October 2016

ROS – Lecture 4

Gazebo simulator
Reading Sensor Data
Wander-Bot

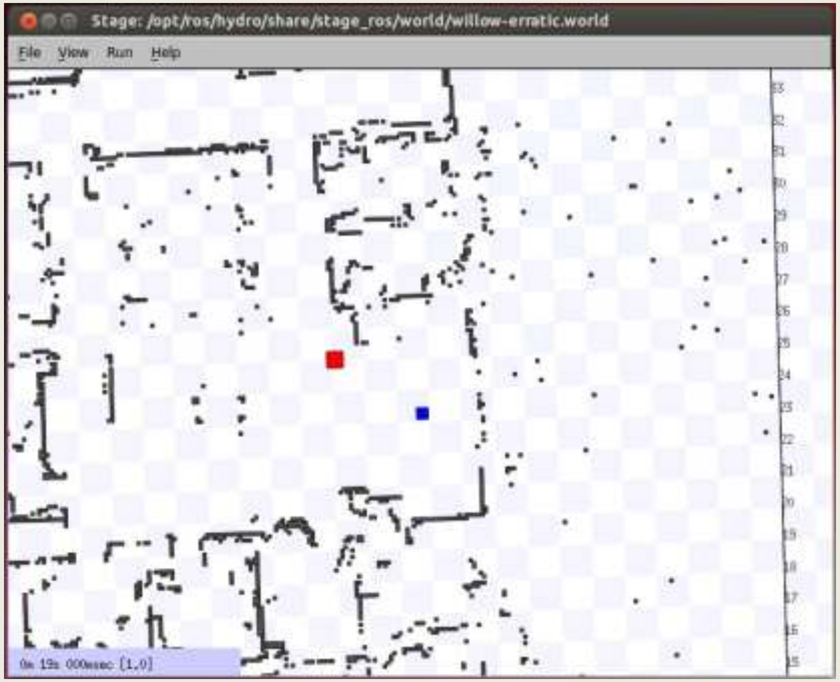
BIRC
BIU Robotics Consortium

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

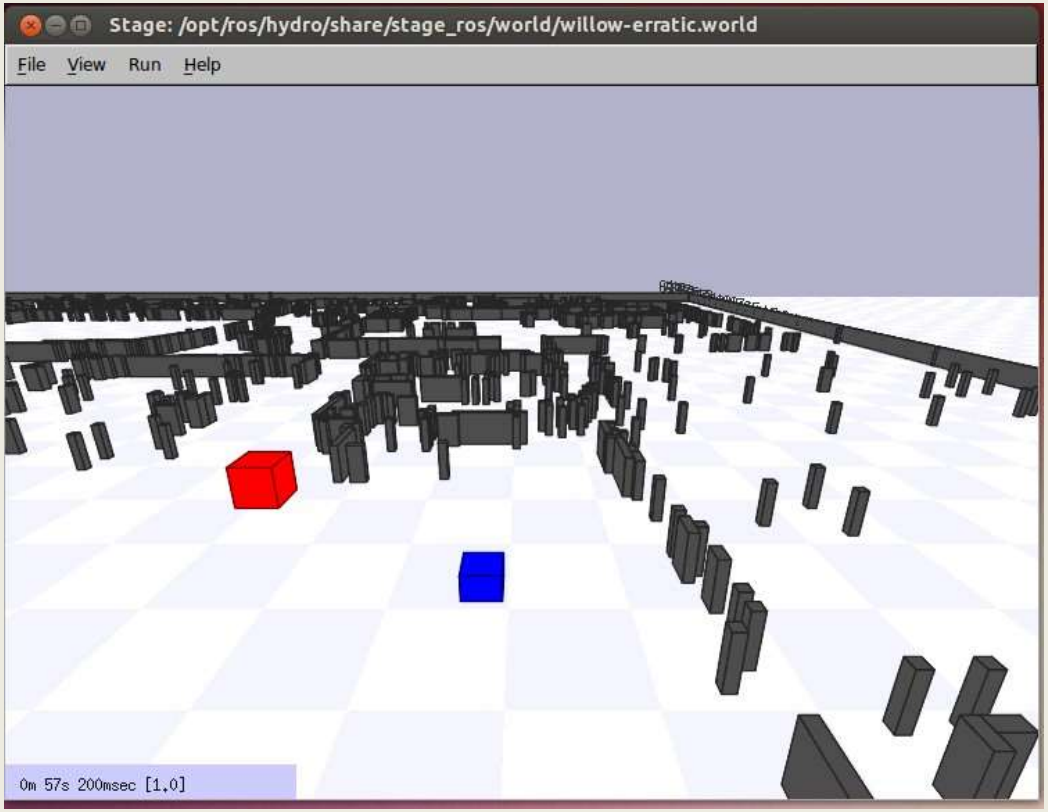
ROS Stage Simulator

- 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

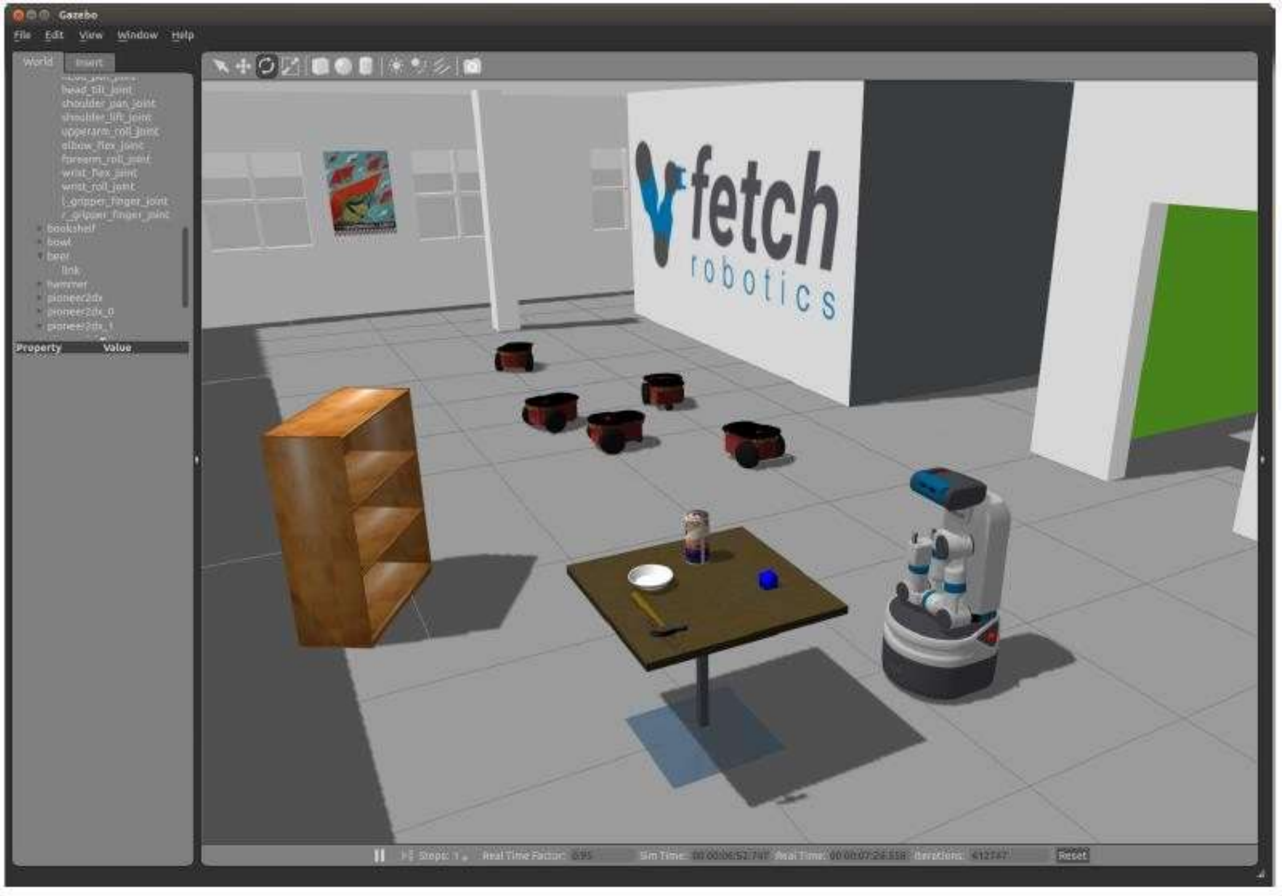


Gazebo

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

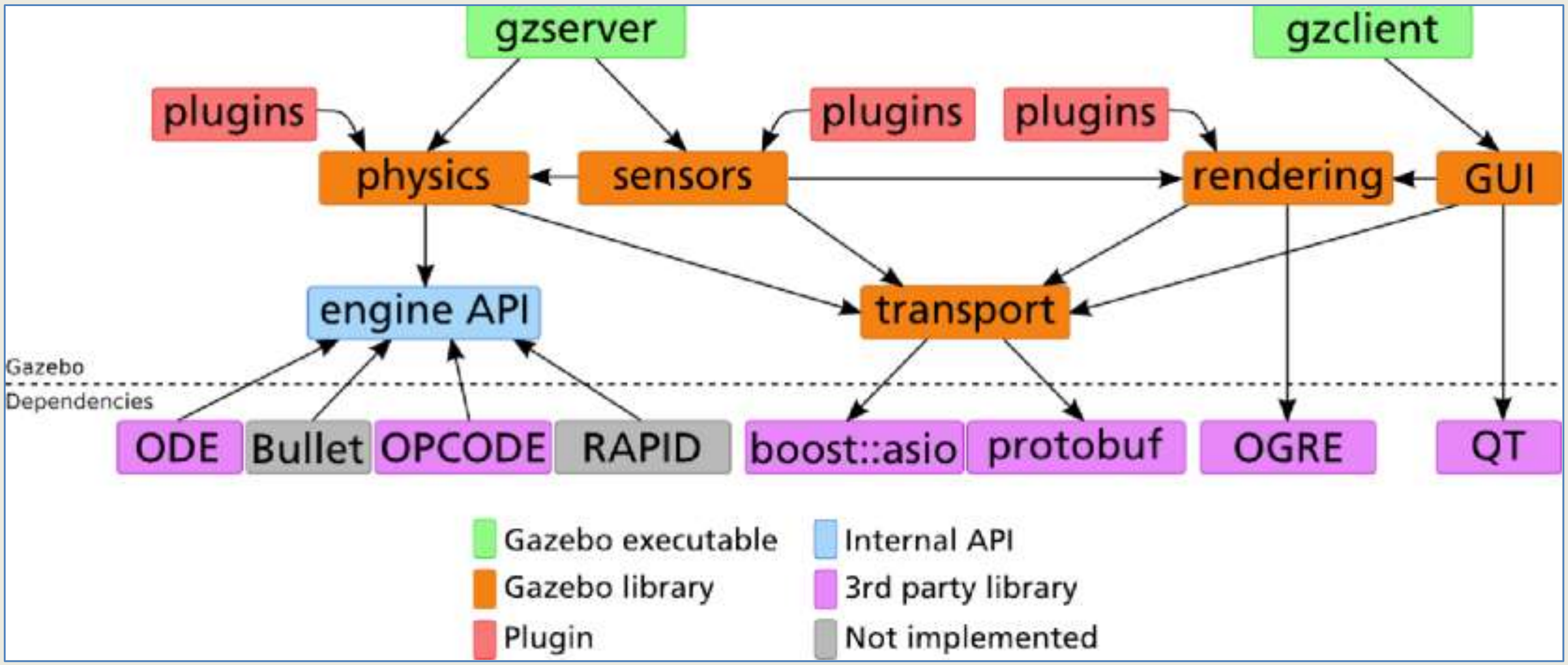
