Introduction to Robot Simulation (Gazebo)

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AE640A: Autonomous Navigation

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Outline

- Recap
  - ROS Communication Layer
  - ROS Ecosystem
  - Libraries/Tools in ROS
- Robot Simulation
  - Why we need it?
- Elements within Simulation
  - Collision and Visual Geometries
  - Joints
  - Sensors
  - Lights

Loads of examples to come!

What is ROS?

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

Slide Credit: Lorenz Mösenlechner, TU Munich

What is ROS not?

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

Slide Credit: Lorenz Mösenlechner, TU Munich

ROS Communication Layer : ROS Core

- **ROS Master**
  - Centralized Communication Server based on XML and RPC
  - Negotiates the communication connections
  - Registers and looks up names for ROS graph resources
- **Parameter Server**
  - Stores persistent configuration parameters and other arbitrary data.
- ***`rosout`***
  - Network based *`stdout`* for human readable messages.

Slide Credit: Lorenz Mösenlechner, TU Munich
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ROS Communication Layer : Graph Resources

- **Nodes**
  - Processes distributed over the network.
  - Serves as source and sink for the data sent over the network
- **Parameters**
  - Persistent data such as configuration and initialization settings, i.e the data stored on the parameter server. e.g camera configuration
- **Topics**
  - Asynchronous many-to-many communication stream
- **Services**
  - Synchronous one-to-many network based functions

Slide Credit: Lorenz Mösenlechner, TU Munich

ROS Communication Protocols: Connecting Nodes

- **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

Slide Credit: Lorenz Mösenlechner, TU Munich

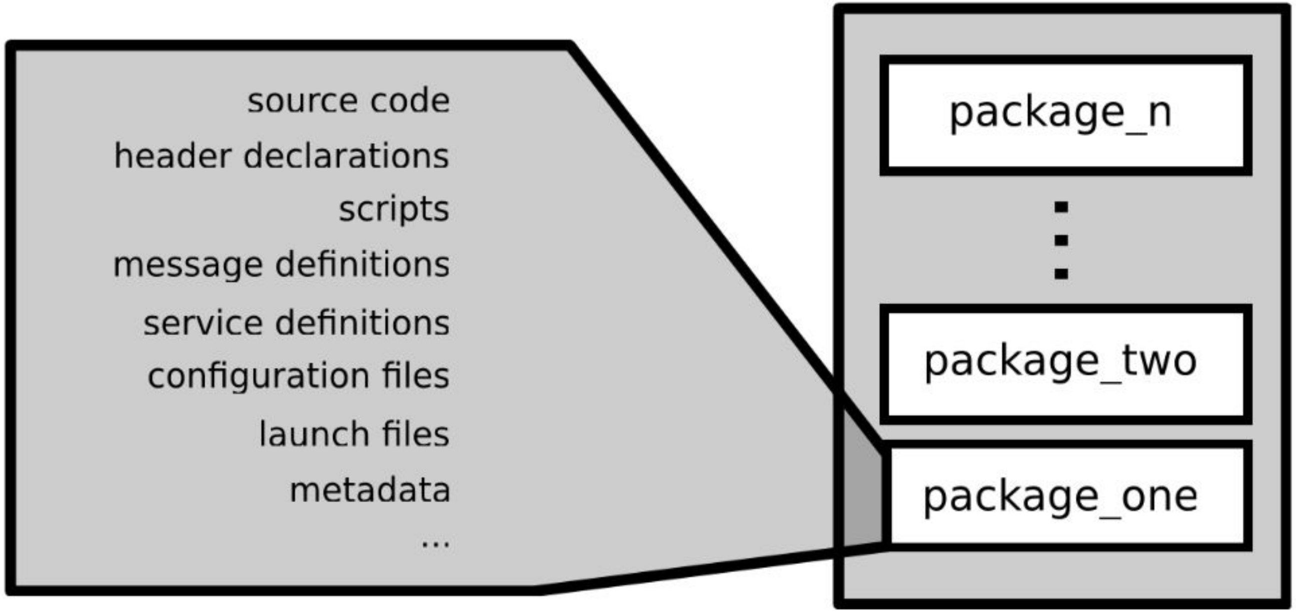
How to organize code in a ROS ecosystem?

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.

Slide Credit: Lorenz Mösenlechner, TU Munich

How to organize code in a ROS ecosystem?



“package” **“stack”**

ROS Launch

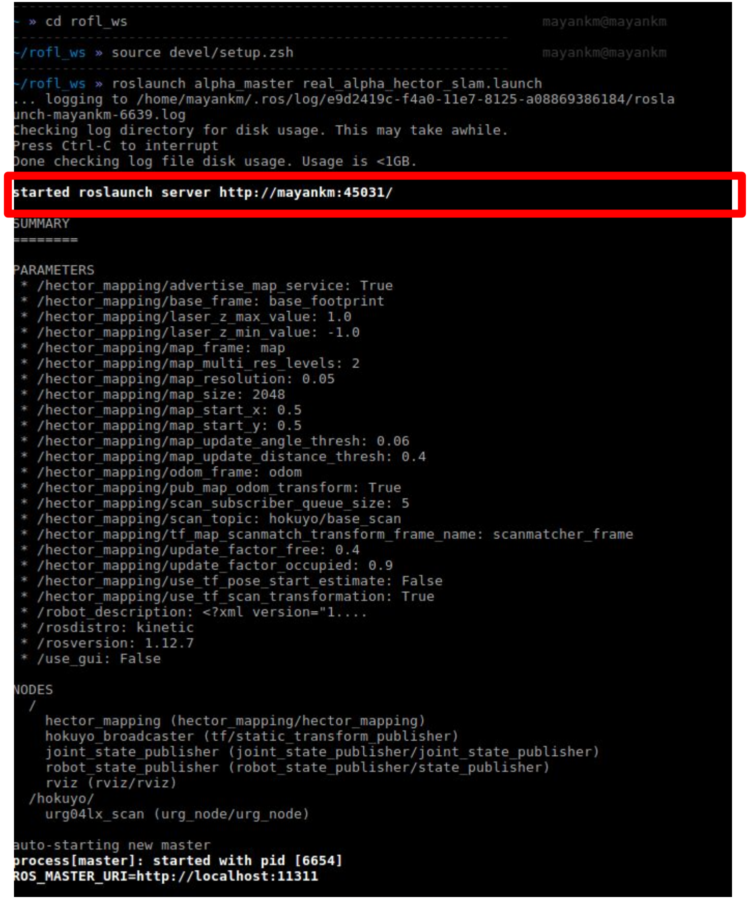
- launch is a tool for launching multiple nodes (as well as setting parameters)
- Are written in XML as *.launch files
- If not yet running, launch automatically starts a roscore

