Some ROS Slides

D.A. Forsyth

Credits

- I didn't make these slides
  - I've cut them from a series of 10 lectures by Roi Yehoshua, at Bar-Ilan
    - without permission (though I'll try and fix this!)
    - URL to full slides on website
      - I've cut slides with details of code, etc - get these from full slides
- Purpose:
  - enough framework to get you started on ROS
    - further tutorial material, etc on website, too

October 2016

BIRC
BIU Robotics Consortium

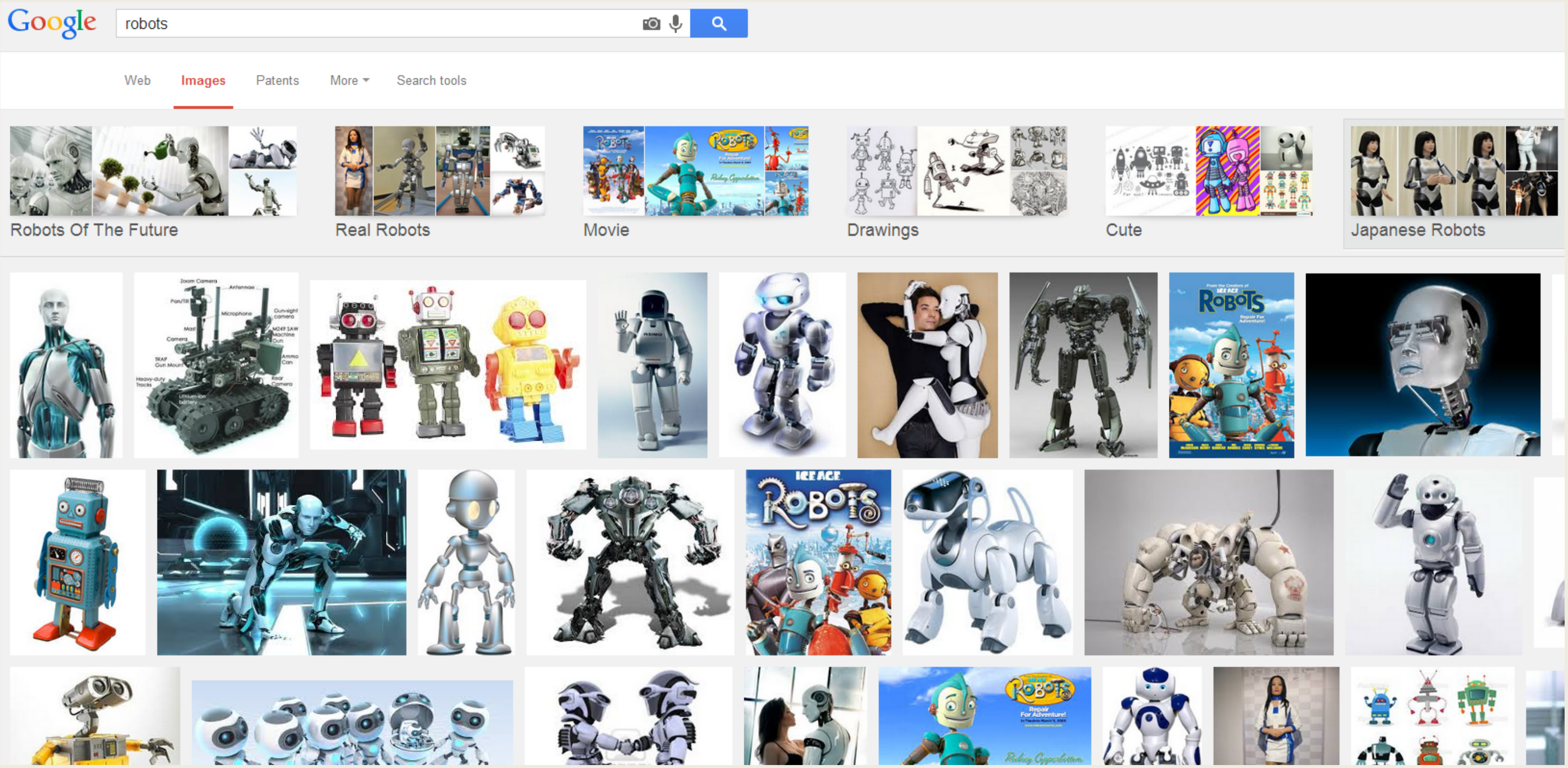
ROS - Lecture 1

ROS Introduction
Main concepts
Basic commands

Lecturer: Roi Yehoshua
roiyeho@gmail.com

The Problem

- Lack of standards for robotics



What is ROS?

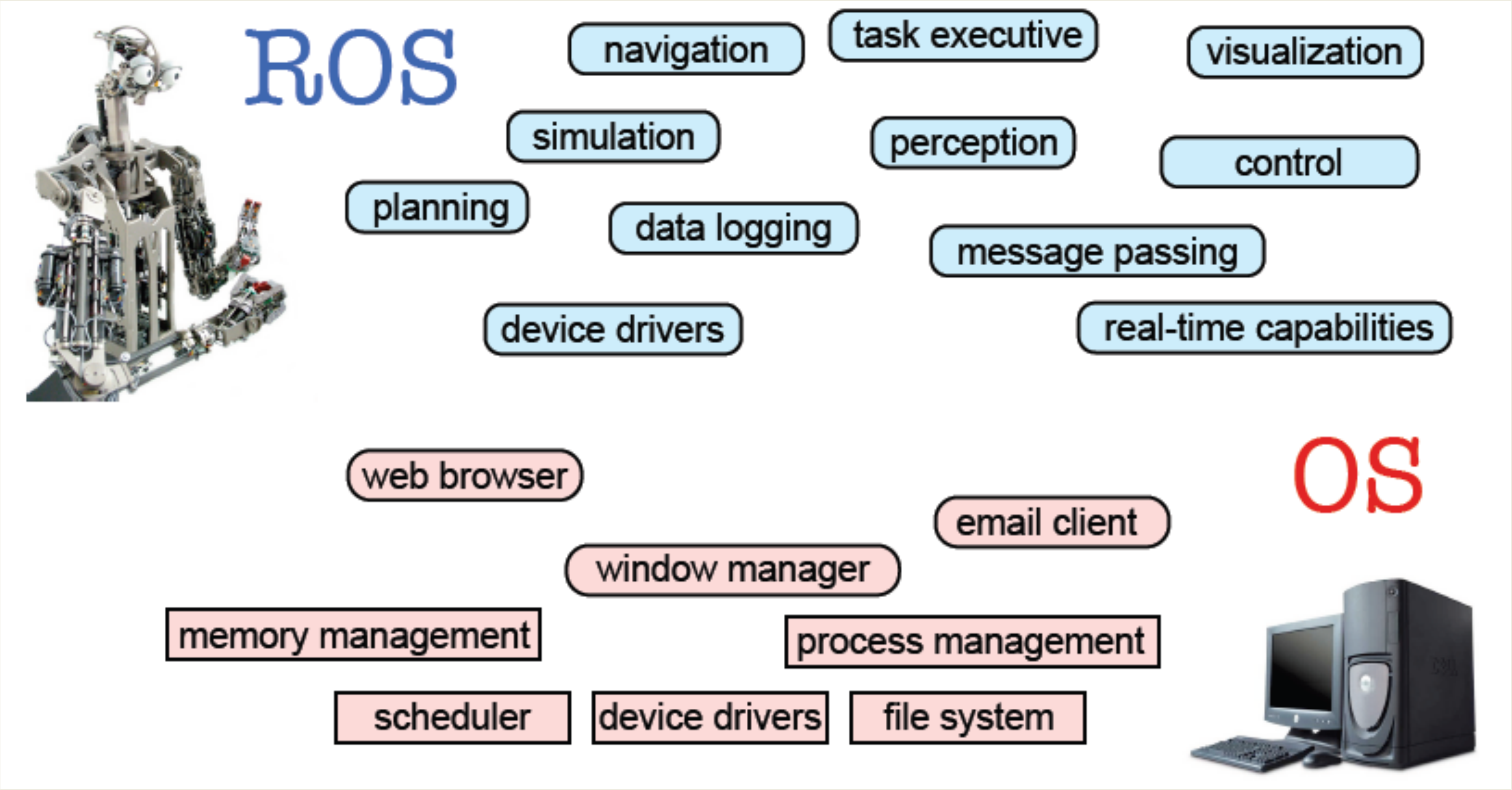
- ROS is an open-source **robot operating system**
- A set of software libraries and tools that help you build robot applications that work across a wide variety of robotic platforms
- Originally developed in 2007 at the Stanford Artificial Intelligence Laboratory and development continued at Willow Garage
- Since 2013 managed by OSRF (Open Source Robotics Foundation)

ROS Main Features

ROS has two "sides"

- The operating system side, which provides standard operating system services such as:
  - hardware abstraction
  - low-level device control
  - implementation of commonly used functionality
  - message-passing between processes
  - package management
- A suite of user contributed packages that implement common robot functionality such as SLAM, planning, perception, vision, manipulation, etc.

ROS Main Features



Taken from Sachin Chitta and Radu Rusu (Willow Garage)

ROS Philosophy

- **Peer to Peer**
  - ROS systems consist of numerous small computer programs which connect to each other and continuously exchange *messages*
- **Tools-based**
  - There are many small, generic programs that perform tasks such as visualization, logging, plotting data streams, etc.
- **Multi-Lingual**
  - ROS software modules can be written in any language for which a *client library has been written*. Currently client libraries exist for C++, Python, LISP, Java, JavaScript, MATLAB, Ruby, and more.
- **Thin**
  - The ROS conventions encourage contributors to create stand-alone libraries and then *wrap those libraries so they send and receive messages to/from other ROS modules*.
- **Free and open source**

ROS Wiki

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

Robots using ROS

http://wiki.ros.org/Robots

	Fraunhofer IPA Care-O-bot		Videre Erratic		TurtleBot
	Aldebaran Nao		Lego NXT		Shadow Hand
	Willow Garage PR2		iRobot Roomba		Robotnik Guardian
	Merlin miabotPro		AscTec Quadrotor		CoroWare Corobot
	Clearpath Robotics Husky		Clearpath Robotics Kingfisher		Festo Didactic Robotino

ROS Core Concepts

- Nodes
- Messages and Topics
- Services
- ROS Master
- Parameters
- Stacks and packages

