ROS Workshop

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Technische Universität München

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Outline

Outline

What is ROS?

More than just a middleware

- A "meta" operating system for robots
- A collection of packaging, software building tools
- An architecture for distributed inter-process/inter-machine communication and configuration
- Development tools for system runtime and data analysis
- A language-independent architecture (c++, python, lisp, java, *and more*)

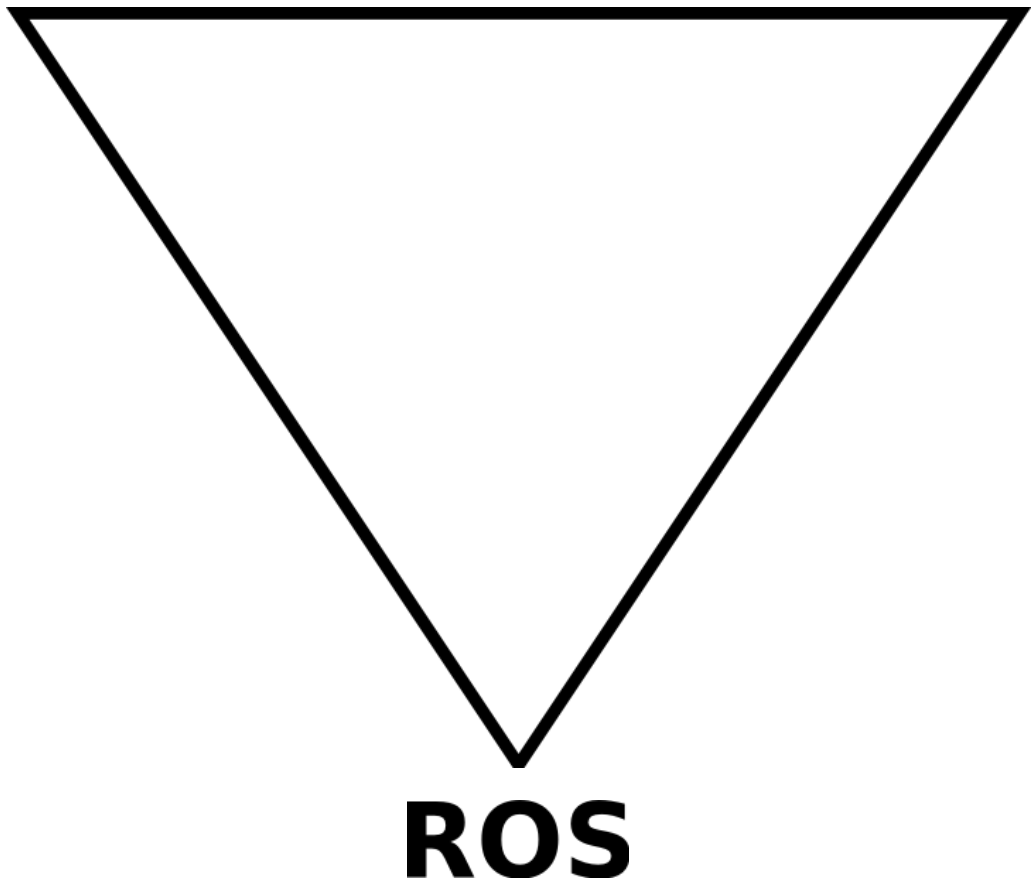
What is ROS not?

No confusion

- An *actual* operating system
- A programming language
- A programming environment / IDE
- A hard real-time architecture

What does ROS get you?

All levels of development



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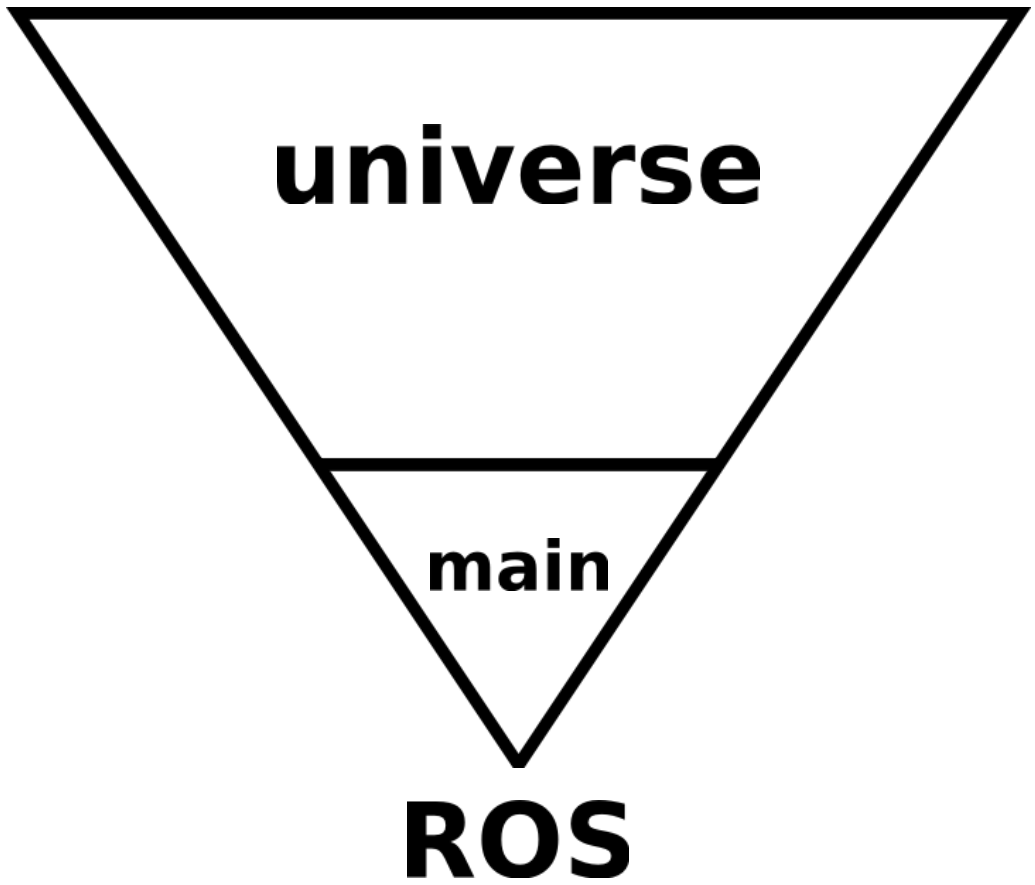

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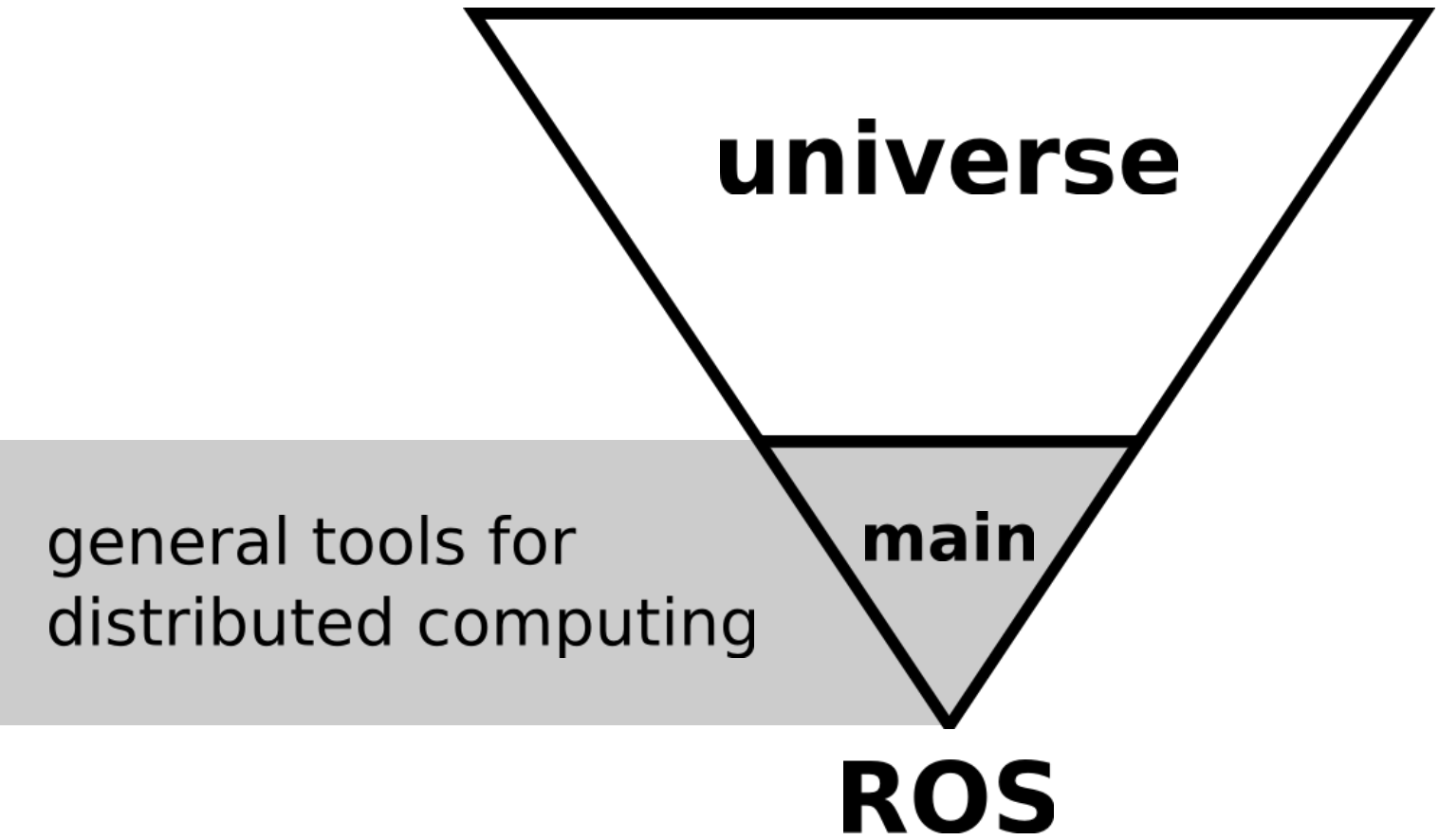

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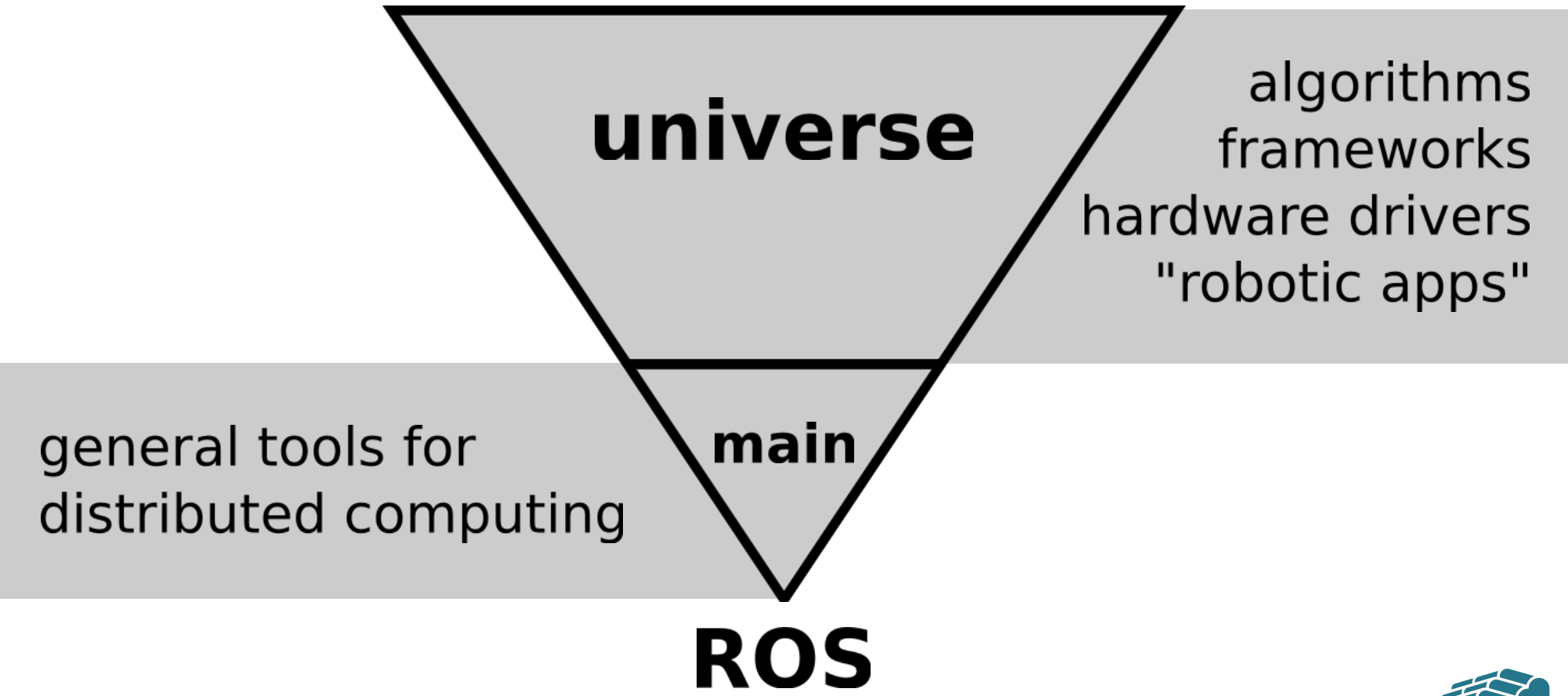

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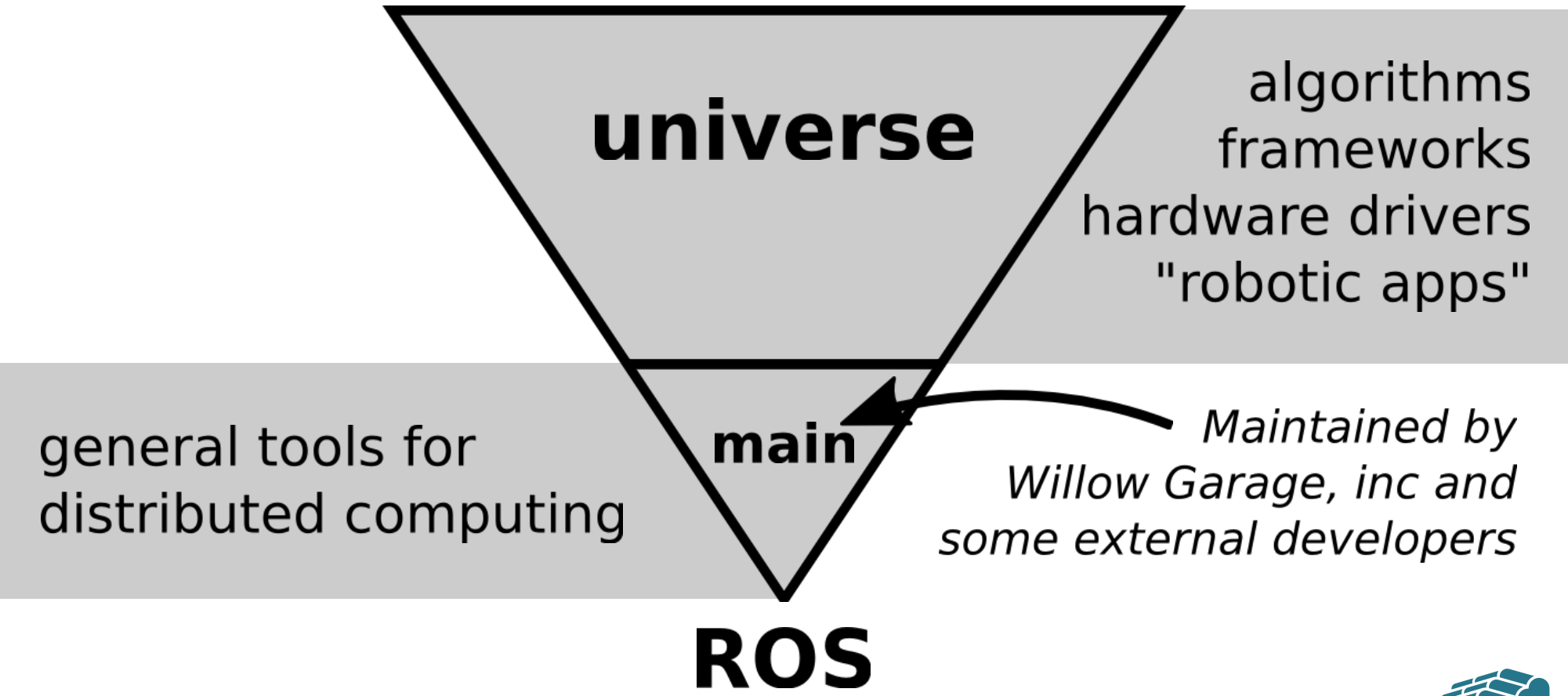

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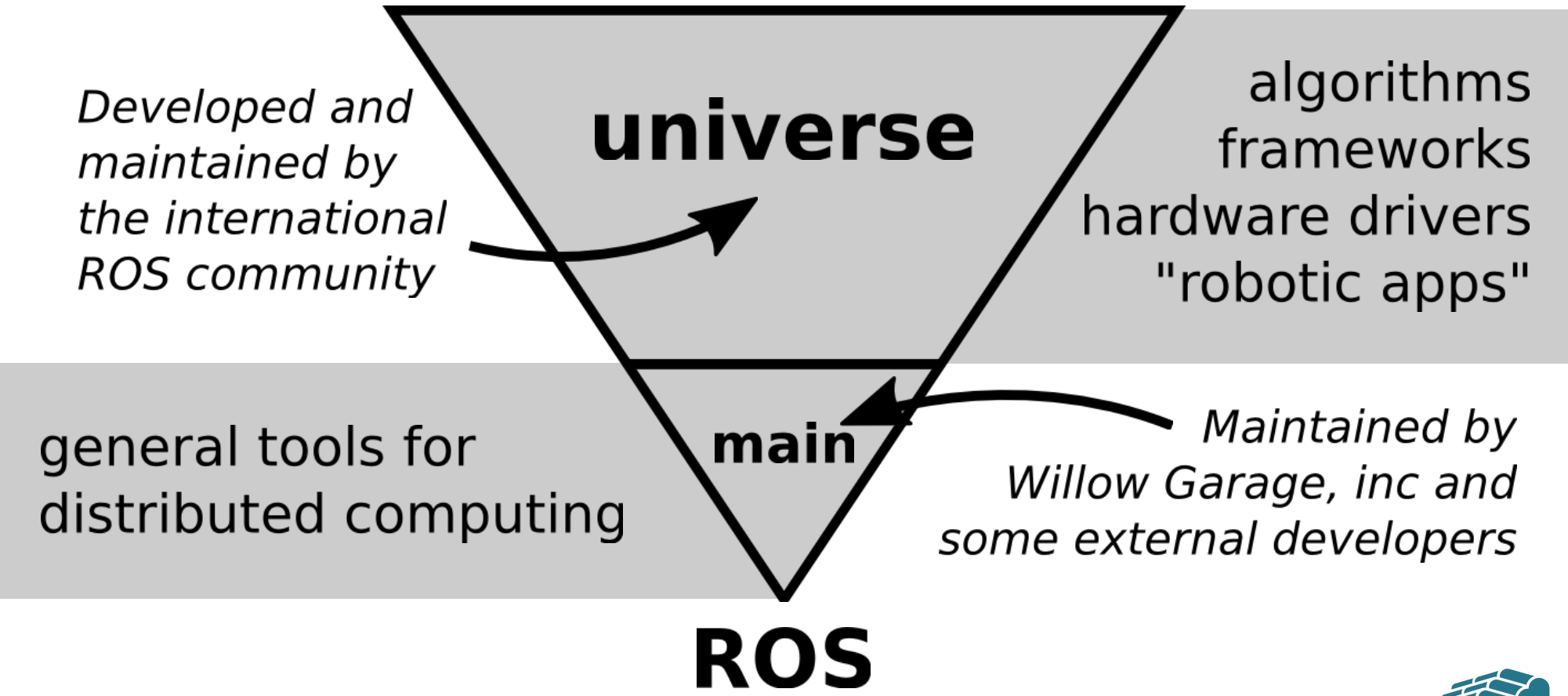

