Introduction to Cognitive Robotics

Module 2: The Robot Operating System (ROS)

Lecture 1: Introduction to ROS; the Turtlesim turtlebot simulator

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ROS

Mobile Robots: ROS

- Introduction to ROS (Robot Operating System)

  (Rhymes with “gloss”)

- Introduction to writing ROS software
  - Using the ROS Turtlebot simulator `Turtlesim`
  - Here in C++
  - Later in the course in Lisp with CRAM

Based mainly on J. M. O’Kane, *A Gentle Introduction to ROS*, 2014.
https://cse.sc.edu/~jokane/agitr/

ROS

ROS is an open-source, meta-operating system for your robot

It provides the services you would expect from an operating system, including hardware abstraction, low-level device control, implementation of commonly-used functionality, message-passing between processes, and package management

It also provides tools and libraries for obtaining, building, writing, and running code across multiple computers

http://wiki.ros.org/ROS/Introduction

Features

- Distributed computation
  - Divide software into small stand-alone parts that, together, achieve the overall goal
  - Communication between multiple concurrent processes that may or may not be running on the same computer
  - Based on component-based software engineering
- Software reuse
  - ROS's standard packages provide stable implementations of many important algorithms

Features

Rapid testing

- Testing the behaviour of high-level parts of the system is facilitated by simulation of low-level parts, including the robot

- Provides a simple way to record and play back sensor data: bags
  A tool called rosbag is used to record and replay

Features

Community support

- Hardware drivers
- Libraries: PCL, OpenCV, TF, …
- Capabilities: navigation, manipulation, control, .
- Applications: fetching beer, making popcorn, …

ROS is not …

- A programming language
  - It supports C++, Lisp, Python, Java, among others
- Just a library
  - also include a central server, command-line tools, graphical tools, build systems.
- An integrated development environment (IDE)

ROS Distributions

- Major versions of ROS are called distributions

- Distributions are named using adjectives that start with successive letters of the alphabet

  …, Groovy, Hydro, Indigo, Jade, Kinetic, Lunar, Melodic, Noetic, … (see http://wiki.ros.org/Distributions)

- Referred to in the ROS documentation by the term distro

- Different distributions use different build systems

  - kinetic uses catkin

Packages

- All ROS software is organized into packages

- A ROS package is a coherent collection of files

  - Serves a specific purpose.
  - Includes executables and supporting files

- All ROS software is part of one package or another

- rospack list provides a list of all installed ROS packages

Packages

- Each package is defined by a manifest

- In a is a file called package.xml

- Defines details about the package
  - name
  - version
  - maintainer
  - dependencies

- The directory containing package.xml is called the package directory

Packages

- To find the directory of a single package, use the rospack find command:

```
rospack find package-name
```

- Use tab completion if you are not sure of the full name and to save time typing

Packages

- To view the files in a package directory

  rosls *package-name*

- To change directory to a package directory

  roscd *package-name*

Packages

Stacks and packages

- You may see references to the concept of a stack
  - A stack is a collection of related packages

- It has now been phased out and replaced by meta-package
  - A meta-package is a package
  - It has a manifest just like any other package
  - but no other packages are stored inside its directory

- Whereas a stack is a container for packages stored as subdirectories

ROS Master

So much for how ROS files are organized

Let’s now turn our attention to how ROS software is organized and executed

Aside:

- As noted already, ROS software adheres to the paradigm on component-based software engineering (CBSE) in which a software system comprises multiple quasi-independent communicating components (programs or processes)

- As we will see, it also adheres to the component-port-connector communication model

ROS Master

- ROS software comprises a collection of small, independent, loosely-coupled programs called nodes that all run at the same time

↑ Coupling is effected by sending messages on topics (see below)

- These nodes must be able to communicate with one another

- The part of ROS that facilitates this communication is called the ROS master

- To start the master, use the roscore command

ROS Master

- Typically, you start roscore in one terminal

- then open other terminals for your “real” work

- There are not many reasons to stop roscore, except when you’ve finished working with ROS