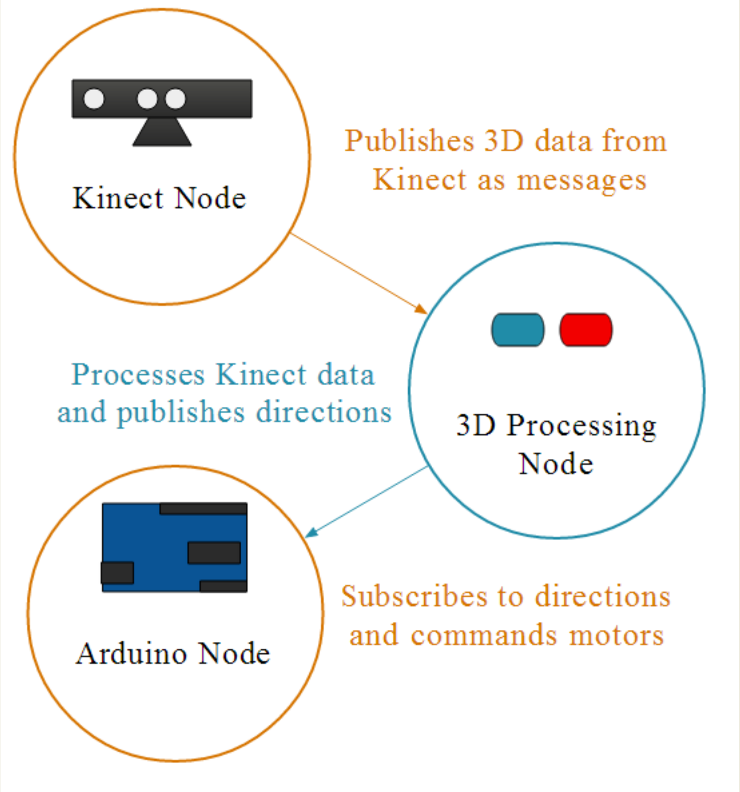
ROS Nodes

- Single-purposed executable programs
  - e.g. sensor driver(s), actuator driver(s), mapper, planner, UI, etc.
- Individually compiled, executed, and managed
- Nodes are written using a ROS **client library**
  - roscpp – C++ client library
  - rospy – python client library
- Nodes can publish or subscribe to a Topic
- Nodes can also provide or use a Service

ROS Topics

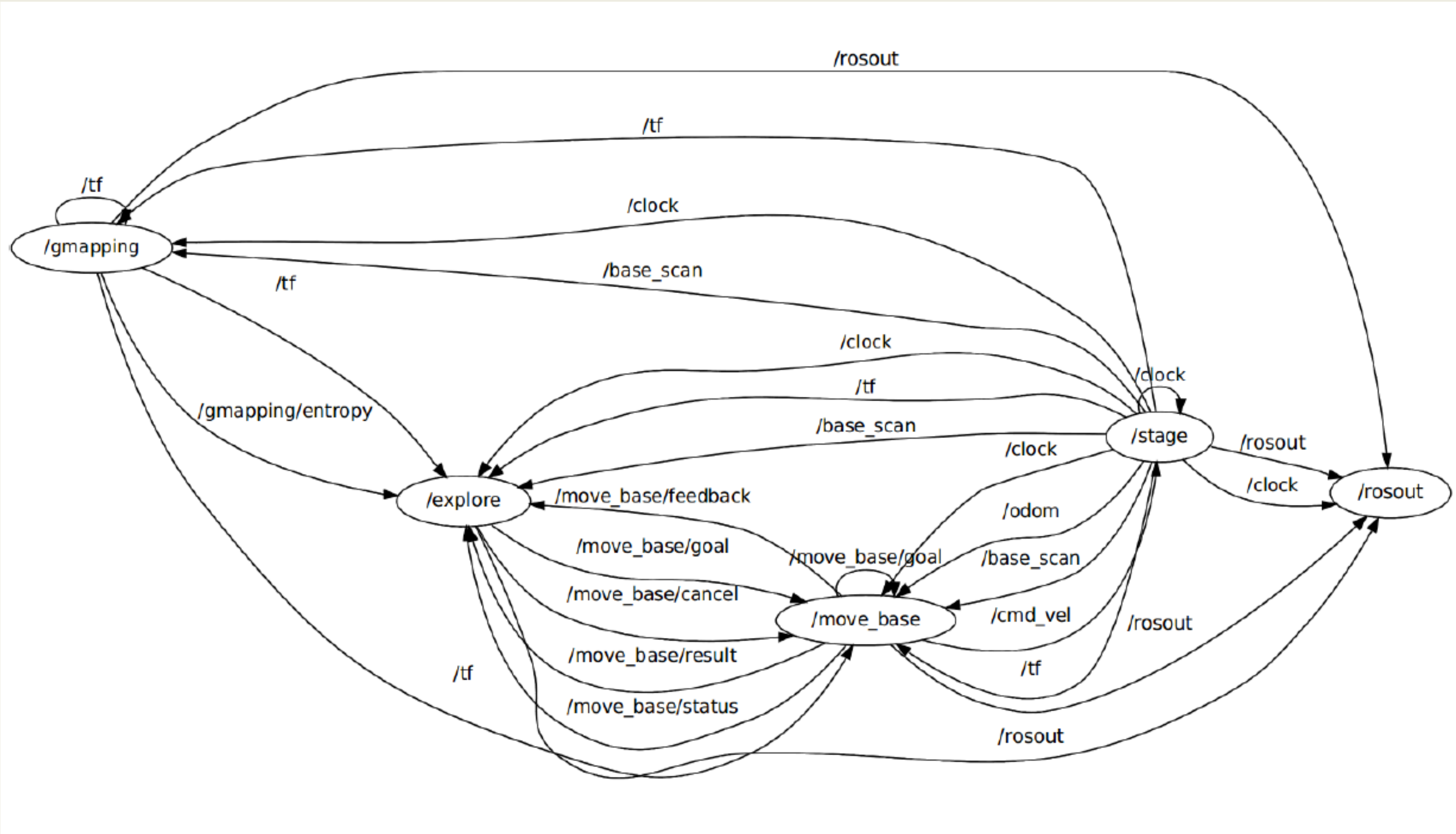
- A topic is a name for a stream of messages with a defined type
  - e.g., data from a laser range-finder might be sent on a topic called scan, with a message type of LaserScan
- Nodes communicate with each other by publishing messages to topics
- Publish/Subscribe model: 1-to-N broadcasting

ROS Topics

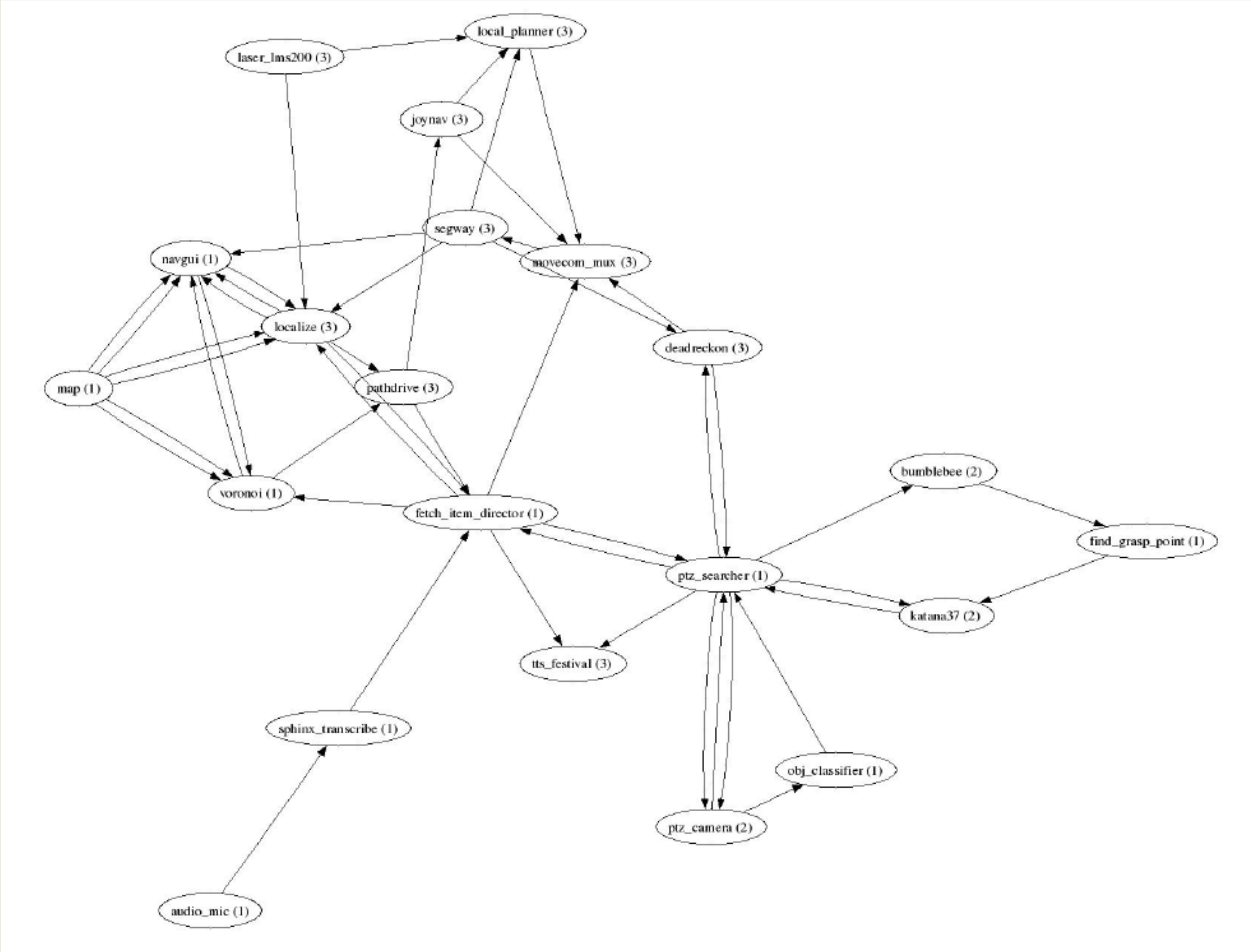


Kinect Node
Publishes 3D data from Kinect as messages
3D Processing Node
Processes Kinect data and publishes directions
Arduino Node
Subscribes to directions and commands motors

The ROS Graph



Fetch an Item Graph



Taken from Programming Robots with ROS (Quigley et al.)

ROS Messages

- Strictly-typed data structures for inter-node communication
- For example, geometry_msgs/Twist is used to express velocity commands:

```
Vector3 linear
Vector3 angular
```

  – Vector3 is another message type composed of:

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

ROS Services

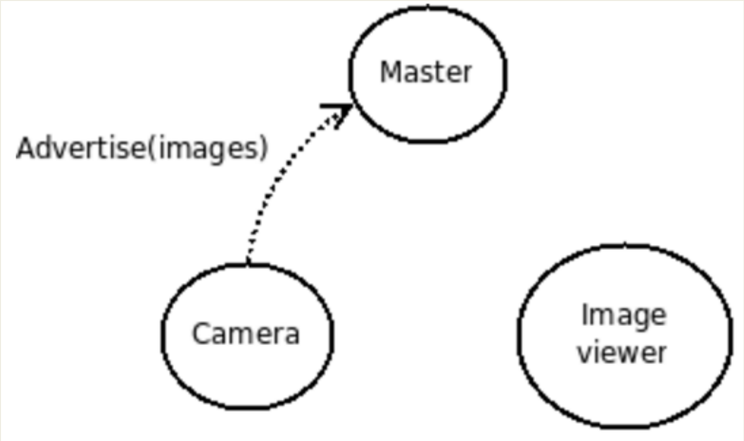
- Synchronous inter-node transactions / RPC
- Service/Client model: 1-to-1 request-response
- Service roles:
  - carry out remote computation
  - trigger functionality / behavior
- Example:
  - map_server/static_map – retrieves the current grid map used by the robot for navigation

ROS Master

- Provides connection information to nodes so that they can transmit messages to each other
  - Every node connects to a master at startup to register details of the message streams they publish, and the streams to which that they to subscribe
  - When a new node appears, the master provides it with the information that it needs to form a direct peer-to-peer connection with other nodes publishing and subscribing to the same message topics