- ROS Indigo comes with Gazebo V2.2
- Gazebo home page - http://gazebosim.org/
- Gazebo tutorials - http://gazebosim.org/tutorials

Gazebo Architecture

<u>Gazebo consists of two processes</u>:

- **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

Gazebo Architecture



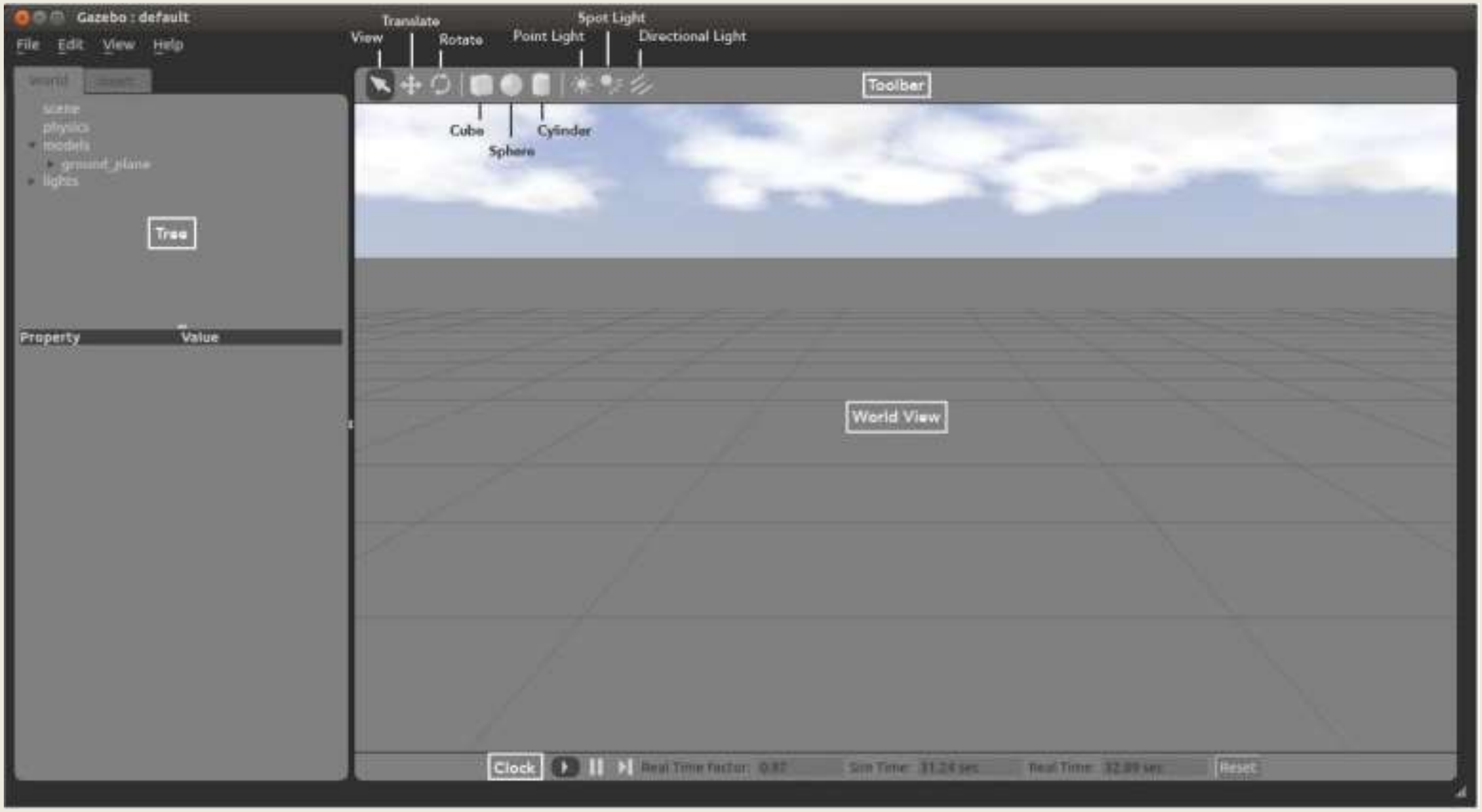
Running Gazebo from ROS

- To launch Gazebo type:

```
$ rosrun gazebo_ros gazebo
```

- Note: When you first launch Gazebo it may take a few minutes to update its model database