- When you reach that point, you can stop the master by typing Ctrl-C in its terminal

ROS Master

- Most ROS nodes connect to the master when they start up
- Typically, they do not attempt to reconnect if that connection fails later on
- Therefore, if you stop roscore, any other nodes running at the time will be unable to establish new connections, even if you restart roscore later
- Bottom line: if you restart `roscore` you will have to restart all the nodes

ROS Master

ROS provides a convenient way of doing this: roslaunch

- `roslaunch` starts many nodes at once
- It will also start a master if none is running
- But will also use an existing master if there is one

Nodes

- Once you've started `roscore`, you can run programs that use ROS.

- A running instance of a ROS program is called a node

It is possible to have multiple instances
of the same ROS program running concurrently

- The command to create a node (also known as "running a ROS program") is rosrun:

rosrun *package-name executable-name*

Doesn't register the executable with the ROS master:
That's done in the node itself

Nodes

- Listing nodes: to get a list of running nodes, use

```
rosnode list
```

- The nodes will be listed with a leading /

  This is to do with naming nodes in the ROS namespace (more later)

- One node will always be listed /rosout

A special node started automatically by roscore.
It's purpose is much the same as standard output std::cout in C/C++

Nodes

- Just a moment ago, we said

  "A running instance of a ROS program is called a node"

  It is possible to have multiple instances of the same ROS program running concurrently

- Each instance must have a different name

- You can explicitly set the name of a node as part of the **rosrun** command:

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

  double underscore

Nodes

- Inspecting a node: to get information about a node, use

  rosnode info *node-name*

For example,
list of topics for which that node is a publisher or subscriber
(more later), process ID, summary of connections to other nodes

- Killing a node: to kill a node, use

  rosnode kill *node-name*

Topics and Messages

- ROS nodes communicate by sending messages

- Messages are organized into named topics

  - A node can publish messages on a topic

  - Another node that wants to receive the topic messages can subscribe to that topic

- The ROS master takes care of linking publishers and subscribers but the messages are sent directly from publisher to subscriber

Topics and Messages

Recall: Exercise

Open a terminal and enter

```
[~]$ roscore
```

Open a second terminal and enter

```
[~]$ rosrun turtlesim turtlesim_node
```

Open a third terminal and enter

```
[~]$ rosrun turtlesim turtle_teleop_key
```

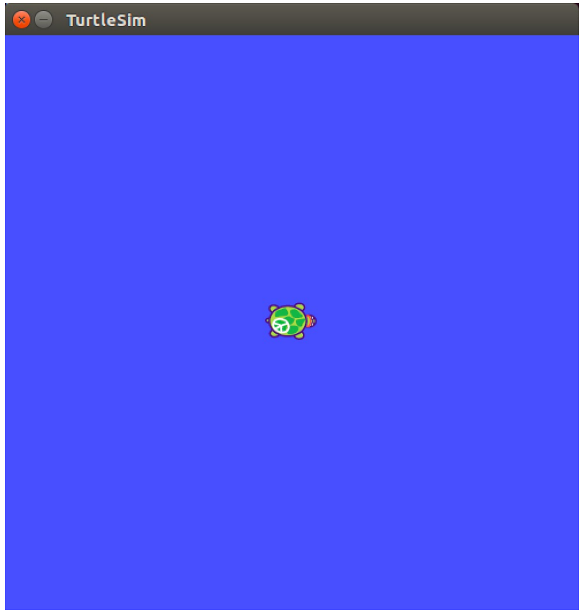
The separate terminals are intended to allow all three commands to execute simultaneously

Topics and Messages

Recall: Exercise

If everything works correctly, you should see a graphical window similar to one below

The appearance of your turtle may differ. The simulator selects from a collection of “mascot” turtles for each of the historical distributions of ROS