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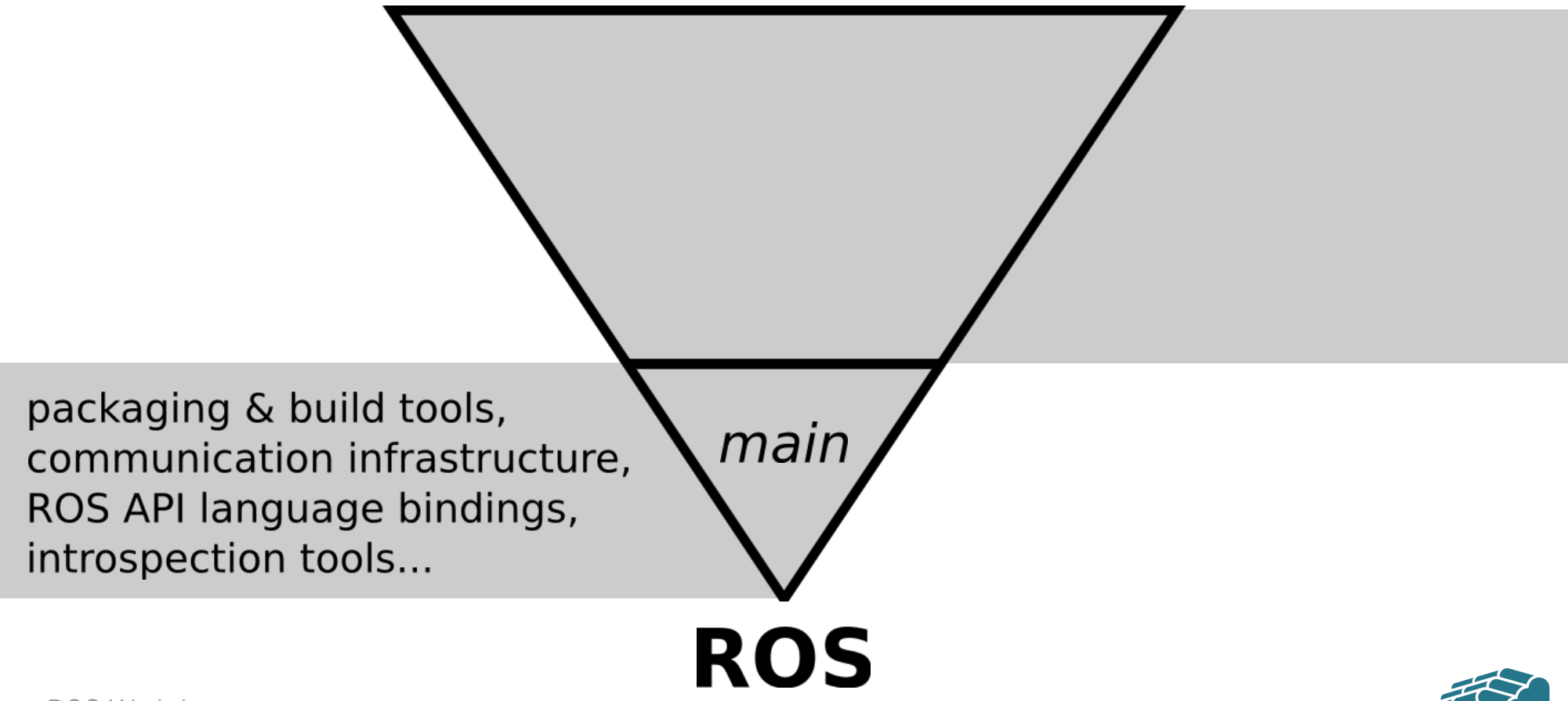

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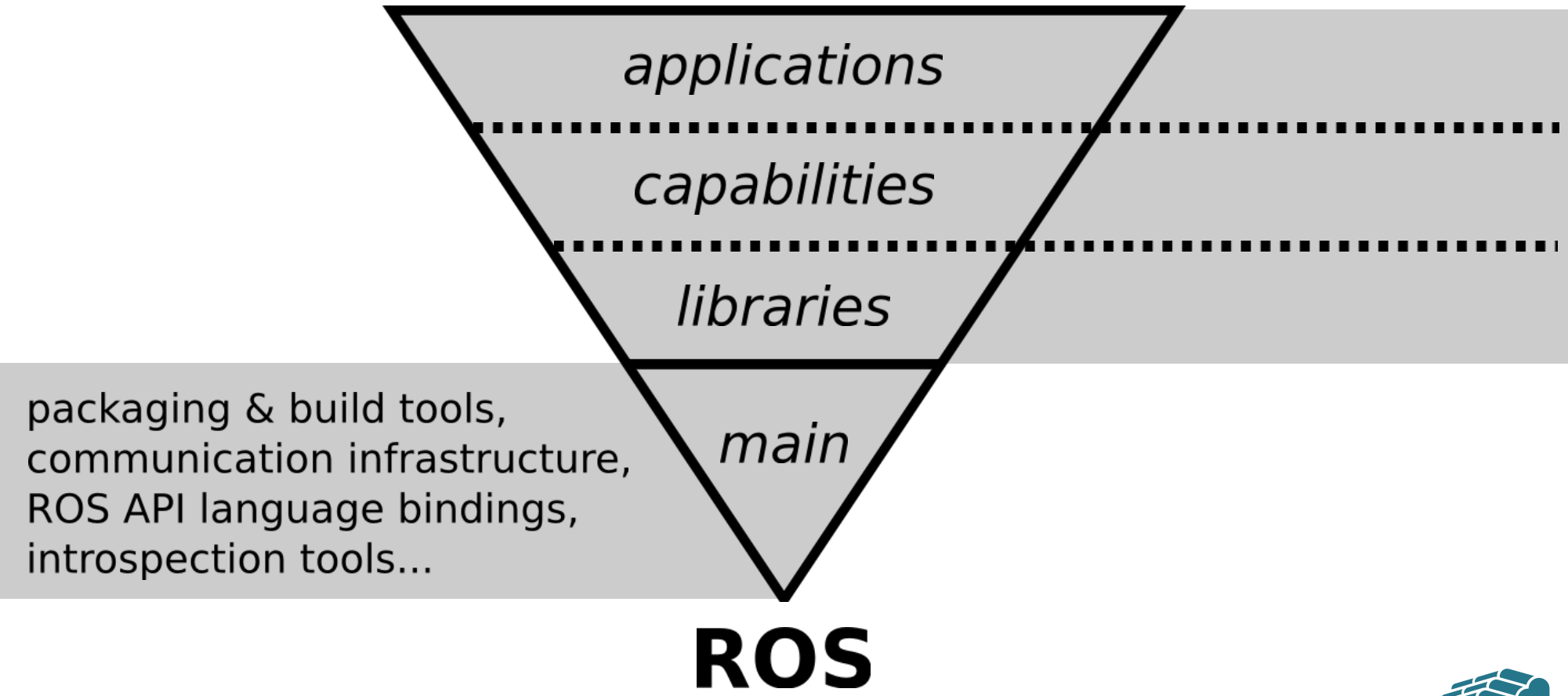

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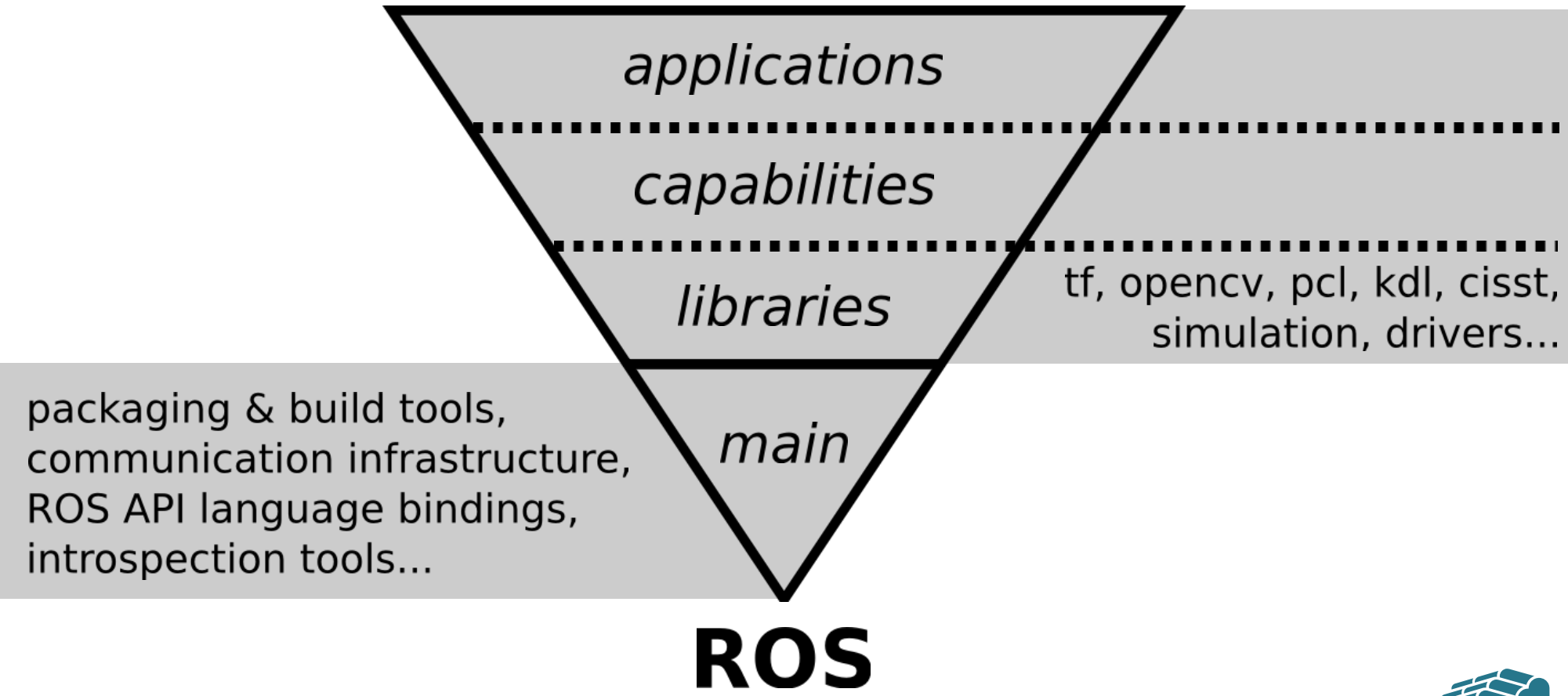

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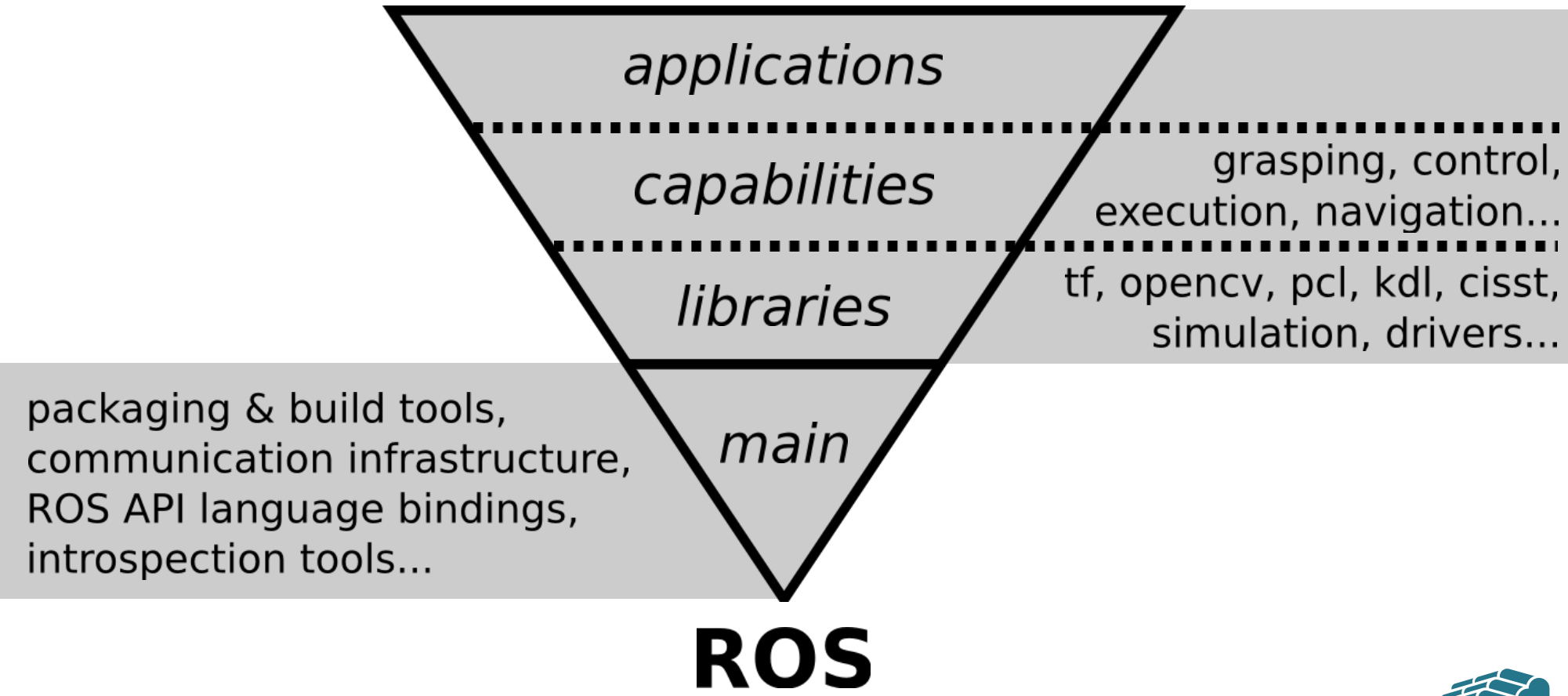

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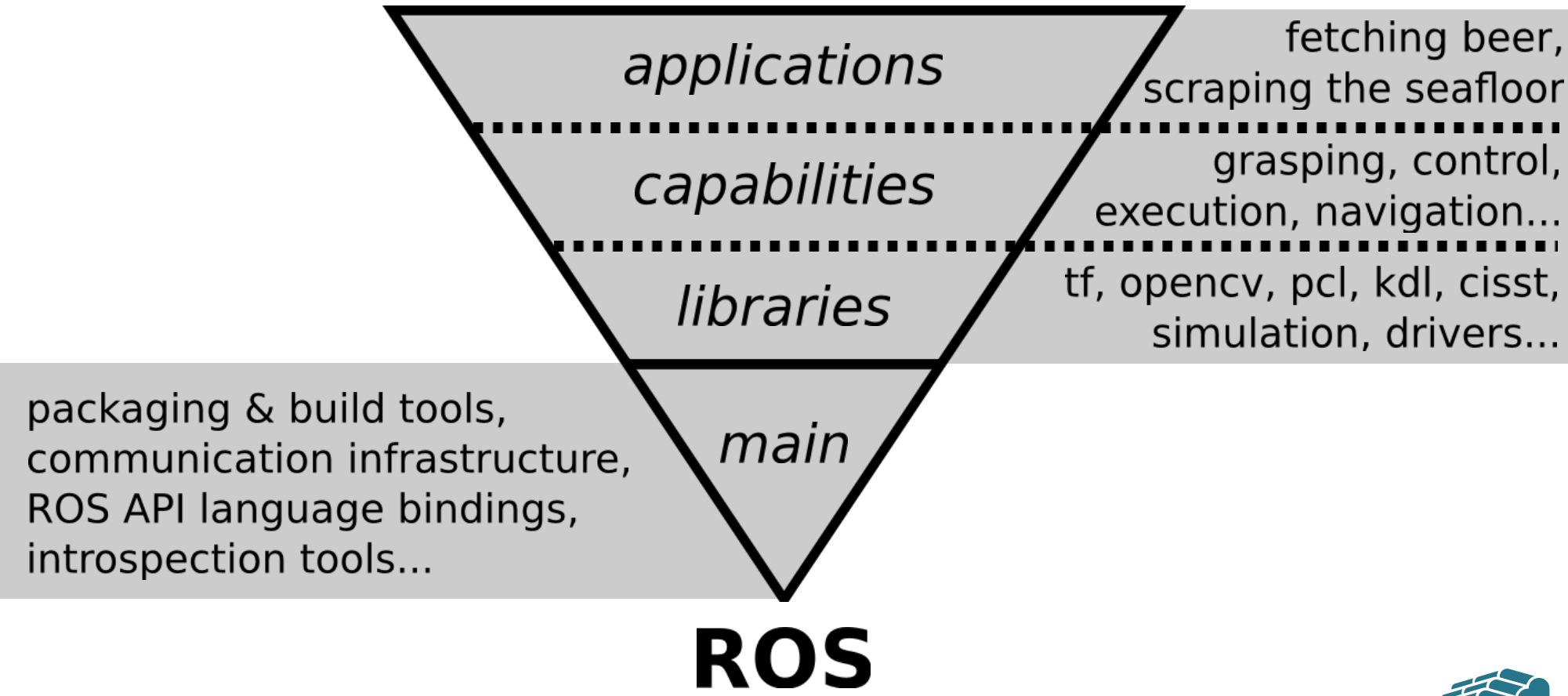
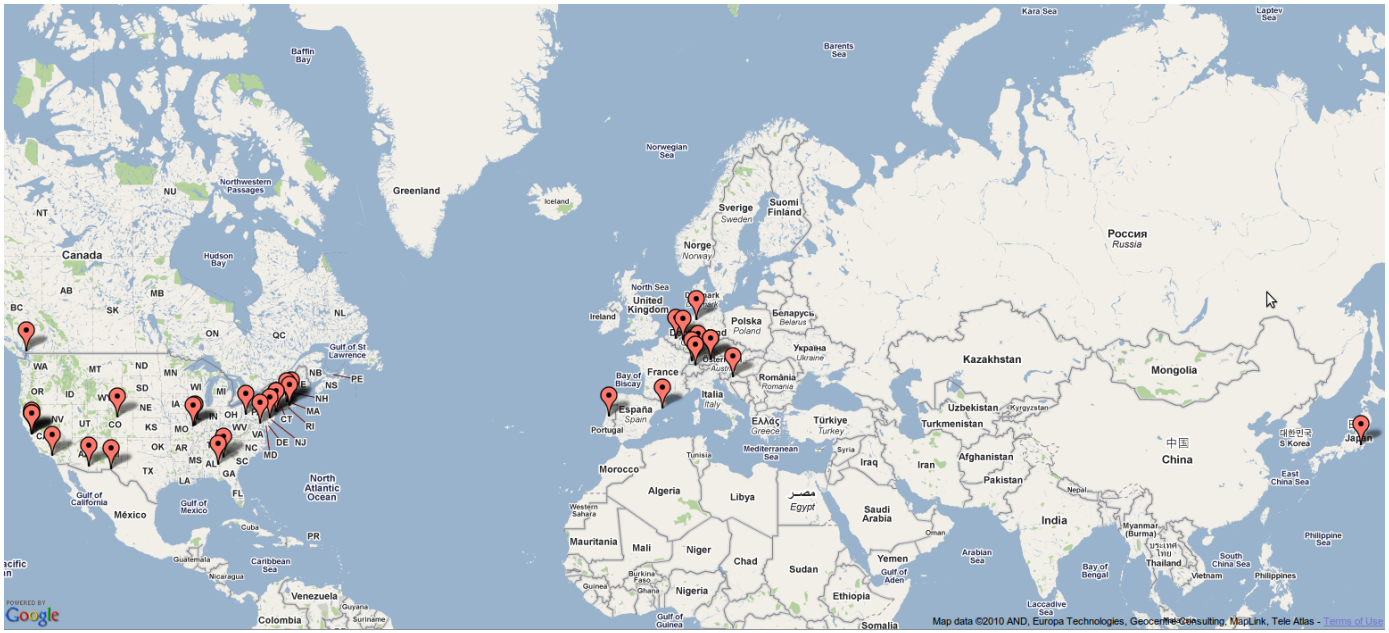