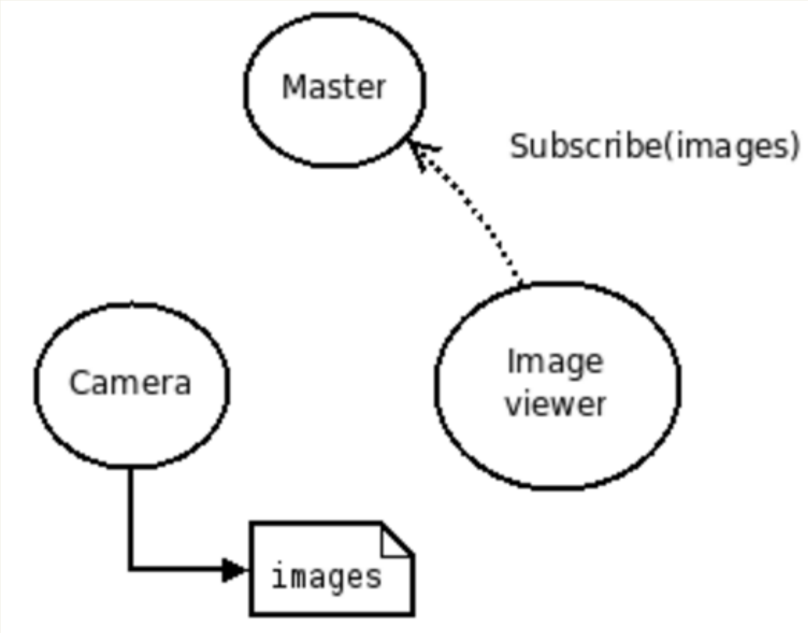
ROS Master

- Let’s say we have two nodes: a Camera node and an Image_viewer node
- Typically the camera node would start first notifying the master that it wants to publish images on the topic "images":



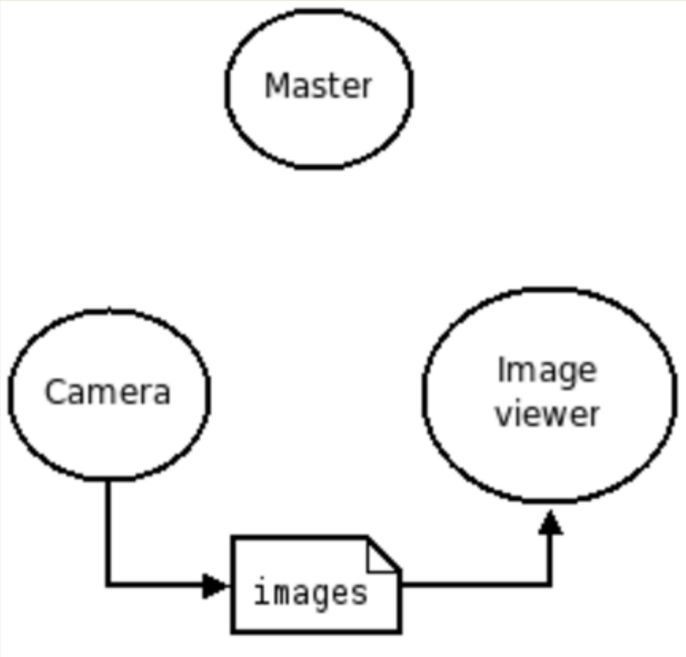
ROS Master

- Now, Image_viewer wants to subscribe to the topic "images" to see if there's maybe some images there:



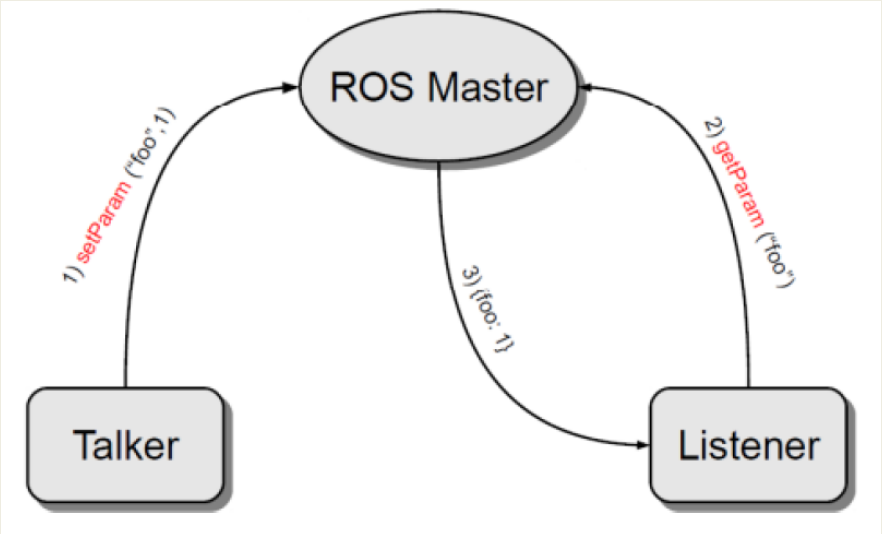
ROS Master

- Now that the topic "images" has both a publisher and a subscriber, the master node notifies Camera and Image_viewer about each others existence, so that they can start transferring images to one another:



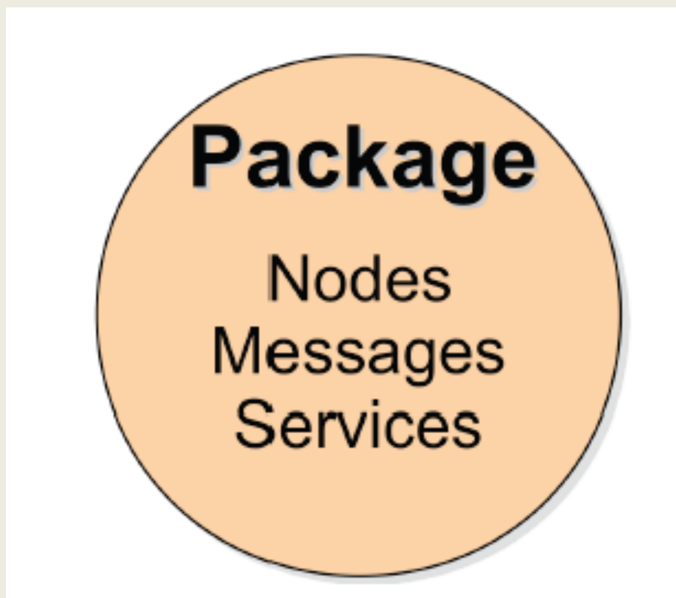
Parameter Server

- A shared, multi-variate dictionary that is accessible via network APIs
- Best used for static, non-binary data such as configuration parameters
- Runs inside the ROS master

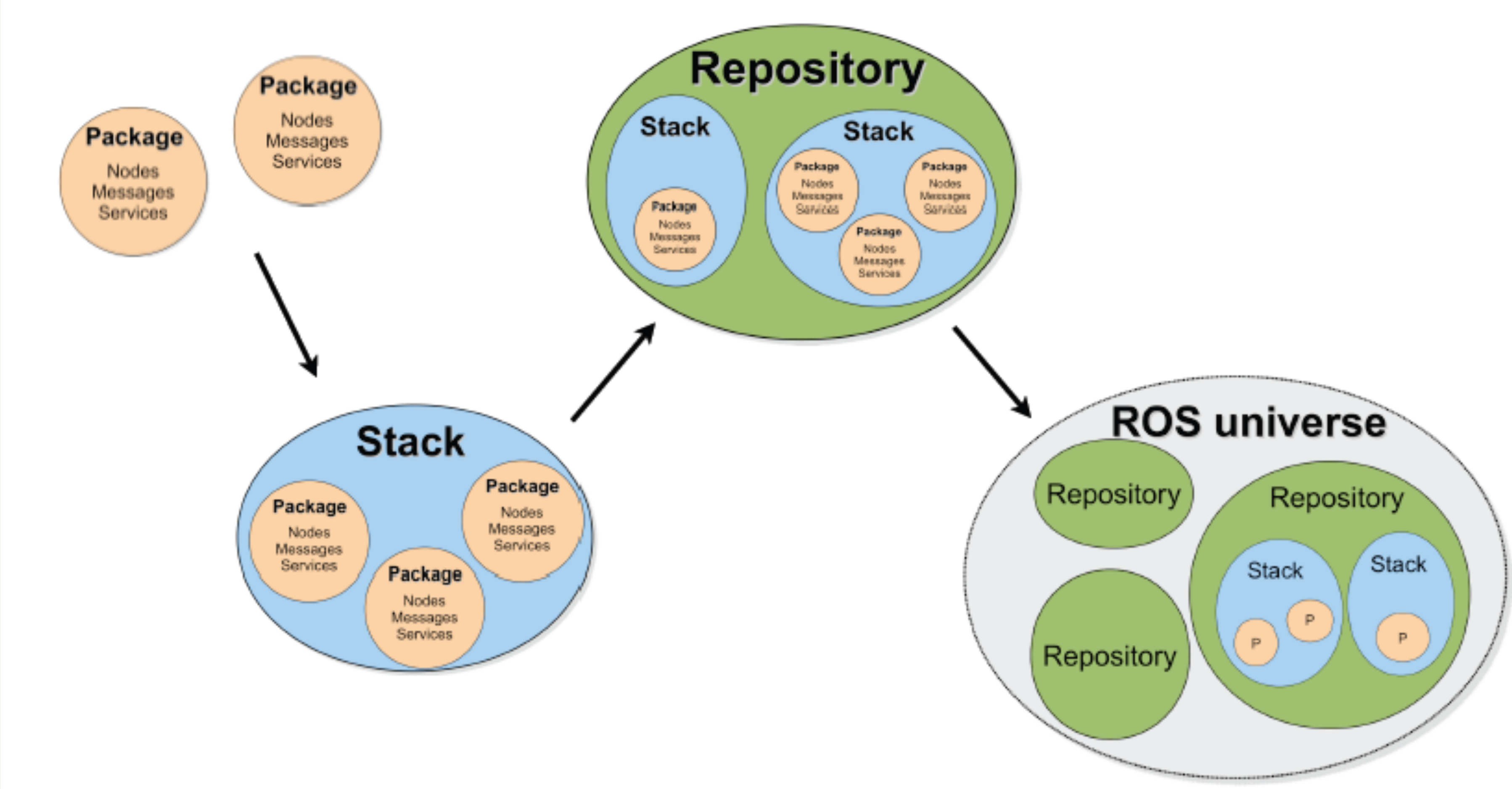


ROS Packages

- Software in ROS is organized in *packages*.
- A package contains one or more nodes and provides a ROS interface
- Most of ROS packages are hosted in GitHub

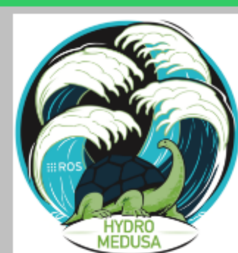


ROS Package System



Taken from Sachin Chitta and Radu Rusu (Willow Garage)