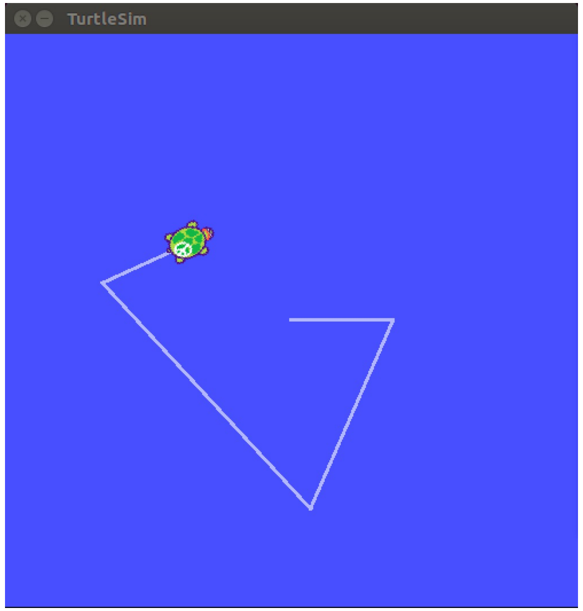


Topics and Messages

Recall: Exercise

Make sure your third terminal (the one executing the **turtle_teleop_key** command) is in focus (i.e. is selected).

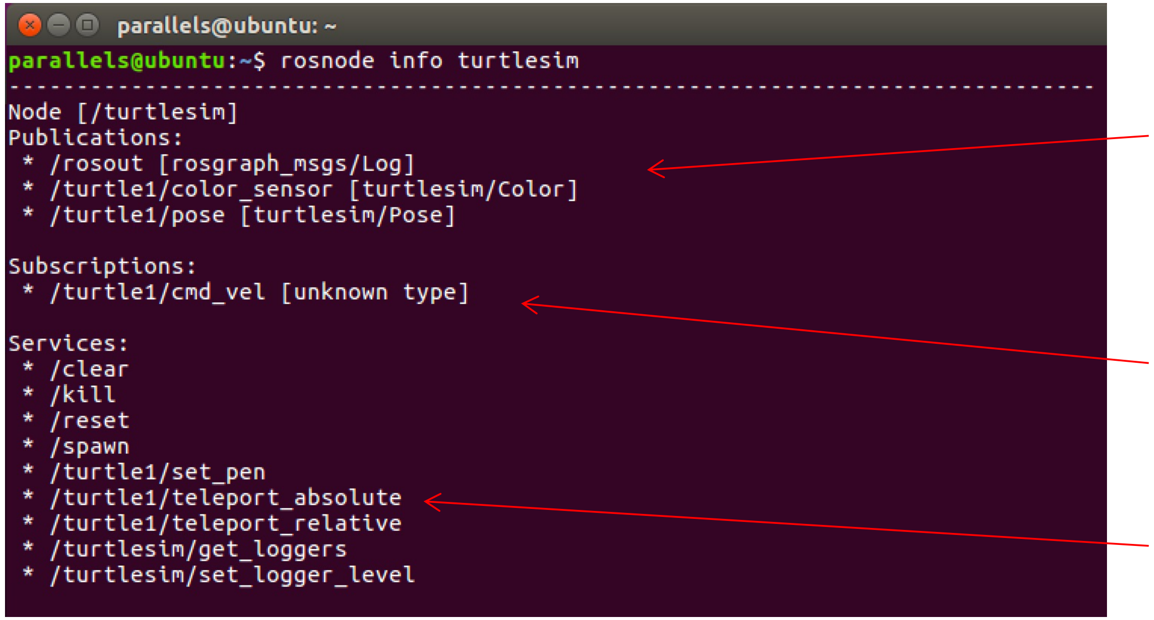
Press the Up, Down, Left, or Right arrow key to move the turtle and leave a trail behind it.