Gazebo User Interface



The World View

- The World View displays the world and all of the models therein
- Here you can add, manipulate, and remove models
- You can switch between View, Translate and Rotate modes of the view in the left side of the Toolbar

View Mode

Translate	Left-press + drag
Orbit	Middle-press + drag
Zoom	Scroll wheel
Accelerated Zoom	Alt + Scroll wheel
Jump to object	Double-click object
Select object	Left-click object

Translate Mode

Translate	Left-press + drag
Translate (x-axis)	Left-press + X + drag
Translate (y-axis)	Left-press + Y + drag
Translate (z-axis)	Left-press + Z + drag

(Orbit & Zoom work in this mode, as well)

Rotate Mode

Rotate (spin) object	Left-press + drag
Rotate (x-axis)	Left-press + X + drag
Rotate (y-axis)	Left-press + Y + drag
Rotate (z-axis)	Left-press + Z + drag

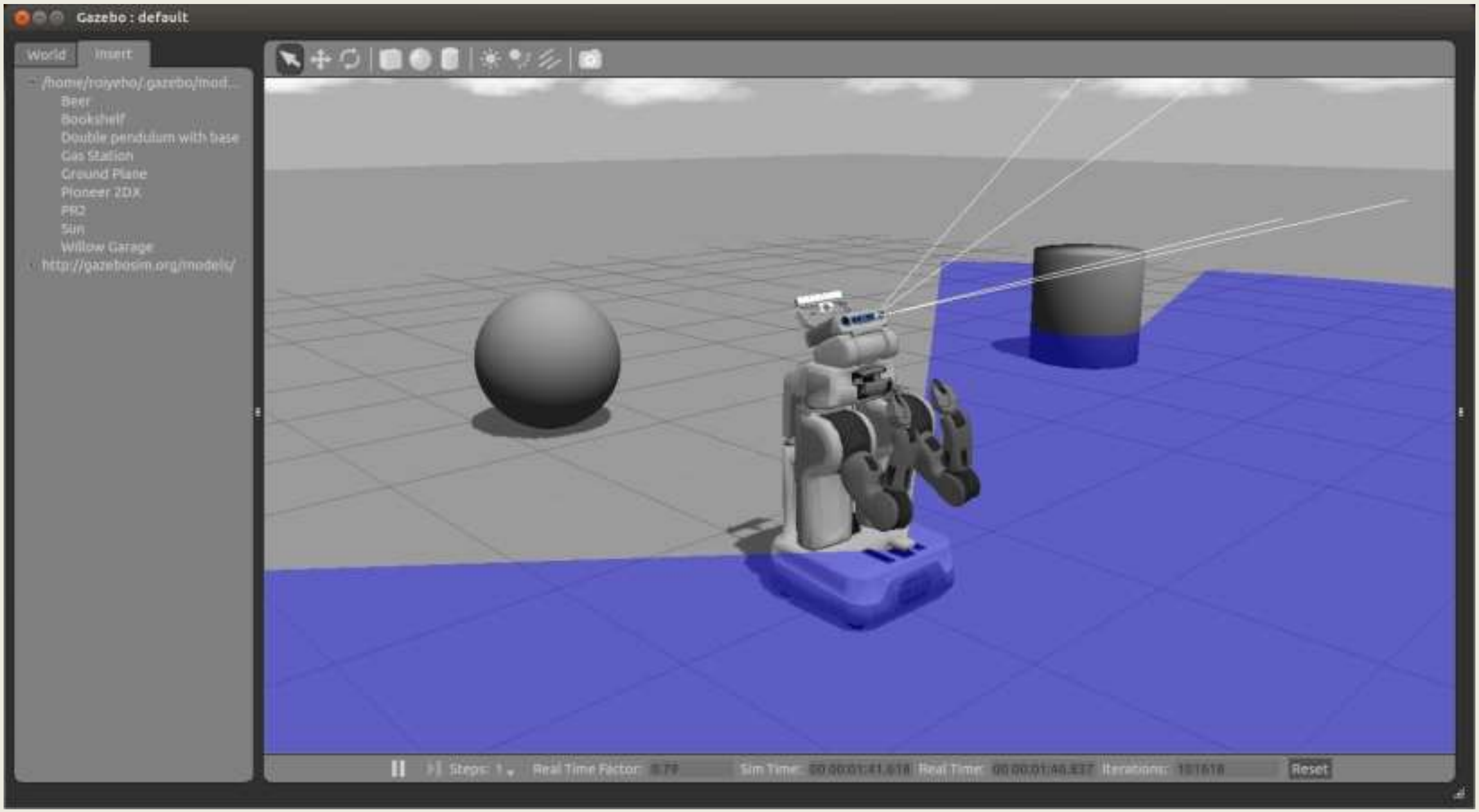
(Orbit & Zoom work in this mode, as well)

Add a Model

<u>To add a model to the world:</u>

- left-click on the desired model in the Insert Tab on the left side
- move the cursor to the desired location in World View
- left-click again to release
- Use the Translate and Rotate modes to orient the model more precisely

