Advanced Techniques for Mobile Robotics

ROS

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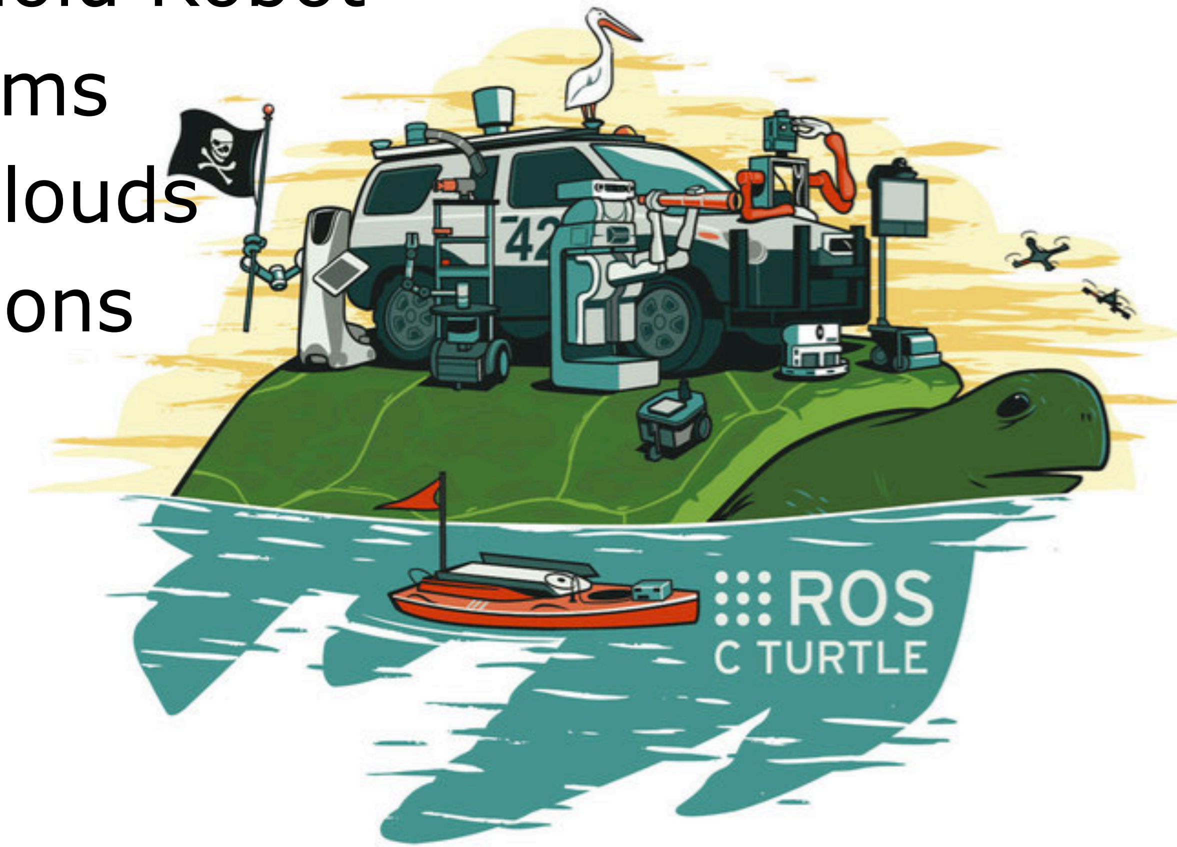
UNI FREIBURG

