/
Group namespaces
Group actions
Hide dead sinks
Hide leaf topics
Hide Debug
Highlight
Fit
turtle1
/turtle1/cmd_vel
/turtlesim
/turtle1/color_sensor
/turtle1/pose
/rmdmia
/rosout
/rosout_agg
/rqt_gui_py_node_3655

Messages and Topics

- Listing active topics:

  `rostopic list`

- You can see messages published on a topic:

  `rostopic echo` *`topic-name`*

- Checking publishing rate and bandwidth consumed:

  `rostopic hz` *`topic-name`*

  `rostopic bw` *`topic-name`*

- Inspecting a topic (also message type)

  `rostopic info` *`topic-name`*

Messages and and Message Type

- Inspecting a message type (structure of the message):

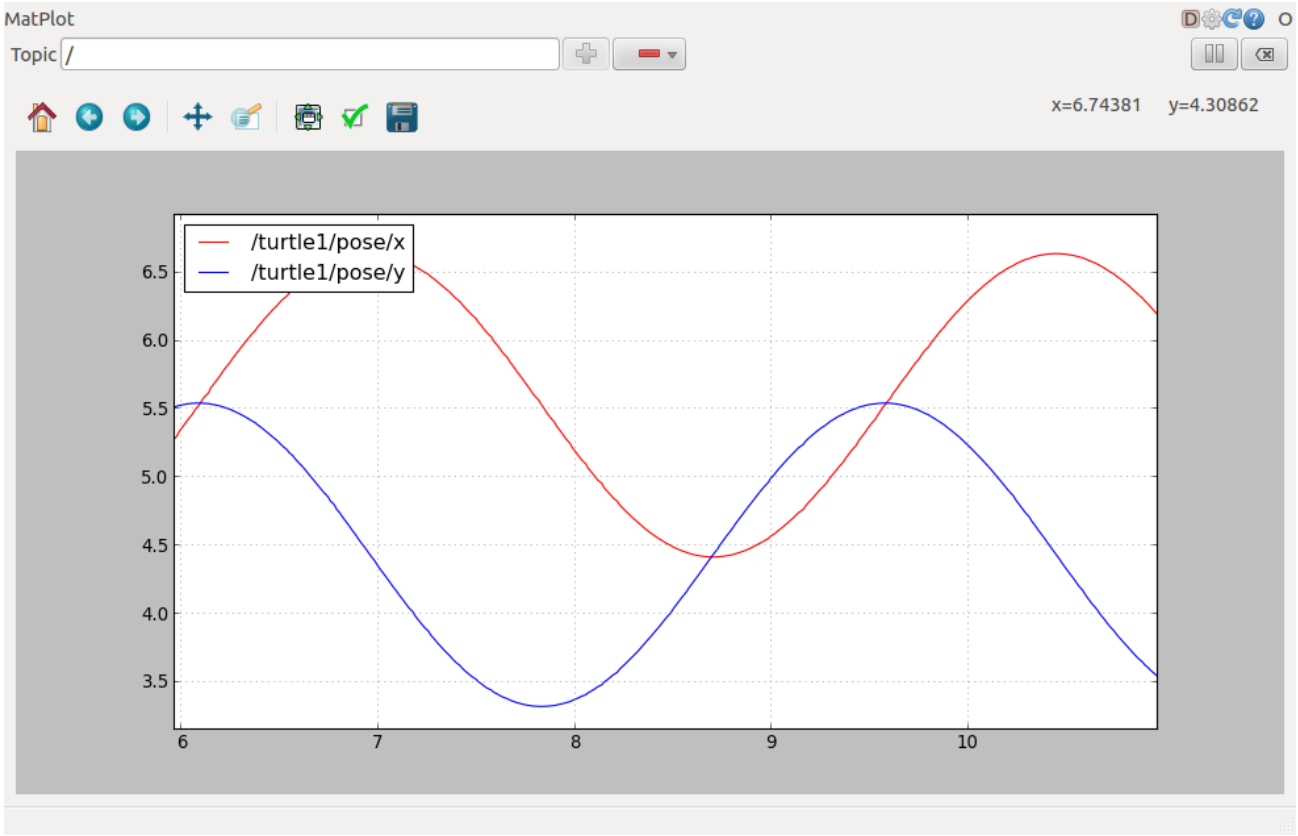
  `rosmsg show` *`message-type-name`*

- Data types of composite fields are message types in their own (useful for preventing code duplication)
- Message types can also contain arrays with fixed or variable length (show with square brackets)