Start a launch file from a package with

```
$ roslaunch package_name file_name.launch
```

More info:
http://wiki.ros.org/roslaunch

Slide Credit: Marco Hutter, ETH Zurich



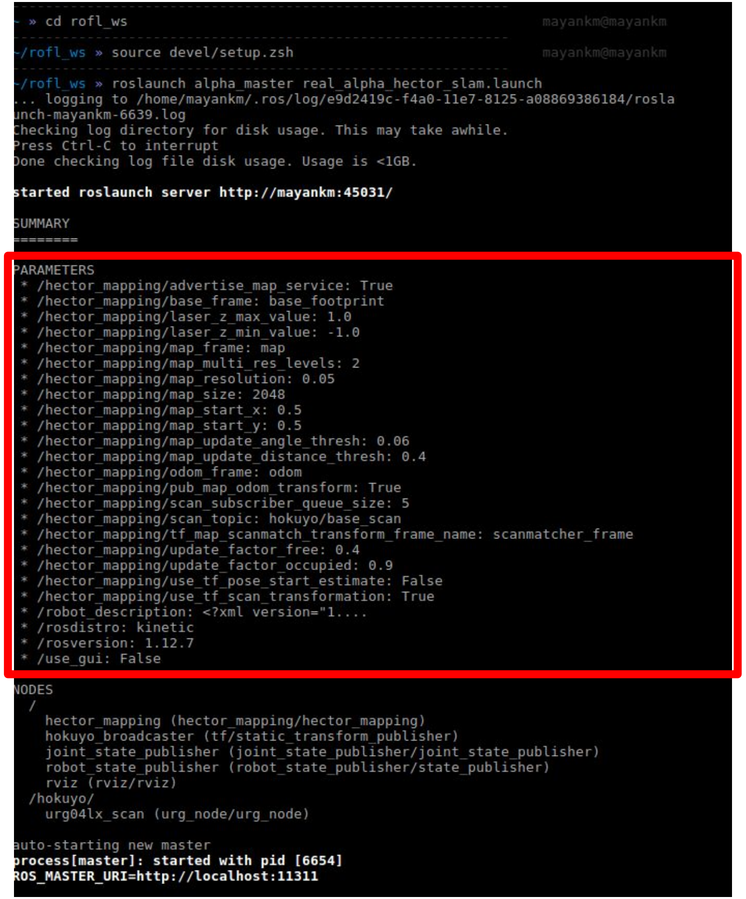
ROS Parameter Server

- Nodes use the parameter server to store and retrieve parameters at runtime
- Best used for static data such as configuration parameters
- Parameters can be defined in launch files or separate YAML files

List all parameters with

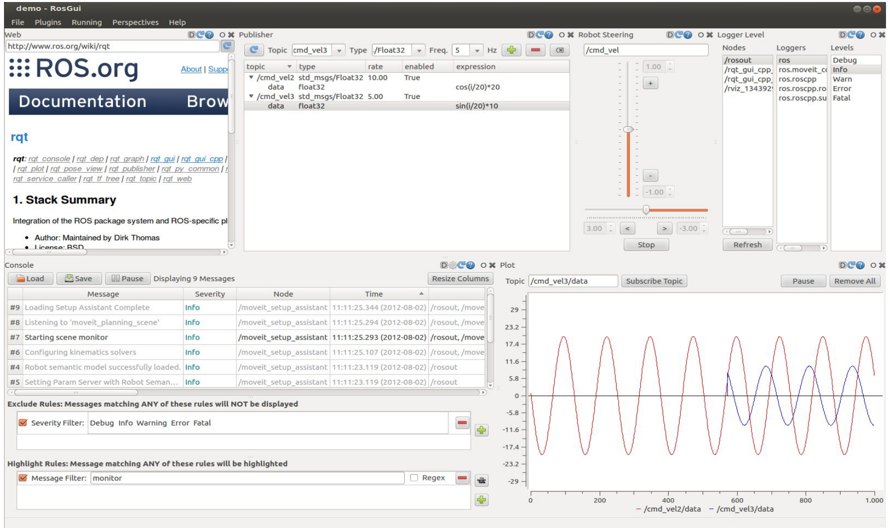
```
$ rosparam list
```

More info:
http://wiki.ros.org/rosparam

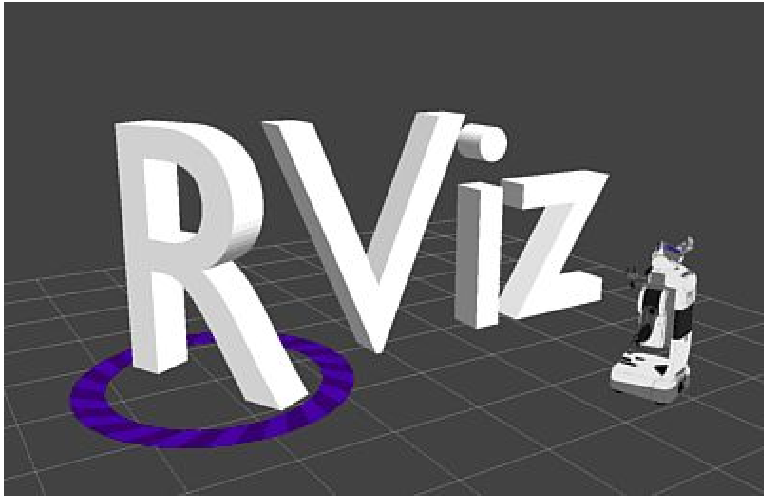


ROS GUI Tools

rqt : A QT based GUI developed for ROS



rviz : Powerful tool for 3D Visualization



(demo in today's class)

More info:
http://wiki.ros.org/rqt

ROS Time

- Normally, ROS uses the PC's system clock as time source (wall time)
- For simulations or playback of logged data, it is convenient to work with a simulated time (pause, slow-down etc.)
- To work with a simulated clock:
  - Set the `/use_sim_time` parameter

```
$ rosparam set use_sim_time true
```

  - Publish the time on the topic /clock from
    - Gazebo (enabled by default)
    - ROS bag (use option --clock)

