DRC Kickoff:
Gazebo Workshop

October 25, 2012
Open Source Robotics Foundation

Table of Contents

Overview

Overview

Objectives

- Describe Gazebo
- Introduce the DRC Simulator
- Provide hands-on experience

Audience Participation

- This is not a lecture, please ask questions

Support Material

- Workshop material will be online

    `http://gazebosim.org`

The Gazebo Simulator

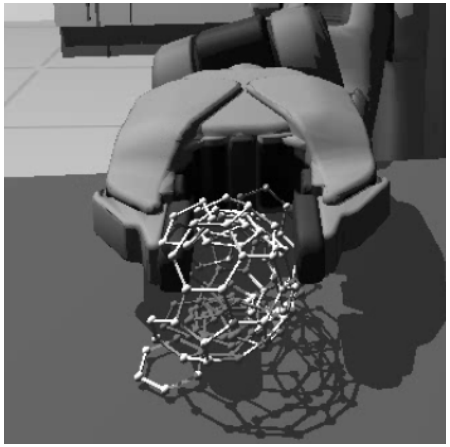
History

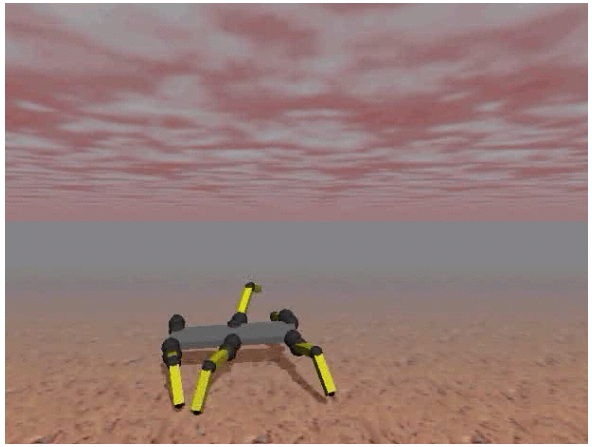
- Created at USC as part of the Player project
- Originally designed for simulation of outdoor mobile robots
- Relies on external robot control software: ROS, Player

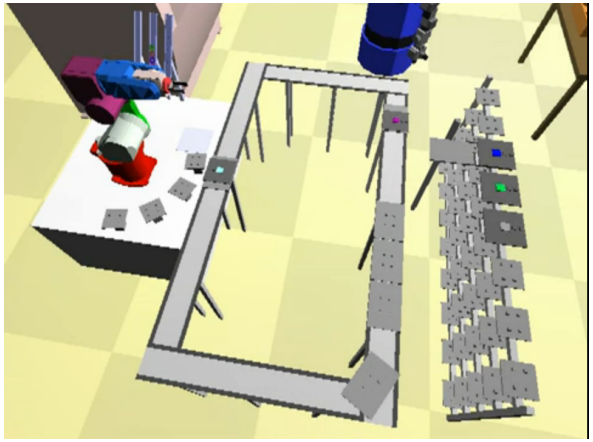
Purpose

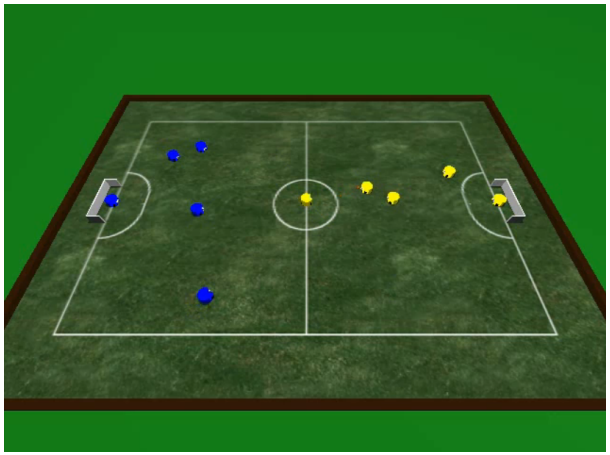
- Simulate the real world
- Test and develop hardware and software
- Regression testing
- Research
    - Human-Robot Interaction
    - Advanced physics simulation
    - Common test suite

Use Cases









Virtual Robotics Challenge (VRC)

Host a simulated version of the DRC

- Common infrastructure
  - Cloud-based simulation

Provide simulated task environments

- Drive a vehicle
- Walk across simple and difficult terrain
- Attach a fire hose to a stand pipe

Post-DRC

- Continue development of Gazebo

Gazebo, ROS, and DRC Simulator

Gazebo

- Current version: 1.2.5
- Stand-alone application

ROS

- Current version: Fuerte, Groovy soon-to-be-released
- Uses Gazebo 1.0

DRC Simulator

- Current version: 1.0.2
- Uses and builds on the stand-alone version of Gazebo
- Uses ROS Fuerte to import and control DRC robot model

Your Code

- May use any robot control software: ROS, Player, custom

Roadmap

DRC Sim 2.0 (Gazebo 1.3) - February 2013

- Real-time performance of DRC robot
- Data logging and playback
- Mechanical vehicles control
- Multiple floor buildings, rubble piles
- Bullet integration

DRC Sim 2.5 (Gazebo 1.4) - April 2013

- GUI model creation
- Integrate validation results
- Mechanical tool interface

DRC Sim 3.0 (Gazebo 1.5) - August 2013

- Digital Elevation Models (DEM)
- Shared memory interface

Gazebo Features

Physics

Multiple Physics Engines

- Abstract interface layer between Gazebo and physics engines
- Near-term: ODE and Bullet
- Far-term: Simbody, DART, Moby, and others

Selective dynamics control

- Physically simulate only parts of a model
- Reduce computation
- Tip: modeling behavior, rather than a kinematically correct robot, is often sufficient