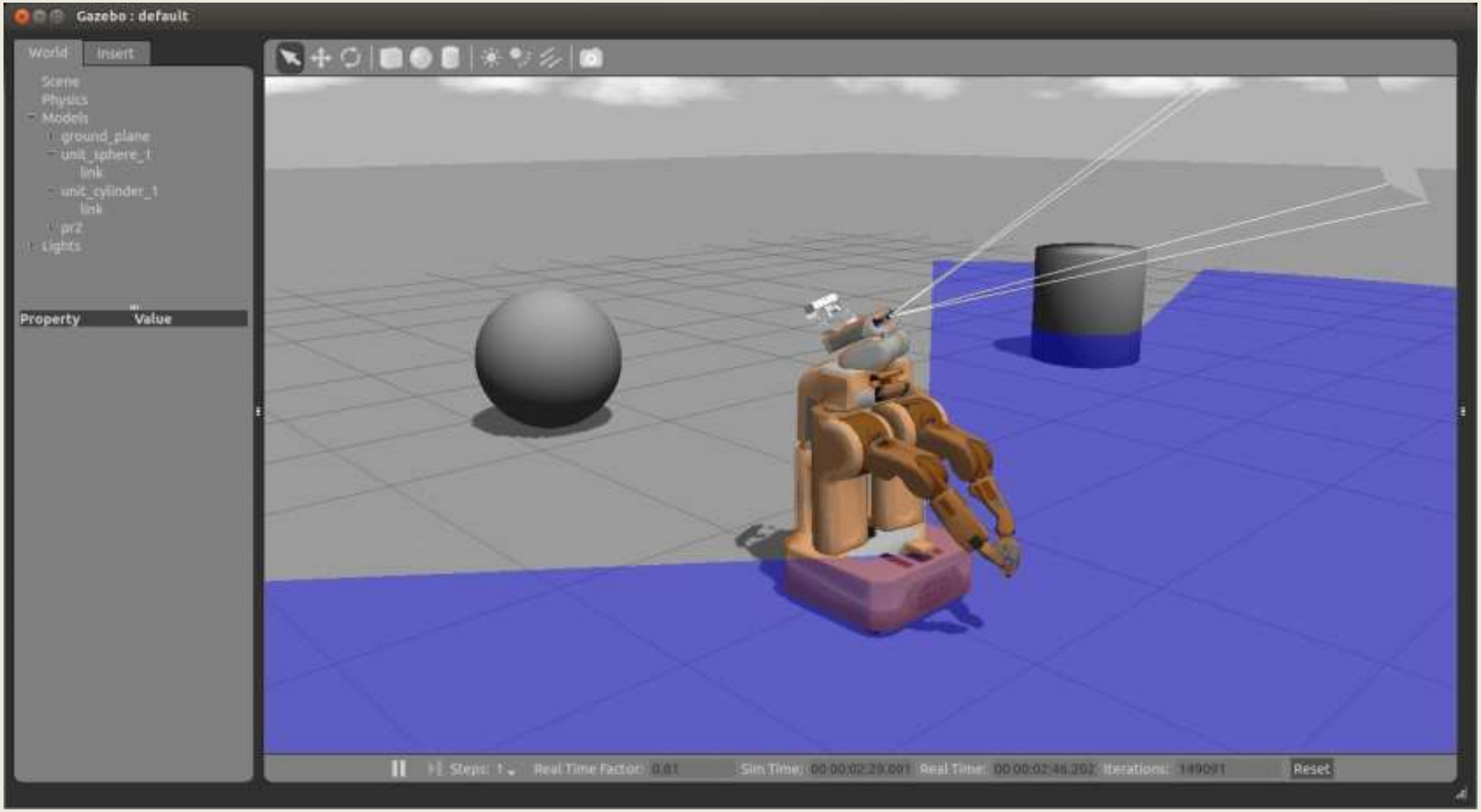
Inserting PR2 Robot



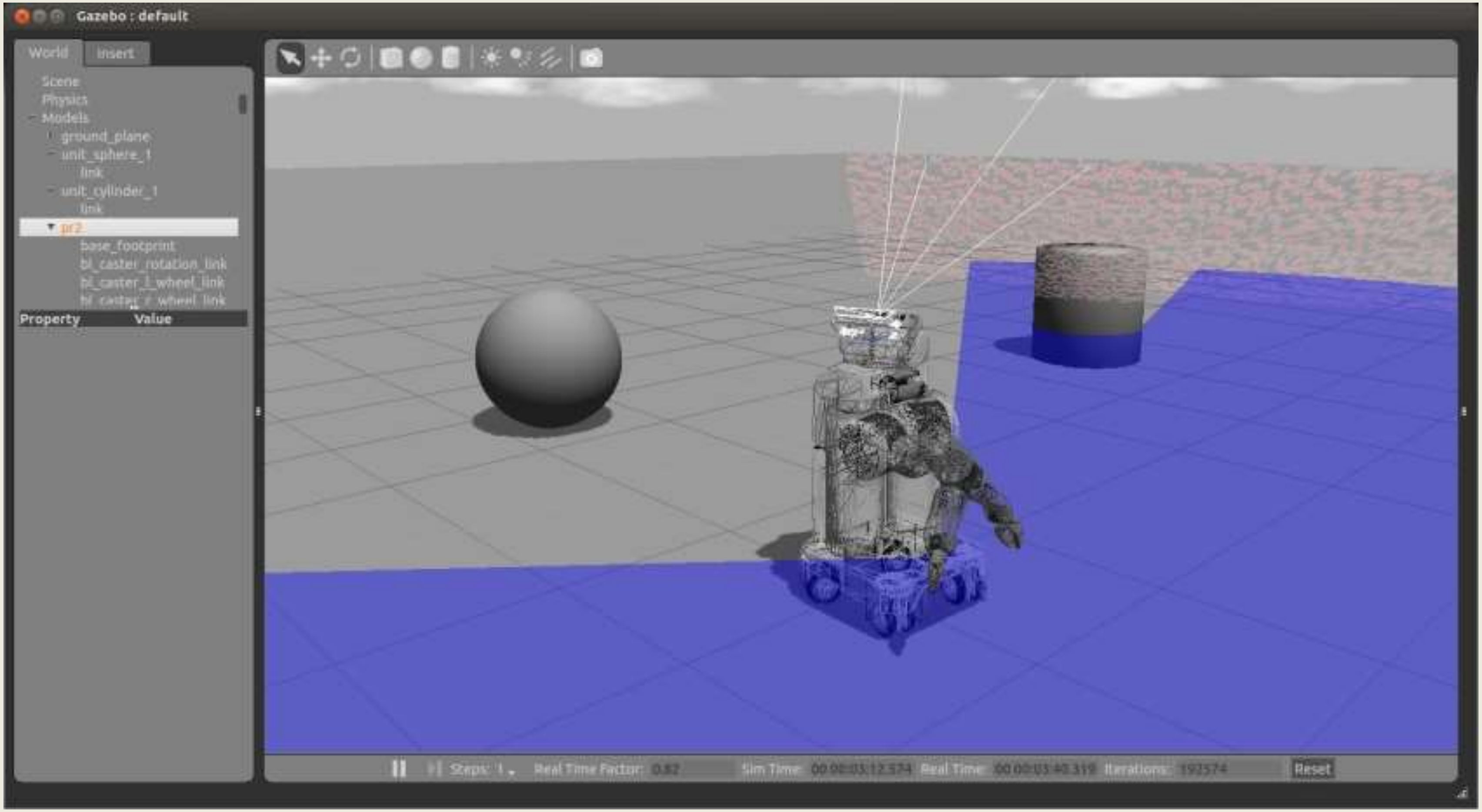
Models Item

- The models item in the world tab contains a list of all models and their links
- Right-clicking on a model in the Models section gives you three options:
  - **Move to** – moves the view to be directly in front of that model
  - **Follow**
  - **View** – allows you to view different aspects of the model, such as Wireframe, Collisions, Joints
  - **Delete** – deletes the model

Collisions View

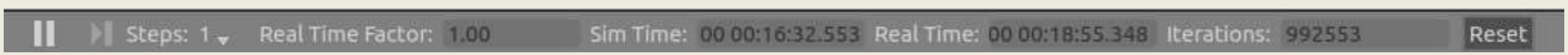


Wireframe View



Clock

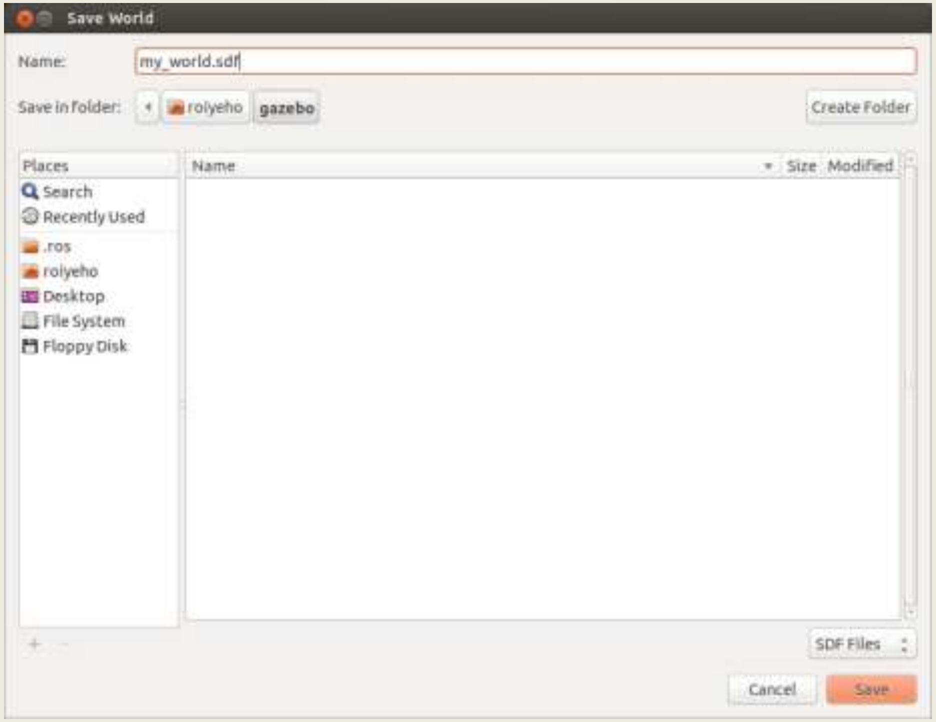
- You can start, pause and step through the simulation with the clock
- It is located at the bottom of the World View