- To take advantage of the simulated time, you should always use the ROS Time APIs:
  - **ros::Time**

```
ros::Time begin = ros::Time::now();
double secs = begin.toSec();
```

  - **ros::Duration**

```
ros::Duration duration(0.5); // 0.5s
```

More info:
http://wiki.ros.org/Clock

Slide Credit: Marco Hutter, ETH Zurich

ROS Bags

- A bag is a format for storing message data
- Binary format with file extension *.bag
- Suited for logging and recording datasets for later visualization and analysis

Record all topics in a bag

```
$ rosbag record --all
```

Record given topics

$ rosbag record *topic_1 topic_2 topic_3*

Show information about a bag

$ rosbag info *bag_name.bag*

Record given topics

$ rosbag play [options] *bag_name.bag*

--rate=factor	Publish rate factor
--clock	Publish the clock time (set param use_sim_time to true)
--loop	Loop playback

More info:
http://wiki.ros.org/Clock

Slide Credit: Marco Hutter, ETH Zurich

Libraries/Tools available with ROS

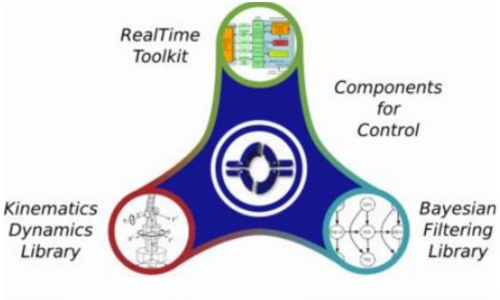
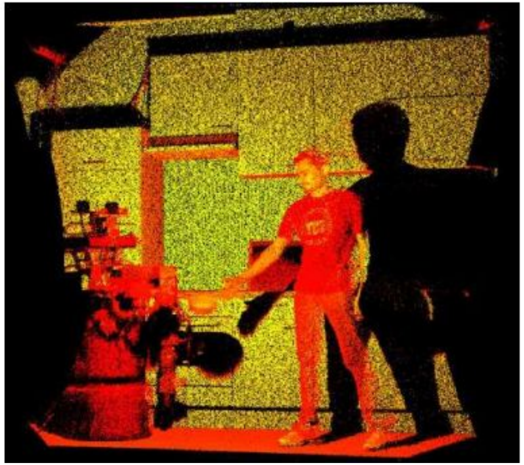


Image Courtesy: Open Source Robotics Foundation

What are Point Clouds?

- “Cloud”/collection of *n*-D points (usually *n=3*)
- Used to represent 3D information about the world:

$$\mathrm{p}_i = \{x_i, y_i, z_i\} \longrightarrow \mathcal{P} = \{\mathrm{p}_1, \mathrm{p}_2, \ldots, \mathrm{p}_i, \ldots, \mathrm{p}_n\}$$



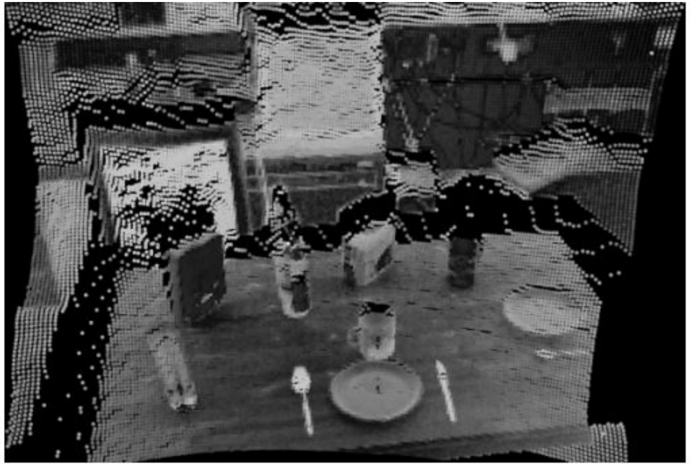


Image Courtesy: Bastian Steder, University of Freiburg

What are Point Clouds?

- besides XYZ data, each point can hold additional information like RGB colors, intensity values, distances, segmentation results, *etc.*

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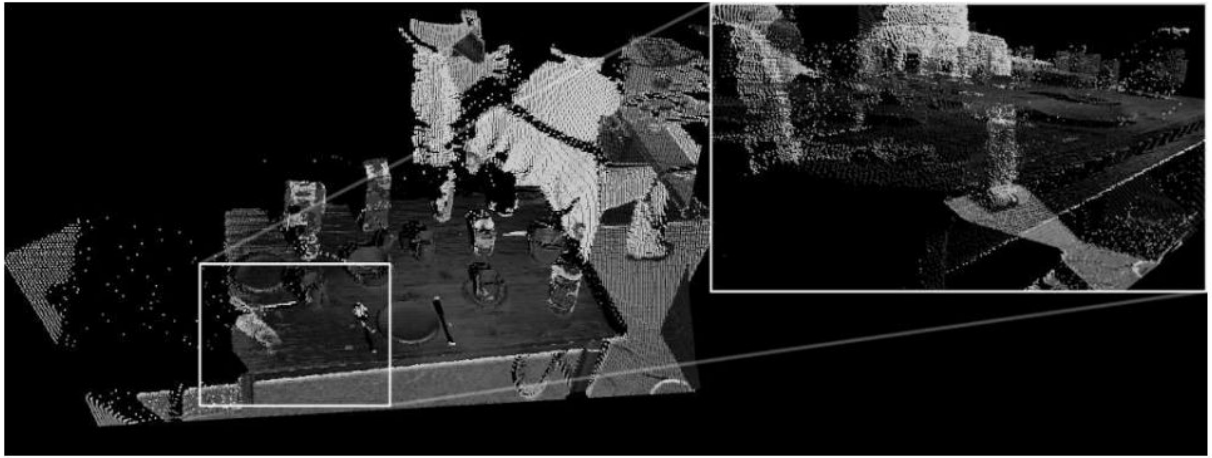