ROS Distribution Releases

Distro	Release date	Poster	*Tuturtle*, turtle in tutorial	EOL date
ROS Kinetic Kame (**Recommended**)	May 23rd, 2016			May, 2021
ROS Jade Turtle	May 23rd, 2015			May, 2017
ROS Indigo Igloo	July 22nd, 2014			April, 2019 (Trusty EOL)
ROS Hydro Medusa	September 4th, 2013			May, 2015

ROS Supported Platforms

- ROS is currently supported only on Ubuntu
  – other variants such as Windows and Mac OS X are considered experimental (will be supported on ROS 2.0)
- ROS distribution supported is limited to <=3 latest Ubuntu versions
- ROS Jade supports the following Ubuntu versions:
  – Vivid (15.04)
  – Utopic (14.04)
  – Trusty (14.04 LTS)
- ROS Indigo supports the following Ubuntu versions:
  – Trusty (14.04 LTS)
  – Saucy (13.10)

ROS Installation

- If you already have Ubuntu installed, follow the instructions at:

- http://wiki.ros.org/ROS/Installation

  - note: there are different distributions, etc described there

ROS Environment

- ROS relies on the notion of combining spaces using the shell environment
  - This makes developing against different versions of ROS or against different sets of packages easier
- After you install ROS you will have setup.*sh files in '/opt/ros/<distro>/', and you could source them like so:

```
$ source /opt/ros/indigo/setup.bash
```

- You will need to run this command on every new shell you open to have access to the ros commands, unless you add this line to your bash startup file (~/.bashrc)
  - If you used the pre-installed VM it's already done for you

ROS Basic Commands

- roscore
- rosrun
- rosnode
- rostopic

roscore

- roscore is the first thing you should run when using ROS

```
$ roscore
```

- roscore will start up:
  - a ROS Master
  - a ROS Parameter Server
  - a rosout logging node

rosrun

- rosrun allows you to run a node
- Usage:

```
$ rosrun <package> <executable>
```

- Example:

```
$ rosrun turtlesim turtlesim_node
```

rosnode

- Displays debugging information about ROS nodes, including publications, subscriptions and connections

Command	
rosnode list$	List active nodes
rosnode ping$	Test connectivity to node
rosnode info$	Print information about a node
rosnode kill$	Kill a running node
rosnode machine$	List nodes running on a particular machine

rostopic

- Gives information about a topic and allows to publish messages on a topic

Command	
rostopic list$	List active topics
rosnode echo /topic$	Prints messages of the topic to the screen
rostopic info /topic$	Print information about a topic
rostopic type /topic$	Prints the type of messages the topic publishes
rostopic pub /topic type args$	Publishes data to a topic

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ROS - Lecture 3

ROS topics
Publishers and subscribers
roslaunch
Custom message types

Lecturer: Roi Yehoshua
roiyeho@gmail.com

ROS Communication Types

Type	Best used for
Topic	One-way communication, especially if there might be multiple nodes listening (e.g., streams of sensor data)
Service	Simple request/response interactions, such as asking a question about a node's current state
Action	Most request/response interactions, especially when servicing the request is not instantaneous (e.g., navigating to a goal location)

ROS Topics

- Topics implement a *publish/subscribe* communication mechanism
  - one of the more common ways to exchange data in a distributed system.
- Before nodes start to transmit data over topics, they must first announce, or *advertise*, both the topic name and the types of messages that are going to be sent
- Then they can start to send, or *publish*, the actual data on the topic.
- Nodes that want to receive messages on a topic can *subscribe* to that topic by making a request to roscore.
- After subscribing, all messages on the topic are delivered to the node that made the request.

ROS Topics

- In ROS, all messages on the same topic *must be of the same data type*
- Topic names often describe the messages that are sent over them
- For example, on the PR2 robot, the topic /wide_stereo/right/image_color is used for color images from the rightmost camera of the wide-angle stereo pair

Topic Publisher

- Manages an advertisement on a specific topic
- Created by calling **NodeHandle::advertise()**
  – Registers this topic in the master node
- Example for creating a publisher:

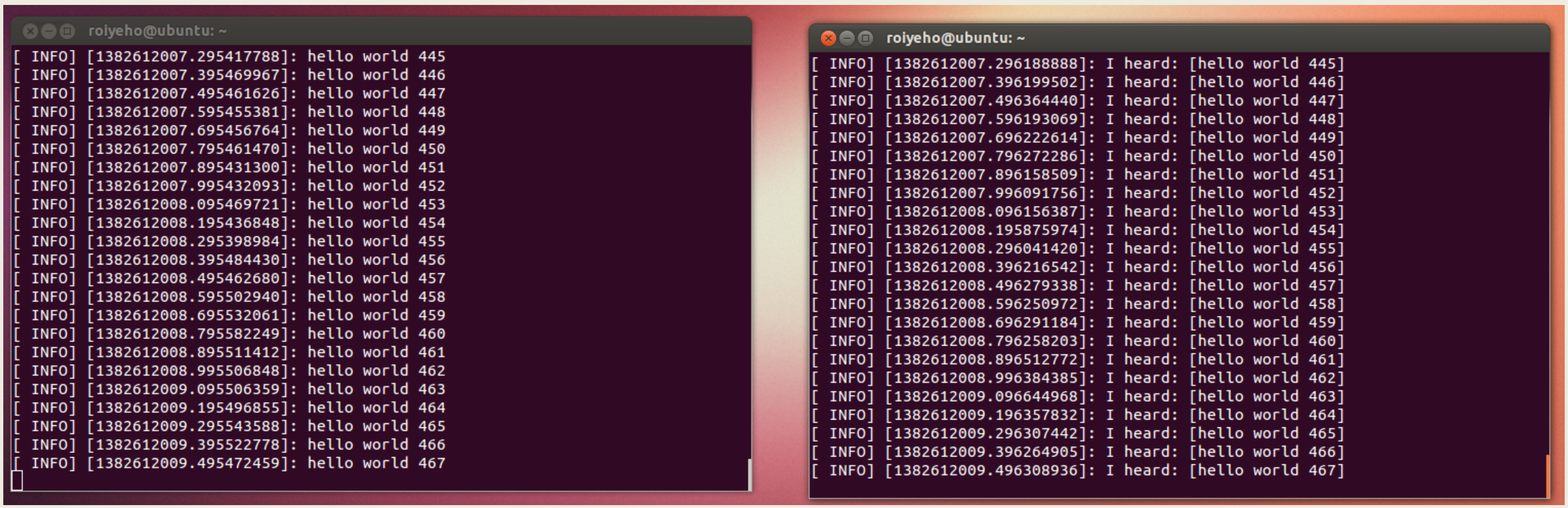
```
ros::Publisher chatter_pub = node.advertise<std_msgs::String>("chatter", 1000);
```

  – First parameter is the topic name
  – Second parameter is the queue size
- Once all the publishers for a given topic go out of scope the topic will be unadvertised

Running the Nodes From Terminal

- Run roscore
- Run the nodes in two different terminals:

```
$ rosrun chat_pkg talker
$ rosrun chat_pkg listener
```



Running the Nodes From Terminal

- You can use rosnode and rostopic to debug and see what the nodes are doing
- Examples:

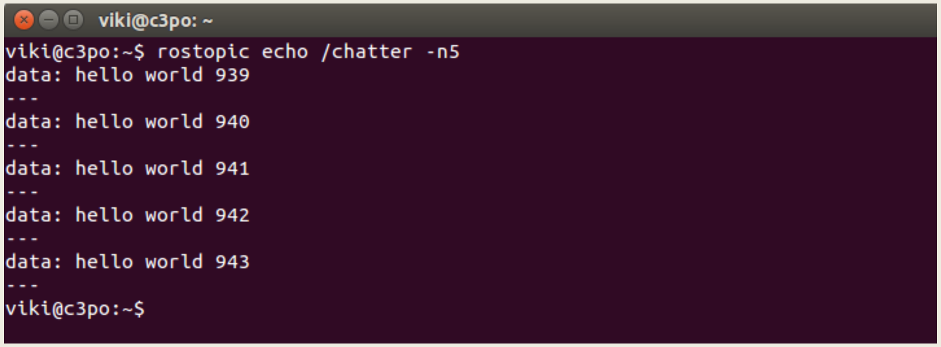
  $rosnode info /talker

  $rosnode info /listener

  $rostopic list

  $rostopic info /chatter

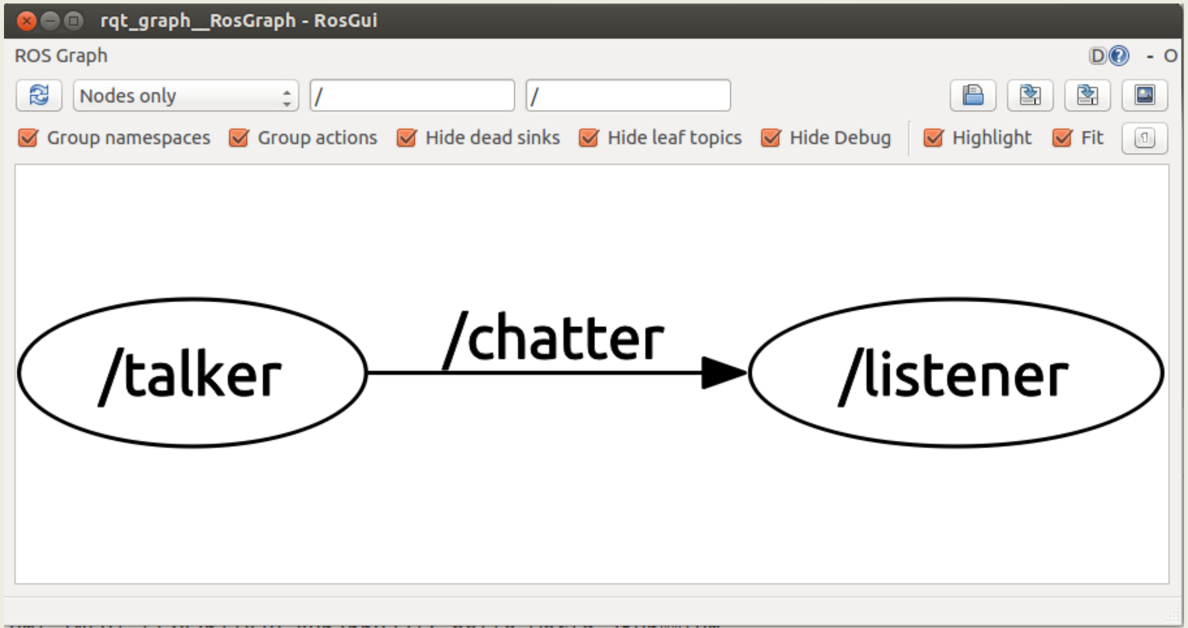
  $rostopic echo /chatter



rqt_graph

- rqt_graph creates a dynamic graph of what's going on in the system
- Use the following command to run it:

```
$ rosrun rqt_graph rqt_graph
```