Hands on: check the structure of all the messages in the topics of the previous exercise

rqt_plot

- Data published on topics can be time plotted



Publishing Messages from Terminal

- Useful for debugging
- Publish message from terminal:

  `rostopic pub -r` *`rate-in-hz topic-name message-type message-content`*
- The message content can be tabbed once the message type is chosen

Hands on: publish a velocity command at 1Hz rate to the /turtle1/cmd_vel topic and plot the position and velocity of the turtle

Services (1)

- Realize request/reply communications
- Defined as a structure composed by a pair of messages (one for the request and one for the reply)
- A *providing node* or *provider* offers a service
- A *client* interested in a service sends a request and waits for a reply

Services (2)

- Display all services of a specific type: `rosservice find` *`service-type`*
- List of services: `rosservice list`
- Print information about a specific service: `rosservice info` *`service-name`*
- Display the node that provides a particular service: `rosservice node` *`service-name`*
- Display the type of a service: `rosservice type` *`service-name`*
- Call a service from the command line: `rosservice call` *`service-name service-args`*
- `rossrv` is similar to `rosmsg`

Creating Messages and Services (1)

- Messages (Services) in ROS are *.msg* (*.srv*) files stored in the corresponding package folder, within the *msg* (*srv*) dir.
- Supported field types for both are:
  - int8, int16, int32, int64 (plus uint*)
  - float32, float64
  - string
  - time, duration
  - other msg files
  - variable length array [] and fixed length array [C]
  - Header: timestamp and coordinate frame information
- srv files have two different message definitions, separated by ---

Creating Messages and Services (2)

Example of msg:

```
Header header
string child_frame_id
geometry_msgs/PoseWithCovariance pose
geometry_msgs/TwistWithCovariance twist
```

Example of srv:

```
int64 A
int64 B
---
int64 Sum
```

Hands on: create a message `Num.msg` with field `num` of type `int64`; create a service `AddTwoInts.srv` and build the package

Parameters

- Hierarchy matching the namespaces
- `rosparam` for setting and reading parameters

```
rosparam set param-name
rosparam get param-name
```

- Parameters can also be listed or deleted

```
rosparam list
rosparam delete param-name
```

Hands on: explore and use services of the turtlesim node

roslaunch

- Launch file usually bring up a set of nodes (`roscore` is automatically launched by `roslaunch`)
- Uses XML files that describe the nodes that should be run, parameters that should be set, and other attributes
- Details at: http://wiki.ros.org/roslaunch/XML

Hands on: create a launch file launching two turtlesim nodes

Bags and rosbag

- Serialized message data in a file
- `rosbag` for recording or playing data

  `rosbag record -a` Record all the topics

  `rosbag info` *`bag-name`* Info on the recorded bag

  `rosbag play --pause` *`bag-name`* Play the recorded bag, starting paused

  `rosbag play -r` *`#number bag-name`* Play the recorded bag at rate #number

Hands on: record a bag while you are teleoperating the turtlesim, then kill every node; start again the turtlesim node and play the bag

Checking for Problems

- Useful when ROS is not behaving the way you expect:

  ```
  roswtf
  ```

- Broad variety of sanity checks (e.g., examination of environment variables, installed files, running nodes)
- Details at: http://wiki.ros.org/roswtf

Homework (1)

- Follow the ROS beginner tutorials:
  - Build and run the “Simple Publisher and Subscriber”
  - Build and run the “Simple Service and Client”
- Modify the *talker* node and the *listener* node
  - Publish the message *Num* (created earlier) on topic *oddNums*:
    - the message *Num* should be sent if the variable count is odd
    - *Num* should contain the value of count
  - Additionally subscribe to topic *oddNums*
  - Create a callback function *oddNumsCallback* to print the content of the received message

Homework (2)

- Create a package with a client and a server.
  - The server should take in input a service with an integer and an array of strings and return an array of strings, that are substrings of the corresponding input strings
  - The client should input a sequence of strings and request a service