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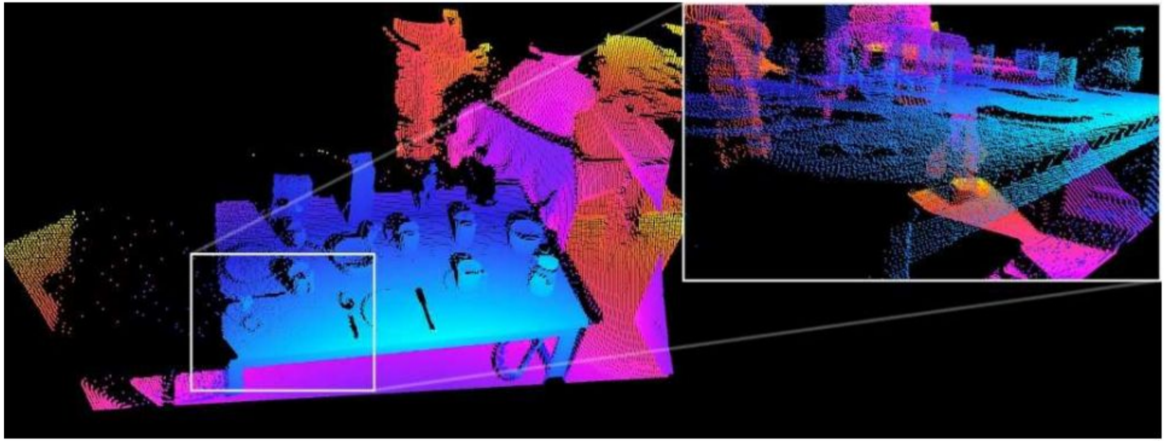

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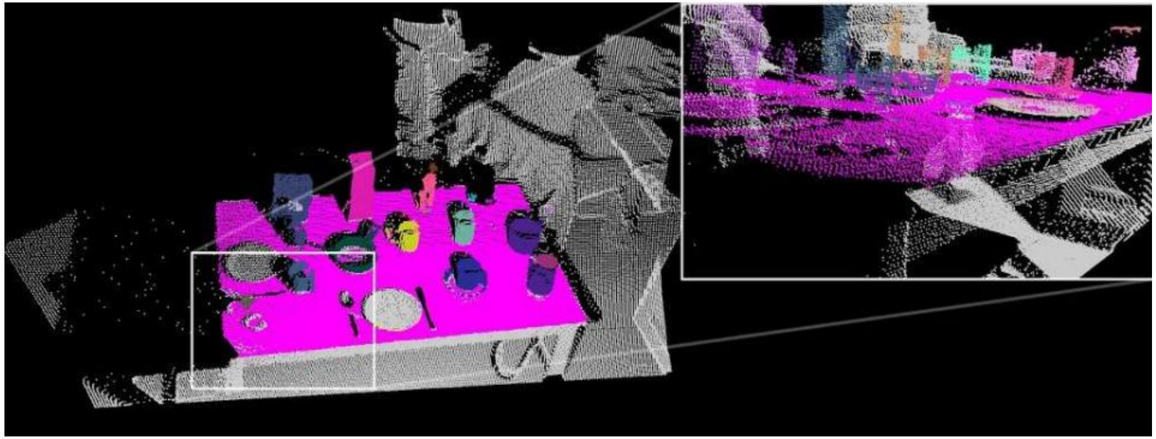


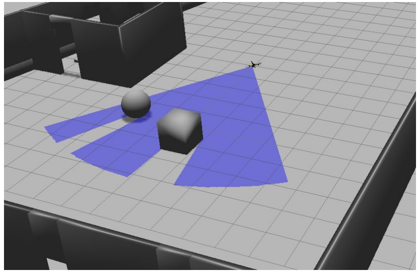
Image Courtesy: Bastian Steder, University of Freiburg

How are Point Clouds collected?

Laser scans
(high quality)

Stereo cameras
(passive & fast but dependent on texture)

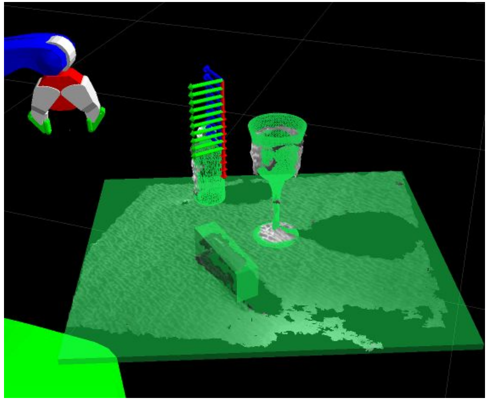
Time of flight cameras
(fast but not as accurate/robust)



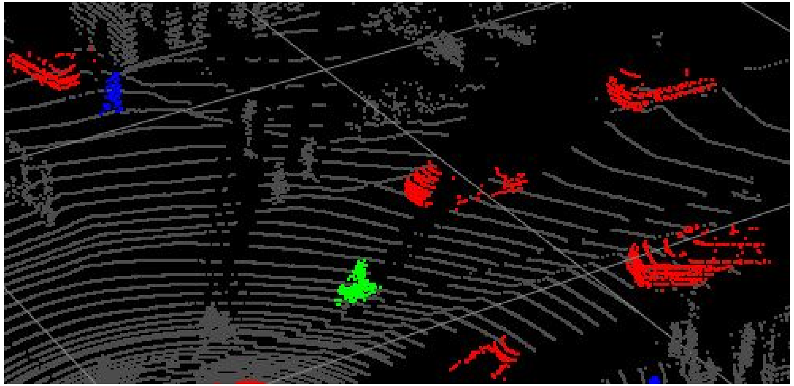
Simulation

How are Point Clouds useful?

- Spatial information of the environment has many important applications
  - Navigation / Obstacle avoidance
  - Grasping
  - Object recognition