The ROS Community

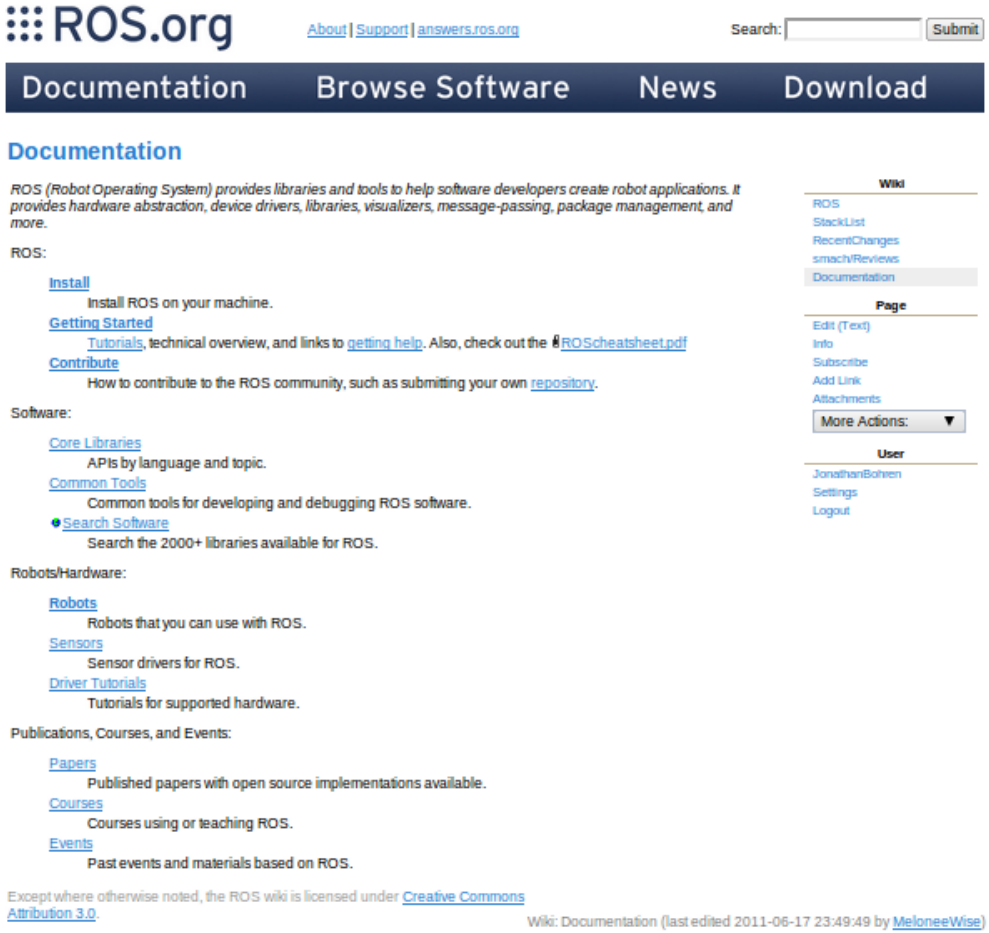
Researchers using common tools to enable collaboration



79 Institutional ROS Repositories, all over the world (July, 2011)

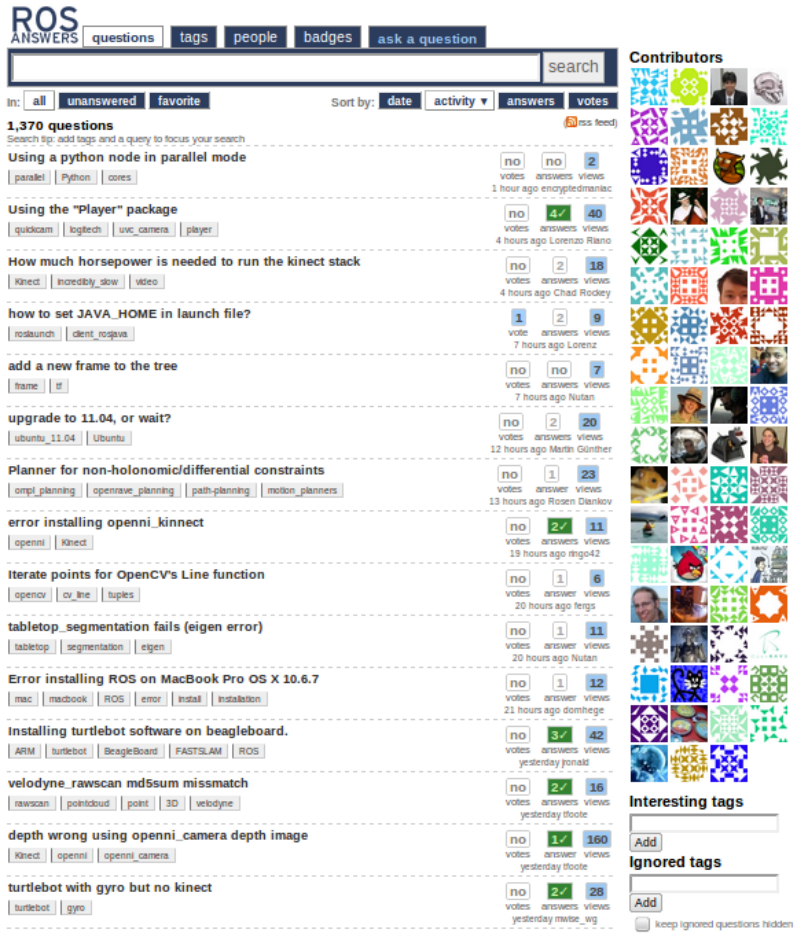
www.ros.org - The ROS Hub

A centralized location for ROS users and developers



answers.ros.org - ROS Questions & Answers

Community-supported help for ROS users



ros mailing lists

Getting in touch with the developer community

- ROS Users - *for general ROS-related discussions*

  `https://code.ros.org/mailman/listinfo/ros-users`
- Other Lists & List Archives

  `http://code.ros.org/lurker`

Outline

ROS Core

Where it all comes together

- ROS Master
  - A centralized XML-RPC server
  - Negotiates communication connections
  - Registers and looks up names for ROS graph resources
- Parameter Server

  Stores persistent configuration parameters and other arbitrary data
- rosout

  Essentially a network-based `stdout` for human-readable messages

ROS "Graph" Abstraction

Named network resources

ROS graph resources:

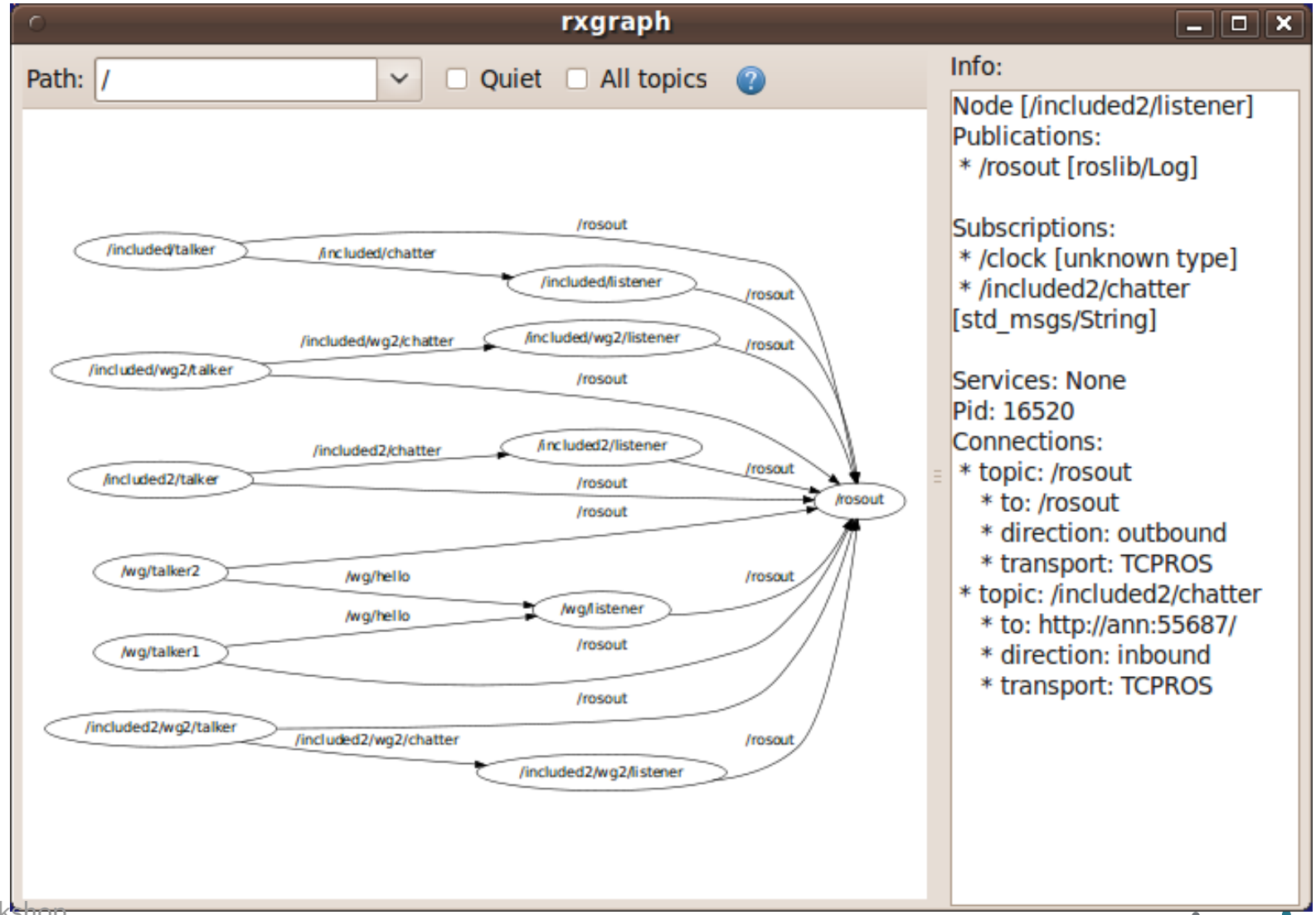
- nodes
  - processes
  - produce and consume data
- parameters
  - persistent data storage
  - configuration, initialization settings
  - stored on parameter server
- topics

  Asynchronous many-to-many communication streams.
- services

  Synchronous one-to-many network-based functions.

ROS "Graph"

rxgraph: communication network visualization



Creating and Running ROS Nodes

Distributing computation with ROS

Launch files

- XML files for launching nodes
- associate a set of parameters and nodes with a single file
- hierarchically compose collections of other launch files
- automatically re-spawn nodes if they crash
- change node names, namespaces, topics, and other resource names *without* recompiling
- easily distribute nodes across multiple machines

Example Launch File

Example launch file

```
<launch>
  <node name="my_node" pkg="foo" type="bar">
    <remap from="/base_laser/scan" to="scan" />
    <rosparam>
      use_foo: True
      frame_id: base_laser
    </rosparam>
  </node>
</launch>
```

- Launch with `roslaunch package foo.launch`

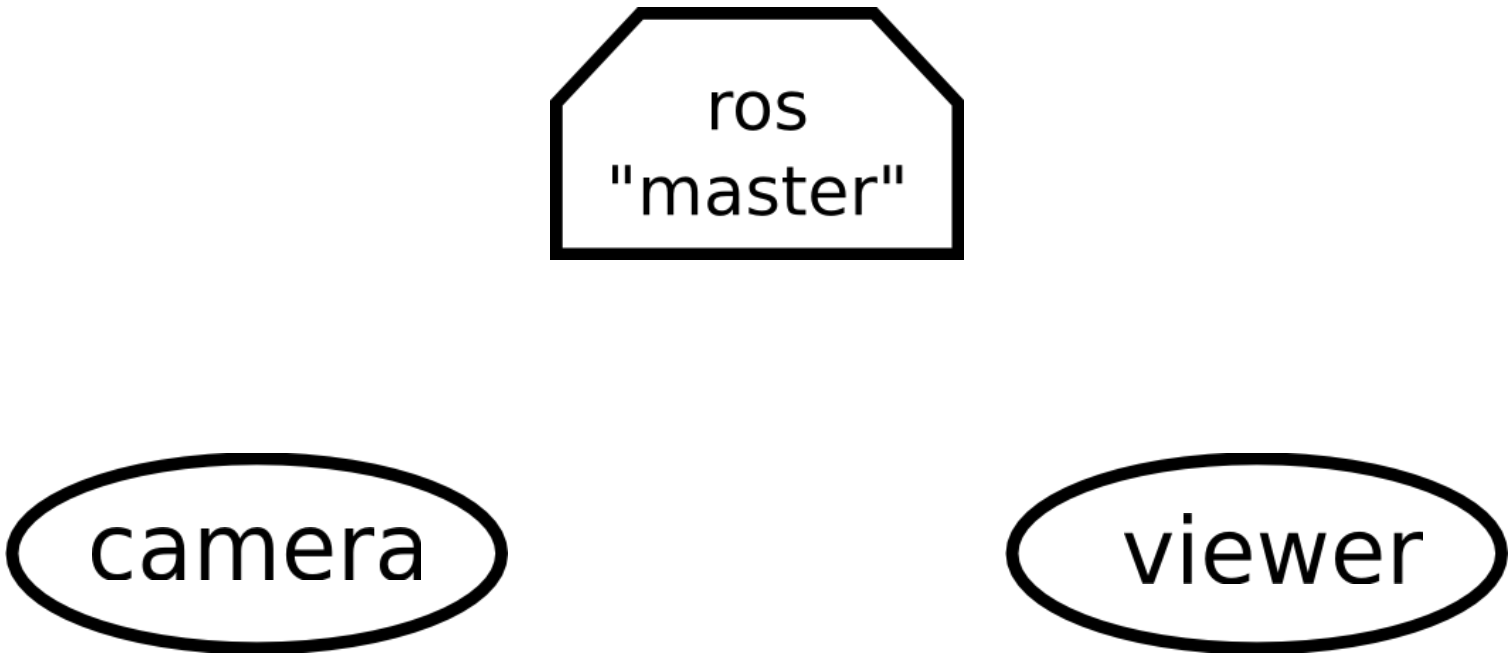
ROS Communication Protocols

Connecting nodes over the network

- ROS Topics
  - Asynchronous "stream-like" communication
  - Strongly-typed (ROS .msg spec)
  - Can have one or more publishers
  - Can have one or more subscribers
- ROS Services
  - Synchronous "function-call-like" communication
  - Strongly-typed (ROS .srv spec)
  - Can have only one server
  - Can have one or more clients
- Actions
  - Built on top of topics
  - Long running processes
  - Cancellation

Asynchronous Distributed Communication

ROS TCP Topics



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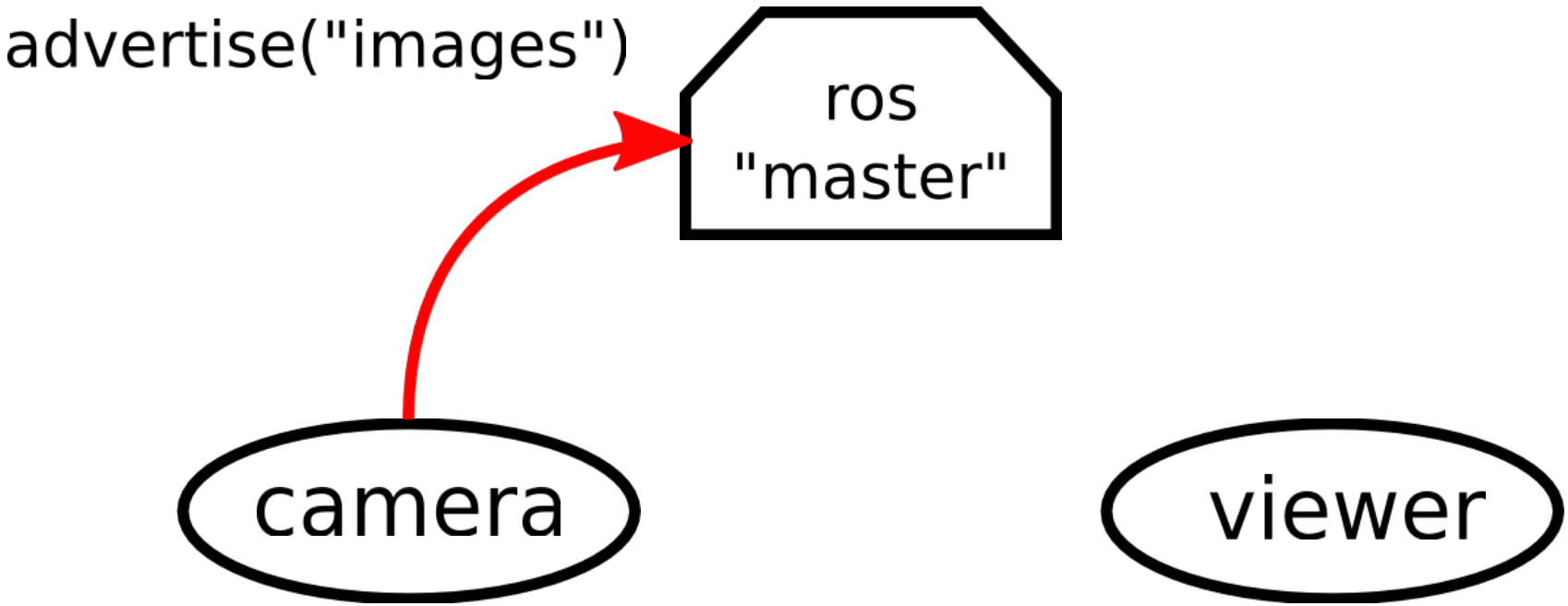

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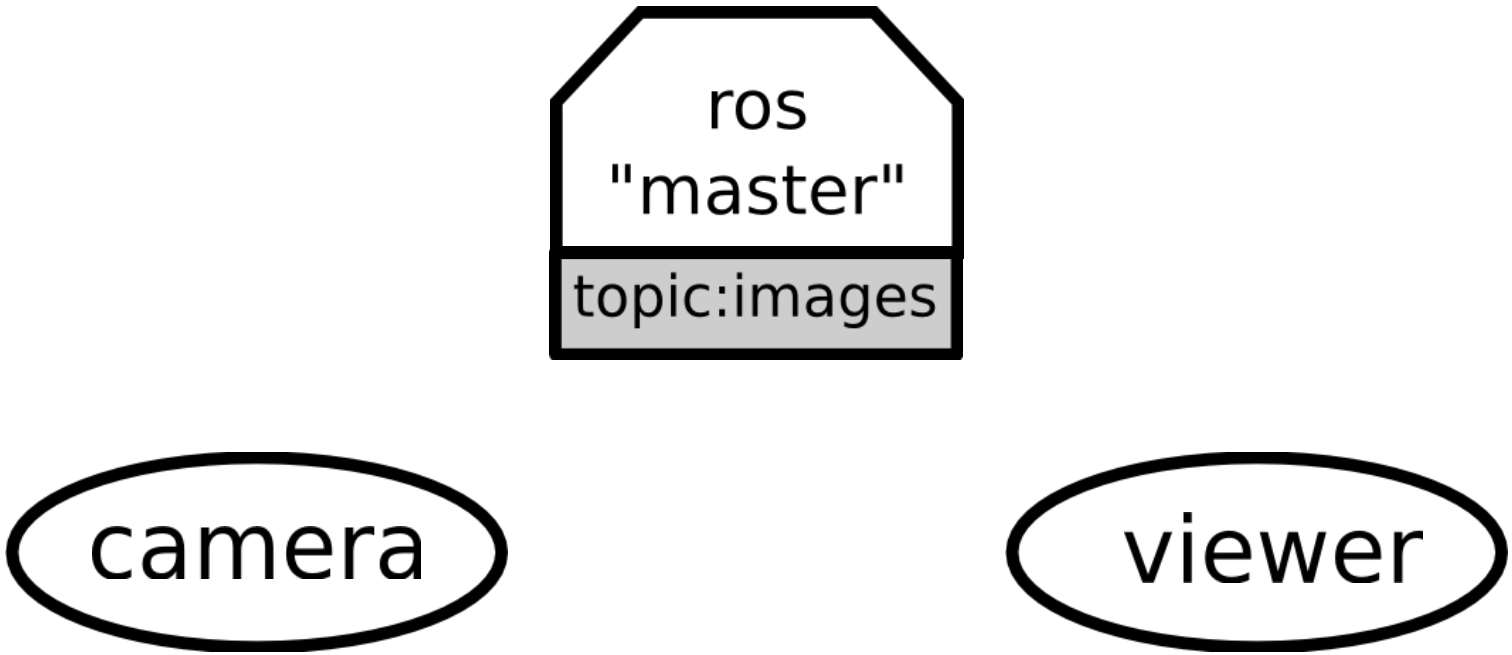