Topics and Messages

Use rosnode info node-name to get a list of the topics and services supported by the node (more on services later)

For example: rosnode info turtlesim yields the following



```
parallels@ubuntu:~$ rosnode info turtlesim
--------------------------------------------------------------------------------
Node [/turtlesim]
Publications:
 * /rosout [rosgraph_msgs/Log]
 * /turtle1/color_sensor [turtlesim/Color]
 * /turtle1/pose [turtlesim/Pose]

Subscriptions:
 * /turtle1/cmd_vel [unknown type]

Services:
 * /clear
 * /kill
 * /reset
 * /spawn
 * /turtle1/set_pen
 * /turtle1/teleport_absolute
 * /turtle1/teleport_relative
 * /turtlesim/get_loggers
 * /turtlesim/set_logger_level
```

turtlesim publishes on these topics

turtlesim subscribes to these topics

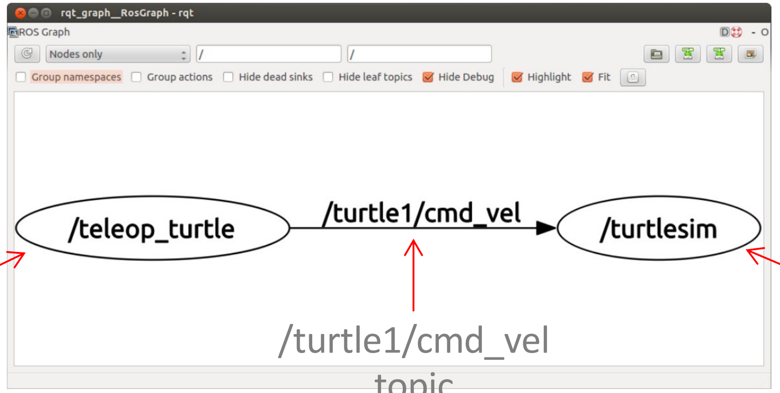
turtlesim can be configured
by using these services

Topics and Messages

- The publish and subscribe relationships between nodes can be represented and visualized as a directed graph

`r` for ROS and `qt` for the Qt GUI toolkit

- The rqt_graph command allows you to draw this graph



rqt_graph__RosGraph - rqt

ROS Graph

Nodes only | / | /

☐ Group namespaces ☐ Group actions ☐ Hide dead sinks ☐ Hide leaf topics ☑ Hide Debug ☑ Highlight ☑ Fit

/teleop_turtle node
(publisher)

/turtle1/cmd_vel
topic

/turtlesim node
(subscriber)

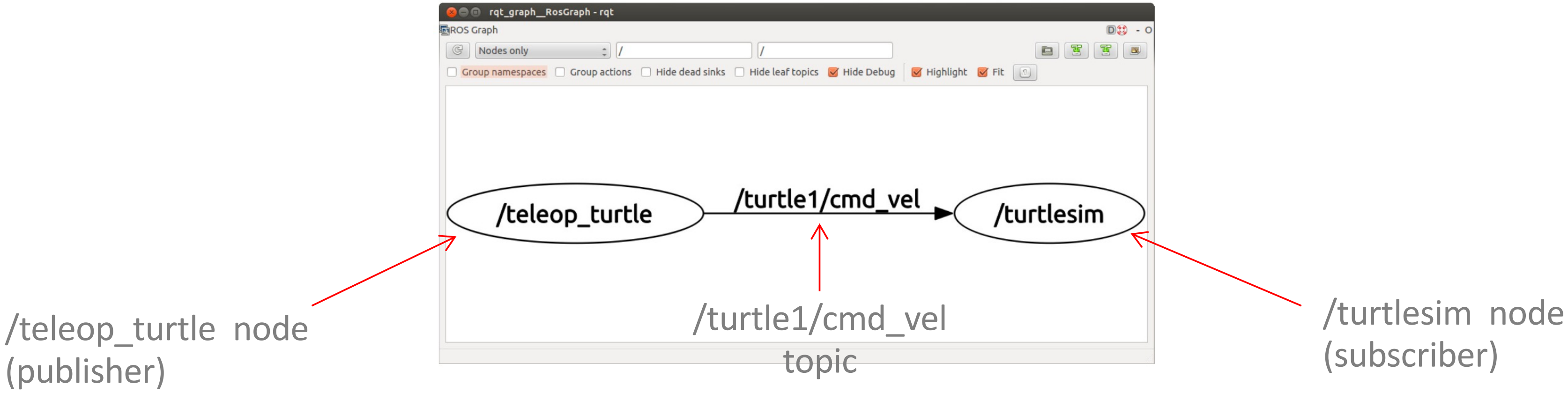
Credit: J. M. O'Kane, A Gentle Introduction to ROS, 2014
https://cse.sc.edu/~jokane/agitr/