Grasping Objects on Table

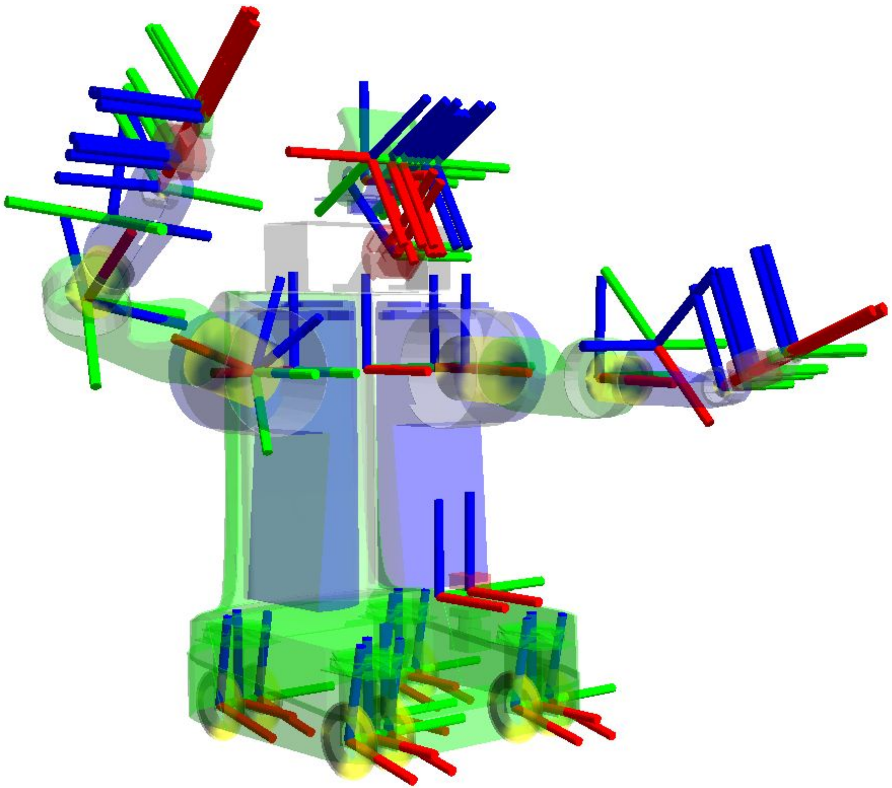


Detection of cars in Point Cloud

More info:
http://wiki.ros.org/pcl

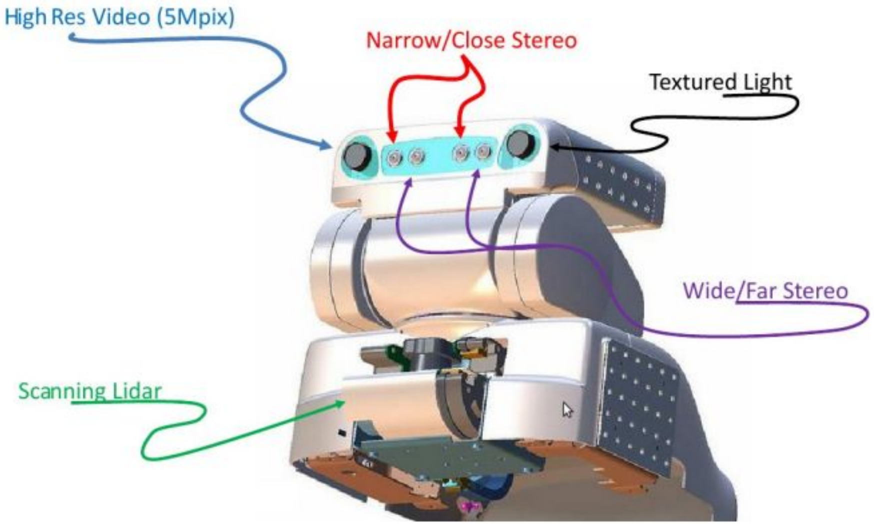
Coordinate frames

- 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



Specifying the Arrangement of Devices

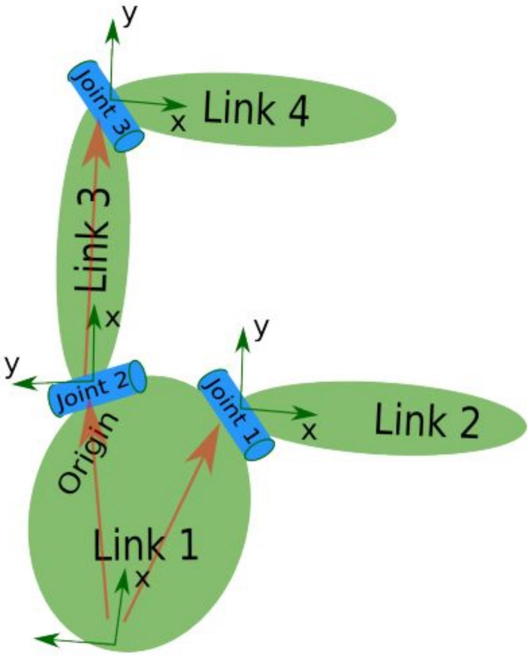
- All these devices are mounted on a robot in an articulated way.
- Some devices are mounted on other devices that can move.
- In order to use all the sensors/ actuators together we need to describe this configuration.
  - For each “device” specify one or more frames of interest
  - Describe how these frames are located w.r.t each other



Slide Credit: Wolfram Burgard, University of Freiburg

Defining the Structure

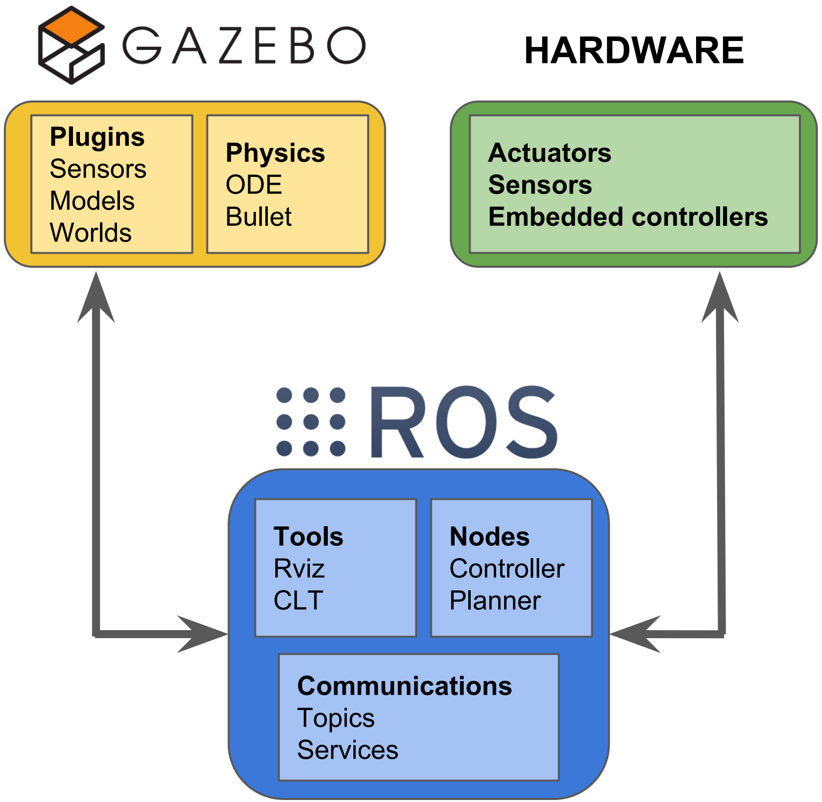
- Each “Link” is a reference frame of a sensor
- Each “joint” defines the transformation that maps the child link in the parent link.
- ROS does not handle closed kinematic chains, thus only a “tree” structure is allowed
- The root of the tree is usually some convenient point on the mobile base (or on its footprint)