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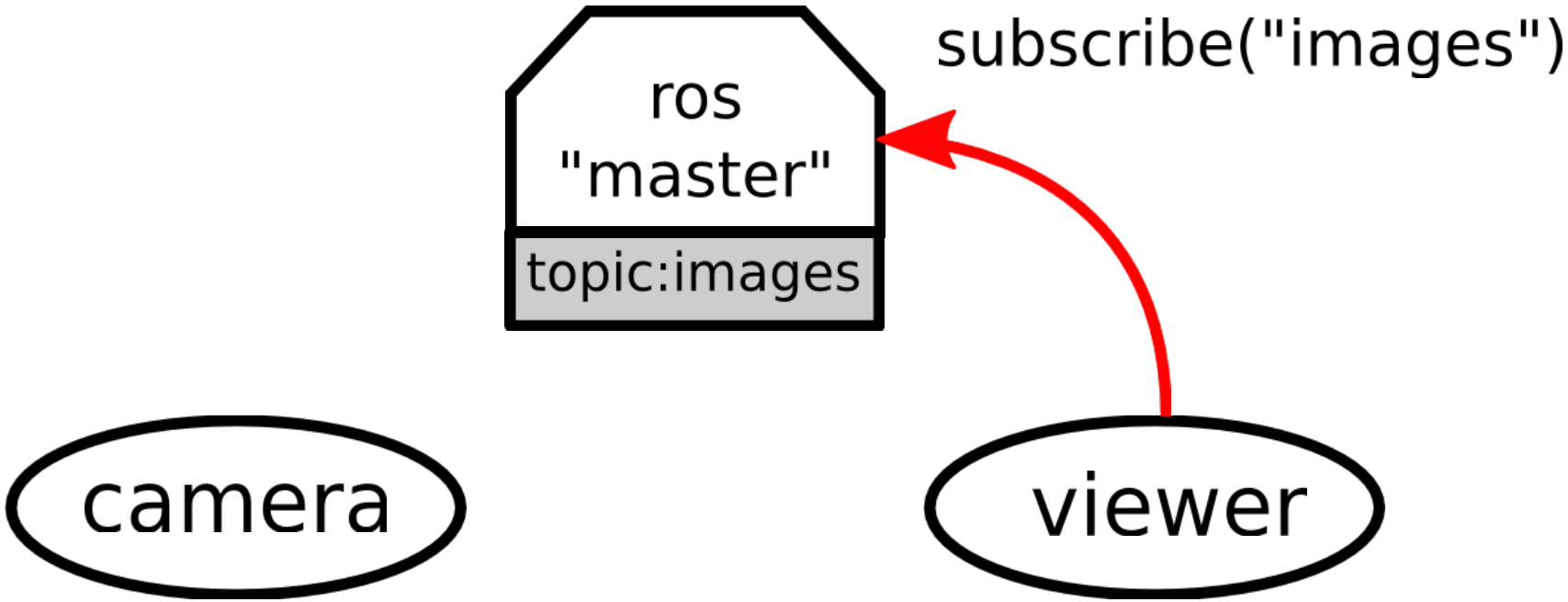

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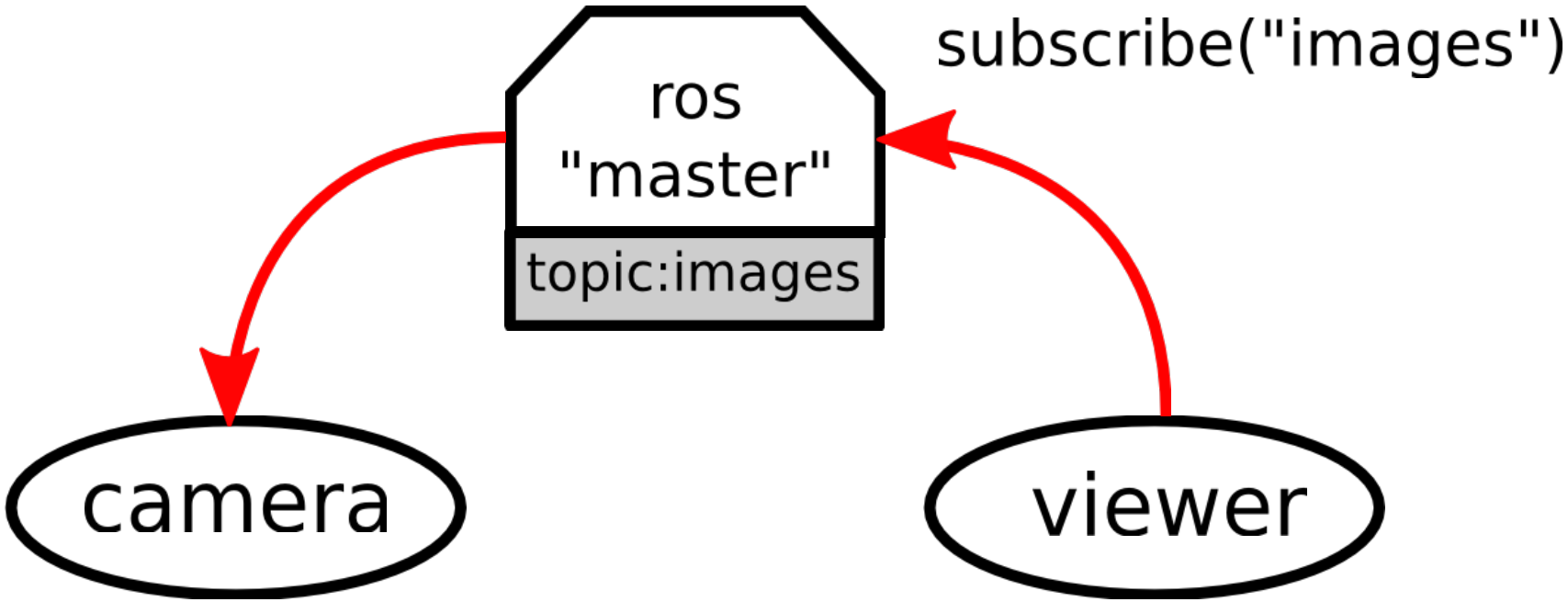

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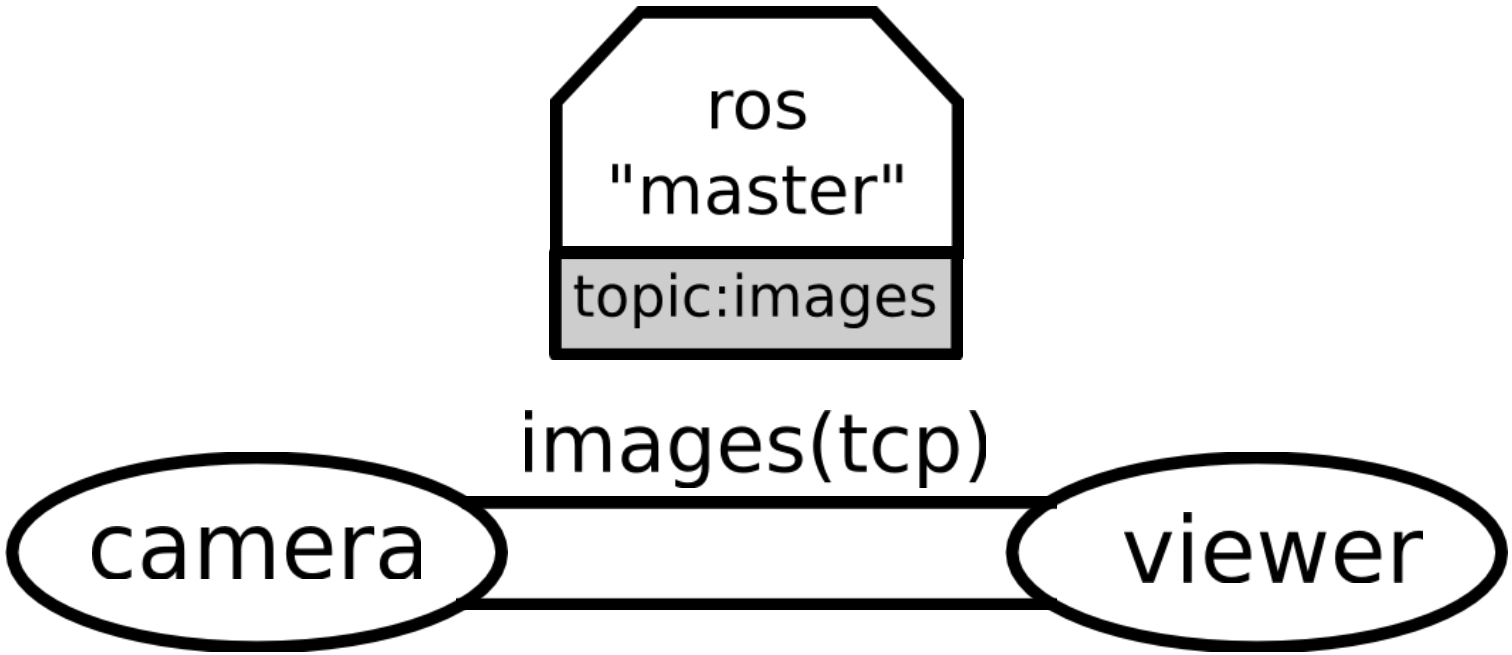

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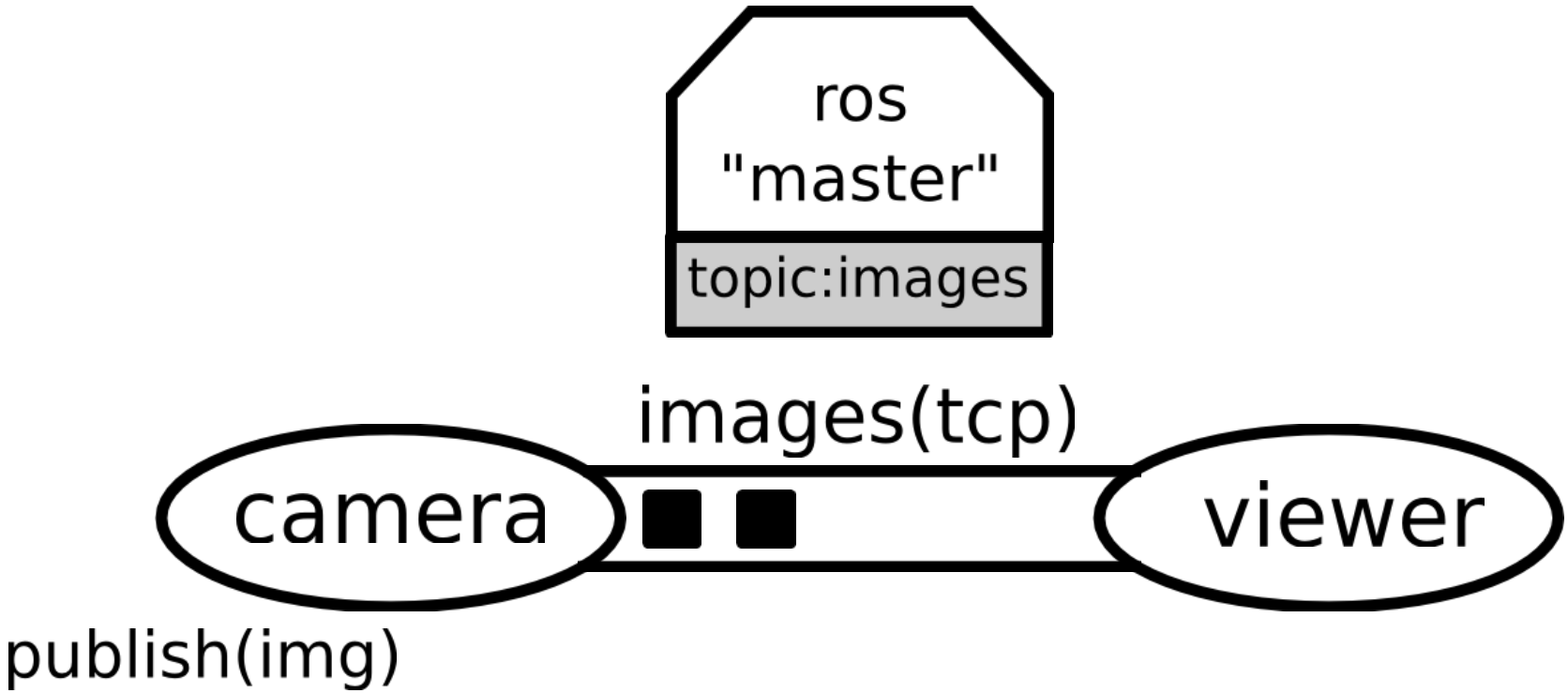

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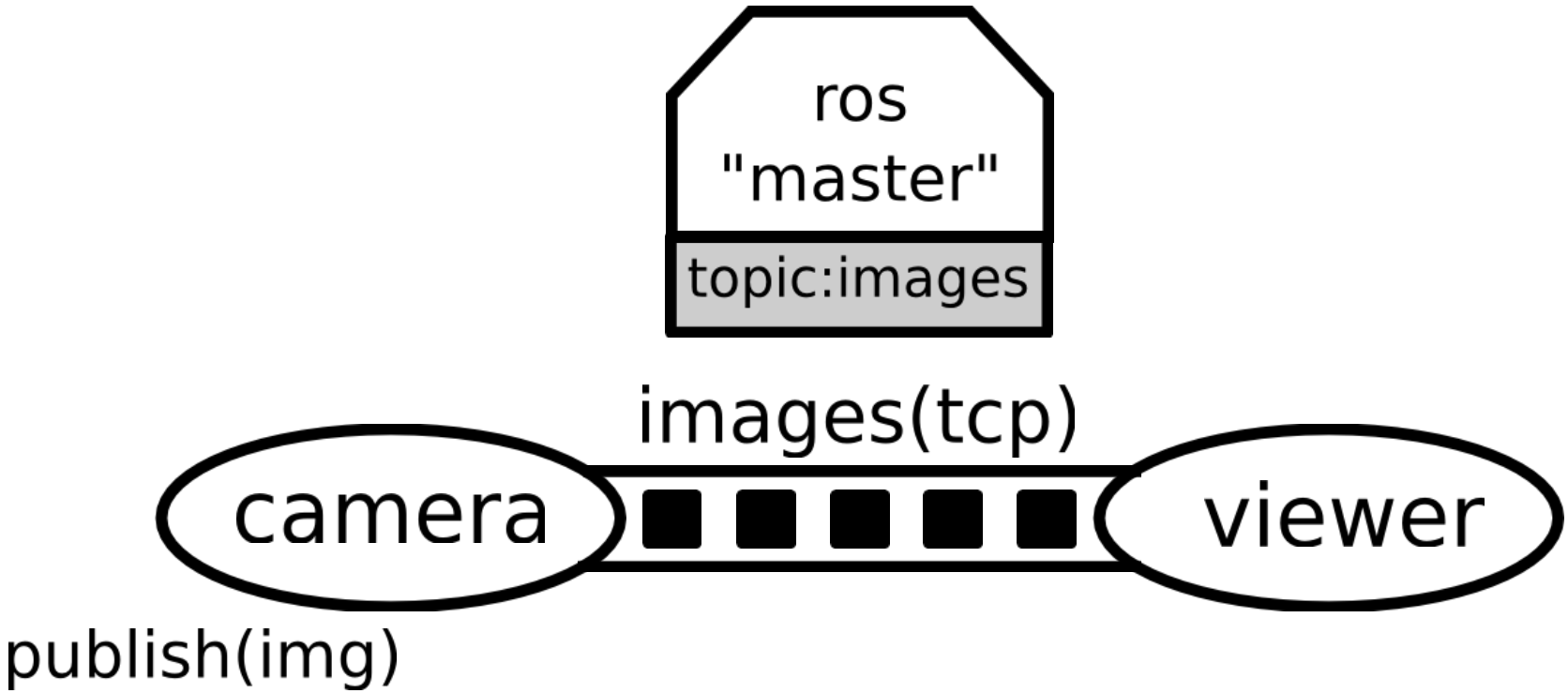

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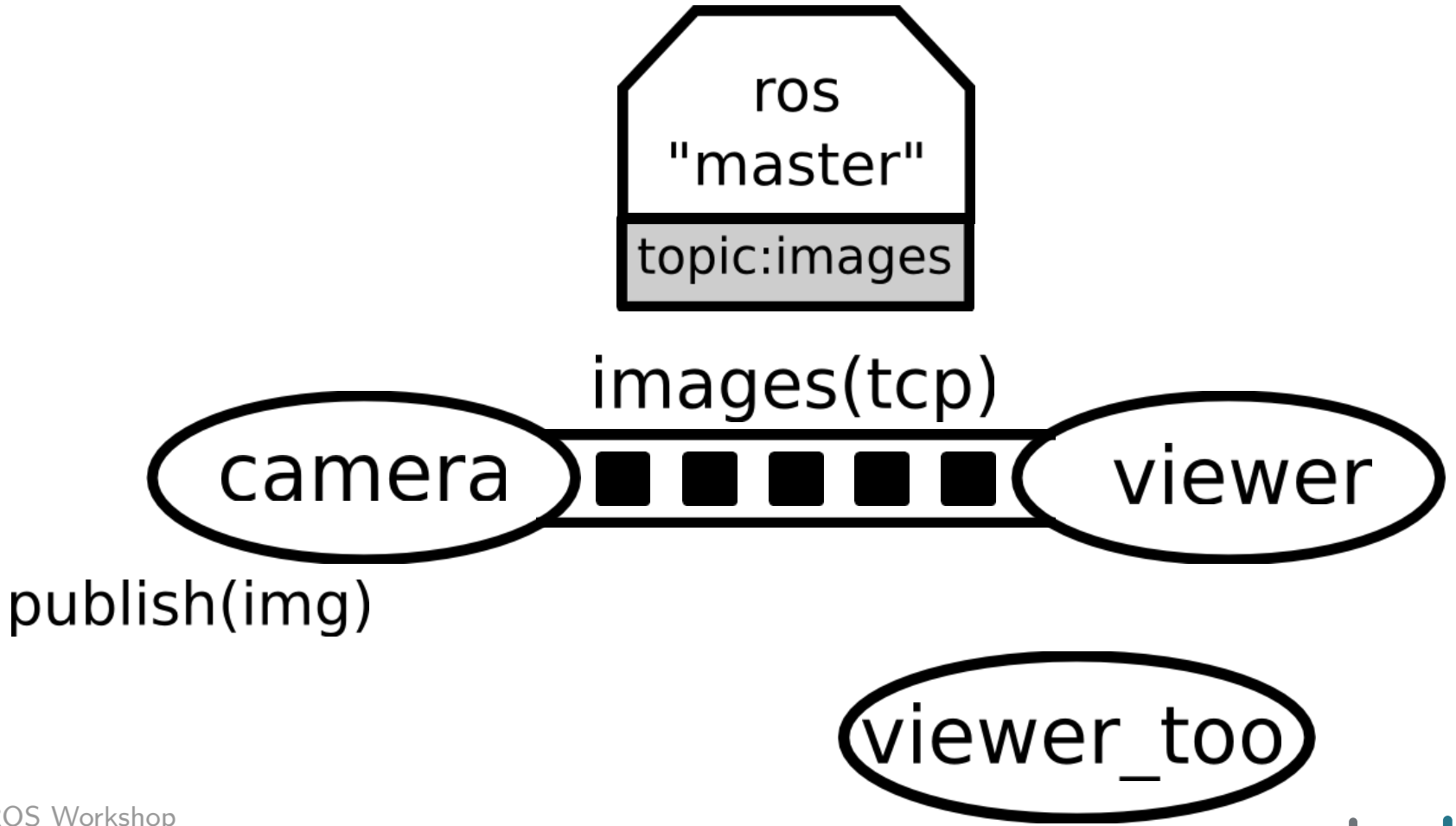