- **Real Time Factor:** Displays how fast or slow the simulation is running in comparison to real time
  - A factor less than 1.0 indicates simulation is running slower than real time
  - Greater then 1.0 indicates faster than real time

Saving a World

- Once you are happy with a world it can be saved through the File->Save As menu.
- Enter my_world.sdf as the file name and click OK



Loading a World

- A saved world may be loaded on the command line:

```
$ gazebo my_world.sdf
```

- The filename must be in the current working directory, or you must specify the complete path

World Description File

- The world description file contains all the elements in a simulation, including robots, lights, sensors, and static objects
- This file is formatted using SDF and has a .world extension
- The Gazebo server (gzserver) reads this file to generate and populate a world

Example World Files

- Gazebo ships with a number of example worlds
- World files are found within the /worlds directory of your Gazebo resource path
  - A typical path might be /usr/share/gazebo-2.2
- In gazebo_ros package there are built-in launch files that load some of these world files
- For example, to launch willowgarage_world type:

```
$ roslaunch gazebo_ros willowgarage_world.launch
```

willowgarage.world

```
<?xml version="1.0" ?>
<sdf version="1.4">
  <world name="default">
    <include>
      <uri>model://ground_plane</uri>
    </include>
    <include>
      <uri>model://sun</uri>
    </include>
    <include>
      <uri>model://willowgarage</uri>
    </include>
  </world>
</sdf>
```

- In this world file snippet you can see that three models are referenced
- The three models are searched for within your local Gazebo Model Database
- If not found there, they are automatically pulled from Gazebo's online database

Launch World Files

- In gazebo_ros package there are built-in launch files that load some of these world files
- For example, to launch willowgarage_world type:

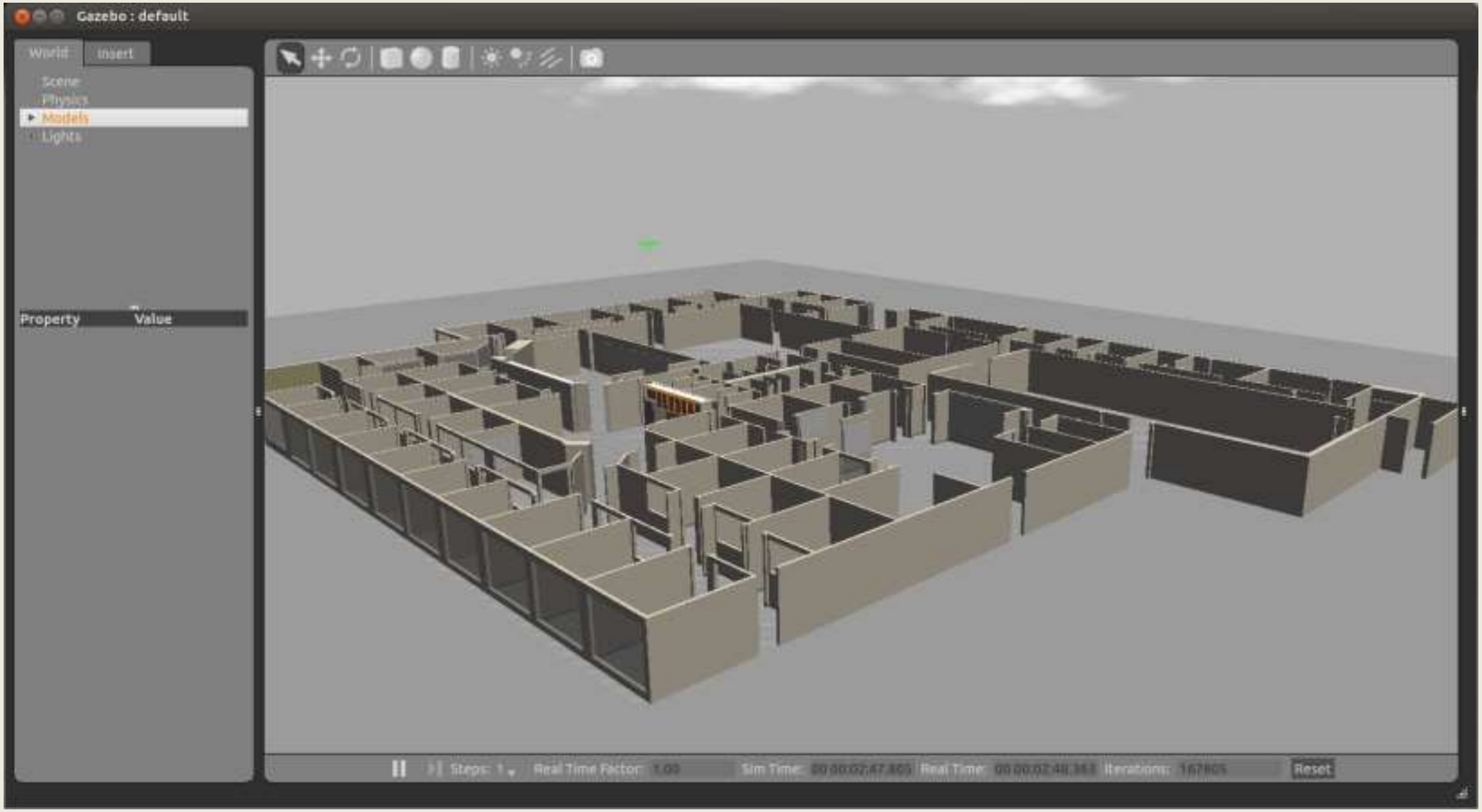
```
$ roslaunch gazebo_ros willowgarage_world.launch
```

willowgarage_world.launch

```
<launch>
  <!-- We resume the logic in empty_world.launch, changing only the name of the world to
be launched -->
  <include file="$(find gazebo_ros)/launch/empty_world.launch">
    <arg name="world_name" value="worlds/willowgarage.world"/> <!-- Note: the
world_name is with respect to GAZEBO_RESOURCE_PATH environmental variable -->
    <arg name="paused" value="false"/>
    <arg name="use_sim_time" value="true"/>
    <arg name="gui" value="true"/>
    <arg name="headless" value="false"/>
    <arg name="debug" value="false"/>
  </include>
</launch>
```

- This launch file inherits most of the necessary functionality from empty_world.launch
- The only parameter we need to change is the world_name parameter, substituting the empty.world world file with willowgarage.world
- The other arguments are simply set to their default values

Willow Garage World



Model Files

- A model file uses the same SDF format as world files, but contains only a single <model> tag
- Once a model file is created, it can be included in a world file using the following SDF syntax:

```
<include filename="model_file_name"/>
```

- You can also include any model from the online database and the necessary content will be downloaded at runtime

willowgarage Model SDF File

```
<?xml version="1.0" ?>
<sdf version="1.4">
  <model name="willowgarage">
    <static>true</static>
    <pose>-20 -20 0 0 0 0</pose>
    <link name="walls">
      <collision name="collision">
        <geometry>
          <mesh>
            <uri>model://willowgarage/meshes/willowgarage_collision.dae</uri>
          </mesh>
        </geometry>
      </collision>
      <visual name="visual">
        <geometry>
          <mesh>
            <uri>model://willowgarage/meshes/willowgarage_visual.dae</uri>
          </mesh>
        </geometry>
        <cast_shadows>false</cast_shadows>
      </visual>
    </link>
  </model>
</sdf>
```

Components of Models

- **Links:** A link contains the physical properties of one body of the model. This can be a wheel, or a link in a joint chain.
  - Each link may contain many collision, visual and sensor elements
- **Collision:** A collision element encapsulates a geometry that is used to collision checking.
  - This can be a simple shape (which is preferred), or a triangle mesh (which consumes greater resources).
- **Visual:** A visual element is used to visualize parts of a link.
- **Inertial:** The inertial element describes the dynamic properties of the link, such as mass and rotational inertia matrix.
- **Sensor:** A sensor collects data from the world for use in plugins.
- **Joints:** A joint connects two links.
  - A parent and child relationship is established along with other parameters such as axis of rotation, and joint limits.
- **Plugins:** A shared library created by a 3D party to control a model.