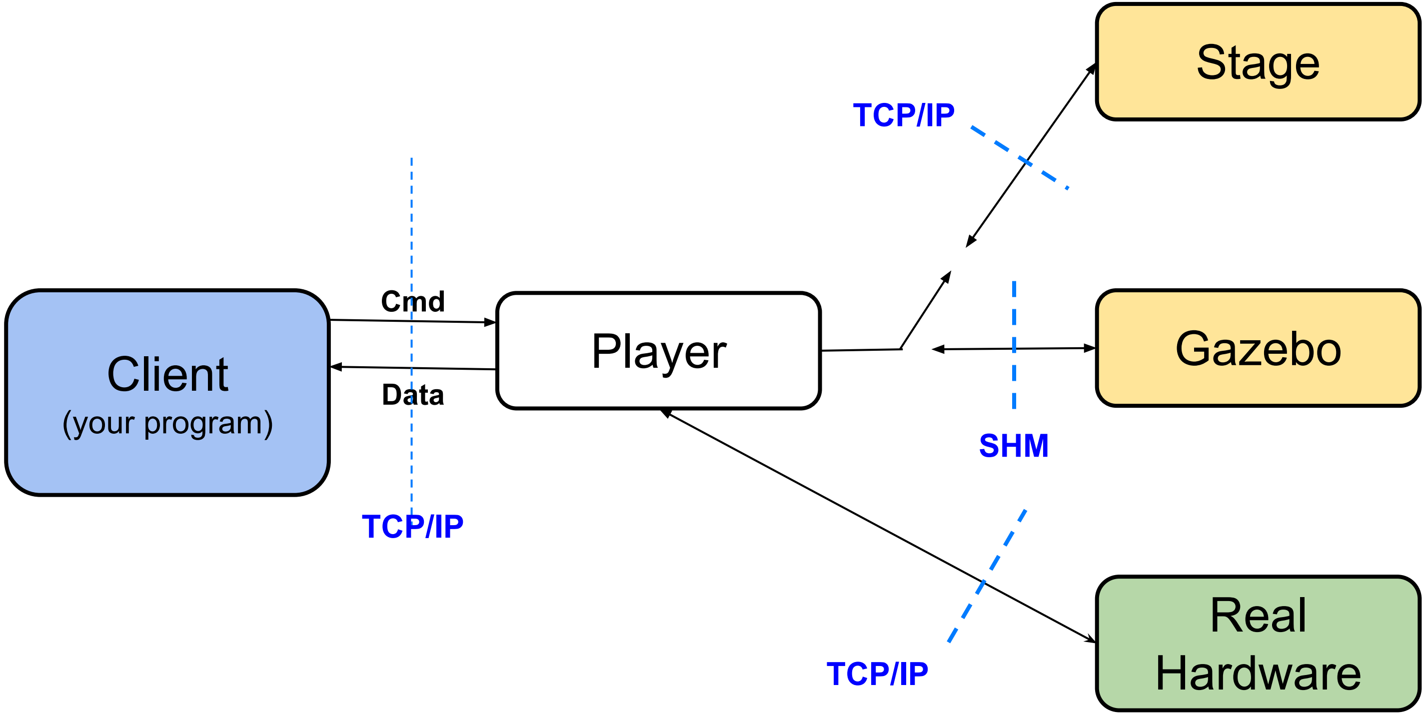
Slide Credit: Wolfram Burgard, University of Freiburg

Robot Simulation

- Simulators mimic the real world, to a certain extent
  - Simulates robots, sensors, and objects in a 3-D dynamic environment
  - Generates realistic sensor feedback and physical interactions between objects
- Why use them?
  - Save time and your sanity
  - Experimentation much less destructive
  - Use hardware you don't have
  - Create really cool videos



Simulation Architecture



Simulation Architecture

Gazebo runs 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

Run Gazebo server and client separately:

```
$ gzserver
$ gzclient
```

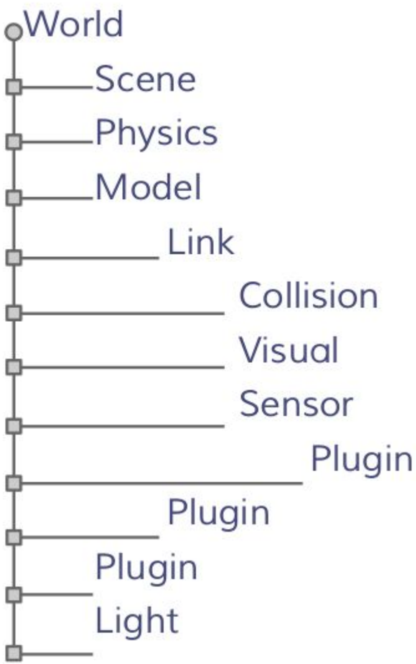
Run Gazebo server and client simultaneously:

```
$ gazebo
```

Elements within Simulation

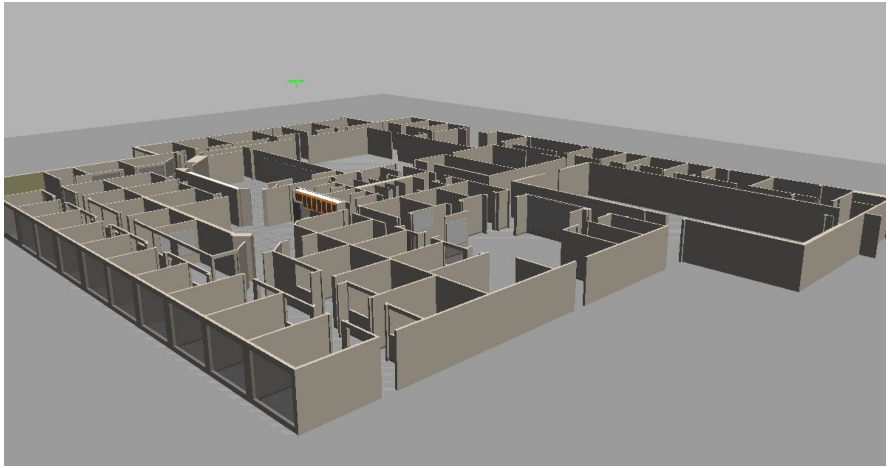
- World
  - Collection of models, lights,plugins and global properties
- Models
  - Collection of links, joints,sensors, and plugins
- Links
  - Collection of collision and visual objects
- Collision Objects
  - Geometry that defines a colliding surface
- Visual Objects
  - Geometry that defines visual representation
- Joints
  - Constraints between links
- Sensors
  - Collect, process, and output data
- Plugins
  - Code attached to a World, Model, Sensor, or the simulator itself