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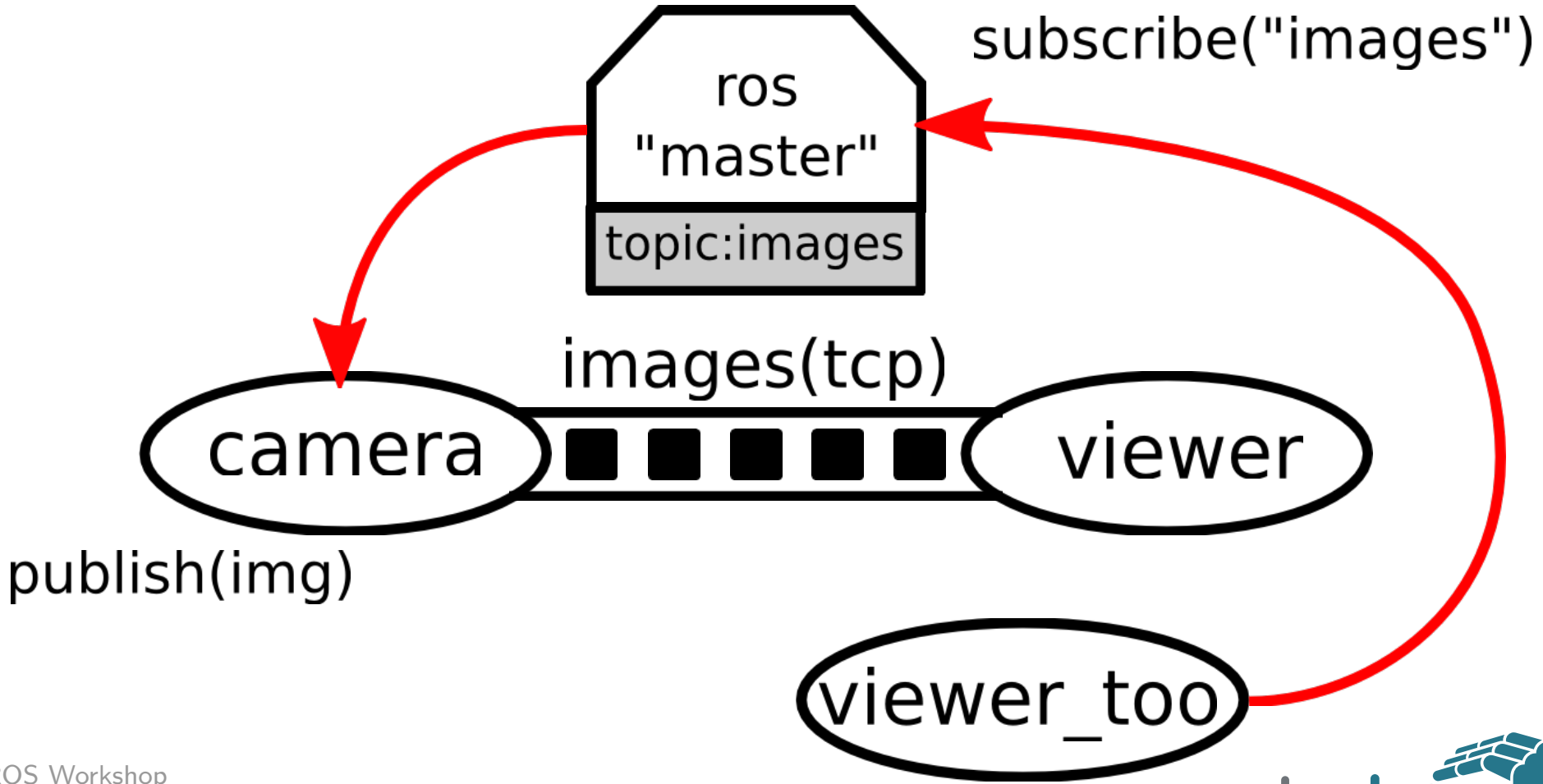

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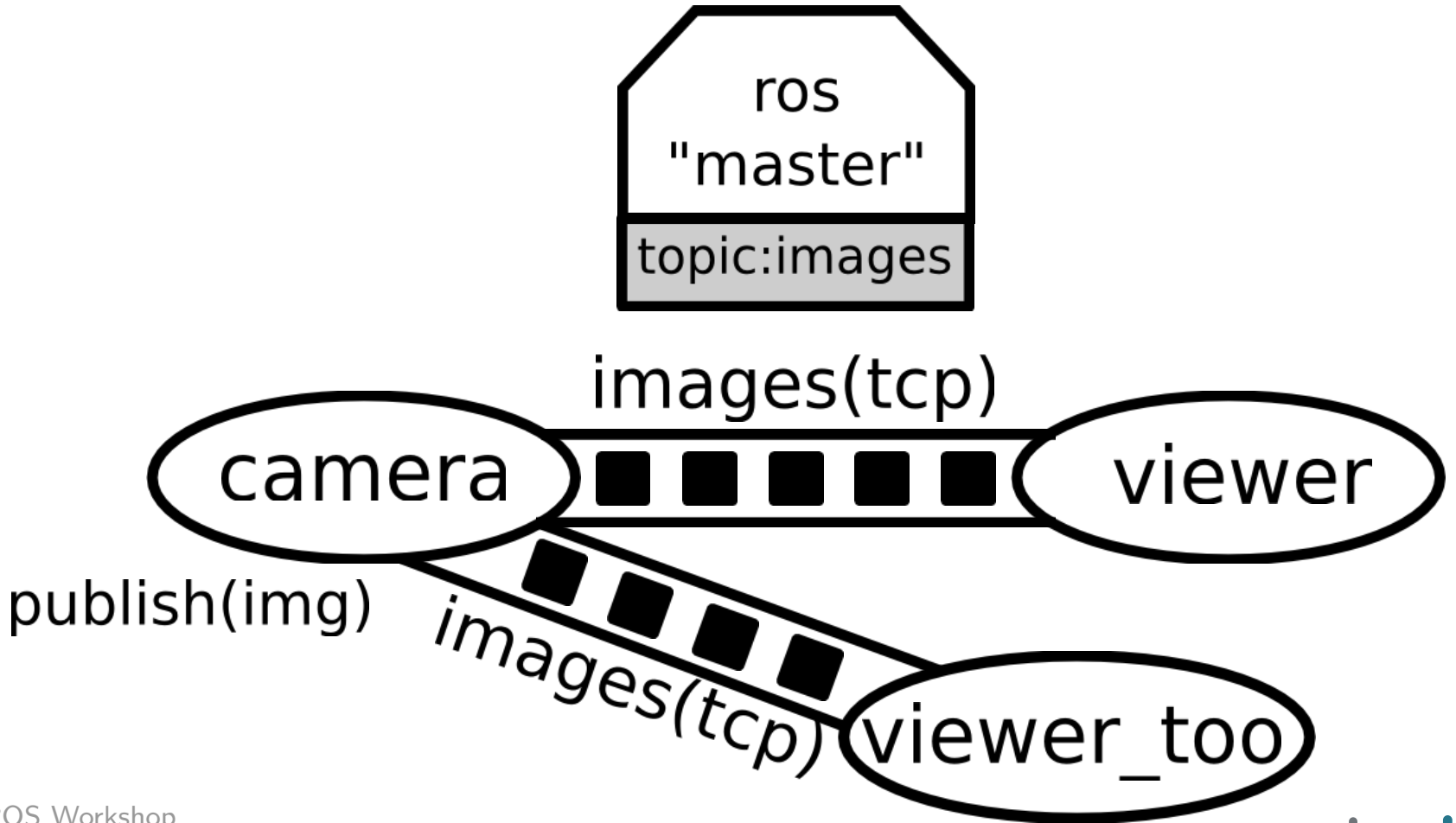


Debugging

rosout

ROS provides mechanisms in all languages for specifying different *levels* of human-readable log messages.

The five default levels are:

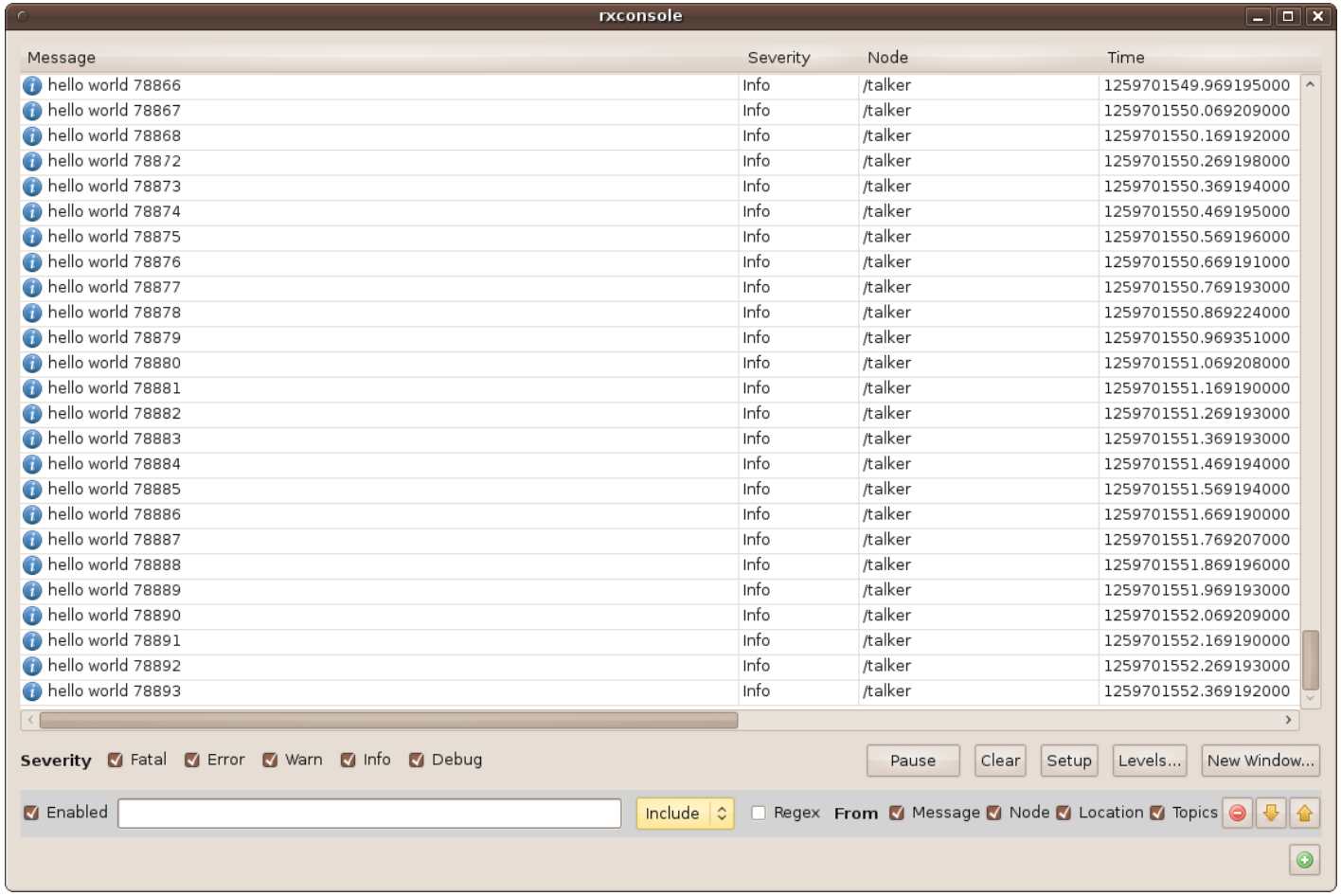
- fatal
- error
- warn
- info
- debug

Corresponding logging commands (C++):

- `ROS_FATAL(...)`
- `ROS_ERROR(...)`
- `ROS_WARN(...)`
- `ROS_INFO(...)`
- `ROS_DEBUG(...)`

Debugging

rxconsole



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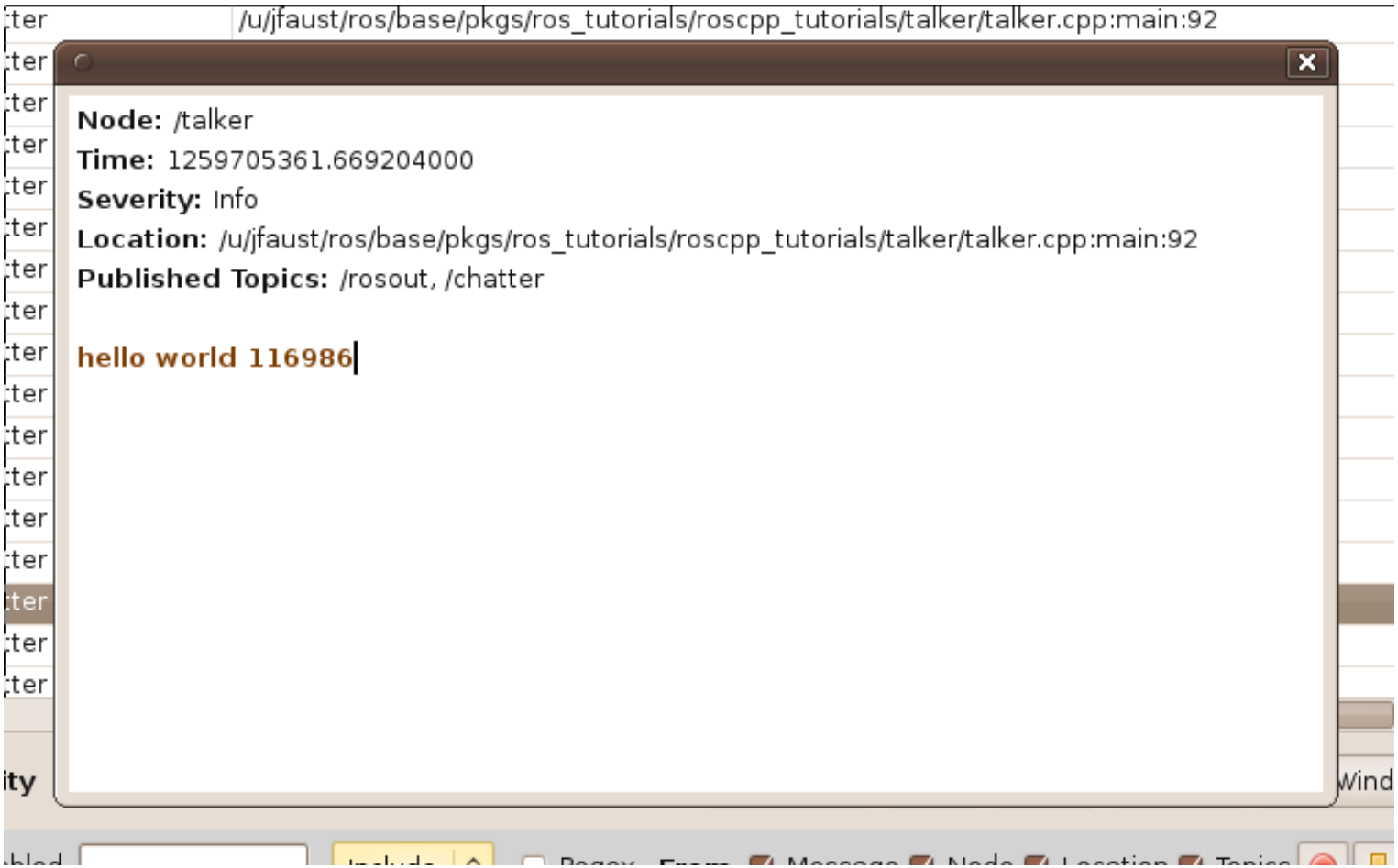

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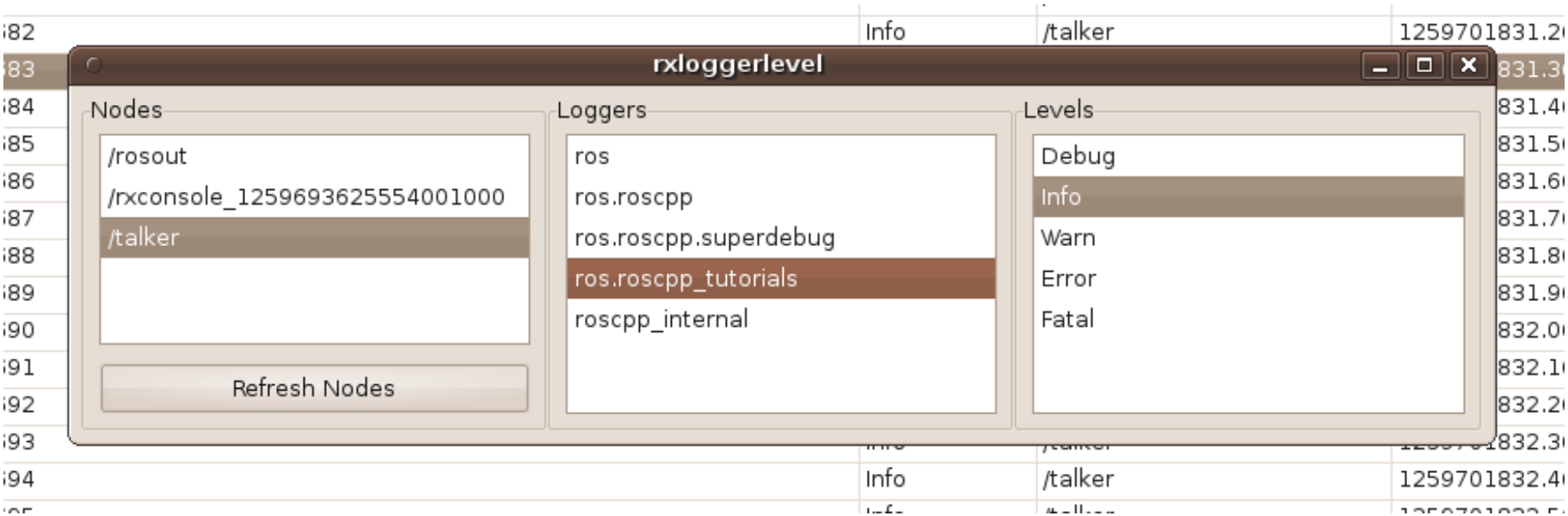


ROS Graph Introspection

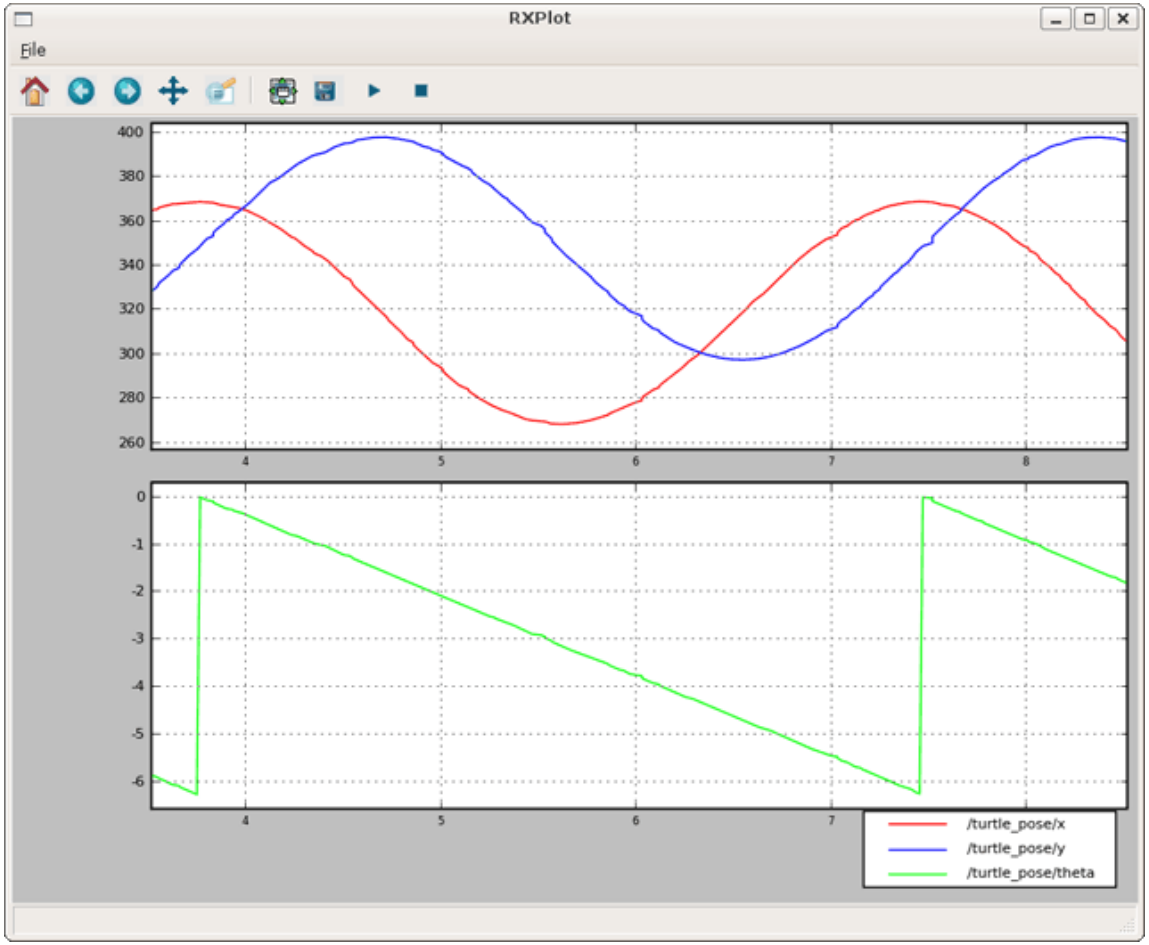
No more wireshark

ROS provides several tools for analyzing the data flowing over ROS communcation resources:

- rosnode
  Gives a user infomation about a node: publications, subscriptions, etc
- rostopic
  Gives datarate, actual data, publishers, subscribes
- rosservice
  Enables a user to call a ROS Service from the command line
- roswtf (wire trouble finder)
  Diagnoses problems with a ROS network

ROS GUI Tools

There are lots...