Meet TurtleBot

- http://wiki.ros.org/Robots/TurtleBot
- A minimalist platform for ROS-based mobile robotics education and prototyping
- Has a small differential-drive mobile base
- Atop this base is a stack of laser-cut “shelves” that provide space to hold a netbook computer and depth camera and other devices
- Does not have a laser scanner
  - Despite this, mapping and navigation can work quite well for indoor spaces

Turtlebot Simulation

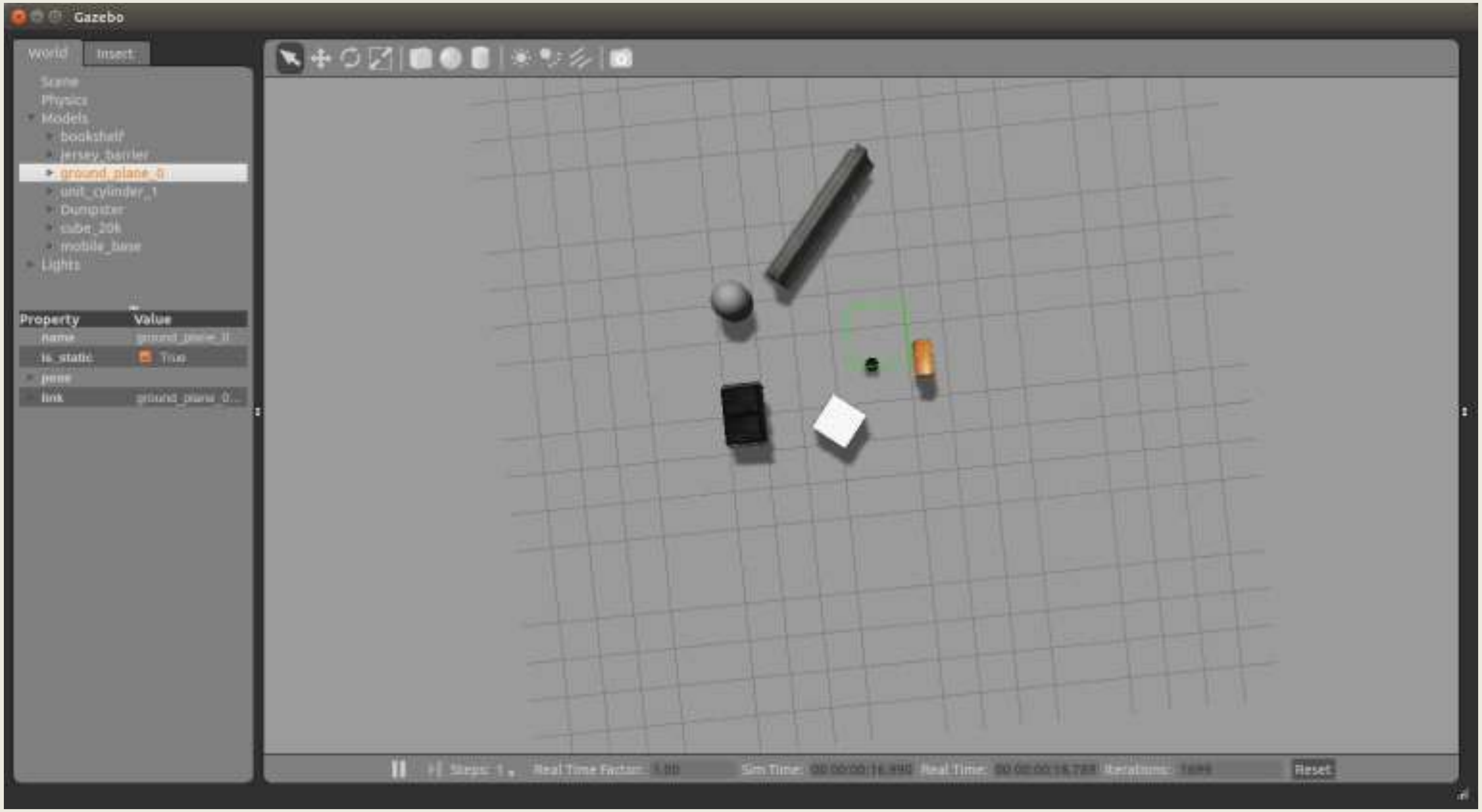
- To install Turtlebot simulation stack type:

```
$ sudo apt-get install ros-indigo-turtlebot-gazebo ros-indigo-turtlebot-apps ros-indigo-turtlebot-rviz-launchers
```

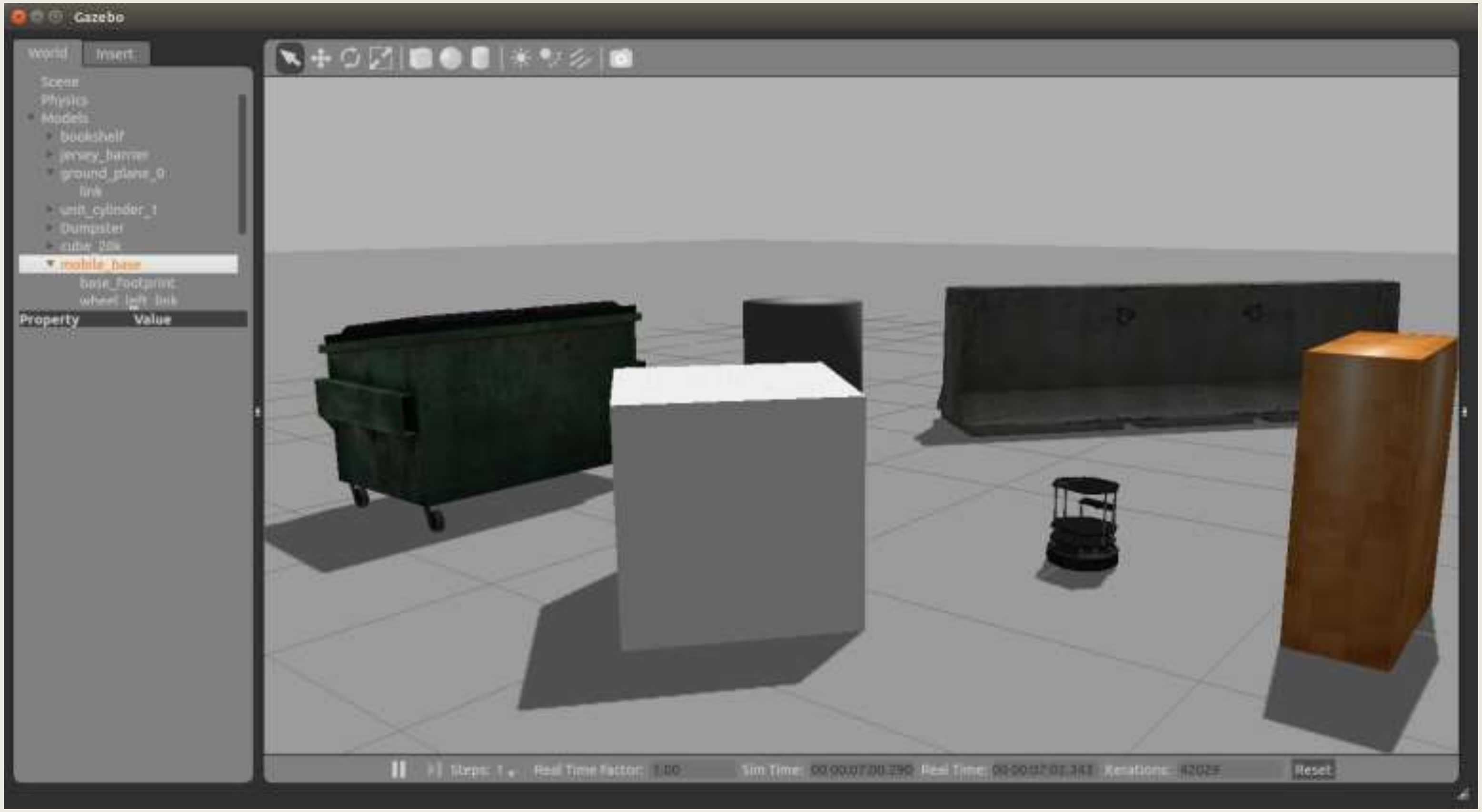
- To launch a simple world with a Turtlebot, type:

```
$ roslaunch turtlebot_gazebo turtlebot_world.launch
```