Element Hierarchy



World

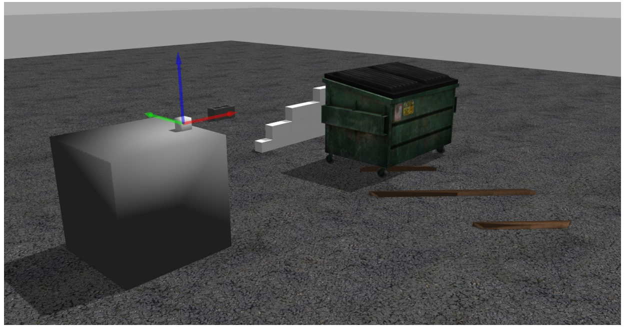
- A world is composed of a model hierarchy
- The Gazebo server (*gzserver*) reads the world file to generate and populate a world
  - This file is formatted using SDF (Simulation Description format) or URDF (Unified Robot Description Format)
  - Has a *".world"* extension
  - Contains all the elements in a simulation, including robots, lights, sensors, and static objects



Willow Garage World

Models

- Each model contains a few key properties:
  - **Physical presence** (optional):
    - Body: sphere, box, composite shapes
    - Kinematics: joints, velocities
    - Dynamics: mass, friction, forces
    - Appearance: color, texture
  - **Interface** (optional):
    - Control and feedback interface (libgazebo)

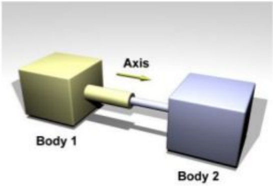


Element Types

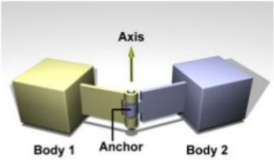
- Collision and Visual Geometries
  - Simple shapes: sphere, cylinder, box, plane
  - Complex shapes: heightmaps, meshes

Element Types

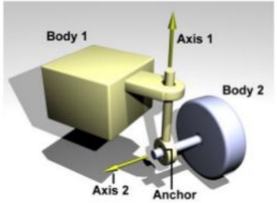
- Collision and Visual Geometries
  - Simple shapes: sphere, cylinder, box, plane
  - Complex shapes: heightmaps, meshes
- Joints
  - Prismatic: 1 DOF translational
  - Revolute: 1 DOF rotational
  - Revolute2: Two revolute joints in series
  - Ball: 3 DOF rotational
  - Universal: 2 DOF rotational
  - Screw: 1 DOF translational, 1 DOF rotational



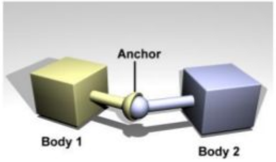
Prismatic



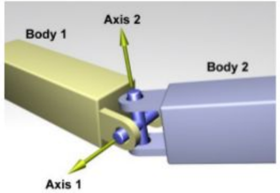
Revolute



Revolute 2



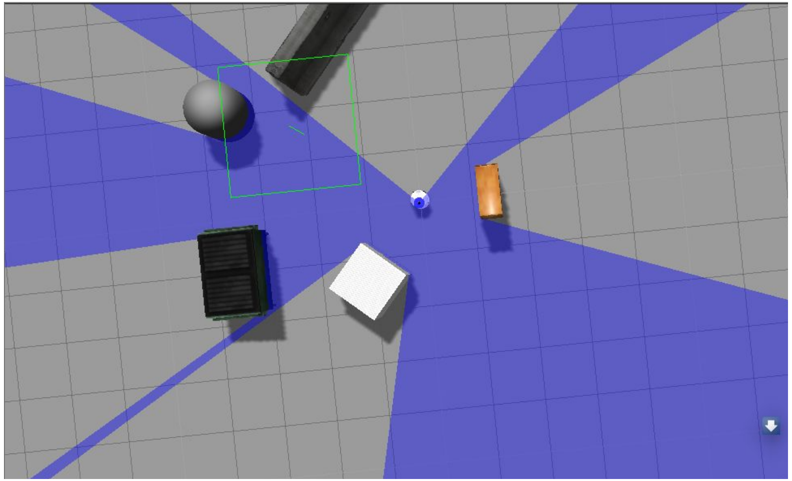
Ball



Universal

Element Types

- Sensors
  - Ray: produces range data
  - Camera (2D and 3D): produces image and/or depth data
  - Contact: produces collision data
  - RFID: detects RFID tags
- Lights
  - Point: omni-directional light source, a light bulb
  - Spot: directional cone light, a spot light
  - Directional: parallel directional light, sun

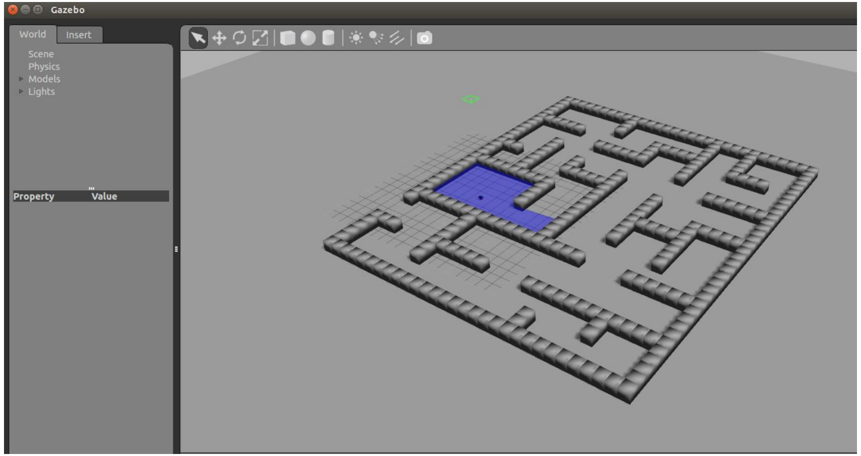


LiDAR sensor in Gazebo

How to use Gazebo to simulate your robot?