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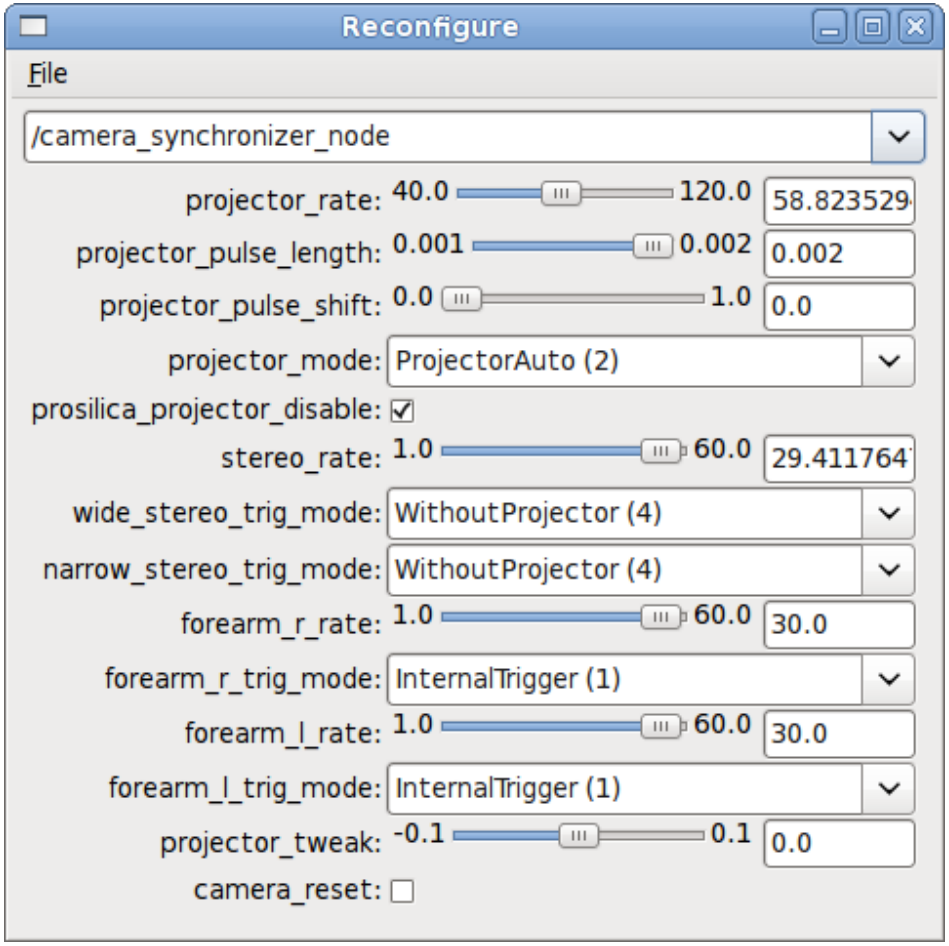

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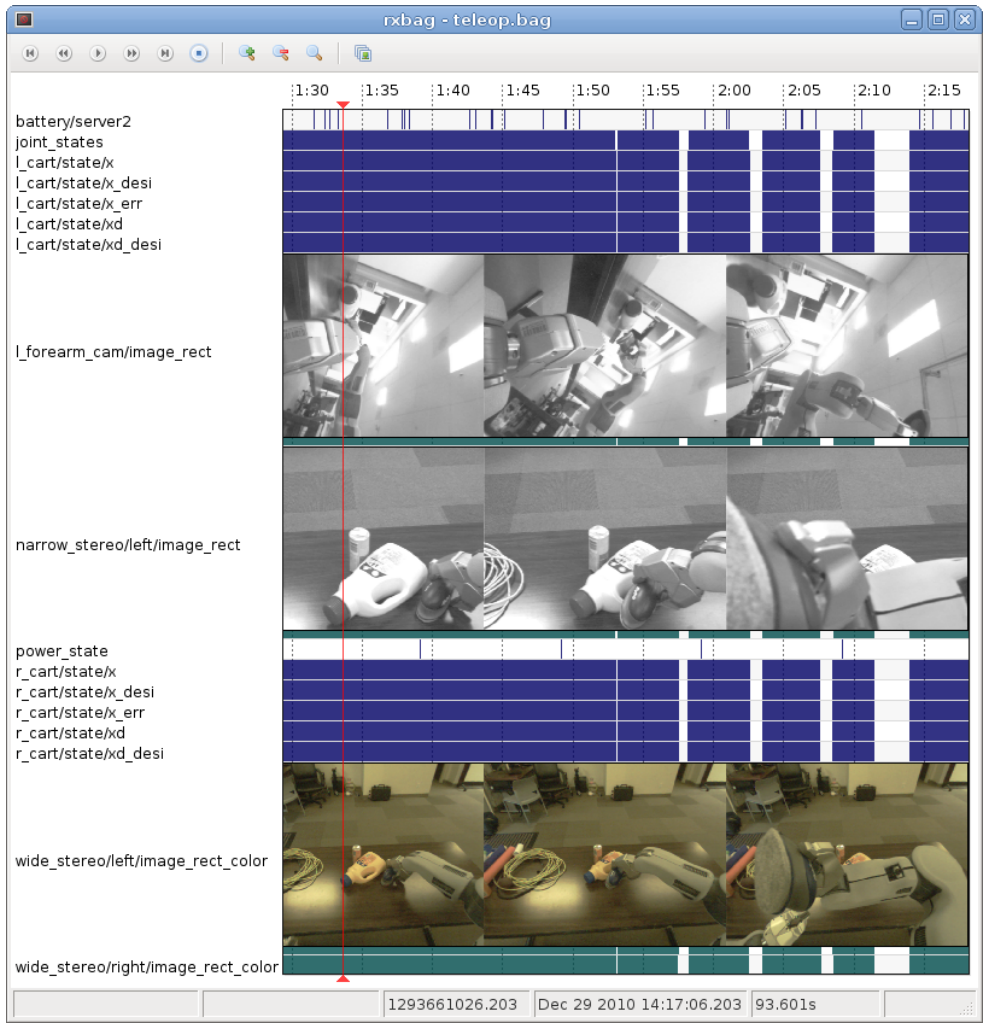
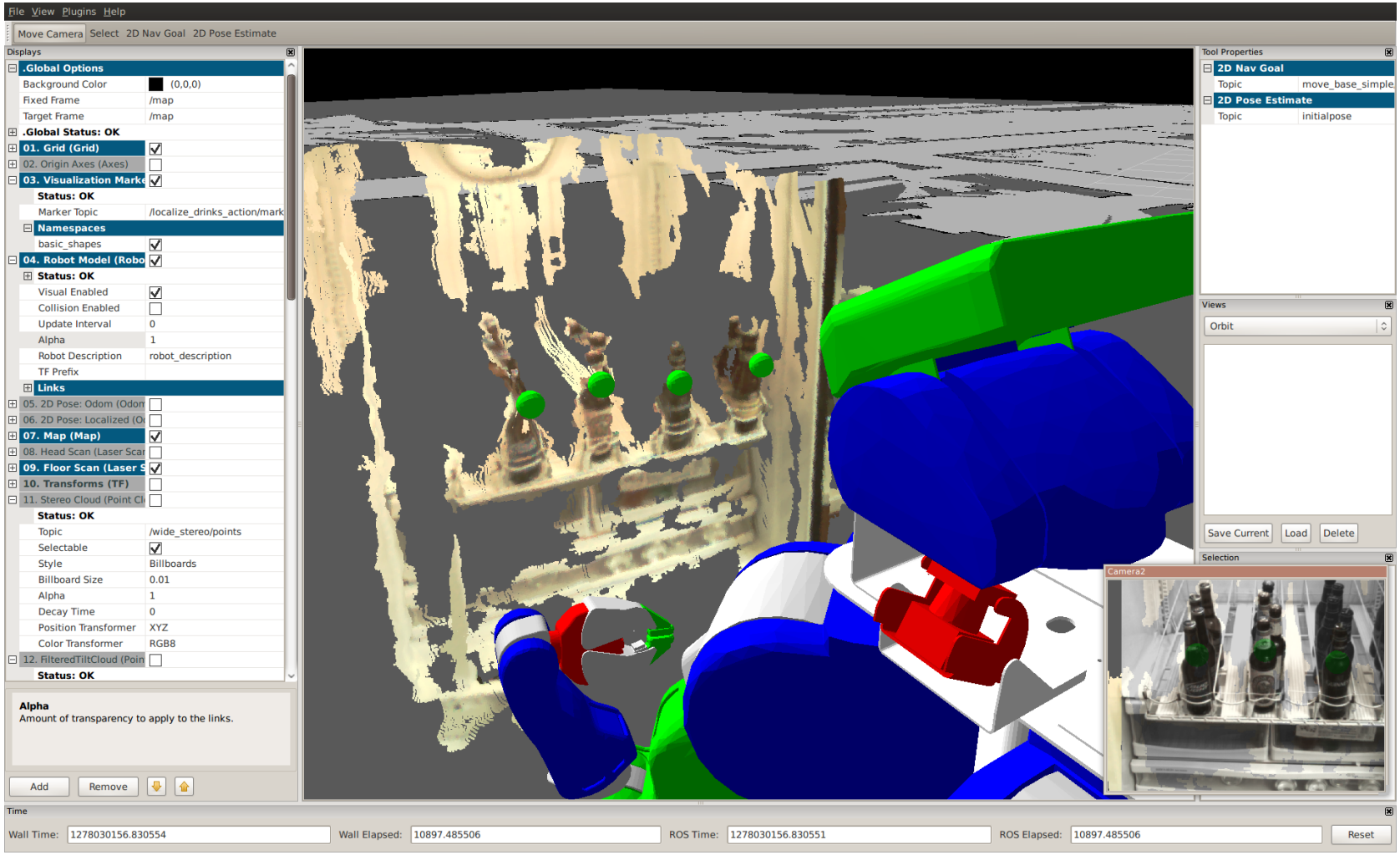


rviz - 3D Visualization

Modular state and sensor visualization



Outline

ROS Stacks & Packages

How to organize code in a ROS ecosystem

ROS code is grouped at two different levels:

- Packages
  A named collection of software that is built and treated as an atomic dependency in the ROS build system.
- Stacks
  A named collection of packages for distribution.

ROS Distributions

Delivering ROS packages to the masses

source code
header declarations
scripts
message definitions
service definitions
configuration files
launch files
metadata
...

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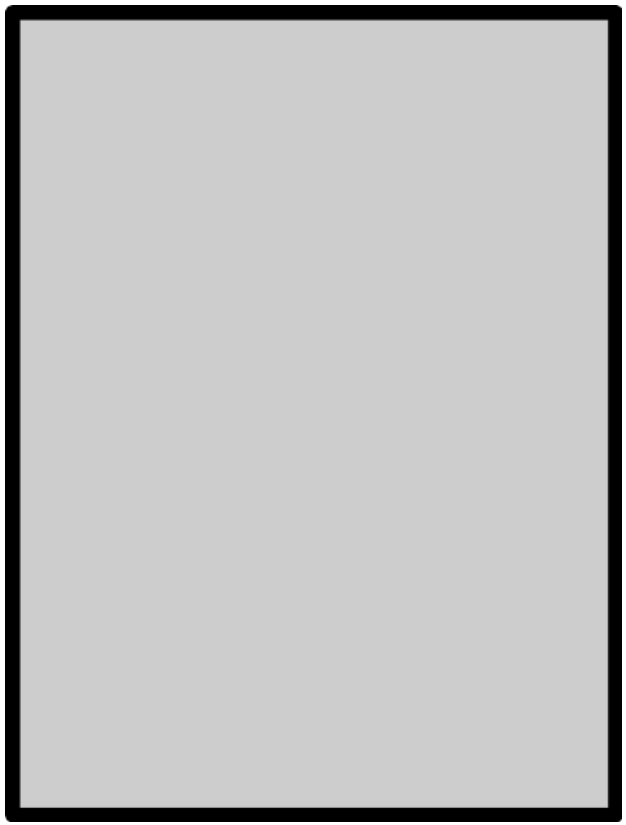

"stack"

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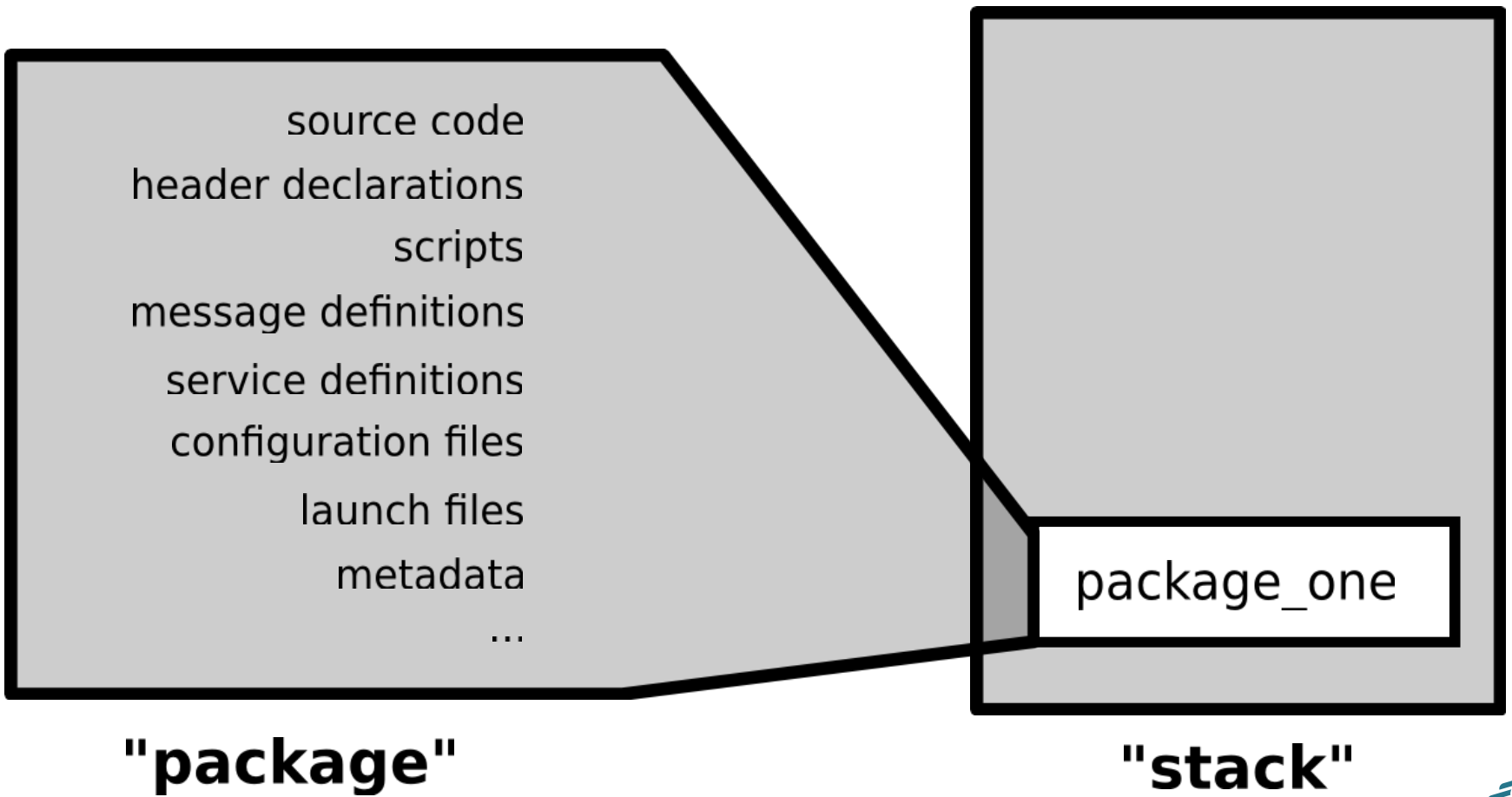

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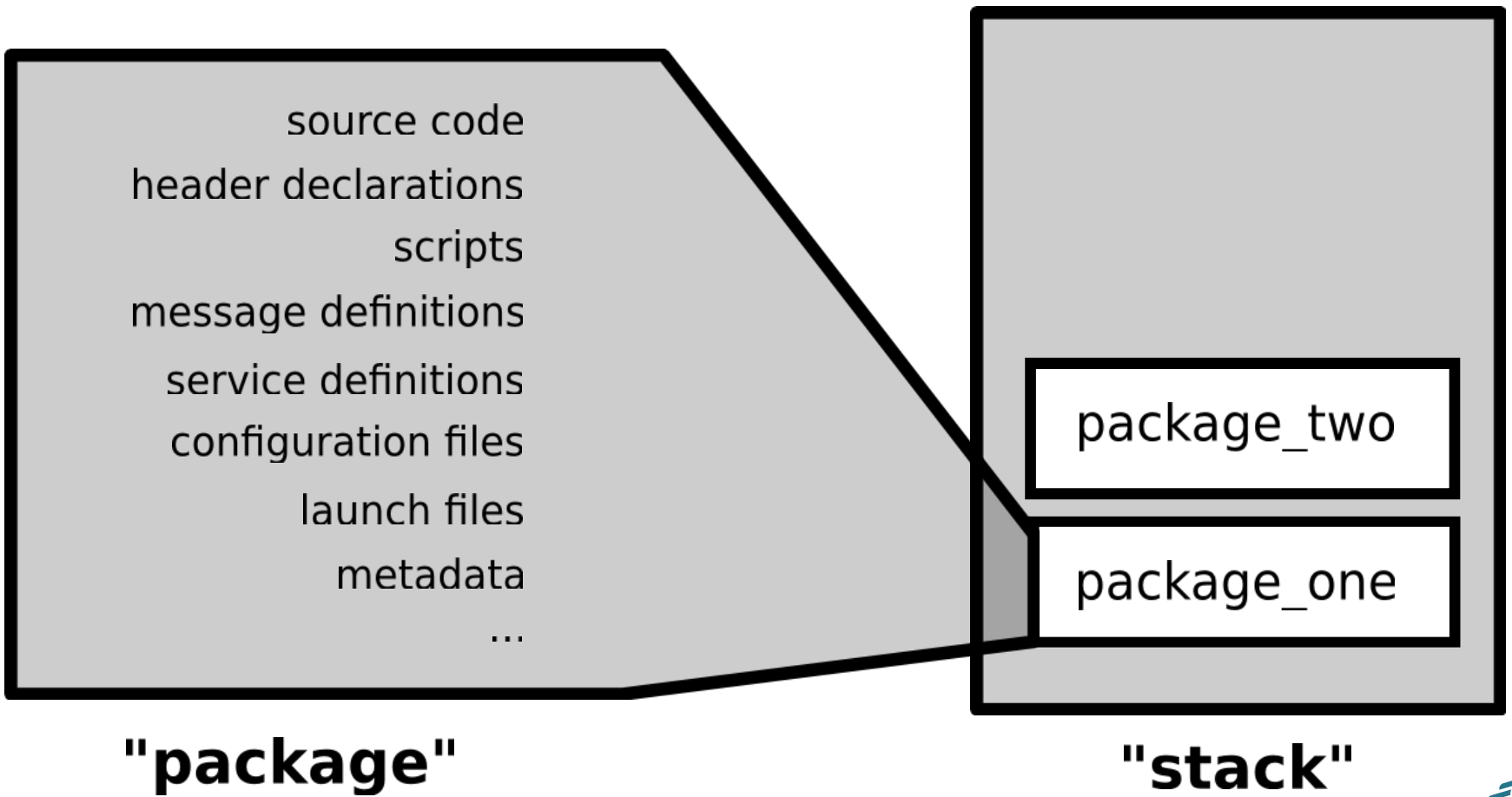