Future

- Friction models
- Noise models

Rendering

Sensor visualization

- Projected camera views
- Laser rays
- RFID range as translucent spheres

Custom GUI overlays

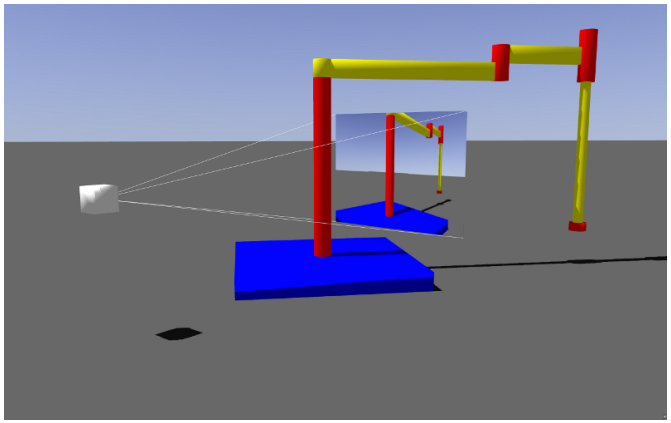
- Create unique interfaces using CEGUI

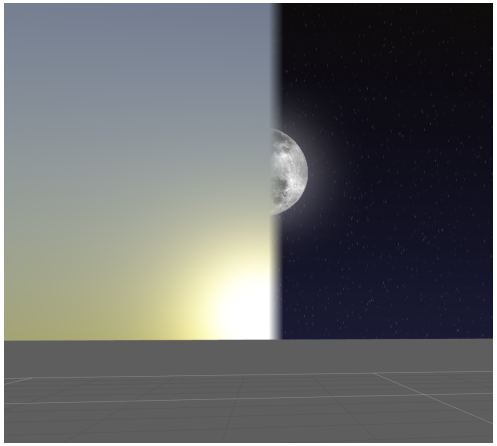
Sky

- Sun, moon, stars
- Volumetric clouds

Future

- User-defined visualizations
- Improved fidelity





Transport

Message passing

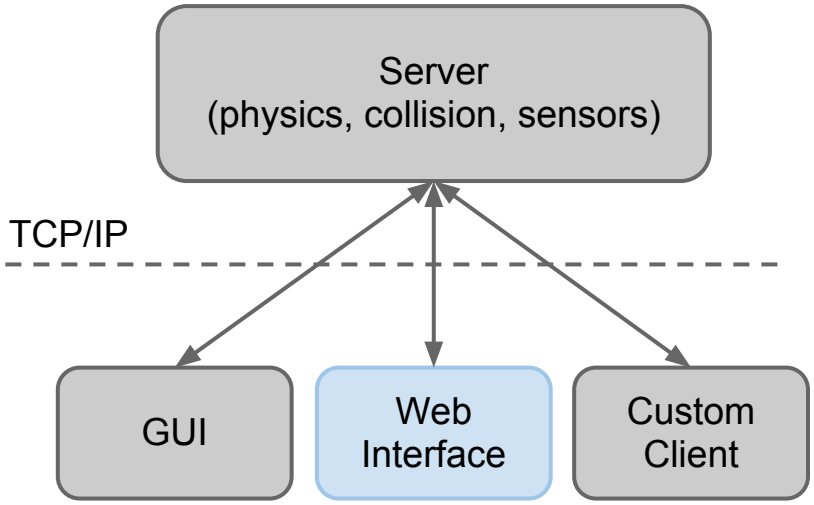
- Google Protobuf
- boost::asio provide socket based comms

Server and client separation

- Many clients, one server
- Custom clients

Future

- Shared memory interface



Model Database

Central repository for all models

- Location: `http://gazebosim.org/models`
- Meshes, textures, plugins
- Accessible through GUI
  - Drag-and-drop models into a running simulation
- Format fully documented
  - Create your own model database

Future

- Web-based tool for browsing and contributing models
- World database

Graphical User Interface

Control joints

- Apply force to joints
- Position and velocity PID controllers

Manipulate pose

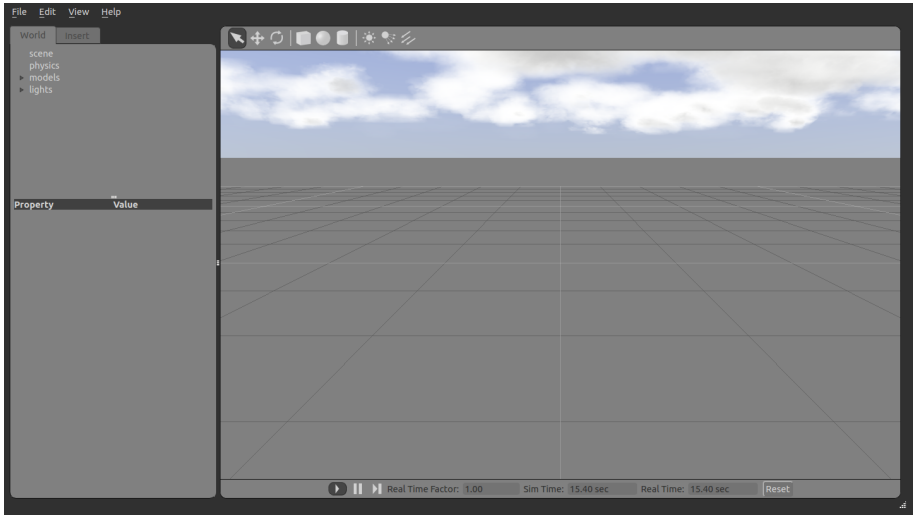
- Drag models, snap to grid

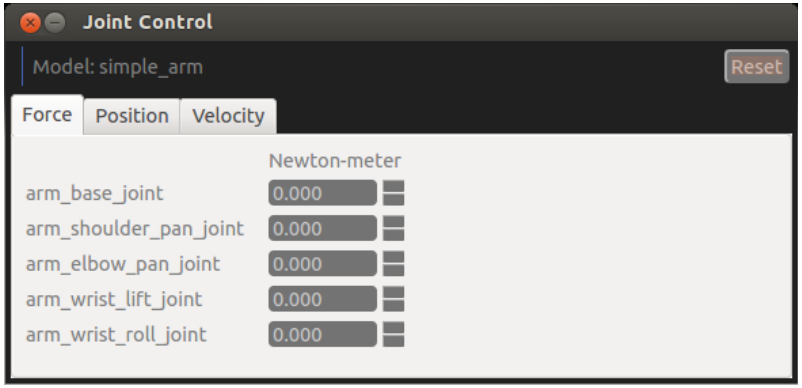
Modify running simulation

- World and model parameters

Future

- Position end effectors using the mouse
- Apply forces and torques to models
- Build models
- Custom visualizations





Documentation

API

- http://gazebosim.org/api
- Doxygen generated

Simulation Description Format (SDF)

- http://gazebosim.org/sdf
- Fully featured and scalable XML description format for robots and simulation

User guide

- http://gazebosim.org/user_guide
- A written guide to installing and using Gazebo

Tutorials

- http://gazebosim.org/wiki/tutorials
- Building models, worlds, plugins
- Using the DRC simulator

Reliability

Static code checking

- cppcheck
- cpplint

Dynamic code checking

- gcc uses most compile time warnings

Regression testing

- Covers physics, math library, sensors, transport layer

Continuous integration

- Jenkins: `http://build.osrfoundation.org`

Validation

- Working with NIST to validate DRC robot and environments

Installation

Requirements

Hardware

- Modern GPU: nVIDIA preferred, less than 4 years old
- Multi-core CPU

Required software

- OGRE - rendering engine
- Boost - threading, transport, command-line parsing
- Protobuf - message serialization
- TinyXML - XML parser
- libCurl, libtar - model database extraction
- FreeImage - heightmap

Optional software (Installed with DRC Simulator package)

- URDF DOM - import URDF files

Installation Methods

Options

- Gazebo: stand-alone version
- DRC Sim: Gazebo 1.2
- ROS: Use ROS installation method
  - Fuerte: Gazebo 1.0.2
  - Groovy: Gazebo 1.0.2