Topics and Messages

/teleop_turtle publishes messages on a topic called /turtle1/cmd_vel

/turtlesim subscribes to those messages

cmd_vel is short for “command velocity”



rqt_graph__RosGraph - rqt

ROS Graph

Nodes only / /

□ Group namespaces □ Group actions □ Hide dead sinks □ Hide leaf topics ☑ Hide Debug ☑ Highlight ☑ Fit

/teleop_turtle node (publisher)

/turtle1/cmd_vel topic

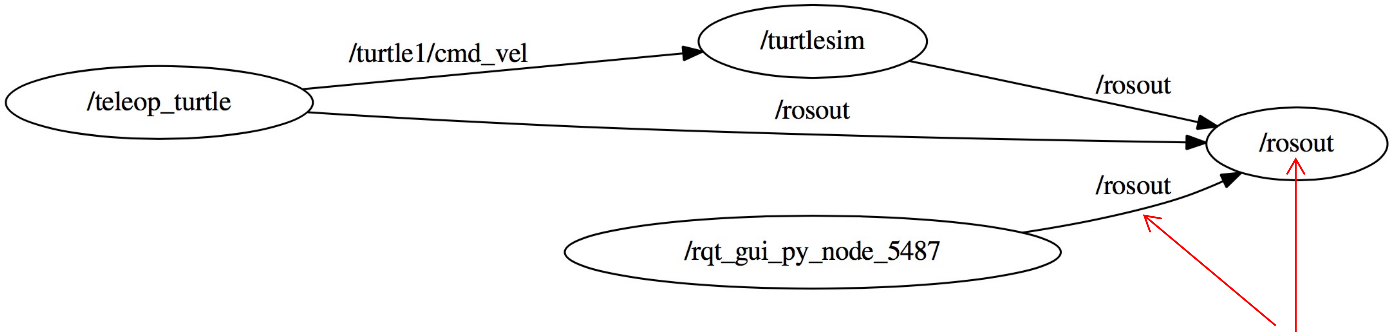
/turtlesim node (subscriber)

Credit: J. M. O’Kane, A Gentle Introduction to ROS, 2014
https://cse.sc.edu/~jokane/agitr/

Topics and Messages

By default, rqt_graph hides nodes that are usually used for debugging, e.g. rosout

- You can disable this by unchecking the “Hide debug” box
- rqt_graph will then draw the following graph



Same name for topic and node
ROS disambiguates based on context

Credit: J. M. O’Kane, A Gentle Introduction to ROS, 2014
https://cse.sc.edu/~jokane/agitr/

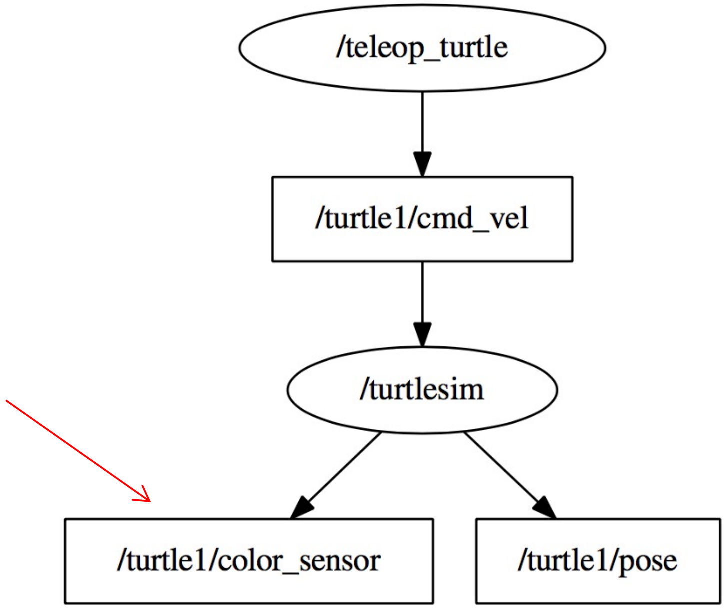
Topics and Messages

Alternative **turtlesim** graph, showing all topics, including those with no publishers or no subscribers, as distinct entities