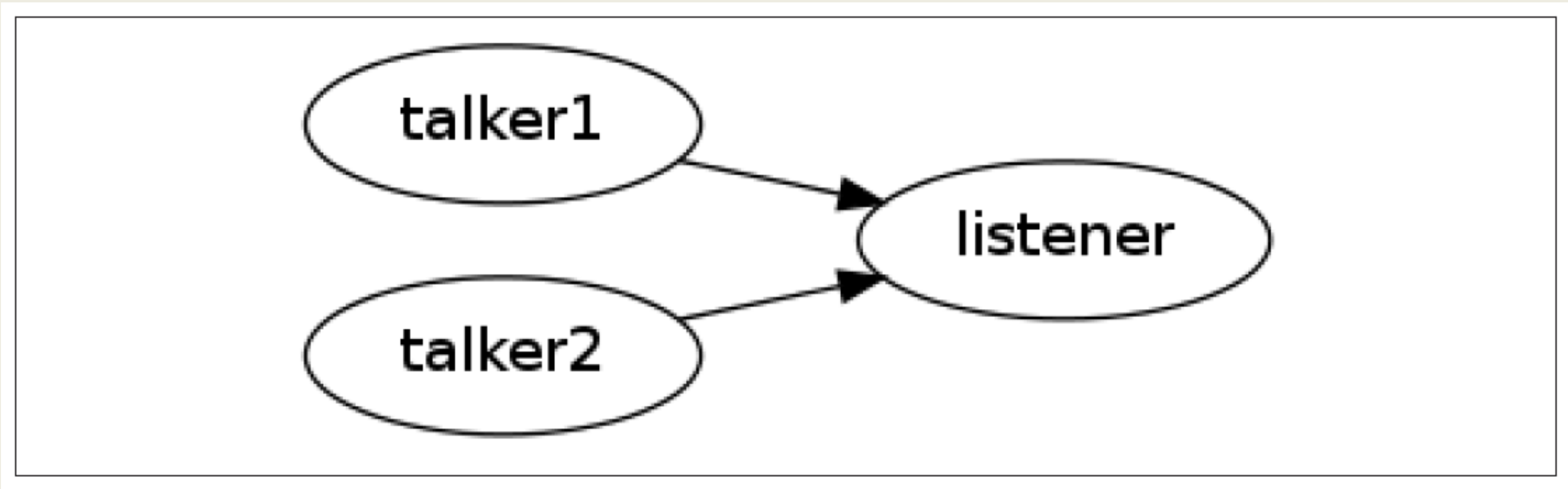


ROS Names

- ROS names must be unique
- If the same node is launched twice, roscore directs the older node to exit
- To change the name of a node on the command line, the special **__name** remapping syntax can be used
- The following two shell commands would launch two instances of talker named talker1 and t

```
$ rosrun chat_pkg talker __name:=talker1
$ rosrun chat_pkg talker __name:=talker2
```

ROS Names



Instantiating two talker programs and routing them to the same receiver

roslaunch

- a tool for easily launching multiple ROS nodes as well as setting parameters on the Parameter Server
- roslaunch operates on launch files which are XML files that specify a collection of nodes to launch along with their parameters
  - By convention these files have a suffix of .launch
- Syntax:

```
$ roslaunch PACKAGE LAUNCH_FILE
```

- roslaunch automatically runs roscore for you

Launch File Example

- Launch file for launching the talker and listener nodes:

```
<launch>
  <node name="talker" pkg="chat_pkg" type="talker"
output="screen"/>
  <node name="listener" pkg="chat_pkg" type="listener"
output="screen"/>
</launch>
```

- Each <node> tag includes attributes declaring the ROS graph name of the node, the package in which it can be found, and the type of node, which is the filename of the executable program
- output="screen" makes the ROS log messages appear on the launch terminal window

Launch File Example

```
$ roslaunch chat_pkg chat.launch
```

/home/viki/catkin_ws/src/chat_pkg/chat.launch http://localhost:11311

```
PARAMETERS
 * /rosdistro: indigo
 * /rosversion: 1.11.8

NODES
  /
    listener (chat_pkg/listener)
    talker (chat_pkg/talker)

ROS_MASTER_URI=http://localhost:11311

core service [/rosout] found
process[talker-1]: started with pid [4346]
[ INFO] [1415527311.166838414]: hello world 0
process[listener-2]: started with pid [4357]
[ INFO] [1415527311.266930155]: hello world 1
[ INFO] [1415527311.366882084]: hello world 2
[ INFO] [1415527311.466933045]: hello world 3
[ INFO] [1415527311.567014453]: hello world 4
[ INFO] [1415527311.567771438]: I heard: [hello world 4]
[ INFO] [1415527311.666931023]: hello world 5
[ INFO] [1415527311.667310888]: I heard: [hello world 5]
[ INFO] [1415527311.767668040]: hello world 6
[ INFO] [1415527311.768178187]: I heard: [hello world 6]
```

Creating Custom Messages

- These primitive types are used to build all of the messages used in ROS
- For example, (most) laser range-finder sensors publish sensor_msgs/LaserScan messages

```
# Single scan from a planar laser range-finder

Header header
# stamp: The acquisition time of the first ray in the scan.
# frame_id: The laser is assumed to spin around the positive Z axis
# (counterclockwise, if Z is up) with the zero angle forward along the x axis

float32 angle_min # start angle of the scan [rad]
float32 angle_max # end angle of the scan [rad]
float32 angle_increment # angular distance between measurements [rad]

float32 time_increment # time between measurements [seconds] - if your scanner
# is moving, this will be used in interpolating position of 3d points
float32 scan_time # time between scans [seconds]

float32 range_min # minimum range value [m]
float32 range_max # maximum range value [m]

float32[] ranges # range data [m] (Note: values < range_min or > range_max should be
discarded)
float32[] intensities # intensity data [device-specific units]. If your
# device does not provide intensities, please leave the array empty.
```

Creating Custom Messages

- Using standardized message types for laser scans and location estimates enables nodes can be written that provide navigation and mapping (among many other things) for a wide variety of robots
- However, there are times when the built-in message types are not enough, and we have to define our own messages

msg Files

- ROS messages are defined by special message-definition files in the *msg* directory of a package.
- These files are then compiled into language-specific implementations that can be used in your code
- Each line in the file specifies a type and a field name

Using rosmsg

- That's all you need to do to create a msg
- Let's make sure that ROS can see it using the rosmsg show command:

```
$ rosmsg show [message type]
```

```
roiyeho@ubuntu: ~
roiyeho@ubuntu:~$ rosmsg show RobotStatus
[multi_sync/RobotStatus]:
std_msgs/Header header
  uint32 seq
  time stamp
  string frame_id
bool is_ready

roiyeho@ubuntu:~$
```

PACMOD

- Publishes a set of relevant vehicle messages
- Subscribes to a set of relevant vehicle messages

Published Topics

Message Type	Topic	Description
can_msgs/Frame	can_rx	All data published on this topic is intended to be sent to the PACMod system via a CAN interface.
pacmod_msgs/GlobalRpt	parsed_tx/global_rpt	High-level data about the entire PACMod system.
pacmod_msgs/SystemRptFloat	parsed_tx/accel_rpt	Status and parsed values [pct] of the throttle subsystem.
pacmod_msgs/SystemRptFloat	parsed_tx/brake_rpt	Status and parsed values [pct] of the steering susbsystem.
pacmod_msgs/SystemRptInt	parsed_tx/turn_rpt	Status and parsed values [enum] of the turn signal subsystem.
pacmod_msgs/SystemRptInt	parsed_tx/shift_rpt	Status and parsed values [enum] of the gear/transmission subsystem.
pacmod_msgs/SystemRptFloat	parsed_tx/steer_rpt	Status and parsed values [rad] of the steering susbsystem.

||pacmod_msgs/VehicleSpeedRpt||parsed_tx/vehicle_speed_rpt|| The vehicle's current speed [mph], the validity of the speed message [bool], and the raw CAN message from the vehicle CAN.||

std_msgs/Float64	as_tx/vehicle_speed	The vehicle's current speed [m/s].
std_msgs/Bool	as_tx/enable	The current status of the PACMod's control of the vehicle. If the PACMod is enabled, this value will be true. If it is disabled or overridden, this value will be false.

pacmod_msgs/PacmodCmd	as_rx/accel_cmd	Commands the throttle subsystem to seek a specific pedal position [pct - 0.0 to 1.0].
pacmod_msgs/PacmodCmd	as_rx/brake_cmd	Commands the brake subsystem to seek a specific pedal position [pct - 0.0 to 1.0].
pacmod_msgs/PacmodCmd	as_rx/shift_cmd	Commands the gear/transmission subsystem to shift to a different gear [enum].
pacmod_msgs/PositionWithSpeed	as_rx/steer_cmd	Commands the steering subsystem to seek a specific steering wheel angle [rad] at a given rotation velocity [rad/s].
pacmod_msgs/PacmodCmd	as_rx/turn_cmd	Commands the turn signal subsystem to transition to a given state [enum].
std_msgs/Bool	as_rx/enable	Enables [true] or disables [false] PACMod's control of the vehicle.

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ROS - Lecture 4

Gazebo simulator
Reading Sensor Data
Wander-Bot

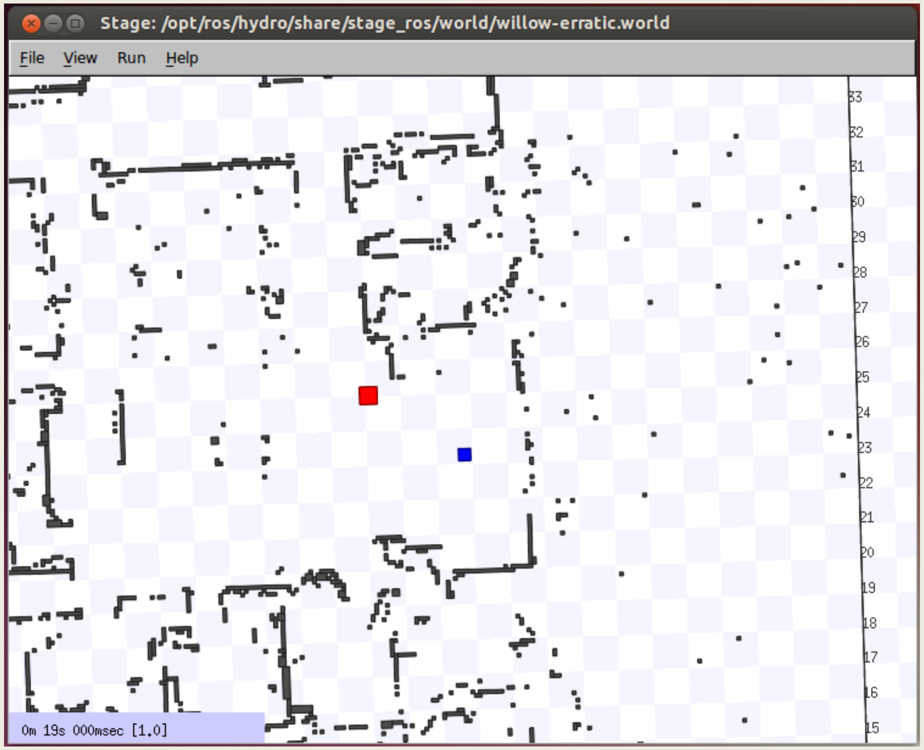
Lecturer: Roi Yehoshua
roiyeho@gmail.com

Simulators

- In simulation, we can model as much or as little of reality as we desire
- Sensors and actuators can be modeled as ideal devices, or they can incorporate various levels of distortion, errors, and unexpected faults
- Automated testing of control algorithms typically requires simulated robots, since the algorithms under test need to be able to experience the consequences of their actions
- Due to the isolation provided by the messaging interfaces of ROS, a vast majority of the robot's software graph can be run identically whether it is controlling a real robot or a simulated robot