Turtlebot Simulation



Turtlebot Simulation

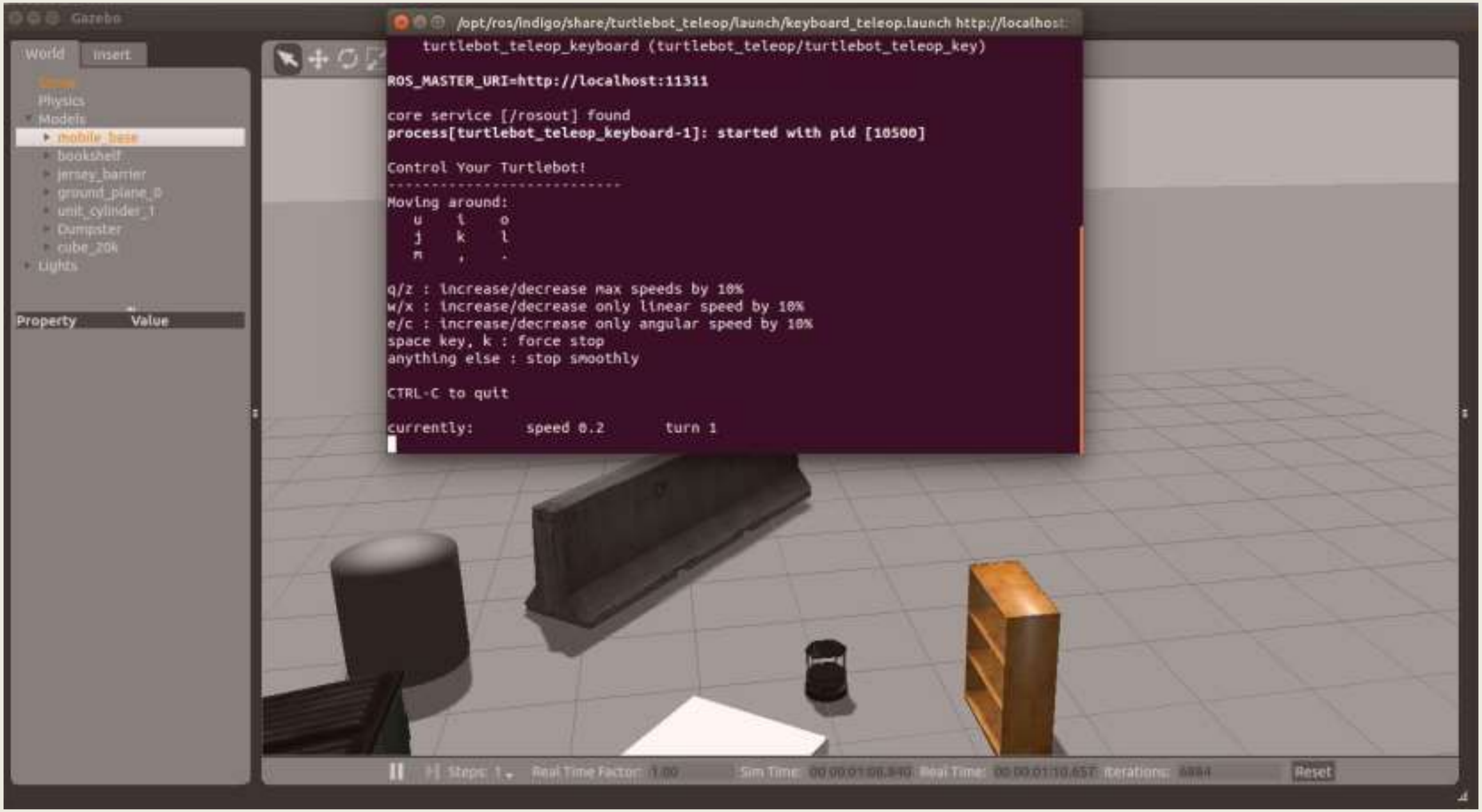


Moving Turtlebot with Teleop

- Let’s launch the teleop package so we can move it around the environment
- Run the following command:

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

Moving Turtlebot with Teleop



Laser Scan Data

- Laser data is published to the topic **/base_scan**
- The message type that used to send information of the laser is sensor_msgs/LaserScan
- You can see the structure of the message using

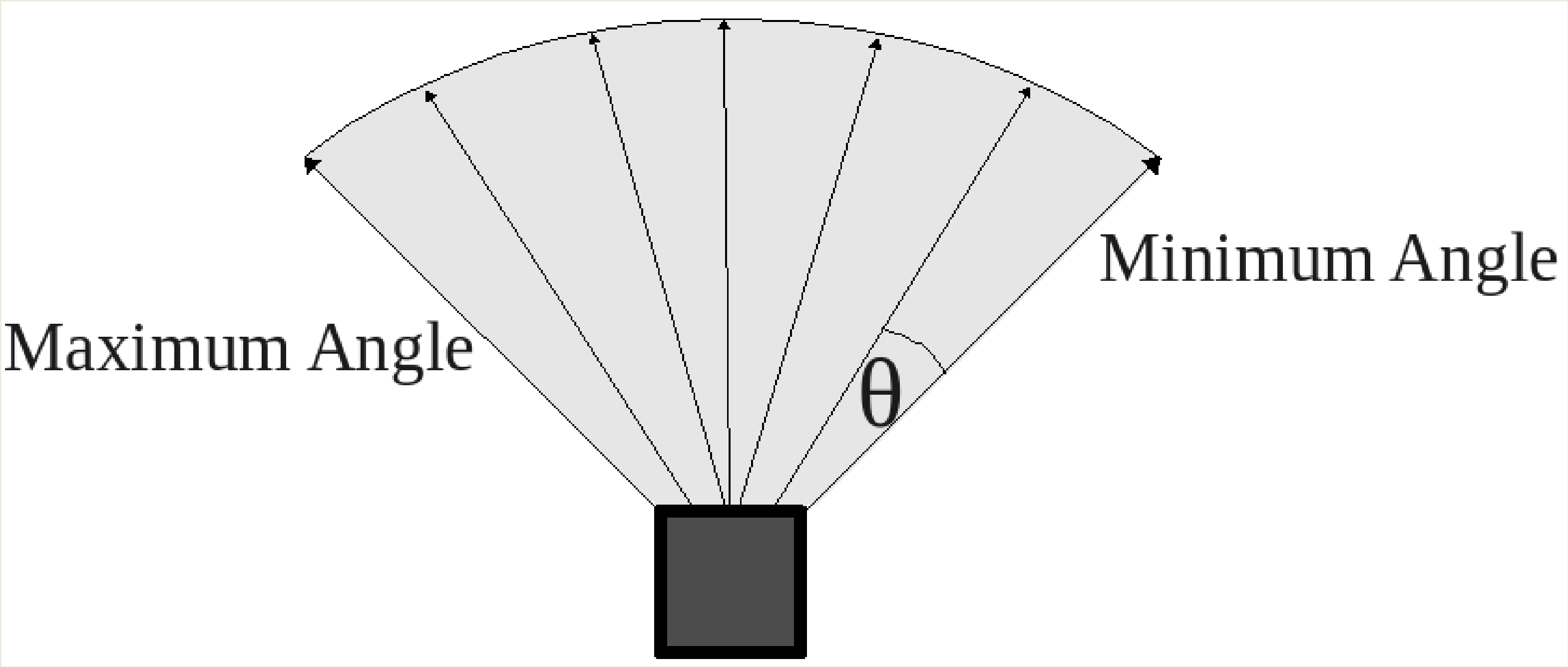
```
$ rosmsg show sensor_msgs/LaserScan
```