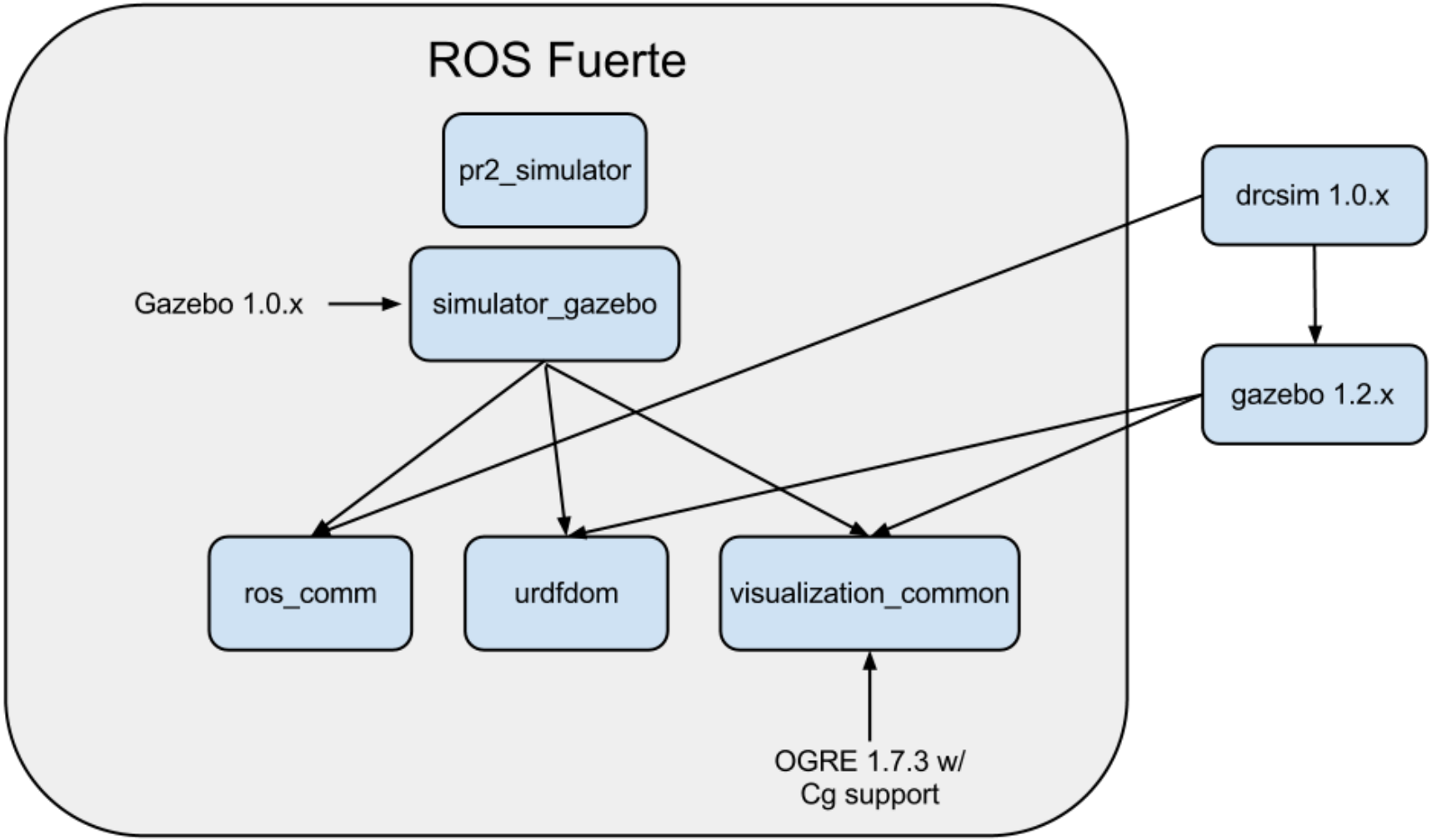
Install

- Ubuntu 12.04 - APT repository
- Other Linux distributions - Tarball available on http://gazebosim.org
- Developers - Mercurial repository hosted on Bitbucket

Future installation methods

- RPM-based Linux distributions
- OSX
- Windows

Installation Methods
DRC Simulator Dependency Graph



Getting / Giving Help

Questions and answers (http://answers.gazebosim.org)

- Search, post or answer questions about Gazebo

Wiki (http://gazebosim.org/wiki)

- Tutorials and general documentation

API (http://gazebosim.org/api)

- Doxygen code documentation

Mailing list (http://kforge.ros.org/mailman/listinfo/gazebo-list)

- Announcements

Bug tracker (http://bitbucket.org/osrf/[gazebo | drcsim]/issues)

- Find and issue bugs, and request new features

Source Code (http://bitbucket.org/osrf/[gazebo | drcsim])

- For developers, Mercurial source checkout and install

Contributing to Gazebo

Step 1: Communicate

- Use mailing list to find out who is working on what
- Announce new models, and features

Step 2: Develop

- Fork Gazebo from Bitbucket

Step 3: Review

- Create a pull request
- Gazebo team will review code, and offer feedback

Step 4: Merge

- Once pull request is accepted

Creating Worlds

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

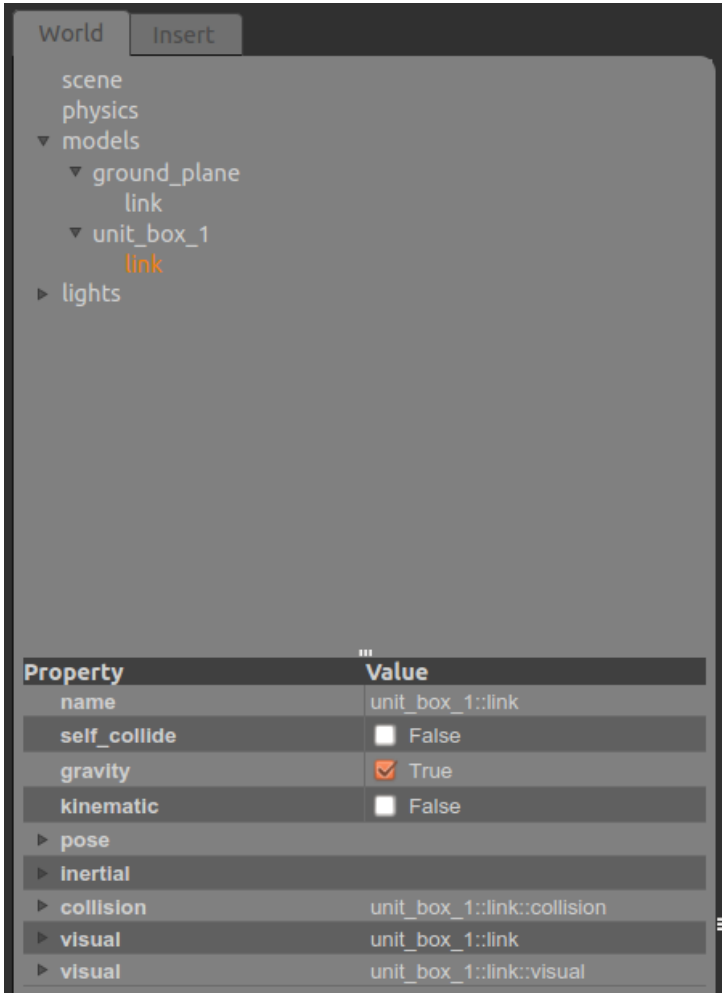
• Collect, process, and output data

Plugins

• Code attached to a World, Model, Sensor, or the simulator itself

Element Hierarchy

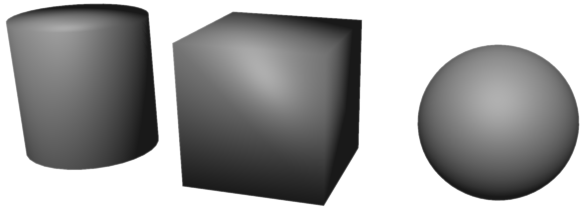
- World
  - Scene
  - Physics
  - Model
    - Link
      - Collision
      - Visual
      - Sensor
        - Plugin
    - Plugin
  - Plugin
  - Light