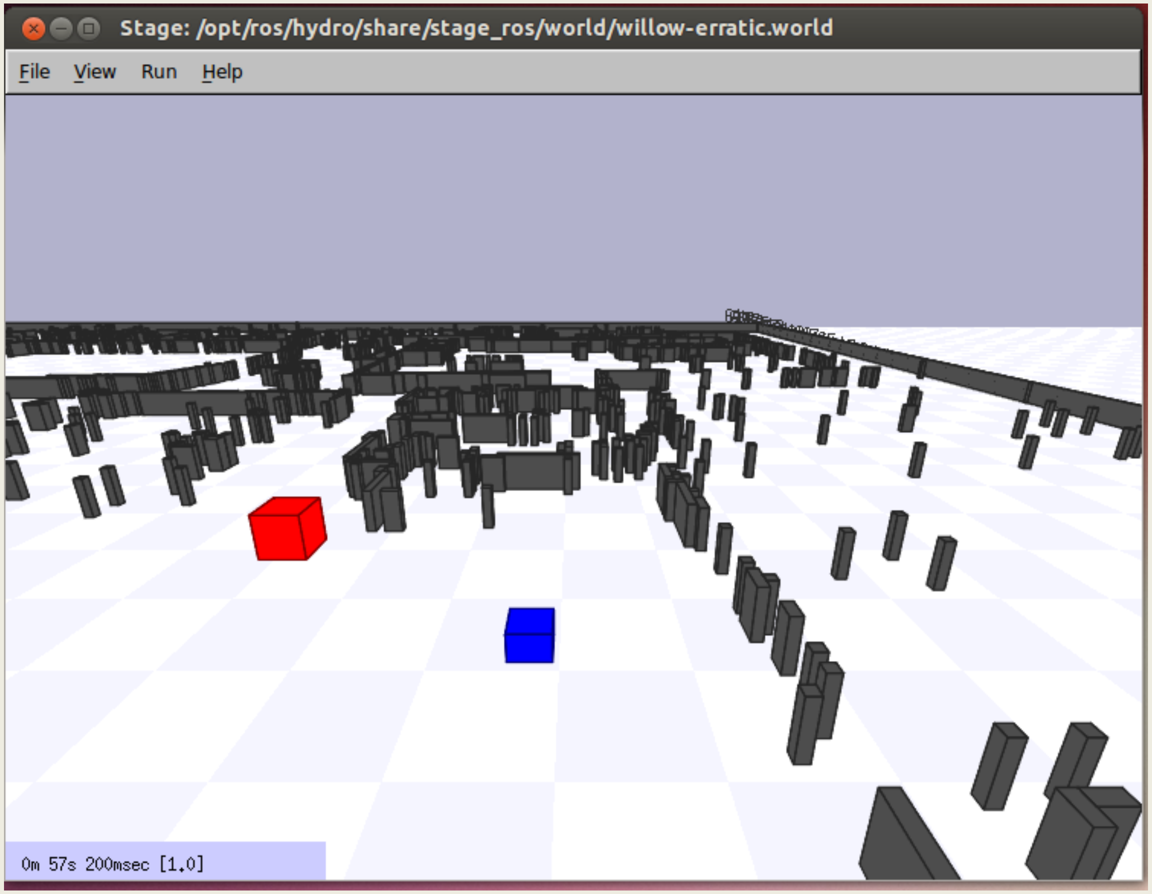
ROS Stage Simulator

- http://wiki.ros.org/simulator_stage
- A 2D simulator that provides a virtual world populated by mobile robots, along with various objects for the robots to sense and manipulate



ROS Stage Simulator

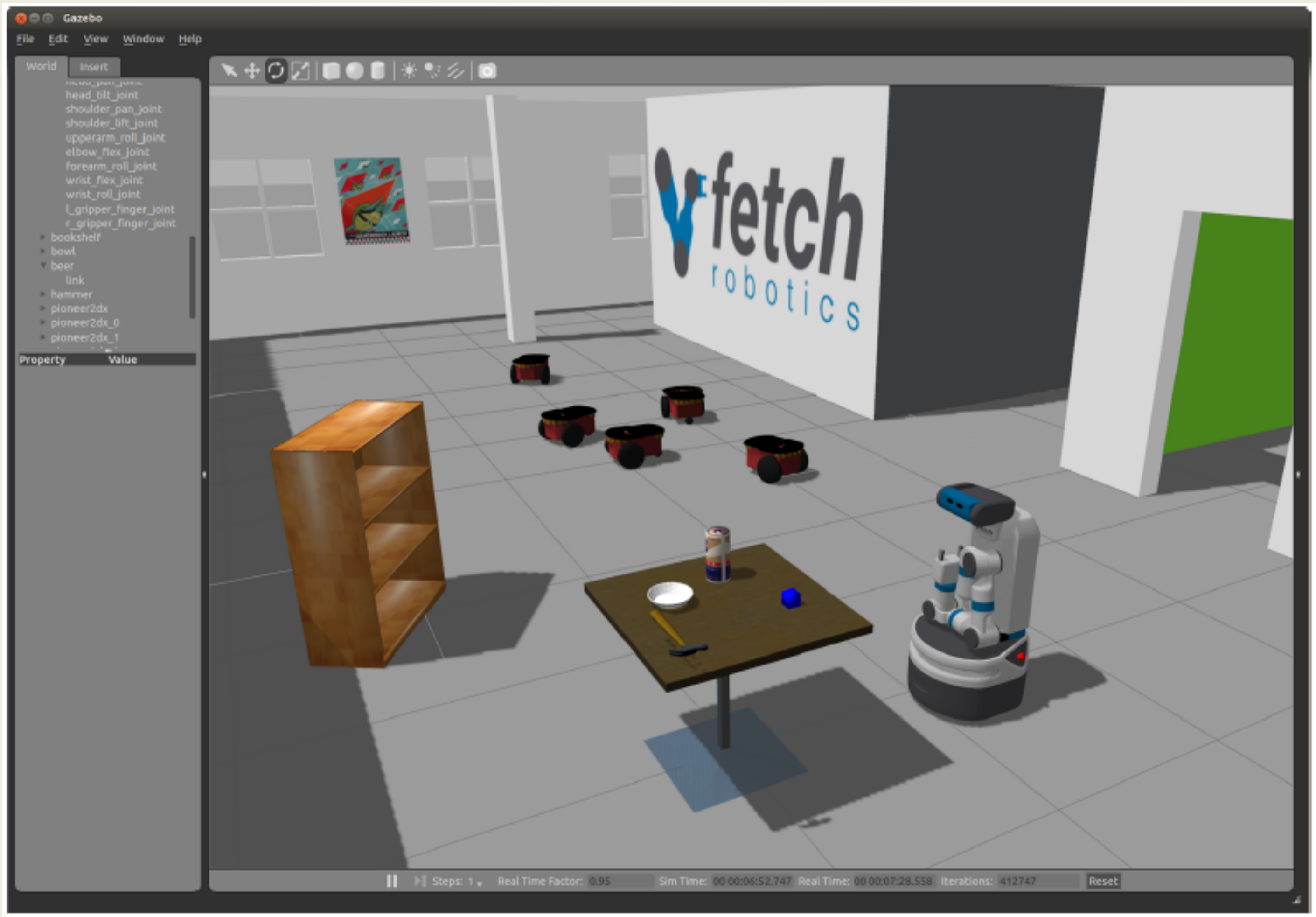
- In perspective view of the robot



Gazebo

- A multi-robot simulator
- Like Stage, it is capable of simulating a population of robots, sensors and objects, but does so in 3D
- Includes an accurate simulation of rigid-body physics and generates realistic sensor feedback
- Allows code designed to operate a physical robot to be executed in an artificial environment
- Gazebo is under active development at the OSRF (Open Source Robotics Foundation)

Gazebo



- [Gazebo Demo]

Gazebo

- ROS Indigo comes with Gazebo V2.2
- Gazebo home page - http://gazebosim.org/
- Gazebo tutorials - http://gazebosim.org/tutorials

Gazebo Architecture

Gazebo consists of two processes:

- **Server:** Runs the physics loop and generates sensor data
  - *Executable*: gzserver
  - *Libraries*: Physics, Sensors, Rendering, Transport
- **Client:** Provides user interaction and visualization of a simulation.
  - *Executable*: gzclient
  - *Libraries*: Transport, Rendering, GUI

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ROS - Lecture 5

Mapping in ROS
rviz
ROS Services

Lecturer: Roi Yehoshua
roiyeho@gmail.com

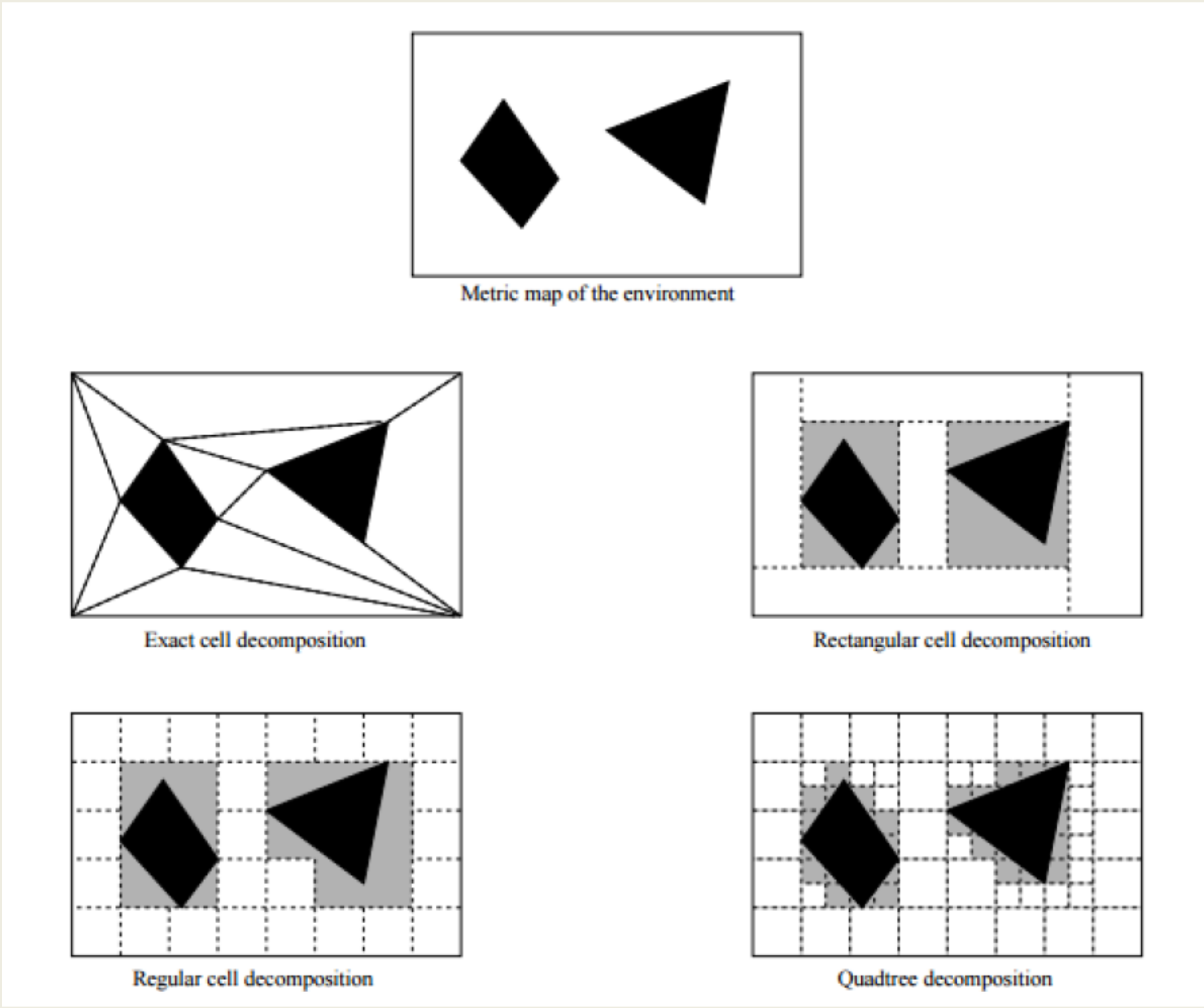
Why Mapping?