/turtle1/color_sensor topic has no subscriber

This is very common

A node publishes irrespective of whether there are subscribers



Credit: J. M. O'Kane, A Gentle Introduction to ROS, 2014
https://cse.sc.edu/~jokane/agitr/

Topics and Messages

Use

- rostopic list to get a list of active topics
- rostopic echo *topic-name* to see the messages that are being published on a topic
- rostopic hz *topic-name* to see how often the messages are sent
- rostopic bw *topic-name* to see the bandwidth used by the messages
- rostopic info *topic-name* to see the information about a topic

Topics and Messages

- A messages has a message type (i.e. a data type) that determines the information in a message

- The message type is printed when you use rostopic info *topic-name*

- The message type is also printed when you use rostopic echo *topic-name*

- Use rosmsg show *message-type-name* to see details about a message type

Topics and Messages

- A message comprises one or more fields
- Each field has a built-in data type (e.g. `int8, bool, string`)
- A field can be a composite field, each with component fields
- Composite fields can be nested:
  - The fields in a composite field can also be a composite field
- The data types of composite fields are message types in their own right

Topics and Messages

For example, the message type for the /turtle1/cmd_vel topic is `geometry_msgs/Twist`

This is a composite message type, comprising two (composite) fields of type `geometry_msgs/Vector3`

```
geometry_msgs/Vector3 linear
   float64 x
   float64 y
   float64 z
geometry_msgs/Vector3 angular
   float64 x
   float64 y
   float64 z
```

Composite fields

This message comprises exactly six numbers of type `float64`

Topics and Messages

If we declare a message of this type

```
geometry_msgs::Twist msg;
```

We can assign a value as follows:

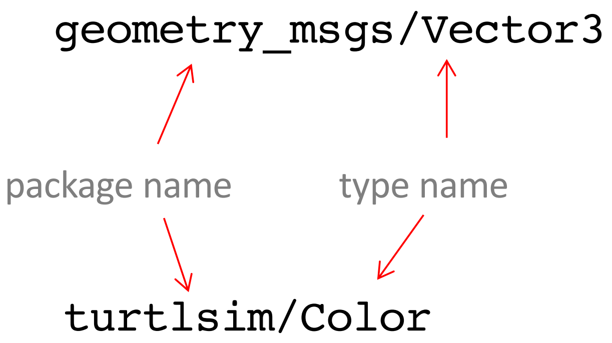
```
msg.linear.x = 0;
```

Topics and Messages

Message type names comprise two parts (separated by /)

1. the name of the package to which it belongs
2. the name of the type

For example



`geometry_msgs/Vector3`

package name

type name

`turtlsim/Color`

Topics and Messages

- We note in passing that ROS allows you to publish messages from the command line in a terminal

```
rostopic pub -r rate-in-hz topic-name message-type message-content
```

- This can be helpful on occasion:

```
rostopic pub -1 /cmd_vel geometry_msgs/Twist -- '[0.1, 0.0, 0.0]' '[0.0, 0.0, 0.5]'
rostopic pub /cmd_vel geometry_msgs/Twist -r 1 -- '[0.1, 0.0, 0.0]' '[0.0, 0.0, -0.5]'
rostopic pub -r 10 /cmd_vel geometry_msgs/Twist '{linear: {x: 0.1, y: 0.0, z: 0.0}, angular: {x: 0.0,y: 0.0,z: 0.0}}'
```