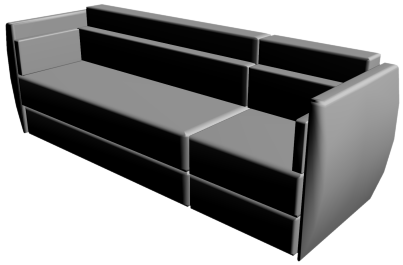
Element Types

Collision and Visual Geometries

- Simple shapes: sphere, cylinder, box, plane
- Complex shapes: heightmaps, meshes



Built into Gazebo



3D Warehouse or model editor

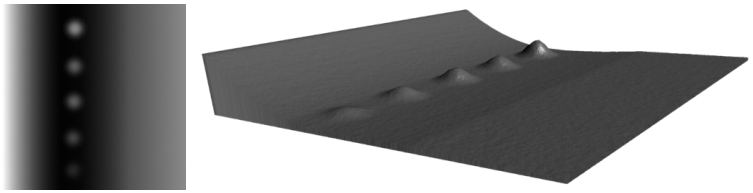


Image editor

Joint Types

Prismatic: 1 DOF translational

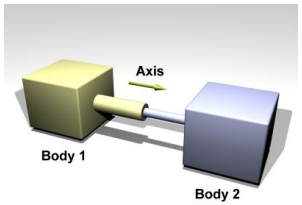
Revolute: 1 DOF rotational

Revolute 2: Two revolute joints in series

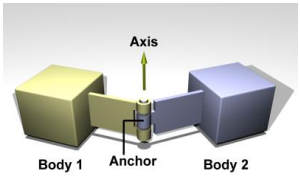
Ball: 3 DOF rotational

Universal: 2 DOF rotational

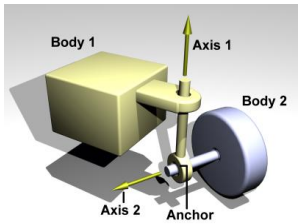
Screw: 1 DOF translation, 1 DOF rotational



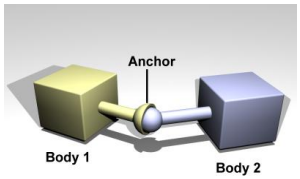
Prismatic



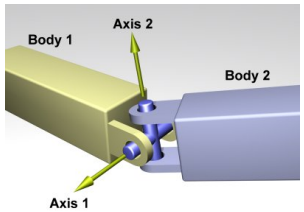
Revolute



Revolute 2



Ball



Universal

Sensors and Lights

Sensors

- Ray: produces range data
- Camera (2D and 3D): produces image and/or depth data
- Contact: produces collision data
- RFID: detects RFID tags

    User contributed

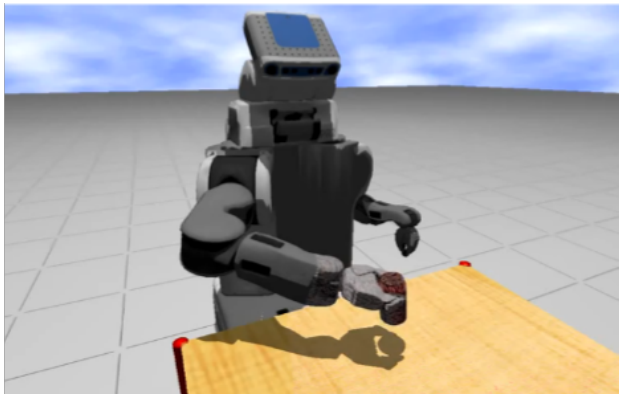
Lights

- Point: omni-directional light source, a light bulb
- Spot: directional cone light, a spot light
- Directional: parallel directional light, sun

Types of Worlds

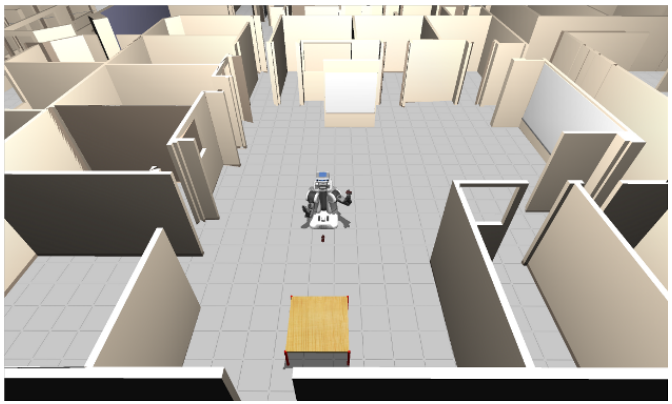
Simple

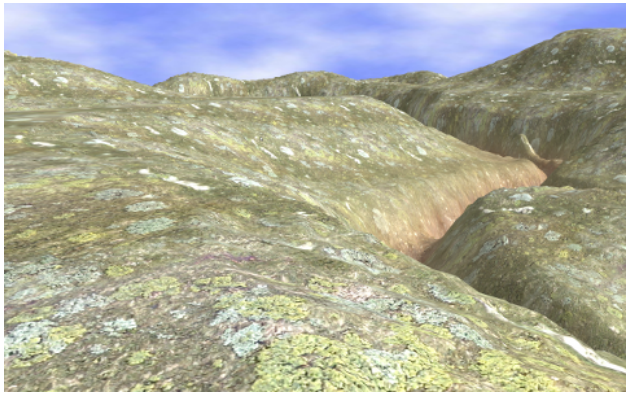
Focused scenario
Manipulation
Perception