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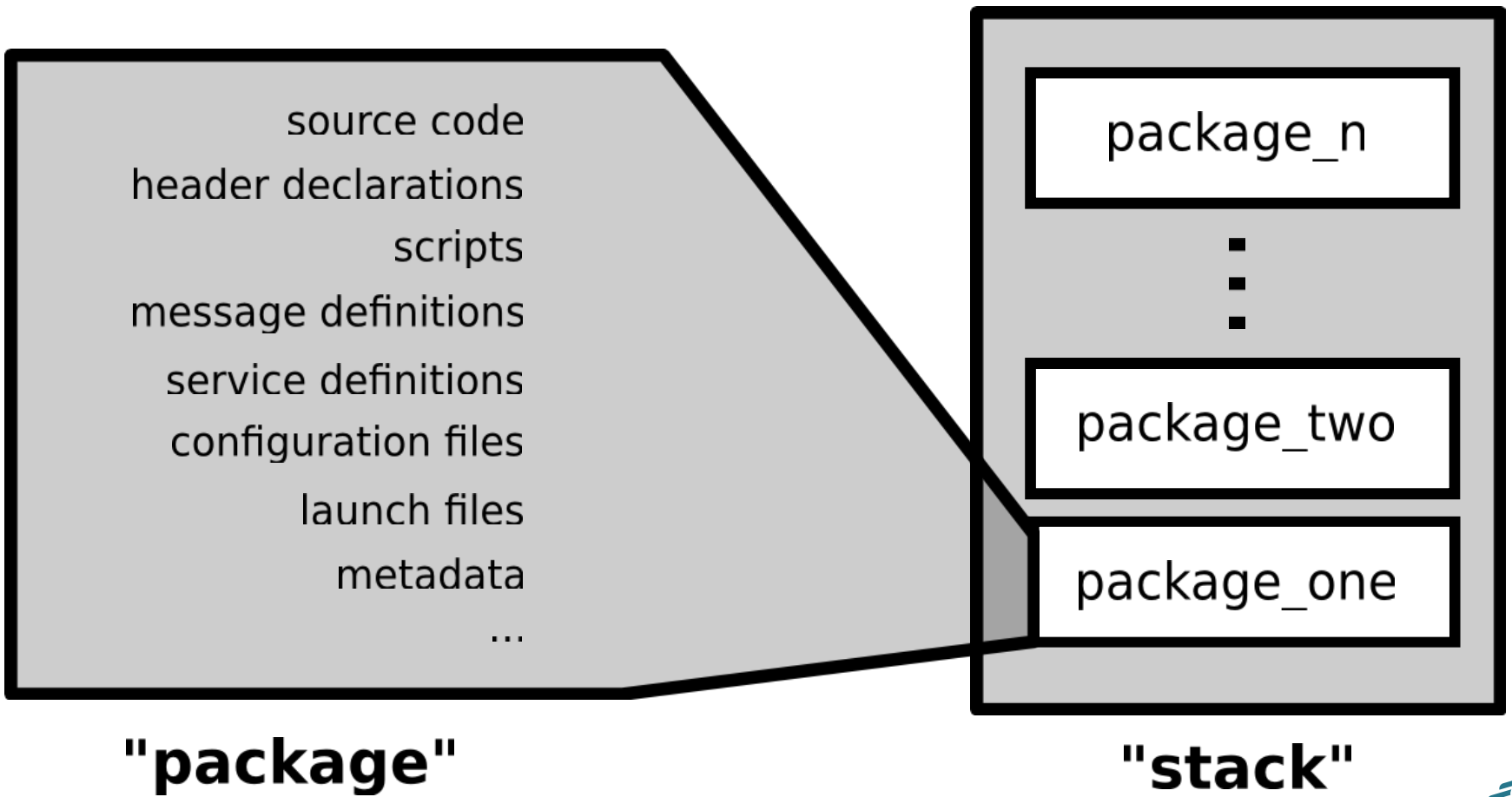

ROS Distributions

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stack_a-0.4.0

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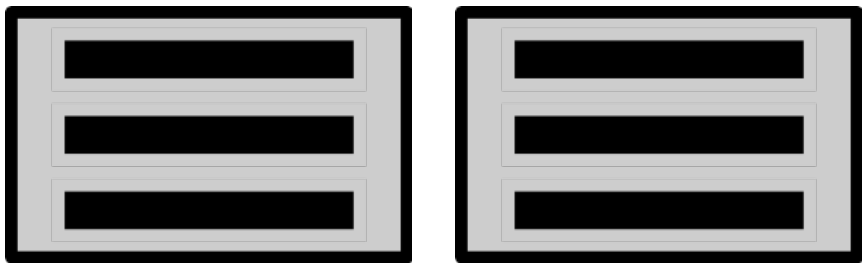

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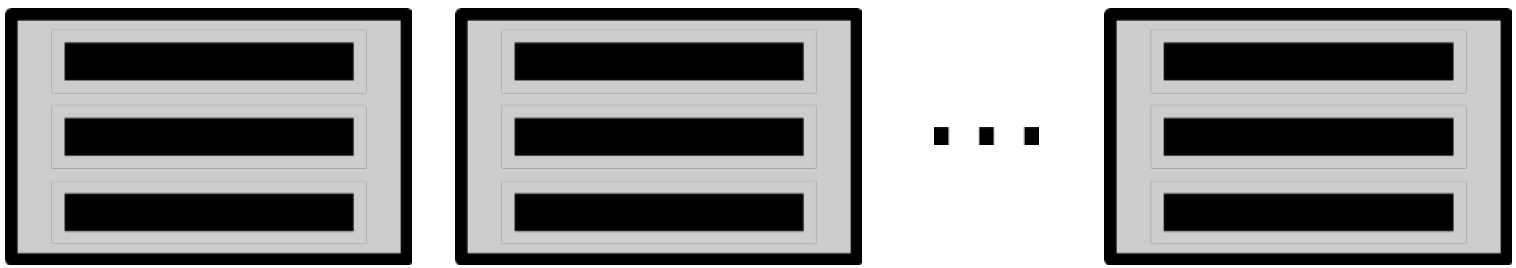

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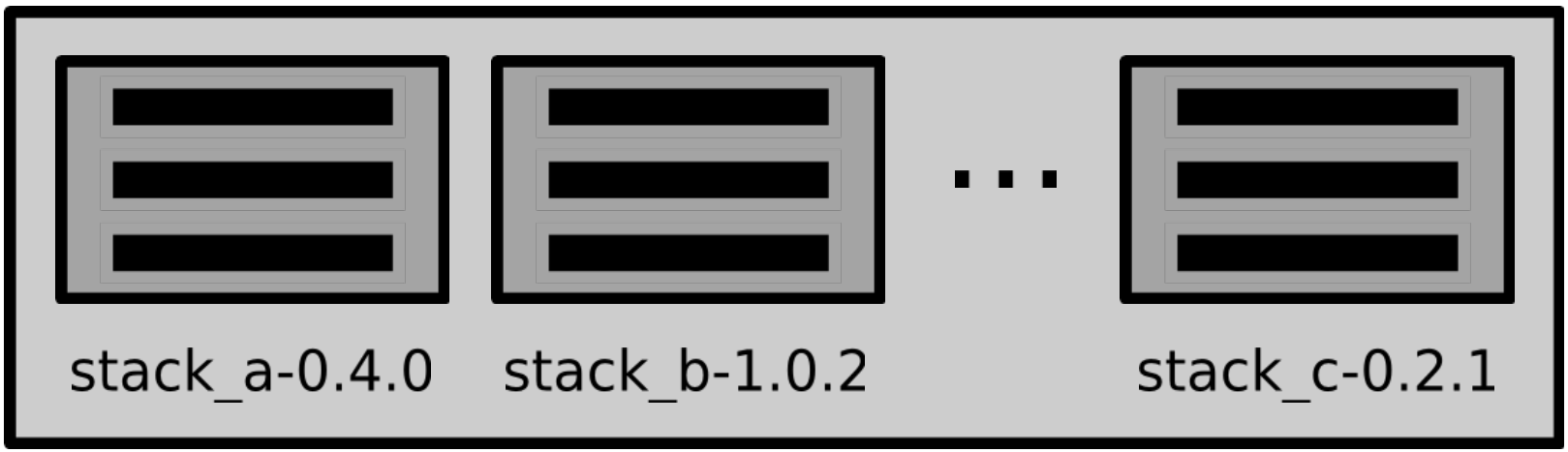

"distribution"

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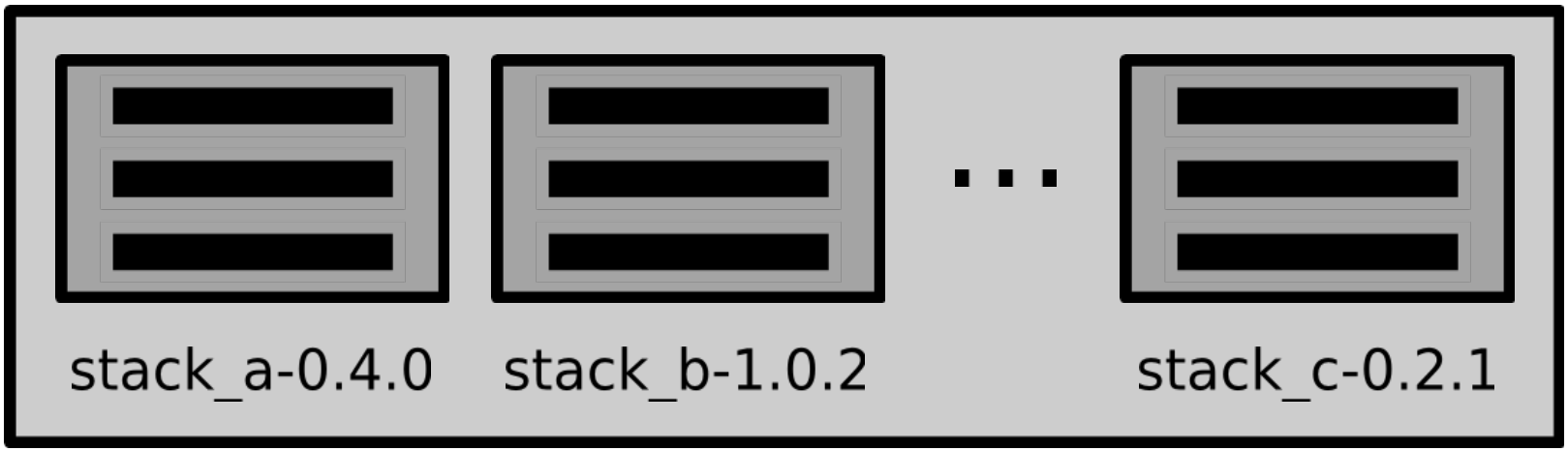


"distribution"

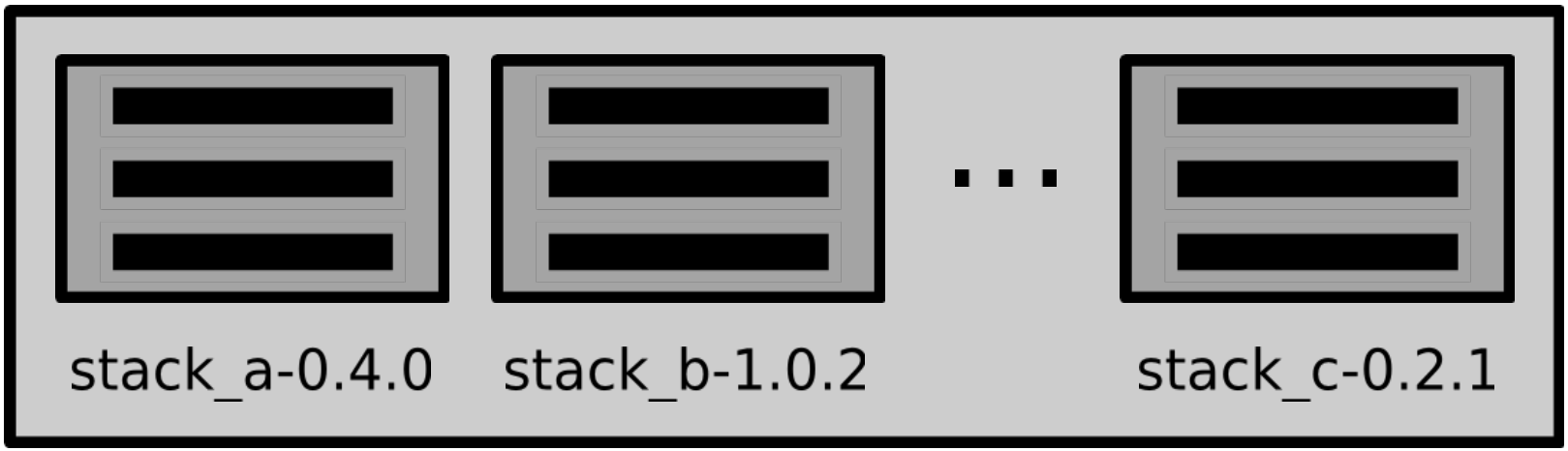
ROS "Box Turtle"
March 2, 2010

ROS "C-Turtle"
August 2, 2010

ROS "Diamondback"
March 2, 2011

ROS Distributions

Delivering ROS packages to the masses



"distribution"

ROS "Box Turtle"
March 2, 2010

ROS "C-Turtle"
August 2, 2010

ROS "Diamondback"
March 2, 2011

Future: *ROS "Elecrtic Emys"*
August, 2011

ROS Meta-Filesystem

Increasing codebase flexibility

The minimal representation of a ROS package is a directory in the `$ROS_PACKAGE_PATH` which contains a single file:

- manifest.xml
  - Contains package metadata (author, license, url, etc)
  - Specifies *system* and *package* dependencies
  - Specifies language-specific *export* flags
- CMakeLists.txt: contains ROS build rules (executables, libraries, custom build flags, etc)
- Makefile: just a proxy to build *this* package
- Create package with *roscreate-pkg*

```
$ roscreate-pkg foo roscpp std_msgs
```

- Build package with *rosmake*

```
$ rosmake foo
```

ROS Packages

The manifest.xml file

```
<package>
  <description brief="foo">
     foo
  </description>
  <author>Lorenz Moesenlechner</author>
  <license>BSD</license>
  <review status="unreviewed" notes="" />
  <url>http://ros.org/wiki/foo</url>
  <depend package="roscpp" />
  <depend package="std_msgs" />
</package>
```

ROS Packages

The CMakeLists.txt file

```
cmake_minimum_required(VERSION 2.4.6)
include($ENV{ROS_ROOT}/core/rosbuild/rosbuild.cmake)

rosbuild_init()

set(EXECUTABLE_OUTPUT_PATH ${PROJECT_SOURCE_DIR}/bin)
set(LIBRARY_OUTPUT_PATH ${PROJECT_SOURCE_DIR}/lib)

rosbuild_genmsg()
rosbuild_gensrv()

rosbuild_add_library(foo src/foo.cpp)
rosbuild_add_executable(hello_world src/hello_world.cpp)
```

Outline

ROSCPP

- Initialization with `ros::init`:
  - register at core
  - set up remappings
  - set up networking
- `ros::NodeHandle` as interface to topics, services and parameters
- `ros::NodeHandle::subscribe`, `ros::NodeHandle::advertise` for topics
- `ros::spin` and `ros::spinOnce` to process ROS messages
- Use `boost::bind` to use member functions as callbacks:

```
boost::bind(Listener::laserCb, this, _1);
```

Messages

- defined in package-name/msg/*.msg files, sent over topics
- basic data types:
  - int{8,16,32,64}
  - float{32,64}
  - string
  - time
  - duration
  - array[]
- Example: Point.msg

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

Simple Publisher (C++)

```
int main(int argc, char *argv[]) {
  ros::init(argc, argv, "talker");
  ros::NodeHandle nh;

  ros::Publisher pub =
    nh.advertise<std_msgs::String>("chatter", 1000);
  ros::Rate loop_rate(10);

  while(ros::ok()) {
    std_msgs::String msg;
    msg.data = "hello_world";
    pub.publish(msg)
    ros::spinOnce();
    loop_rate.sleep();
  }
  return 0;
}
```

Simple Subscriber (C++)

```
void msgCallback(const std_msgs::String::ConstPtr &msg) {
  ROS_INFO("Message: %s", msg->data.c_str());
}

int main(int argc, char *argv[]) {
  ros::init(argc, argv, "talker");
  ros::NodeHandle nh;

  ros::Subscriber sub =
    nh.subscribe<std_msgs::String>("chatter",
      1000, msgCallback);

  ros::spin();

  return 0;
}
```

Services

- Defined in package-name/srv/*.srv.
- Definition similar to message files, Request message + response message.
- Example: beginner_tutorials/AddTwoInts

```
int64 a
int64 b
---
int64 sum
```

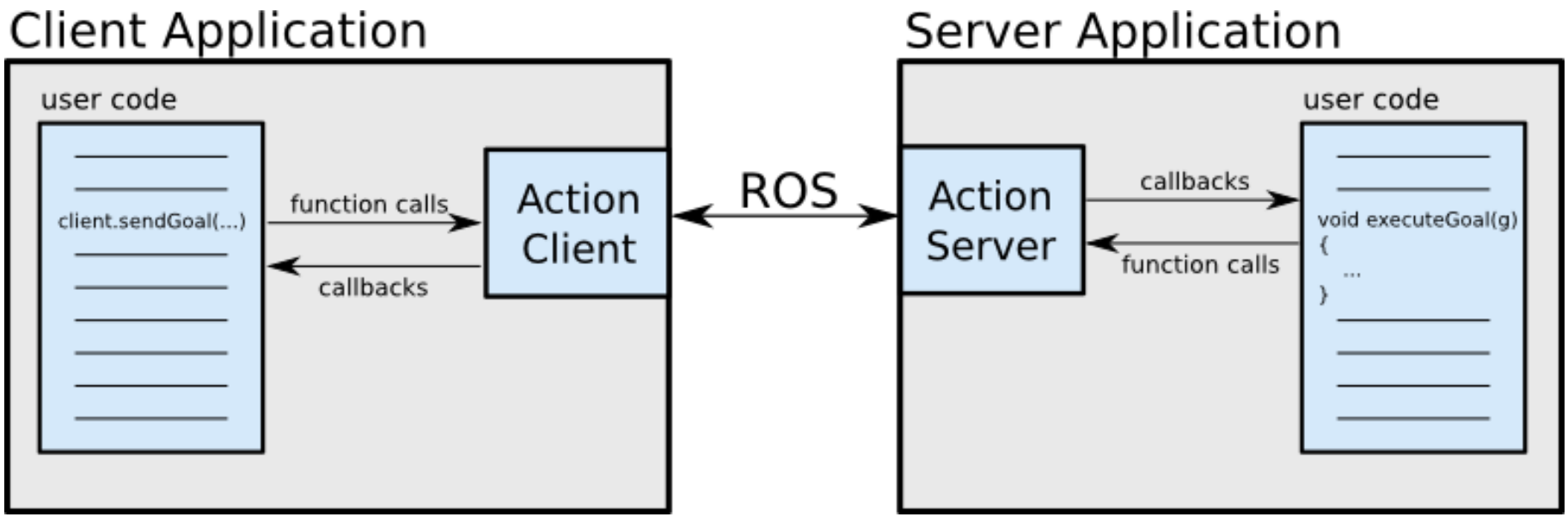
Service Client

```
int main(int argc, char **argv)
{
  ros::init(argc, argv, "add_two_ints_client");
  ros::NodeHandle n;
  ros::ServiceClient client = n.serviceClient<AddTwoInts>(
    "add_two_ints");
  AddTwoInts srv;
  srv.request.a = 1;
  srv.request.b = 2;
  if (client.call(srv)) {
    ROS_INFO("Sum: %ld", (long int)srv.response.sum);
  } else {
    ROS_ERROR("Failed to call service add_two_ints");
    return 1;
  }
  return 0;
}
```