- Building maps is one of the fundamental problems in mobile robotics
- Maps allow robots to efficiently carry out their tasks, such as localization, path planning, activity planning, etc.
- There are different ways to create a map of the environment

Cellular Decomposition

- Decompose free space for path planning
- Exact decomposition
  - Cover the free space exactly
  - Example: trapezoidal decomposition, meadow map
- Approximate decomposition
  - Represent part of the free space, needed for navigation
  - Example: grid maps, quadtrees, Voronoi graphs

Cellular Decomposition



Occupancy Grid Map (OGM)

- Maps the environment as a grid of cells
  - Cell sizes typically range from 5 to 50 cm
- Each cell holds a probability value that the cell is occupied in the range [0,100]
- Unknown is indicated by -1
  - Usually unknown areas are areas that the robot sensors cannot detect (beyond obstacles)

Occupancy Grid Map

White pixels represent free cells
Black pixels represent occupied cells
Gray pixels are in unknown state

Occupancy Grid Maps

- Pros:
  - Simple representation
  - Speed
- Cons:
  - Not accurate - if an object falls inside a portion of a grid cell, the whole cell is marked occupied
  - Wasted space

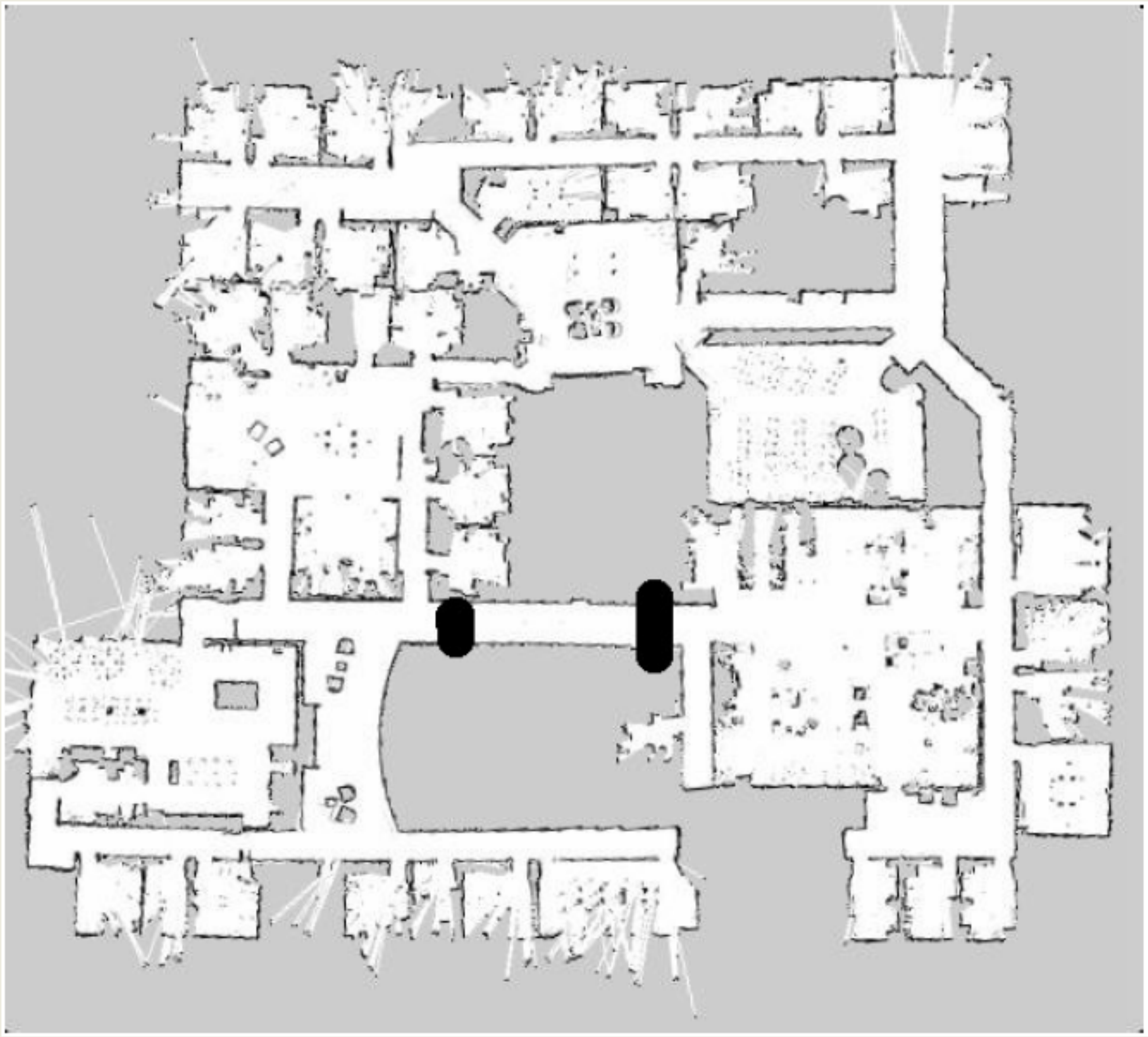
Maps in ROS

- Map files are stored as images, with a variety of common formats being supported (such as PNG, JPG, and PGM)
- Although color images can be used, they are converted to grayscale images before being interpreted by ROS
- Associated with each map is a YAML file that holds additional information about the map

Editing Map Files

- Since maps are represented as image files, you can edit them in your favorite image editor
- This allows you to tidy up any maps that you create from sensor data, removing things that shouldn't be there, or adding in fake obstacles to influence path planning
- For example, you can stop the robot from planning paths through certain areas of the map by drawing a line across a corridor you don't want to the robot to drive through

Editing Map Files



SLAM

- **Simultaneous localization and mapping** (SLAM) is a technique used by robots to build up a map within an unknown environment while at the same time keeping track of their current location
- A chicken or egg problem: An unbiased map is needed for localization while an accurate pose estimate is needed to build that map

gmapping

- http://wiki.ros.org/gmapping
- The gmapping package provides laser-based SLAM as a ROS node called **slam_gmapping**
- Uses the FastSLAM algorithm
- It takes the laser scans and the odometry and builds a 2D occupancy grid map
- It updates the map state while the robot moves
- ROS with gmapping video

Install gmapping

- gmapping is not part of ROS Indigo installation
- To install gmapping run:

```
$ sudo apt-get install ros-indigo-slam-gmapping
```

  – You may need to run sudo apt-get update before that to update package repositories list

Run gmapping

- Now move the robot using teleop

```
$ roslaunch turtlebot_teleop keyboard_teleop.launch
```

- Check that the map is published to the topic /map

```
$ rostopic echo /map -n1
```

- Message type is nav_msgs/OccupancyGrid
- Occupancy is represented as an integer with:
  - 0 meaning completely free
  - 100 meaning completely occupied
  - the special value -1 for completely unknown

map_server

- map_server allows you to load and save maps
- To install the package:

```
$ sudo apt-get install ros-indigo-map-server
```

- To save dynamically generated maps to a file:

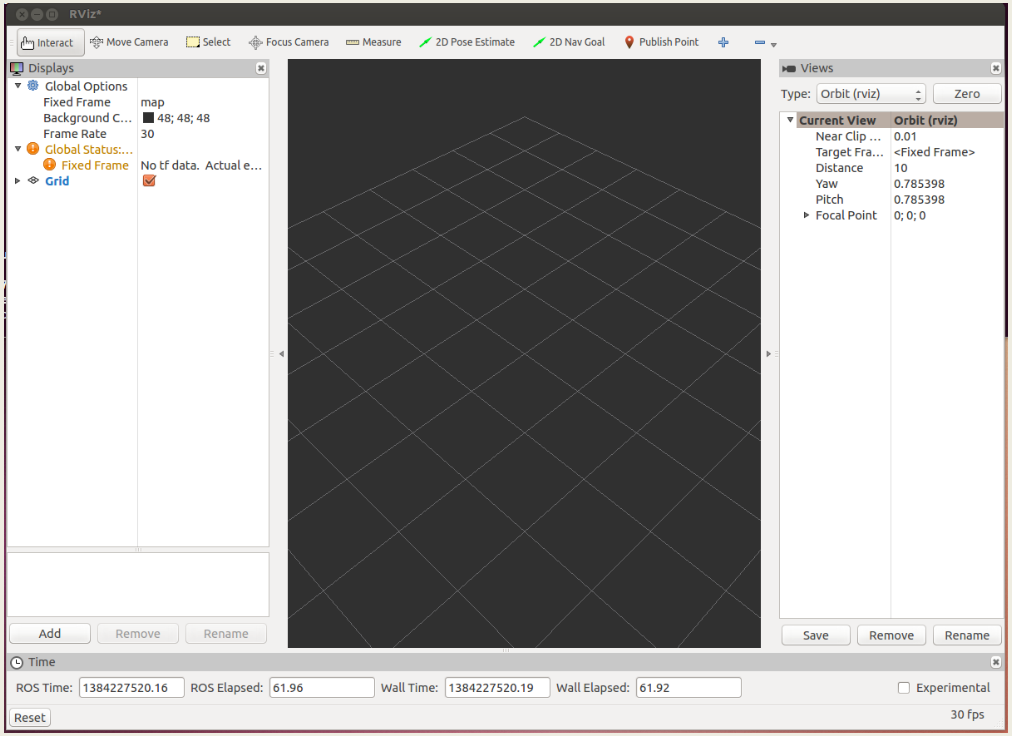
```
$ rosrun map_server map_saver [-f mapname]
```