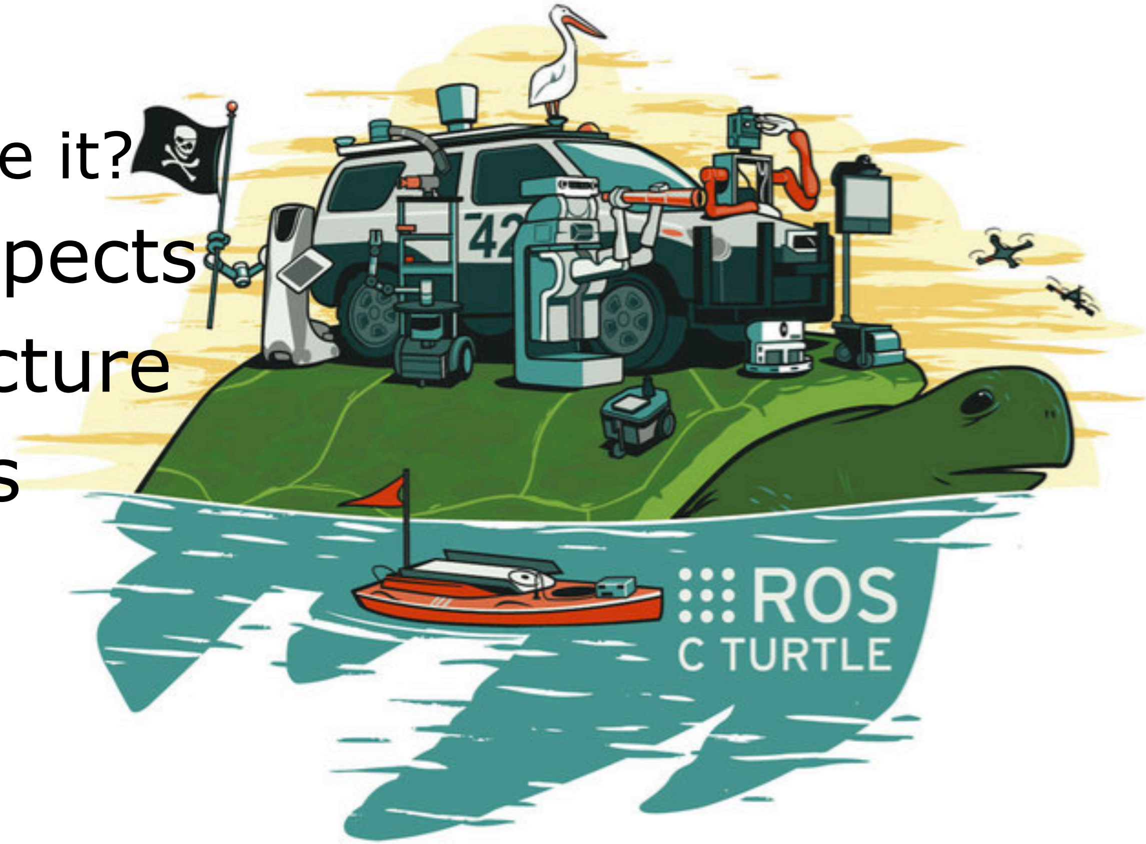
Today’s Lecture

- **ROS – Robot Operating System**
- PR2 – Humanoid Robot
- TF – Transforms
- PCL – Point Clouds
- ROS Applications



ROS Overview Talk

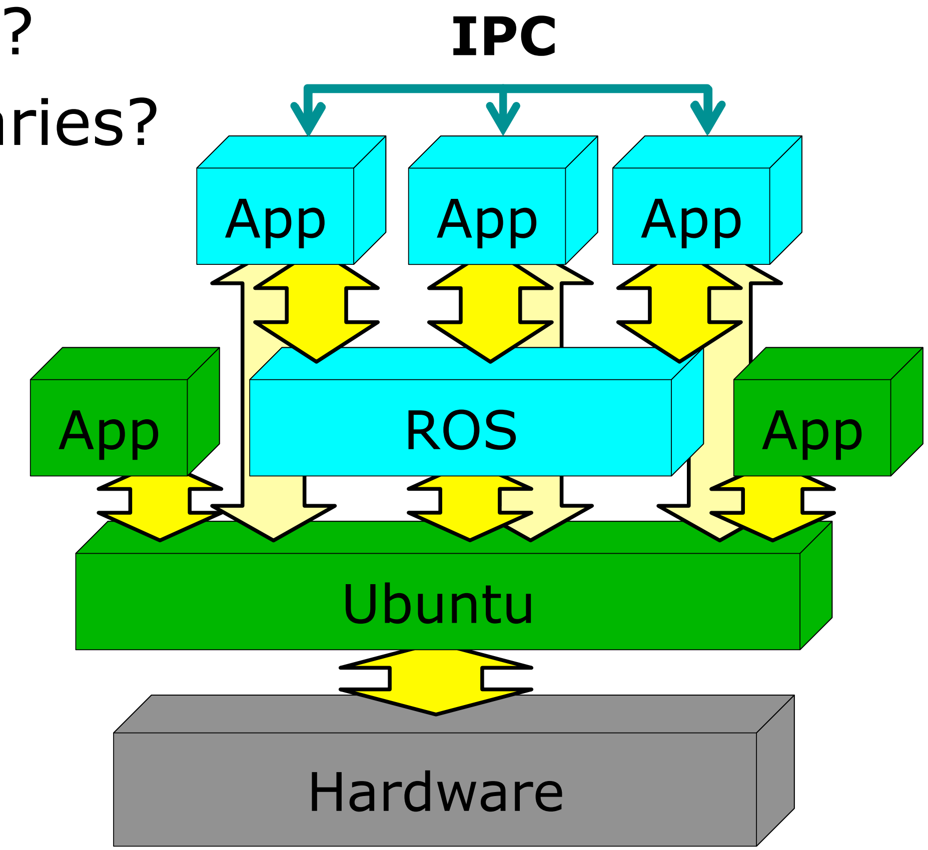
- High Level Overview
  - What is ROS?
  - Who made it?
  - Why do we use it?
- Middleware Aspects
- Software Structure
- Client Libraries



High Level Overview

What is ROS?