Services

Service calls: an alternative way of communicating with nodes

- Bi-directional
  - One node sends information to another node (e.g. requesting information)
  - The other node responds (e.g. with the required information)
  - In contrast, when a message is published, there is no concept of a response, and no guarantee that there is even a node subscribing to topic and receiving the messages
- One-to-one
  - Each service call is initiated by one node and the response goes back to it
  - In contrast, topics and message may have many publishers and many subscribers

Services

Terminology

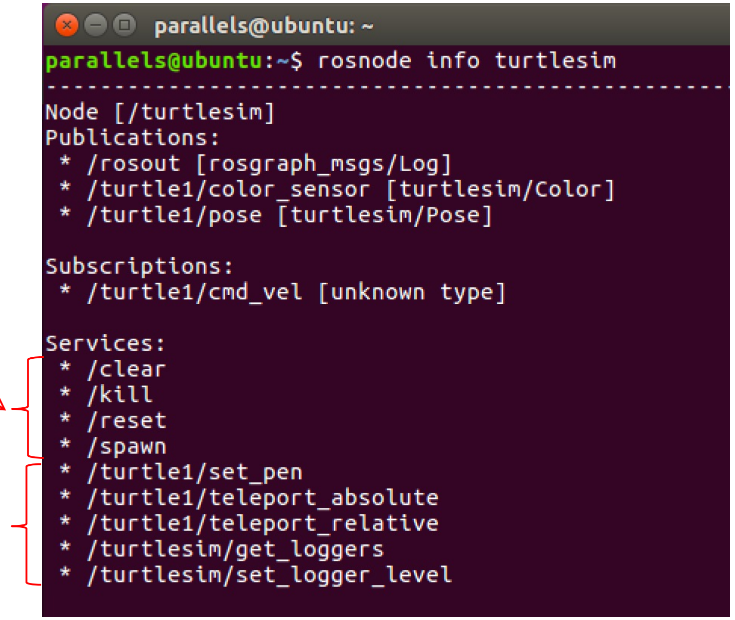
- Client node sends some data called a request to a server node
  - Waits for a reply
- Server node receives the request
  - Takes some action
  - Sends some data called a response back to the client
- The content of the request and the response is determined by the service data type
  - Similar to the message type associated with a topic
  - Two parts (and possibly two different types): request and response

Services

Two basic types of service

- General services that can be used with different nodes
- Services that are for specific nodes

As we have seen, use rosnode info *node-name*
to list the services offered by a node



```
parallels@ubuntu:~$ rosnode info turtlesim
--------------------------------------------------------------------------------
Node [/turtlesim]
Publications:
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 * /turtle1/color_sensor [turtlesim/Color]
 * /turtle1/pose [turtlesim/Pose]

Subscriptions:
 * /turtle1/cmd_vel [unknown type]

Services:
 * /clear
 * /kill
 * /reset
 * /spawn
 * /turtle1/set_pen
 * /turtle1/teleport_absolute
 * /turtle1/teleport_relative
 * /turtlesim/get_loggers
 * /turtlesim/set_logger_level
```
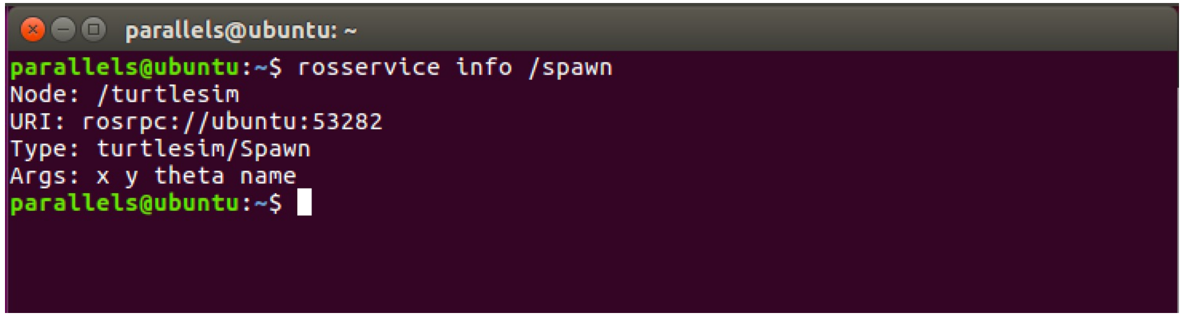