Indoor

Path planning
Mobile manipulation
Clone real environment





Outdoor

Aerial robots
Outdoor mobile and legged robots

System Components

Physics Library

- Loads and runs the dynamics engine

Sensor Library

- Generates sensor data

Rendering Library

- Draws the world for the GUI and Sensor Library

Transport and Messages Library

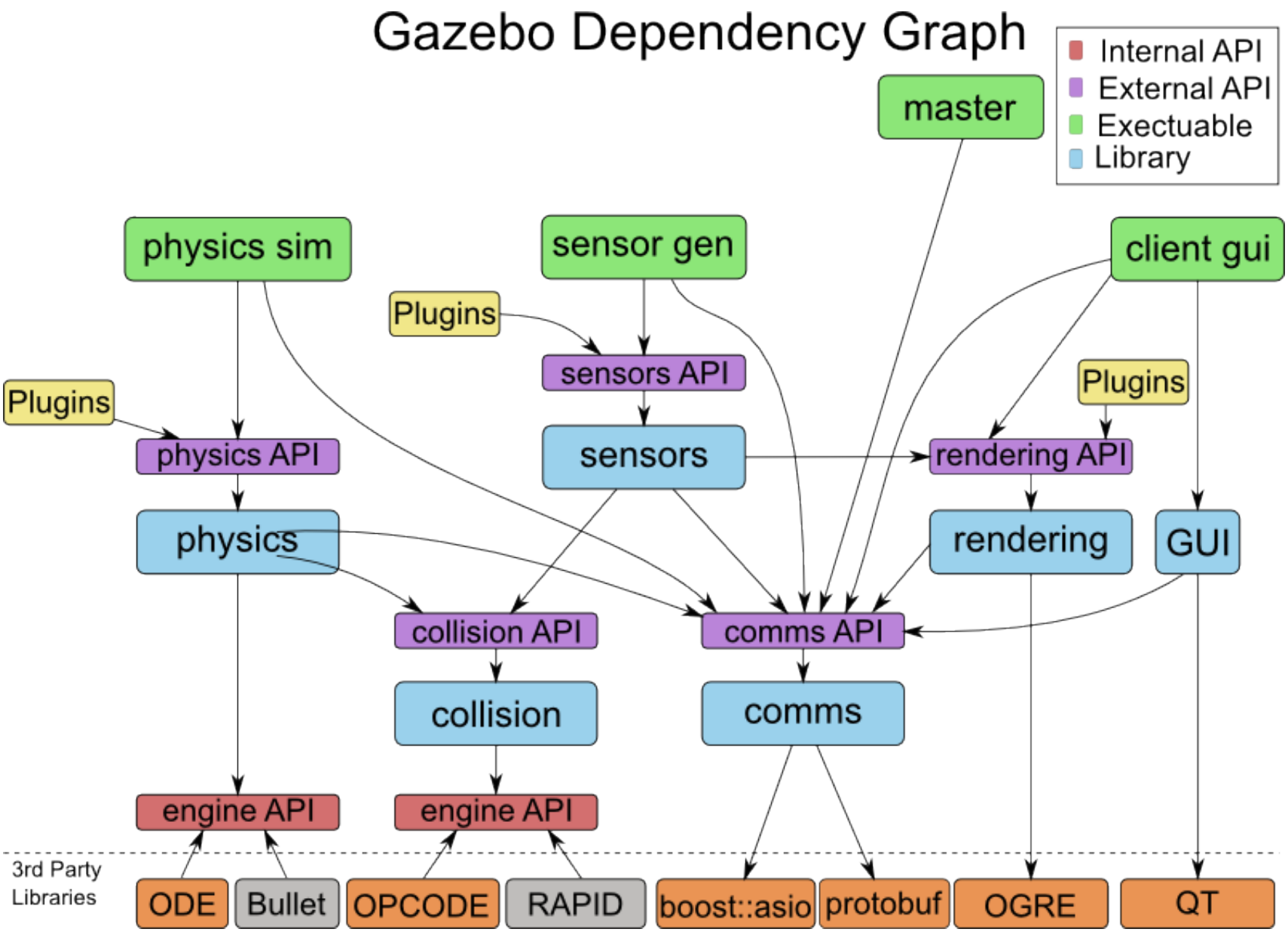
- Implements socket-based connections for message passing

Math and Common Libraries

- Internal math functions, and shared utilities

GUI and Command line tools

- Executables to visualize and manipulate simulation


Gazebo Dependency Graph
Internal API
External API
Exectuable
Library
master
physics sim
sensor gen
client gui
Plugins
sensors API
Plugins
Plugins
physics API
sensors
rendering API
physics
rendering
GUI
collision API
comms API
collision
comms
engine API
engine API
3rd Party Libraries
ODE
Bullet
OPCODE
RAPID
boost::asio
protobuf
OGRE
QT

World Definition

Simulation Description Format (SDF)

- `http://gazebosim.org/sdf`
- XML-based format that describes models and environments

Graphical Interface

- Import models (model database)
- Place models
- Manipulate models
- Save worlds

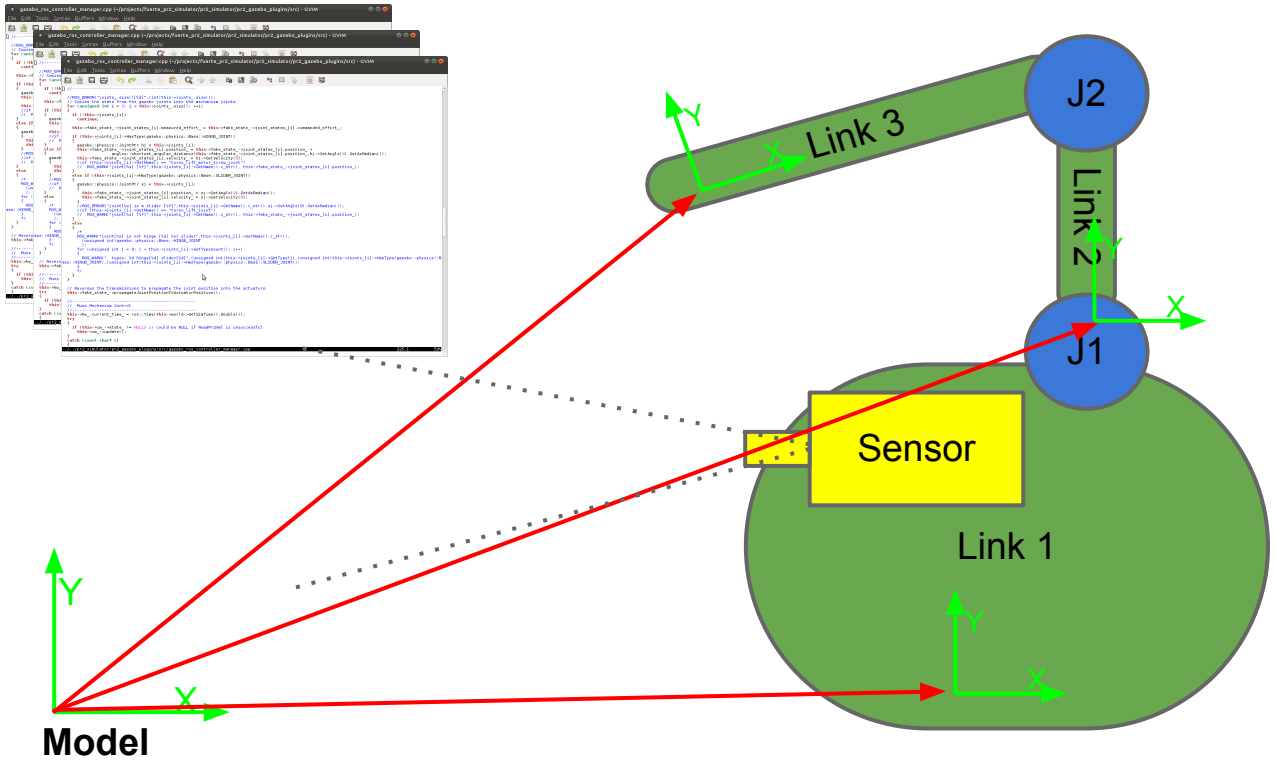
Simulation Units

- Controllable simulation speed
- Choosing consistent set of simulation units: MKS