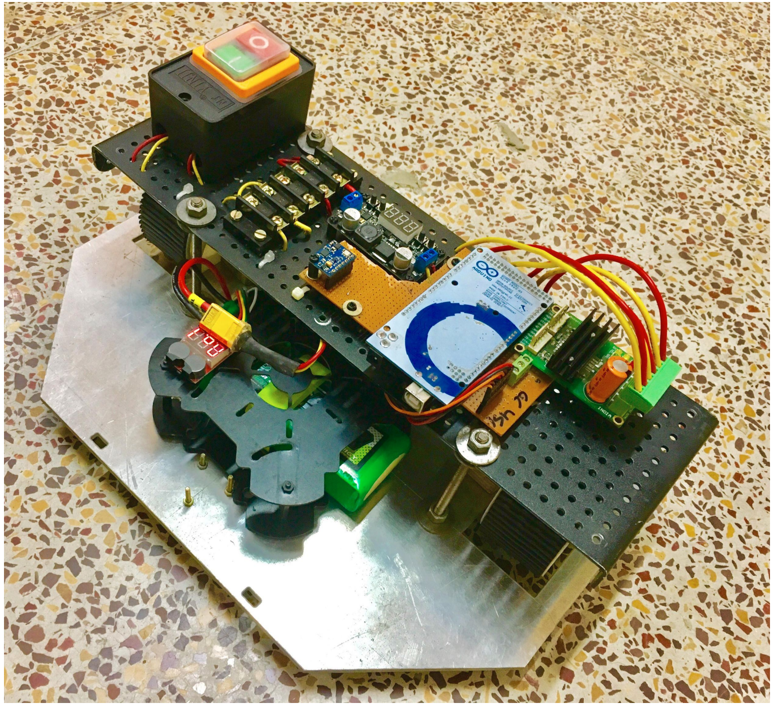
Steps:

1. load a world
2. load the description of the robot
3. spawn the robot in the world
4. publish joints states
5. publish robot states
6. run rviz



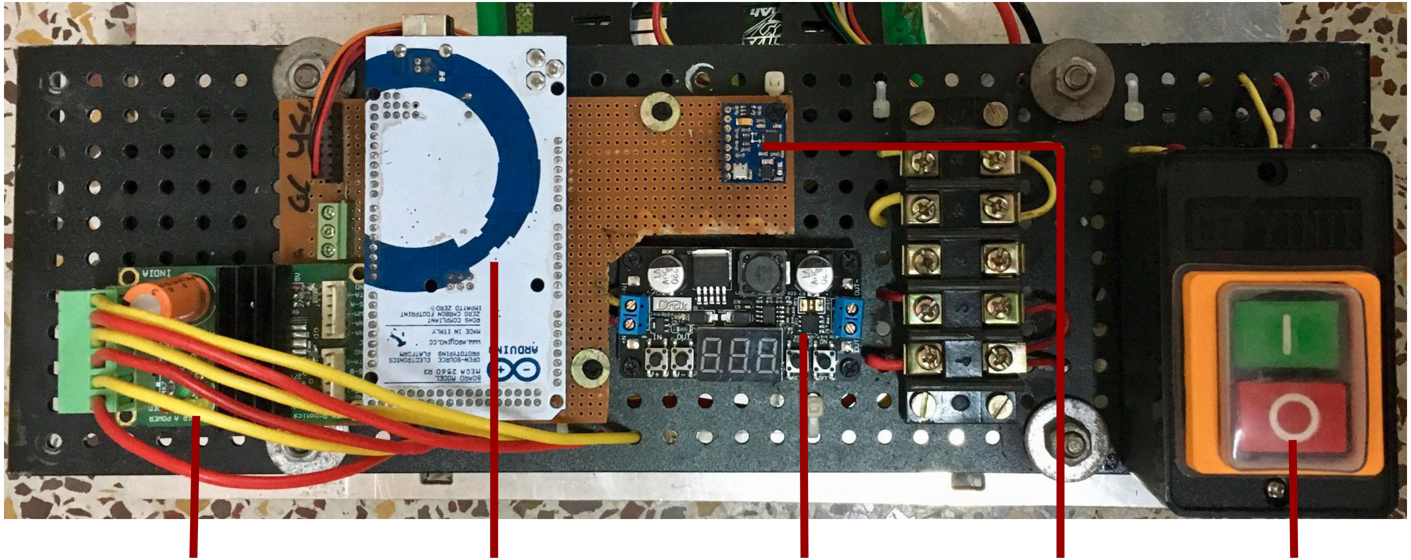
Meet Robot "*Alpha*"

- Two-wheeled differential drive robot
- Sensors:
  - Rotary Encoders
  - IMU
  - Camera
  - Kinect 360
  - Hokuyo URG-04
- Actuator
  - Brushed DC Motor



Meet Robot “*Alpha*”

- How to design and create your own robot?



Real-Time Appearance-Based (RTAB) Mapping

- RGB-D Graph-Based SLAM approach based on an incremental appearance-based loop closure detector
- Can be used alone with a hand-held Kinect or stereo camera for 6DoF RGB-D mapping

More info:
http://wiki.ros.org/rtabmap

Rao-Blackwellized Particle Filter SLAM (GMapping)

- Uses a particle filter in which each particle carries an individual map of the environment
- Optimized for long-range laser scanners like SICK LMS or PLS scanner

DEMO

More info:
https://www.openslam.org/gmapping.html

Meet Robot “*Alpha*”

- All source code available online, feel free to test them out and contribute!

https://github.com/Mayankm96/Phase-VII

Homework

- Install Ubuntu 16.04 and ROS Kinetic on laptop
  - Software setup scripts here
- Checkout ROS Wiki and Tutorials
  - Wiki (http://wiki.ros.org/)
  - Tutorials (http://wiki.ros.org/ROS/Tutorials)
  - Available Packages (http://www.ros.org/browse/list.php)

- Go through the lecture videos on 'Programming for Robotics' by ETH Zurich *(optional)*

References

- Gazebo Website (http://gazebosim.org/)
- Koenig, N & Howard, A. "**Design and use paradigms for Gazebo, an open-source multi-robot simulator"** (2004). IEEE/RSJ International Conference on Intelligent Robots and Systems. 2149 - 2154 vol.3. 10.1109/IROS.2004.1389727.
- M. Labbé and F. Michaud, "**Long-term online multi-session graph-based SPLAM with memory management,**" in Autonomous Robots, accepted, 2017. (Springer)