- map_saver generates the following files in the current directory:
  - **map.pgm** - the map itself
  - **map.yaml** - the map's metadata

rviz

- rviz is a ROS 3D visualization tool that lets you see the world from a robot's perspective

```
$ rosrun rviz rviz
```



rviz Useful Commands

- Use right mouse button or scroll wheel to zoom in or out
- Use the left mouse button to pan (shift-click) or rotate (click)

rviz Displays

- The first time you open rviz you will see an empty 3D view
- On the left is the **Displays** area, which contains a list of different elements in the world, that appears in the middle
  - Right now it just contains global options and grid
- Below the Displays area, we have the **Add** button that allows the addition of more elements

rviz Displays

Display name	Description	Messages Used
Axes	Displays a set of Axes	
Effort	Shows the effort being put into each revolute joint of .a robot	sensor_msgs/JointStates
Camera	Creates a new rendering window from the perspective of a camera, and overlays the image on .top of it	sensor_msgs/Image sensor_msgs/CameraInfo
Grid	Displays a 2D or 3D grid along a plane	
Grid Cells	Draws cells from a grid, usually obstacles from a .costmap from the navigation stack	nav_msgs/GridCells
Image	.Creates a new rendering window with an Image	sensor_msgs/Image
LaserScan	Shows data from a laser scan, with different options .for rendering modes, accumulation, etc	sensor_msgs/LaserScan
Map	.Displays a map on the ground plane	nav_msgs/OccupancyGrid

rviz Displays

Display name	Description	Messages Used
Markers	Allows programmers to display arbitrary primitive shapes through a topic	visualization_msgs/Marker visualization_msgs/MarkerArray
Path	.Shows a path from the navigation stack	nav_msgs/Path
Pose	Draws a pose as either an arrow or axes	geometry_msgs/PoseStamped
Point Cloud(2)	Shows data from a point cloud, with different options for rendering modes, accumulation, .etc	sensor_msgs/PointCloud sensor_msgs/PointCloud2
Odometry	.Accumulates odometry poses from over time	nav_msgs/Odometry
Range	Displays cones representing range .measurements from sonar or IR range sensors	sensor_msgs/Range
RobotModel	Shows a visual representation of a robot in the correct pose (as defined by the current TF .transforms)	
TF	.Displays the tf transform hierarchy	

ROS Services

- The next step is to learn how to load the map into the memory in our own code
  - So we can use it to plan a path for the robot
- For that purpose we will use a ROS service called static_map provided by the map_server node

ROS Services

- Services are just synchronous remote procedure calls
  – They allow one node to call a function that executes in another node
- We define the inputs and outputs of this function similarly to the way we define new message types
- The server (which provides the service) specifies a callback to deal with the service request, and advertises the service.
- The client (which calls the service) then accesses this service through a local proxy

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ROS - Lecture 6

ROS tf system
Get robot's location on map

Lecturer: Roi Yehoshua
roiyeho@gmail.com

What is tf?

- A robotic system typically has many coordinate frames that change over **time**, such as a world frame, base frame, gripper frame, head frame, etc.
- tf is a transformation system that allows making computations in one frame and then transforming them to another at any desired point in time
- tf allows you to ask questions like:
  – What is the current pose of the base frame of the robot in the map frame?
  – What is the pose of the object in my gripper relative to my base?
  – Where was the head frame relative to the world frame, 5 seconds ago?

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ROS - Lecture 7

ROS navigation stack
Costmaps
Localization
Sending goal commands (from rviz)

Lecturer: Roi Yehoshua
roiyeho@gmail.com

Robot Navigation

- One of the most basic things that a robot can do is to move around the world.
- To do this effectively, the robot needs to know where it is and where it should be going
- This is usually achieved by giving the robot a map of the world, a starting location, and a goal location
- In the previous lesson, we saw how to build a map of the world from sensor data.
- Now, we'll look at how to make your robot autonomously navigate from one part of the world to another, using this map and the ROS navigation packages

ROS Navigation Stack

- http://wiki.ros.org/navigation
- The goal of the navigation stack is to move a robot from one position to another position safely (without crashing or getting lost)
- It takes in information from the odometry and sensors, and a goal pose and outputs safe velocity commands that are sent to the robot
- ROS Navigation Introductory Video

Navigation Stack Main Components

Package/Component	Description
map_server	offers map data as a ROS Service
gmapping	provides laser-based SLAM
amcl	a probabilistic localization system
global_planner	implementation of a fast global planner for navigation
local_planner	implementations of the Trajectory Rollout and Dynamic Window approaches to local robot navigation
move_base	links together the global and local planner to accomplish the navigation task

Install Navigation Stack

- The navigation stack is not part of the standard ROS Indigo installation
- To install the navigation stack type:

```
$ sudo apt-get install ros-indigo-navigation
```

Navigation Stack Requirements

<u>Three main hardware requirements</u>

- The navigation stack can only handle a differential drive and holonomic wheeled robots
  - It can also do certain things with biped robots, such as localization, as long as the robot does not move sideways
- A planar laser must be mounted on the mobile base of the robot to create the map and localization
  - Alternatively, you can generate something equivalent to laser scans from other sensors (Kinect for example)
- Its performance will be best on robots that are nearly square or circular

Navigation Planners

- Our robot will move through the map using two types of navigation—global and local
- The **global planner** is used to create paths for a goal in the map or a far-off distance
- The **local planner** is used to create paths in the nearby distances and avoid obstacles

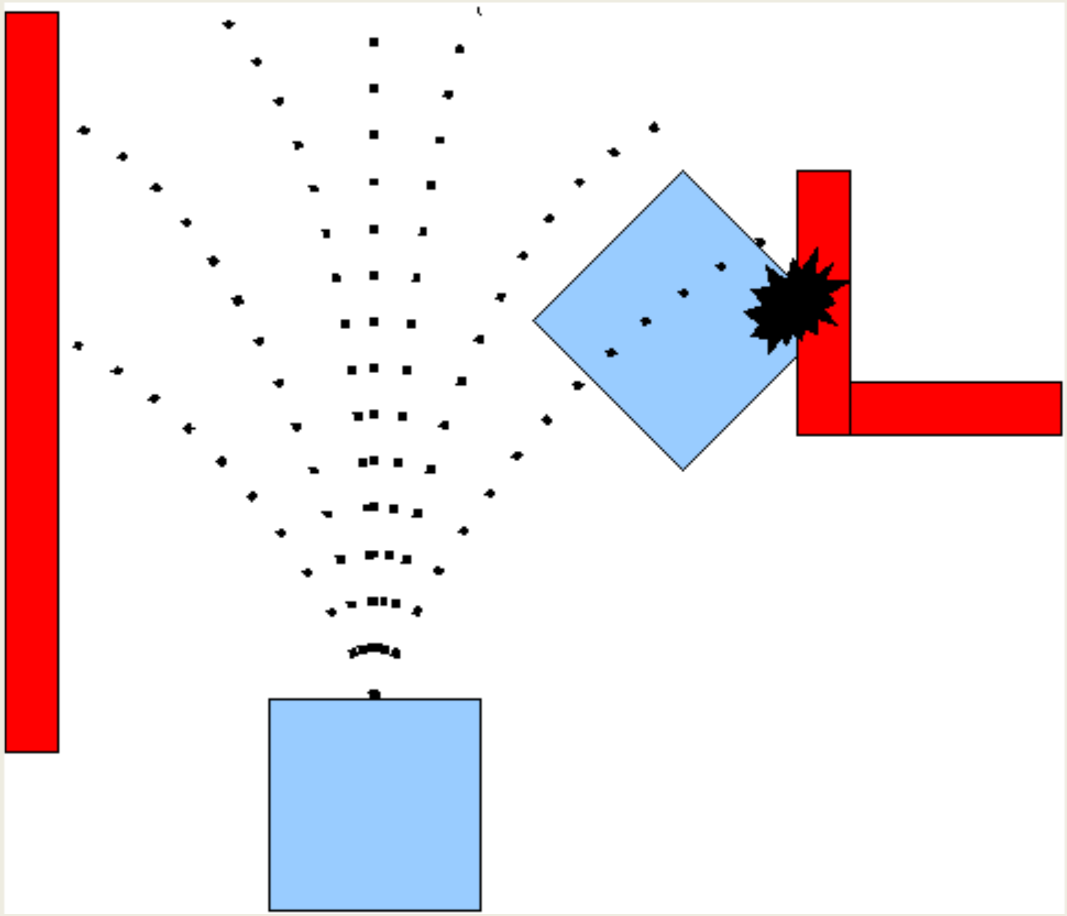
Global Planner

- NavFn provides a fast interpolated navigation function that creates plans for a mobile base
- The global plan is computed before the robot starts moving toward the next destination
- The planner operates on a costmap to find a minimum cost plan from a start point to an end point in a grid, using Dijkstra's algorithm
- The global planner generates a series of waypoints for the local planner to follow

Local Planner

- Chooses appropriate velocity commands for the robot to traverse the current segment of the global path
- Combines sensory and odometry data with both global and local cost maps
- Can recompute the robot's path on the fly to keep the robot from striking objects yet still allowing it to reach its destination
- Implements the **Trajectory Rollout and Dynamic Window** algorithm

Trajectory Rollout Algorithm



Taken from ROS Wiki http://wiki.ros.org/base_local_planner

Trajectory Rollout Algorithm

1. Discretely sample in the robot's control space (dx,dy,dθ)
2. For each sampled velocity, perform forward simulation from the robot's current state to predict what would happen if the sampled velocity were applied for some (short) period of time
3. Evaluate each trajectory resulting from the forward simulation, using a metric that incorporates characteristics such as: proximity to obstacles, proximity to the goal, proximity to the global path, and speed
4. Discard illegal trajectories (those that collide with obstacles)
5. Pick the highest-scoring trajectory and send the associated velocity to the mobile base
6. Rinse and repeat

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ROS - Lecture 10

OpenCV
Vision in ROS
Follow-Bot

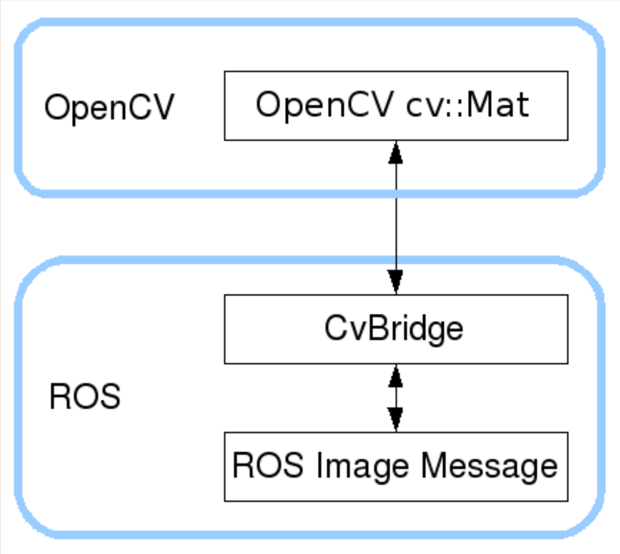
Lecturer: Roi Yehoshua
roiyeho@gmail.com

OpenCV

- Open Source Computer Vision Library
- Contains efficient, well-tested implementations of many popular computer vision algorithms
- Created/Maintained by Intel
- Routines focused on real time image processing and 2D + 3D computer vision
- http://docs.opencv.org/2.4/index.html
- http://docs.opencv.org/3.1.0/examples.html (examples)

ROS and OpenCV

- ROS passes images in its own sensor_msgs/Image message
- cv_bridge is a ROS package that provides functions to convert between ROS sensor_msgs/Image messages and the objects used by OpenCV



Acquiring Images

- Images in ROS are sent around the system using the sensor_msgs/Image message type
- To have images stream into our nodes, we need to subscribe to a topic where they are being published
- Each robot will have its own method for doing this, and names may vary
- Use rostopic list to find out what topics contain the robot's camera data