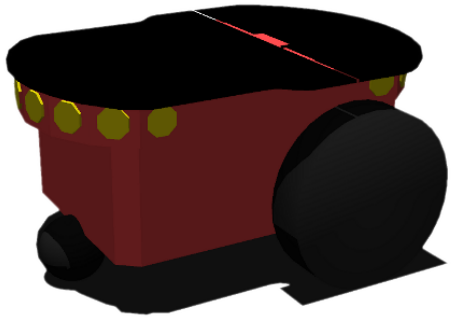
World Creation Demo

What is a Model

Any collection of links, joints, sensors and plugins



Robot Models



Simple platforms

- Built-in shapes
- Mesh skinning

Realistic physical properties

- Meshes as collision objects
- Mass and inertia properties
- Surface friction
- 6 joint types

Full sensor suite

- Laser range finders
- Mono/Stereo cameras
- Kinect
- Contact
- Joint force/torques

Non-Robot Models

Building a Model

Step 1: Collect meshes

- Make custom meshes: Sketchup, Blender
- Export from Solid Works (http://ros.org/wiki/sw_urdf_exporter)
- Online repositories: 3D Warehouse

Step 2: Make an SDF file

- Start simple
- Add links and collision elements one at a time
- Add joints last

Step 3: Include Model in a World

```
<include>
  <uri>model://my_model</uri>
</include>
```

Step 4: Share your model

- Add to model database

Step 1: Collect Meshes

Reduce complexity

- Meshes with low polygon count are more efficient
- Use normal maps for improved visualization

Center the mesh

- Move the center of the mesh to (0, 0, 0) in editor before export to Collada or STL
- This will simplify placement within Gazebo

Scale the mesh

- Make sure the mesh is in meters, and sized properly

Step 2: Make an SDF File

Step 2a: Static model

- Skips physics update, and allows easy placement of model components

Step 2b: Add each link

- Add collision and visual objects for each link
- Test your model with each addition

Step 2c: Add each joint

- Remove static constraint
- Reduce joint count, and test each joint

Step 2d: Add sensors

- Connect sensors to appropriate links

Step 2e: Add plugins

- Add plugins to control joints and sensors

Step 2f: Test and tune

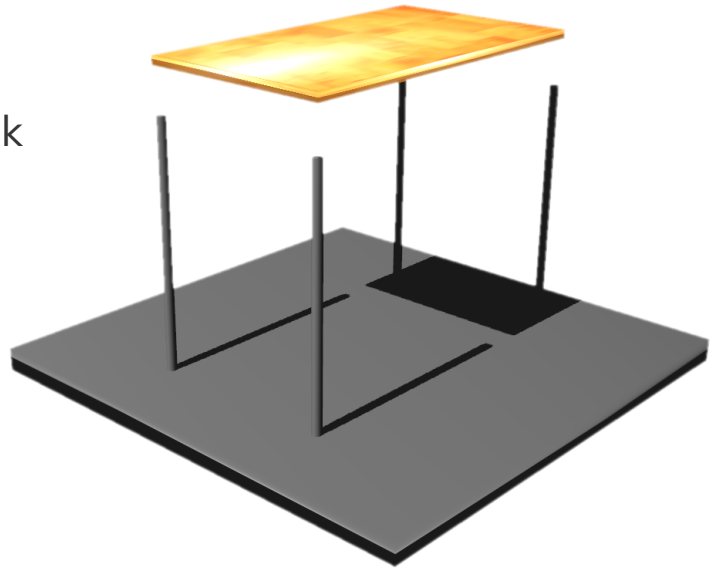
Efficient Models

Static models

- Not dynamically-simulated
- Act only as collision objects
- Static models can be animated

Reduce joints

- Add collision and visual objects for each link
- Test your model with each addition



Contributing Models

Model Repository

- Hosted on Bitbucket
- https://bitbucket.org/osrf/gazebo_models
- Fork the repository, add your model, submit a pull request

Create a new repository

- Follow the model database format
- Advertise your repository on the Gazebo mailing list

Mailing list

- See who is creating models
- Ask for help

Model Creation Demo

Plugin Development

Plugin Overview

Direct access to Gazebo API

- Location: http://gazebosim.org/api

Easily Shared

- Model database

Dynamically-Loaded

- Insert and remove from a running system

Examples

- Tutorials: http://gazebosim.org/Tutorials
- Source: <gazebo_source>/plugins

Plugin Types

World

- Plugin receives a pointer to the World instance

Model

- Plugin receives a pointer to a Model instance

Sensor

- Plugin receives a pointer to a Sensor instance

System

- Plugin receives the command line arguments

Plugin Types

Plugin Basics

- Inherits from appropriate parent plugin class.

```
namespace gazebo
{
  class MyPlugin : public WorldPlugin { };
}
```

- Parent objects and parameters are provided via Load function.

```
namespace gazebo
{
  class MyPlugin : public WorldPlugin
  {
    MyPlugin::Load(physics::WorldPtr _world,
                   sdf::ElementPtr _sdf) { }
  };
  GZ_REGISTER_WORLD_PLUGIN(MyPlugin)
}
```

World Plugin

Usage

- Include in SDF file

```
<world name="default">
  <plugin name="my_plugin" filename="libmy_plugin.so"/>
</world>
```

Finding Plugins

- GAZEBO_PLUGIN_PATH environment variable tells Gazebo where to look for plugins

Purpose

- Access to all models
- Control physics engine

World Plugin Demo

Model Plugin

Usage

- Include in SDF file

```
<model name="my_model">
  <plugin name="my_plugin" filename="libmy_plugin.so"/>
</model>
```

Purpose

- Control model behavior

  Joints, sensors, link pose

Model Plugin Demo

Sensor Plugin

Usage

- Include in SDF file

```
<sensor name="my_sensor">
  <plugin name="my_plugin" filename="libmy_plugin.so"/>
</sensor>
```

Purpose

- Gather and modify sensor data
- Add noise models

Examples

- ROS laser plugin
- ROS camera plugin

System Plugin

Usage

- Command line only

  gzserver -s <plugin_library_file>

  gzclient -g <plugin_library_file>

  gazebo -s <plugin_library_file> -g <plugin_library_file>

Purpose

- Modify system paths (resources, plugins, models)
- Control Gazebo bring-up, execution and shutdown

Examples

- ROS API system plugin

Distributed Simulation Environment

Distributed Simulation Environment

Purpose

- Simulation in the cloud
- Separate client from server
- Run on separate machines

How it works

- Master
  - Tracks server and clients
- Server
  - Run physics simulation
  - Generate simulated sensor data
- Client(s)
  - Visualize worlds
  - User interactions

Running the Master, Server, Client

Specify Master

- Environment variable

  GAZEBO_MASTER_URI=http://localhost:11345

Server

- Automatically starts a master if none present

  Command: gzserver <world_filename>

Client

- World visualization is the most common use case

  Command: gzclient

Running on a Local Network
JOHN REMOVE ME

Step 1

- Set GAZEBO_MASTER_URI=http://localhost:11345 on all machines

  export GAZEBO_MASTER_URI=http://localhost:11345

Step 2

- Start a server on one machine

  gzserver <world_filename>

Step 3

- Start a client on a different machine

  gzclient

Debugging

Command line tools

- gzstats
  - A client that prints out info from a server
  - Check general server performance status