LaserScan Message

- http://docs.ros.org/api/sensor_msgs/html/msg/LaserScan.html

```
# 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.
```

Laser Scanner



Hokuyo Laser

- A common laser sensor used in robotics
  http://www.hokuyo-aut.jp/02sensor/07scanner/urg_04lx.html

Hokuyo Laser

Model No.	URG-04LX
Power source	5VDC ± 5%*1
Current consumption	500mA or less(800mA when start-up)
Measuring area	60 to 4095mm(white paper with 70mm□) 240°
Accuracy	60 to 1,000mm : ±10mm, 1,000 to 4,095mm : 1% of measurement
Repeatability	60 to 1,000mm : ±10mm
Angular resolution	Step angle : approx. 0.36° (360° /1,024 steps)
Light source	Semiconductor laser diode(λ=785nm), Laser safety class 1(IEC60825-1, 21 CFR 1040.10 & 1040.11)
Scanning time	100ms/scan
Noise	25dB or less
Interface	USB, RS-232C(19.2k, 57.6k, 115.2k, 250k, 500k, 750kbps), NPN open-collector(synchronous output of optical scanner : 1 pce)
Communication specifications	Exclusive command(SCIP Ver.1.1 or Ver.2.0)*2
Ambient temperature/humidity	-10 to +50 degrees C, 85% or less(Not condensing, not icing)
Vibration resistance	10 to 55Hz, double amplitude 1.5mm Each 2 hour in X, Y and Z directions
Impact resistance	$196m/s^2$, Each 10 time in X, Y and Z directions
Weight	Approx. 160g
Accessory	Cable for power・communication/input・output(1.5m) 1 pce, D-sub connector with 9 pins 1 pce*3

LaserScan Message

- Example of a laser scan message from Stage: (rostopic echo /scan –n1)

```
roiyeho@ubuntu: ~
---
header:
  seq: 1594
  stamp:
    secs: 159
    nsecs: 500000000
  frame_id: base_laser_link
angle_min: -2.35837626457
angle_max: 2.35837626457
angle_increment: 0.00436736317351
time_increment: 0.0
scan_time: 0.0
range_min: 0.0
range_max: 30.0
ranges: [2.427844524383545, 2.42826247215271, 2.4287266731262207, 2.4292376041412354, 2.429795026779175, 2.430398941
040039, 2.4310495853424072, 2.4317471981048584, 2.4324913024902344, 2.4332826137542725, 2.4341206550598145, 2.435005
6648254395, 2.4359381198883057, 2.436917543411255, 2.437944173812866, 2.439018487930298, 2.4401402473449707, 2.44130
94520568848, 2.4425265789031982, 2.443791389465332, 2.4451043605804443, 2.446465253829956, 2.4478745460510254, 2.449
3319988250732, 2.450838088989258, 2.452392816543579, 2.453996419906616, 2.455648899078369, 2.457350492477417, 2.4591
01438522339, 2.460901975631714, 2.462752103805542, 2.4646518230438232, 2.466601848602295, 2.468601942062378, 2.47065
23418426514, 2.4727535247802734, 2.474905490875244, 2.4771084785461426, 2.479362726211548, 2.481668472290039, 2.4840
259552001953, 2.4864354133605957, 2.4888970851898193, 2.4914112091064453, 2.4939777851104736, 2.4965975284576416, 2.
4992706775665283, 2.5019969940185547, 2.504777193069458, 2.5076115131378174, 2.510500192642212, 2.5134434700012207,
2.516441822052002, 2.5194954872131348, 2.5226047039031982, 2.5257697105407715, 2.5289909839630127, 2.53226900100708,
 2.5356037616729736, 2.5389959812164307, 2.542445659637451, 2.5459535121917725, 2.5495197772979736, 2.55314469337463
4, 2.5568289756774902, 2.560572624206543, 2.5643761157989 5, 2.568240165710449, 2.572165012359619, 2.576151132583618,
 2.5801987648010254, 2.584308624267578, 2.5884809494018555, 2.5927164554595947, 2.597015380859375, 2.601378202438354
5, 2.6058056354522705, 2.610297918319702, 2.6148557662963867, 2.6194796562194824, 2.6241698265075684, 2.628927230834
961, 2.6337523460388184, 2.63478422164917, 2.6436073780059814, 2.6486384868621826, 2.6537396907806396, 3.44798207283
02, 3.4547808170318604, 3.461672306060791, 3.4686577320098877, 3.4757378101348877, 3.4829134941101074, 3.49018549919
1284, 3.4975550174713135, 3.5050225257873535, 3.5125889778137207, 3.5202558040618896, 3.5280232429504395, 3.53589296
3409424, 3.543865442276001, 3.5519418716430664, 3.5601232051849365, 3.568410634994507, 3.5768051147460938, 3.5853075
```

Depth Image to Laser Scan

- TurtleBot doesn't have a LIDAR by default
- However, the image from its depth camera can be used as a laser scan
- The node depthimage_to_laserscan takes a depth image and generates a 2D laser scan based on the provided parameters
- This node is run automatically when you run the turtlebot simulation in Gazebo
- The output range arrays contain NaNs and +-Infs (when the range is less than range_min or larger than range_max)
  - Comparisons with NaNs always return false

Depth Image to Laser Scan

- tutrlebot_world.launch

```
<launch>
  ...
  <!-- Fake laser -->
  <node pkg="nodelet" type="nodelet" name="laserscan_nodelet_manager"
args="manager"/>
  <node pkg="nodelet" type="nodelet" name="depthimage_to_laserscan"
       args="load depthimage_to_laserscan/DepthImageToLaserScanNodelet
laserscan_nodelet_manager">
    <param name="scan_height" value="10"/>
    <param name="output_frame_id" value="/camera_depth_frame"/>
    <param name="range_min" value="0.45"/>
    <remap from="image" to="/camera/depth/image_raw"/>
    <remap from="scan" to="/scan"/>
  </node>
</launch>
```

LaserScan Message

- Example of a laser scan message from TurtleBot: (rostopic echo /scan –n1)

```
viki@c3po:~$ rostopic echo /scan -n1
header:
  seq: 115
  stamp:
    secs: 27
    nsecs: 290000000
  frame_id: /camera_depth_frame
angle_min: -0.521567881107
angle_max: 0.524276316166
angle_increment: 0.00163668883033
time_increment: 0.0
scan_time: 0.0329999998212
range_min: 0.449999988079
range_max: 10.0
ranges: [nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, n
an, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, n
an, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, n
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an, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, nan, n
```

Wander-bot

- We'll now put all the concepts we've learned so far together to create a robot that can wander around its environment
- This might not sound terribly earth-shattering, but such a robot is actually capable of doing meaningful work: there is an entire class of tasks that are accomplished by driving across the environment
- For example, many vacuuming or other floor-cleaning tasks can be accomplished by cleverly algorithms where the robot, carrying its cleaning tool, traverses its environment somewhat randomly
- The robot will eventually drive over all parts of the environment, completing its task

Wander-bot

- **Refer:** Morgan Quigley O’ Reiley: Programming Robots with ROS – **Chapter 7: Wander-bot**

Ex. 4

- Implement a simple walker algorithm much like a Roomba robot vaccum cleaner
- The robot should move forward until it reaches an obstacle, then rotate in place until the way ahead is clear, then move forward again and repeat
- Bonus: rotate the robot in the direction that is more free from obstacles