Services

Use rosservice info *service-name* to determine the service data type of a service

For example, rosservice info /spawn gives



```
parallels@ubuntu:~$ rosservice info /spawn
Node: /turtlesim
URI: rosrpc://ubuntu:53282
Type: turtlesim/Spawn
Args: x y theta name
parallels@ubuntu:~$
```

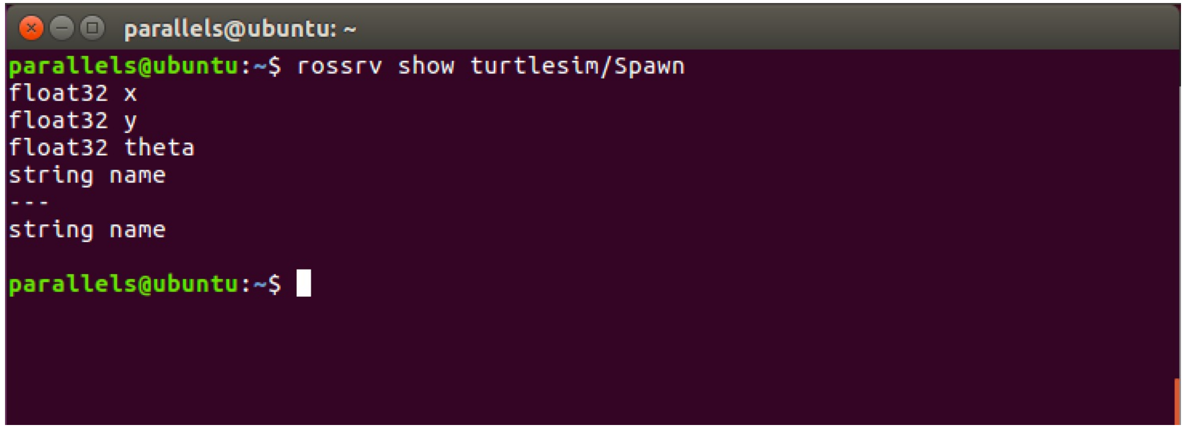
The service data type is
turtlesim/Spawn

There are four arguments in this data type:
x, y, theta (specifying the turtles pose ... location and orientation)
name (specifying the name of the new turtle being spawned)

Services

Use rossrv show *service-data-type-name* to get details about the service data type

For example, rossrv show turtle1/Spawn gives



```
parallels@ubuntu:~$ rossrv show turtlesim/Spawn
float32 x
float32 y
float32 theta
string name
---
string name

parallels@ubuntu:~$ 
```

The part is the request
i.e. information sent to the
server by the client

This part is the response
i.e. information sent back
to the client by the server

Checking for Problems

- When ROS is not behaving the way you expect, use the command line tool

  roswtf

- It performs a variety of sanity checks
  - For example, roswtf checks whether the rosdep portions of the install process have been completed (see later)

ROS Resources

Wiki	http://wiki.ros.org/
Installation	http://wiki.ros.org/ROS/Installation
Tutorials	http://wiki.ros.org/ROS/Tutorials
Tutorial Videos	http://www.youtube.com/playlist?list=PLDC89965A56E6A8D6
ROS Cheat Sheet	http://www.tedusar.eu/files/summerschool2013/ROScheatsheet.pdf

Recommended Reading

http://wiki.ros.org/catkin/Tutorials/create_a_workspace

http://wiki.ros.org/ROS/Tutorials/CreatingPackage

http://wiki.ros.org/roscpp/Overview/InitializationandShutdown

http://wiki.ros.org/roscpp/Overview/NodeHandles

http://wiki.ros.org/ROS/Tutorials/BuildingPackages

http://wiki.ros.org/ROS/Tutorials/WritingPublisherSubscriber(c++)

J. M. O'Kane, A Gentle Introduction to ROS, 2014.
https://cse.sc.edu/~jokane/agitr/