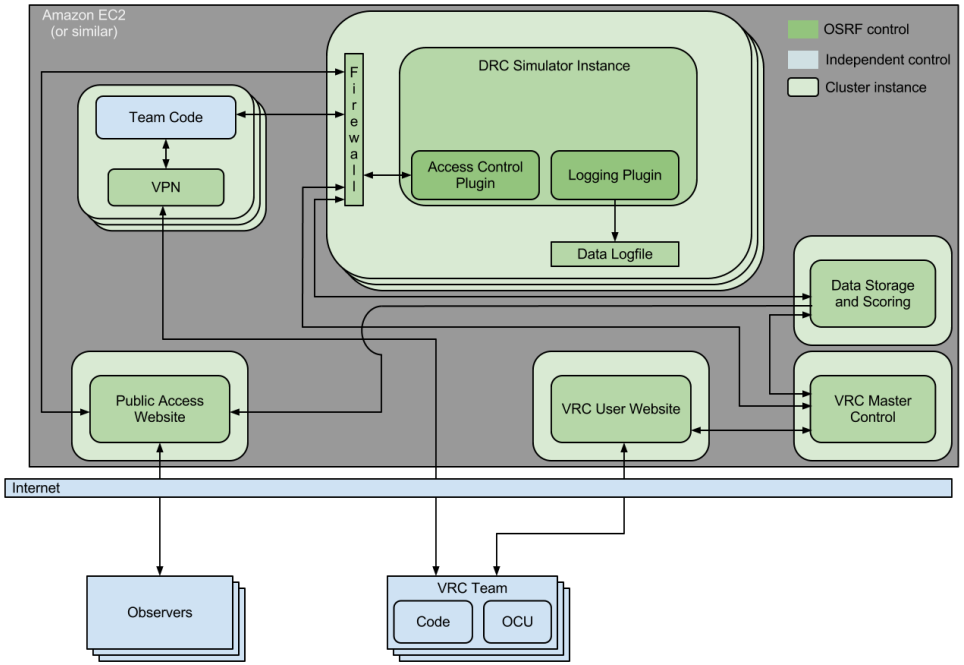
- gztopic
  - A client that lists all topics that are active
  - Debug message passing between server and cilent

Cloud Simulation

Web interface to cloud machines

- Automatically launch Gazebo instances
- Teams may request configuration and time

Scale-up access over a few months



Lunch Break

1 hour

After lunch: Q&A, Tutorials

Post Lunch Question and Answer

Exercise 1: Building a mobile robot

Exercise 1
Overview

Topics Covered

- Construction of a two-wheeled mobile base
- Attaching meshes to visual elements
- Attaching sensors to links
- Constructing a simple gripper
- Attaching a gripper to a mobile base

Wiki Tutorials

http://gazebosim.org/wiki/Tutorials

Section: Building a Robot

Exercise 2: Controlling a mobile robot

Exercise 2
Simulation Controls Overview

Animation vs. Dynamic control

- Animation
  - Fast.
  - Disregard physics, constraints*.
  - No collision responses.

- Dynamic control
  - Velocity control - leveraging integrator only
  - Force control - leveraging physics engine (f = ma)
  - Can be computationally intensive

- Controllers with sensor feedback.
- Gazebo's built-in PID class.

Exercise 2
Simulation Controls Overview

Topics Covered

- Animating pose of rigid body links with the animation engine.
- Controlling pose of rigid body links by setting velocities.
- Controlling joints by applying forces.
- Controlling a robot with its simulated onboard sensor.
- Controlling a joint with Gazebo's builtin PID class.

Wiki Tutorials

http://gazebosim.org/wiki/Tutorials

Section: Controlling a Robot

Exercise 3: Building a world

Exercise 3
Overview

Topics Covered

- Constructing a world using the graphical interface
- Modifying world parameters
- Controlling the world via a plugin

Wiki Tutorials

http://gazebosim.org/wiki/Tutorials

Section: Making a World

Exercise 4: ROS Integration

Exercise 4
ROS Integration Overview

Gazebo in ROS or ROS in Gazebo?

- ROS wrapped thirdparty Gazebo installation (http://ros.org/wiki/simulator_gazebo)

  Fuerte ← Gazebo 1.0.x

- Gazebo standalone installation (http://gazebosim.org)

Model Description Formats: COLLADA, URDF, SDF, SRDF, YADF?