Actions

Using function calls and callbacks

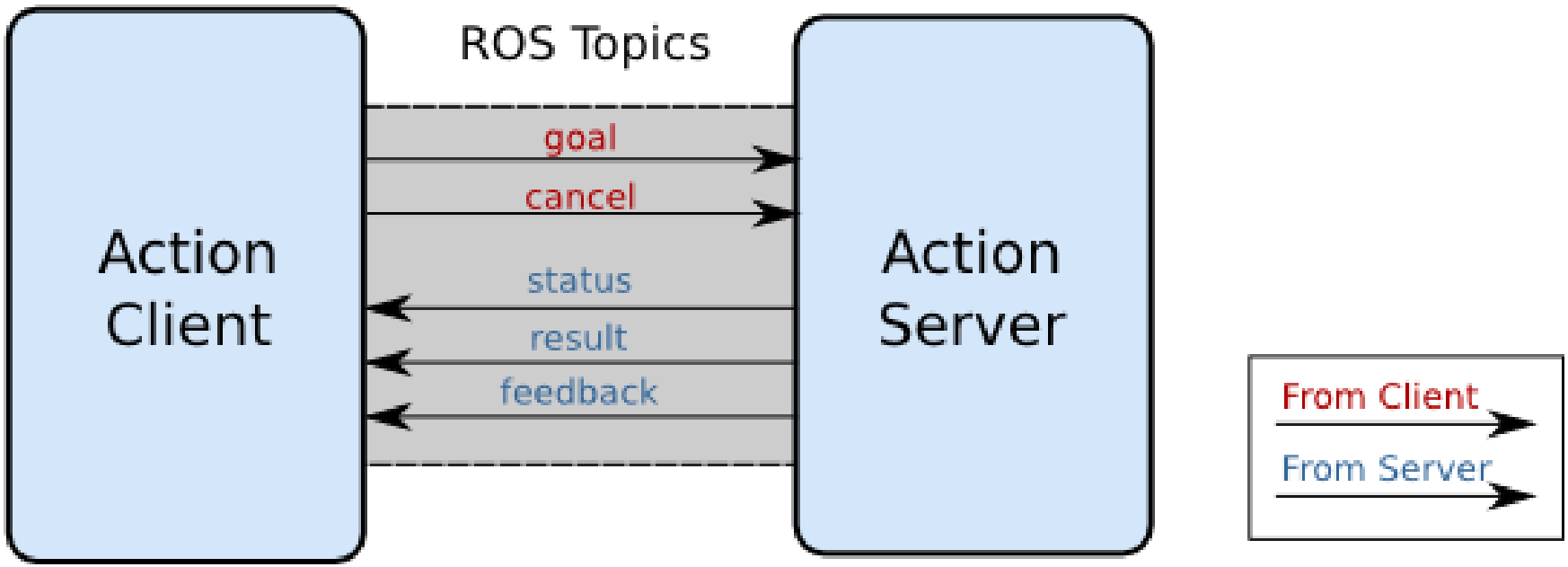
- request goals (client side)
- execute goals (server side)



Actions

- action protocol relies on ROS topics to transport messages

Action Interface



Action Definitions

- Similar to messages and services.
- Definition: Request + result + feedback
- Defined in ros-package/action/*.action
- Generated by CMake macro genaction().
- Example: actionlib_tutorials/Fibonacci.action

```
#goal definition
int32 order
---
#result definition
int32[] sequence
---
#feedback
int32[] sequence
```

Simple Action Client (C++)

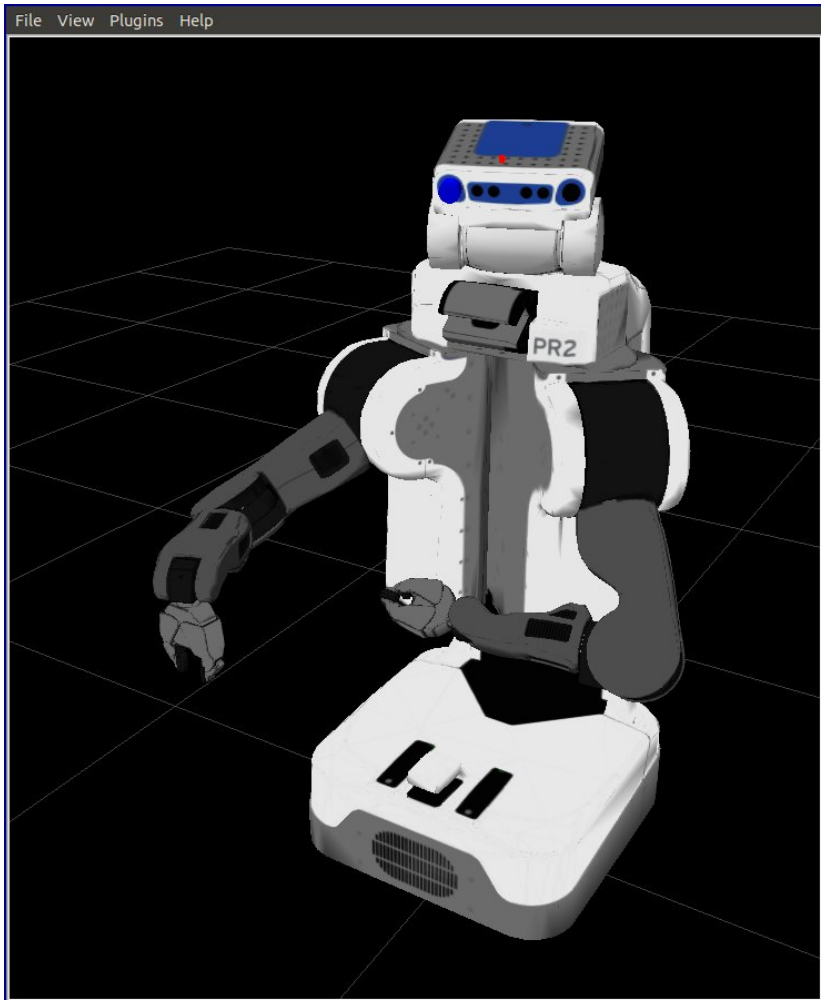
```
int main (int argc, char **argv) {
  ros::init(argc, argv, "test_fibonacci");

  actionlib::SimpleActionClient<FibonacciAction> ac(
      "fibonacci", true);
  ac.waitForServer();
  learning_actionlib::FibonacciGoal goal;
  goal.order = 20;
  ac.sendGoal(goal);
  bool finished_before_timeout = ac.waitForResult(
    ros::Duration(30.0));

  return 0;
}
```

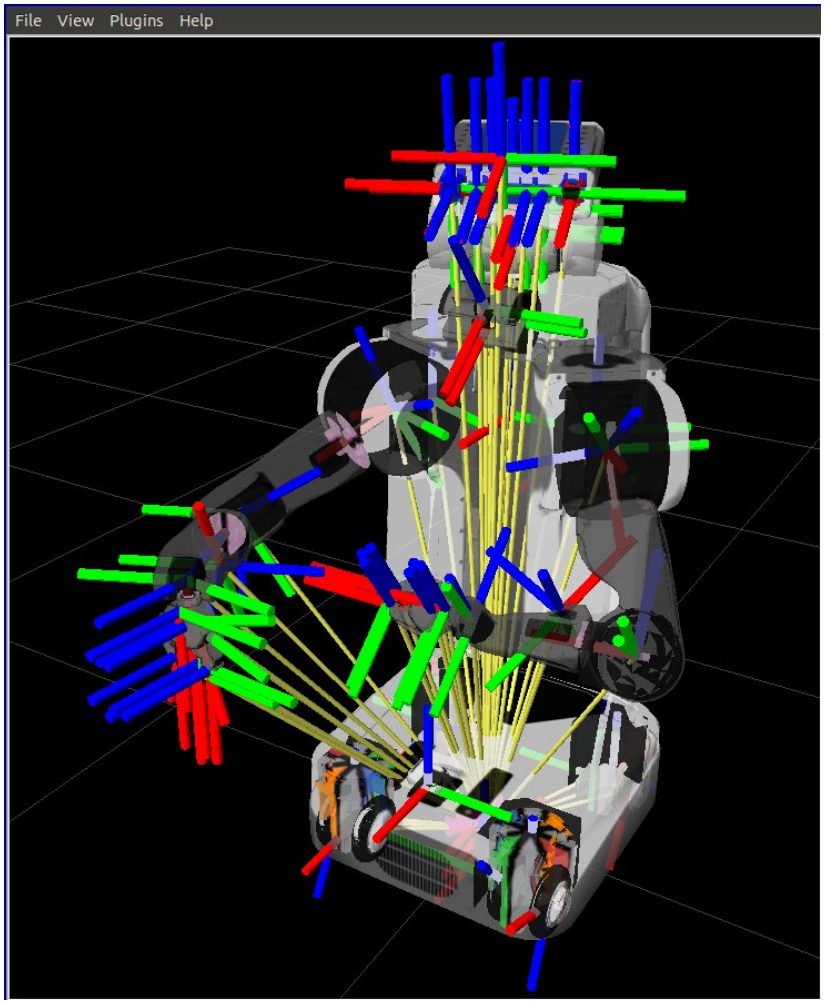
Outline

Coordinate frames



- robots consist of many links
- every link describes its own coordinate system
- sensor measurements are local to the corresponding link
- links change their position over time

Coordinate frames



- robots consist of many links
- every link describes its own coordinate system
- sensor measurements are local to the corresponding link
- links change their position over time

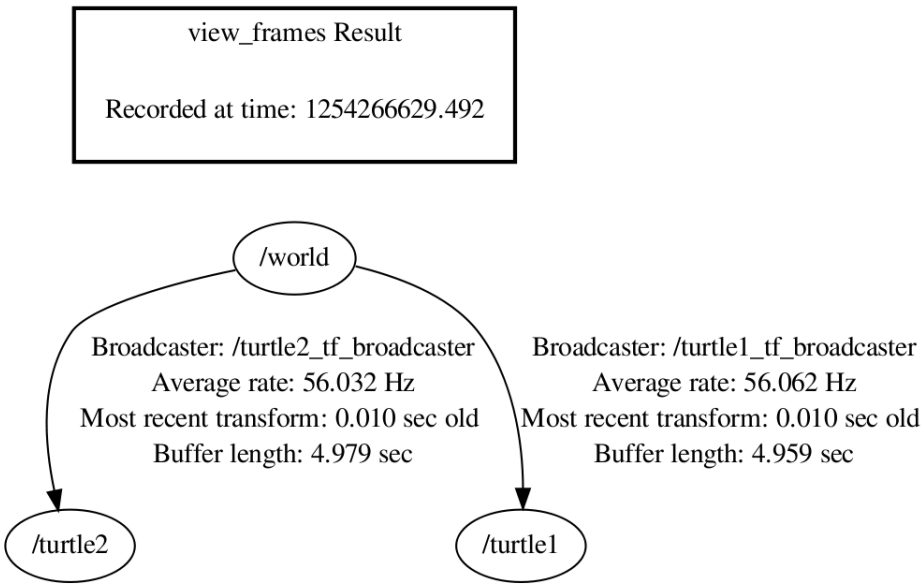
Transforms are distributed

- Transforms are produced by different nodes:
  - Localization in map (AMCL, gmapping)
  - Odometry (base controller)
  - Joint positions (robot controllers and robot_state_publisher)
- Many publishers, many consumers
- Distributed system, redundancy issues, ...

What is TF?

- decentralized: many publishers, many subscribers
- A coordinate frame tracking system
  - standardized protocol for publishing transforms
  - Classes and methods for looking up, calculating and sending transforms
  - transforms are published on the /tf topic
- No central instance managing the tree of transforms
- Command line tools

The transform tree



- Consists of frames (links) and the transforms between them.
- Each link is cached (10 secs default caching time)
- Works with multiple disconnected trees
- Transforms must form a proper tree (no cycles)

Utilities

- `rosrun tf tf_echo <source_frame> <target_frame>`
- `rosrun tf tf_monitor`
- `rosrun view_frames`
- `rosrun tf static_transform_publisher`
- rviz

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tf_echo

```
$ rosrun tf tf_echo turtle1 turtle2

Success at 1253585684.557003974
[0.000000 0.000000 0.140754 0.990045] Euler(0.282446 -0.000000 0.000000)
Translation: [-0.000036 -0.000010 0.000000]
Success at 1253585685.544698953
[0.000000 0.000000 0.140754 0.990045] Euler(0.282446 -0.000000 0.000000)
Translation: [-0.000036 -0.000010 0.000000]
Success at 1253585686.557049989
```

Utilities

- `rosrun tf tf_echo <source_frame> <target_frame>`
- `rosrun tf tf_monitor`
- `rosrun view_frames`
- `rosrun tf static_transform_publisher`
- rviz

tf_monitor

```
$ rosrun tf tf_monitor
RESULTS: for all Frames

Frames:
Frame: turtle1 published by /turtle1_tf_broadcaster Average Delay: 0.000382455 Max Delay: 0...
Frame: turtle2 published by /turtle2_tf_broadcaster Average Delay: 0.000267847 Max Delay: 0...

All Broadcasters:
Node: /turtle1_tf_broadcaster 64.6996 Hz, Average Delay: 0.000382455 Max Delay: 0.000991178
Node: /turtle2_tf_broadcaster 64.7127 Hz, Average Delay: 0.000267847 Max Delay: 0.00133464
```

Utilities

- `rosrun tf tf_echo <source_frame> <target_frame>`
- `rosrun tf tf_monitor`
- `rosrun view_frames`
- `rosrun tf static_transform_publisher`
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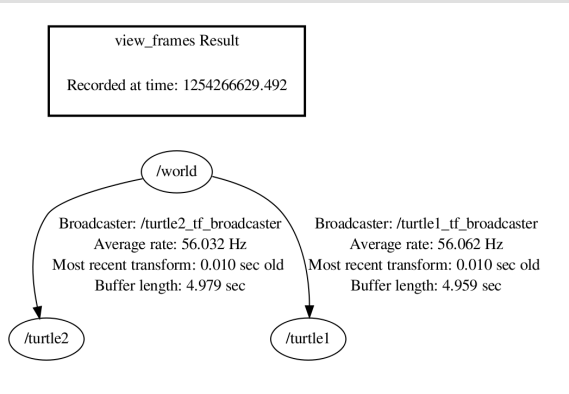
view_frames



Utilities

- tf_echo
- tf_monitor
- view_frames
- static_transform_publisher
- rviz

static_transform_publisher

```
$ rosrun tf static_transform_publisher x y z yaw pitch roll frame_id child_frame_id period

$ rosrun tf static_transform_publisher x y z qx qy qz qw frame_id child_frame_id period
```

TF data types

- Transforms and poses
- stamped data types (via ROS header)
- Header contains time stamp and frame names
- StampedTransform and PoseStamped
- StampedTransform: frame name and child frame name

Publishing transforms

- Launch files and static_transform_publisher
- URDF, joint states and robot_state_publisher
  - Make a robot description file (URDF) and load it on the parameter server
  - Implement a node that reads joint states and publishes them
  - Run the robot_state_publisher node

  $\Rightarrow$ Simulation tutorial tomorrow for URDF introduction
- Nodes that publish transforms

Publishing transforms (C++)

TransformBroadcaster

```
tf::TransformBroadcaster br;

tf::Transform transform;
transform.setOrigin(tf::Vector(x, y, z));
transform.setRotation(
  tf::createQuaternionFromRPY(yaw, pitch, roll));
br.sendTransform(
  tf::StampedTransform(
    transform, ros::Time::now(), "/map", "/odom"));
```

Using transforms (C++)

TransformListener

```
tf::TransformListener listener;
tf::StampedTransform transform;
try {
  listener.lookupTransform(
    "/map", "/r_wrist_roll_link", ros::Time(0),
    transform);
} catch(tf::TransformException ex) {
  ROS_ERROR("%s", ex.what());
}
```

Using transforms (C++)

TransformListener

```
tf::TransformListener listener;
tf::StampedTransform transform;
try {
  listener.lookupTransform(
    "/map", "/r_wrist_roll_link", ros::Time(0),
    transform);
} catch(tf::TransformException ex) {
  ROS_ERROR("%s", ex.what());
}
```

- *canTransform*
- *lookupTranform*
- *transformPoint*
- *transformPose*
- *transformQuaternion*

TF and time

- TF buffers transforms for 10 seconds
- query transforms in the past
- TF interpolates frames
- fixed frame: frame that doesn't move (reference)

TF and time

TransformListener methods

```
listener.lookupTransform("/turtle2", "/turtle1",
  ros::Time(0), transform);

listener.lookupTransform("/turtle2", "/turtle1",
  ros::Time::now(), transform);
```

- *lookupTransform*
  - Time 0: return the newest transform
  - Time now: would lead to an error because TF doesn't do extrapolation

TF and time

TransformListener methods

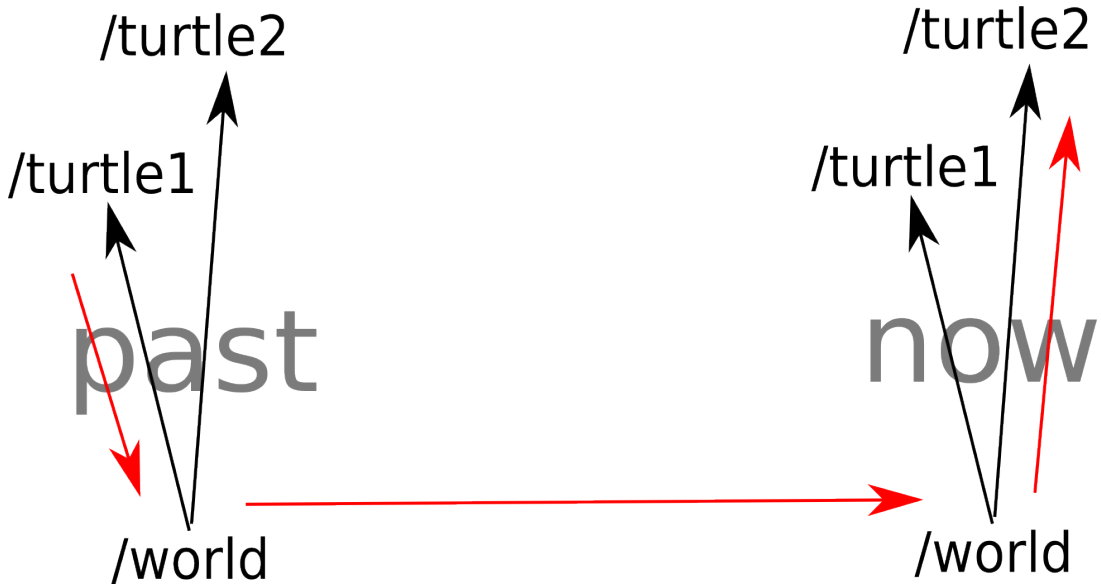
```
listener.lookupTransform("/turtle2", "/turtle1",
  ros::Time(0), transform);

listener.lookupTransform("/turtle2", "/turtle1",
  ros::Time::now(), transform);

ros::Time now = ros::Time::now();
listener.waitForTransform("/turtle2", "/turtle1", now,
  ros::Duration(3.0));
listener.lookupTransform("/turtle2", "/turtle1", now,
  transform);
```

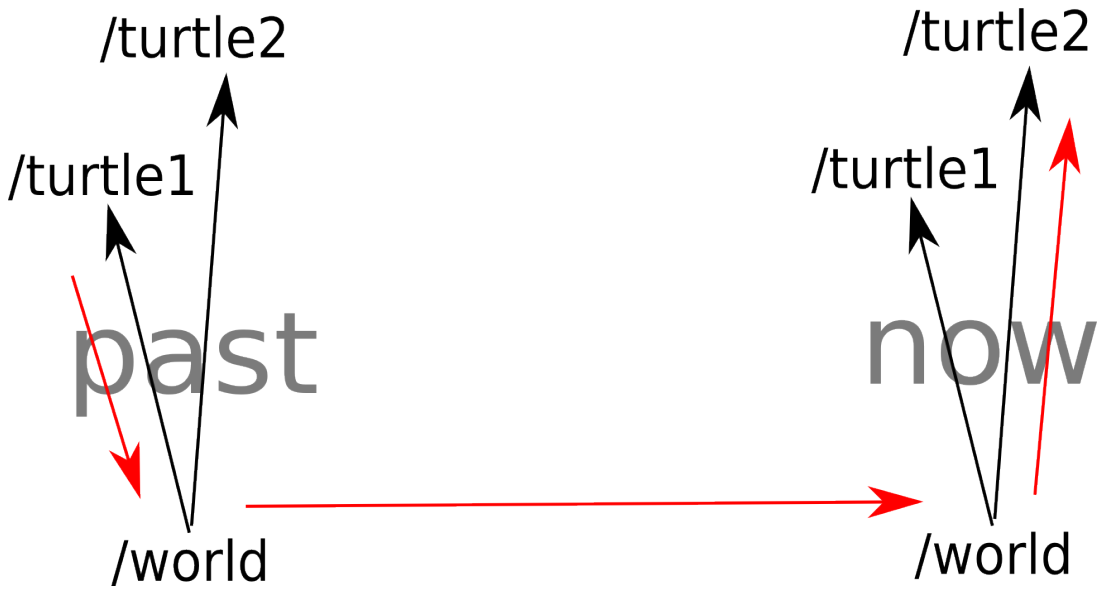
- *lookupTransform*
  - Time 0: return the newest transform
  - Time now: would lead to an error because TF doesn't do extrapolation
- *waitForTransform*: block until transform is possible

Time traveling



- Go where turtle 1 has been 5 secs ago relative turtle 2 now
- Implementation:
  - Find transform from turtle 2 to fixed frame now
  - Find transform from fixed frame to turtle 1 5 secs ago
  - Multiply the two transforms to get result

Time traveling




```
listener.waitForTransform(
  "/turtle2", now, "/turtle1", past, "/world",
  ros::Duration(3.0));
listener.lookupTransform(
  "/turtle2", now, "/turtle1", past, "/world",
  transform);
```

Thank you for your attention

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