- Solidworks to URDF exporter

  http://ros.org/wiki/sw_urdf_exporter

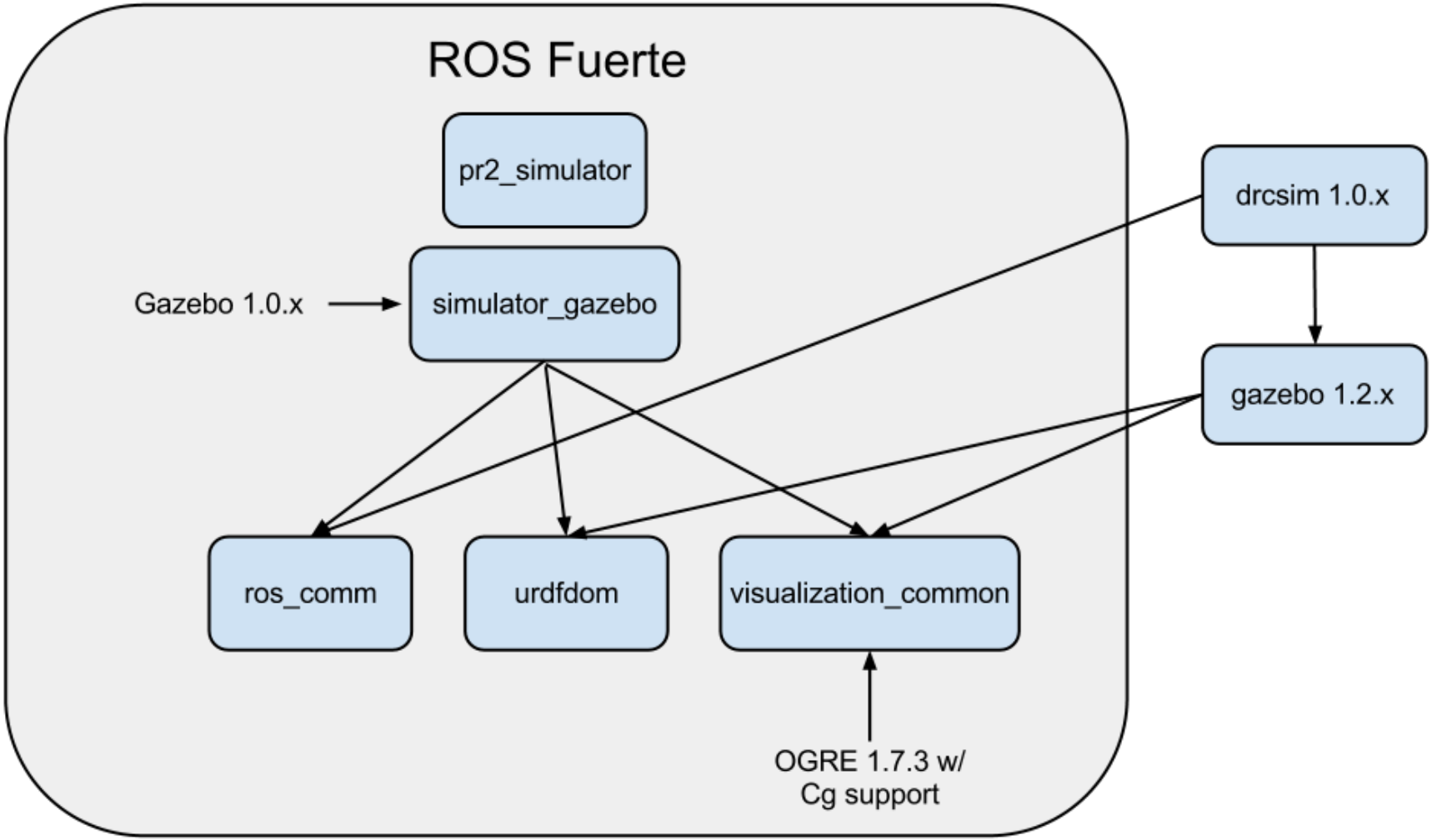
- URDF Dependencies

  http://ros.org/wiki/urdf

  URDF support built at compile time in Gazebo 1.2.x*

  ```
  sudo apt-get install ros-fuerte-urdfdom
  ```

Exercise 4
ROS Integration Overview



Exercise 4
ROS Integration Overview

Gazebo Plugins with ROS dependencies

- For simulating ROS drivers for real robots

  http://ros.org/wiki/wge100_camera_firmware
  http://ros.org/wiki/microstrain_3dmgx2_imu
  http://ros.org/wiki/prosilica
  ...

- Using high level ROS applications with Gazebo

  http://ros.org/wiki/navigation
  http://ros.org/wiki/pr2_interactive_manipulation
  http://moveit.ros.org
  ...

Exercise 4
ROS Integration Overview

Topics Covered

- Managing ROS dependencies
- Building a Gazebo plugin with ROS

Wiki Tutorials

http://gazebosim.org/wiki/Tutorials

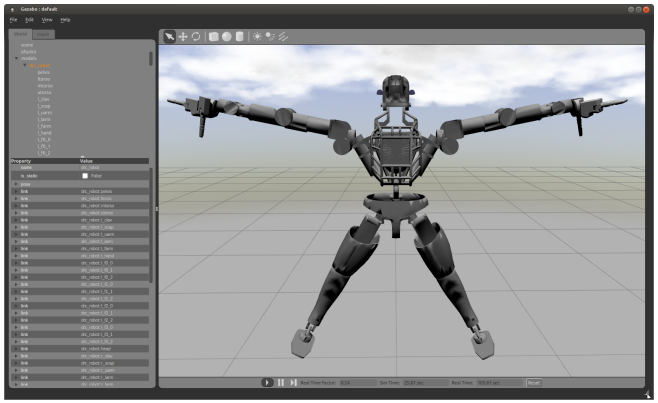
Section: ROS Integration

Exercise 5: DRC Simulator

Exercise 5
DRC Robot Overview

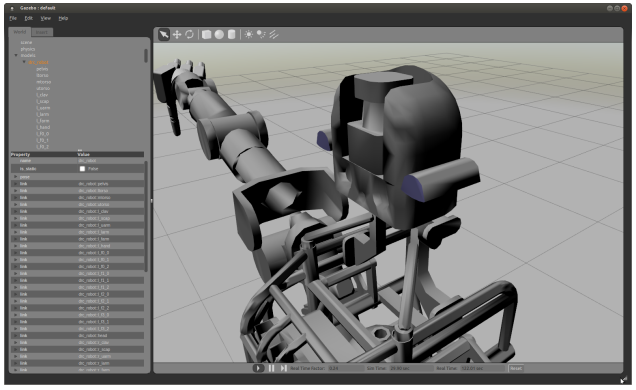
DRC Robot Dynamics Model

- Initial URDF generated form simplified CAD model subject to change.



DRC Robot Sensor Suite

- Real sensor suite hardware TBD.
- For now, "Best guess" sensor suite.
  - Hokuyo laser
  - Stereo camera



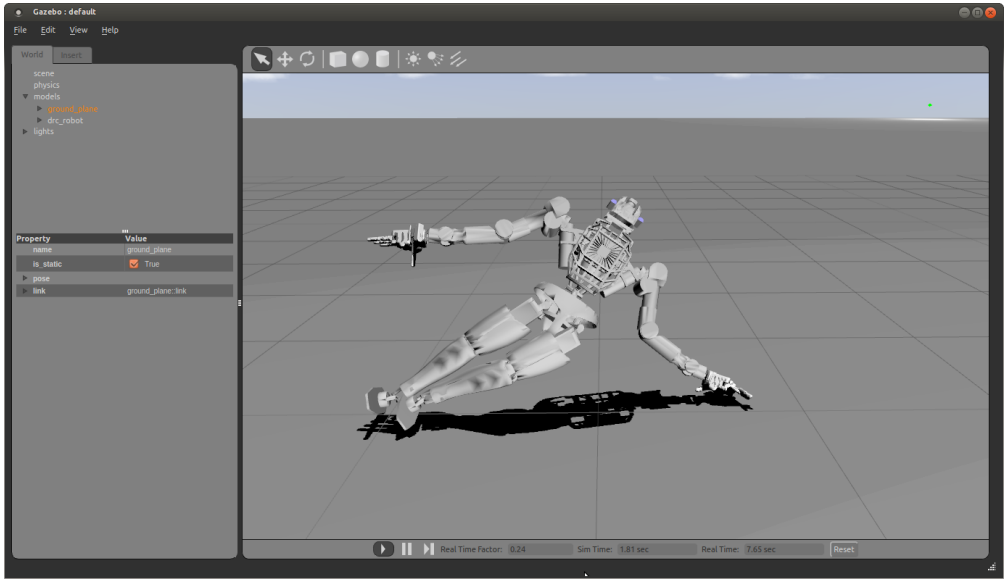
Exercise 5
DRC Robot Overview

DRC Robot Dynamics Controls API

- Initial simulation tutorials "place holder" controllers derived from PR2 controllers

  http://ros.org/wiki/pr2_controllers, http://ros.org/wiki/pr2_mechanism

- Walking controllers interface TBD.



Exercise 5
DRC Robot Overview

Topics Covered

- Visualize and log sensor data with rviz and rxbag.
- DRC Robot basic joint control using PR2 mechanism controllers.
- Teleporting the DRC Robot.
- Customizing the DRC Robot world contents.
- Animating the DRC Robot with ROS JointTrajectory messages.

  (http://gazebosim.org/wiki/trajectory_msgs)

Wiki Tutorials

http://gazebosim.org/wiki/Tutorials

Section: DRC Tutorials