- An Operating System like Windows, GNU/Linux?
- A Software Distribution?
- A Middleware?
- A Set of Libraries?



High Level Overview

Who made ROS?

- Privatly Owned Company
- Based in Menlo Park, California
- Hardware: PR2, Texai
- Software: ROS (OpenCV, Player, PCL)
- Strong Open Source Commitment

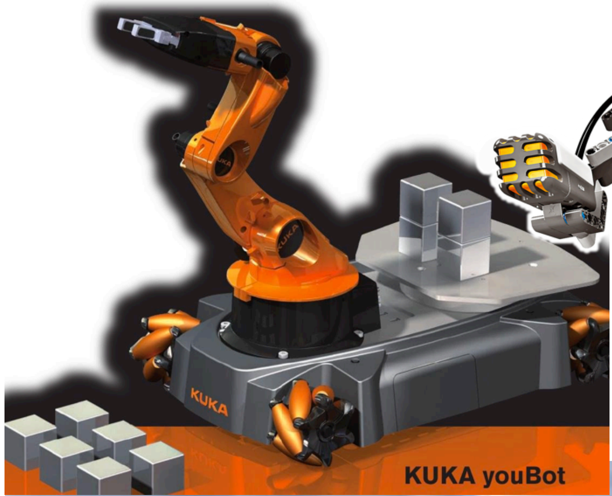
High Level Overview

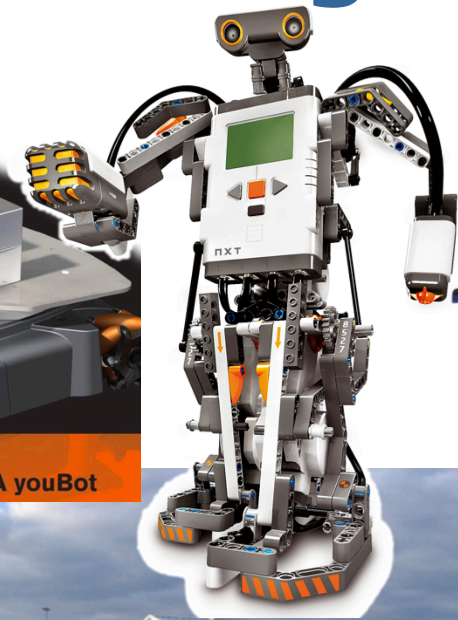
Why do we use ROS?

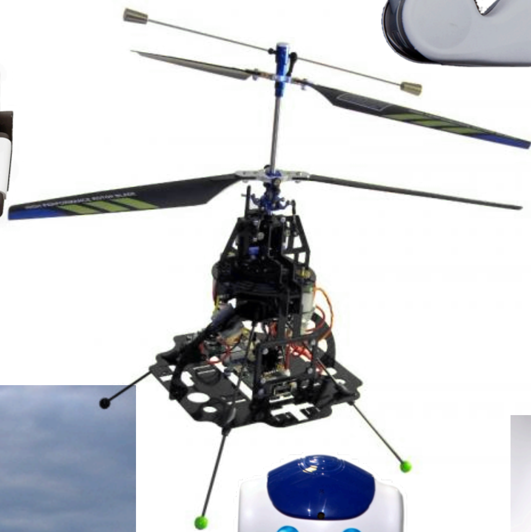
- Great functionality
  - Middleware (this session)
  - Development tools (2nd Session)
  - Advanced libraries (3rd Session)
  - Hardware drivers
- Large scientific community
  - A lot of state-of-the-art software available
  - Easy to exchange/integrate/build-upon existing projects
  - Open source (mostly BSD)
  - Actively developed by full-time staff
- To stop reinventing the wheel...


How Robotics Research Keeps...
Re-Inventing the Wheel
First, someone publishes...
...a paper with a proof-of-concept robot.
This prompts another lab to try to build on this result...
...but they can't get any details on the software used to make it work...
BARF!
...and all the code used by previous lab members is a mess.
So, a grandiose plan is formed to write a new software API...
...and countless sleepless nights are spent writing code from scratch.
But inevitably, time runs out...
...and they write code that barely works but lets them publish...

Robots Using ROS







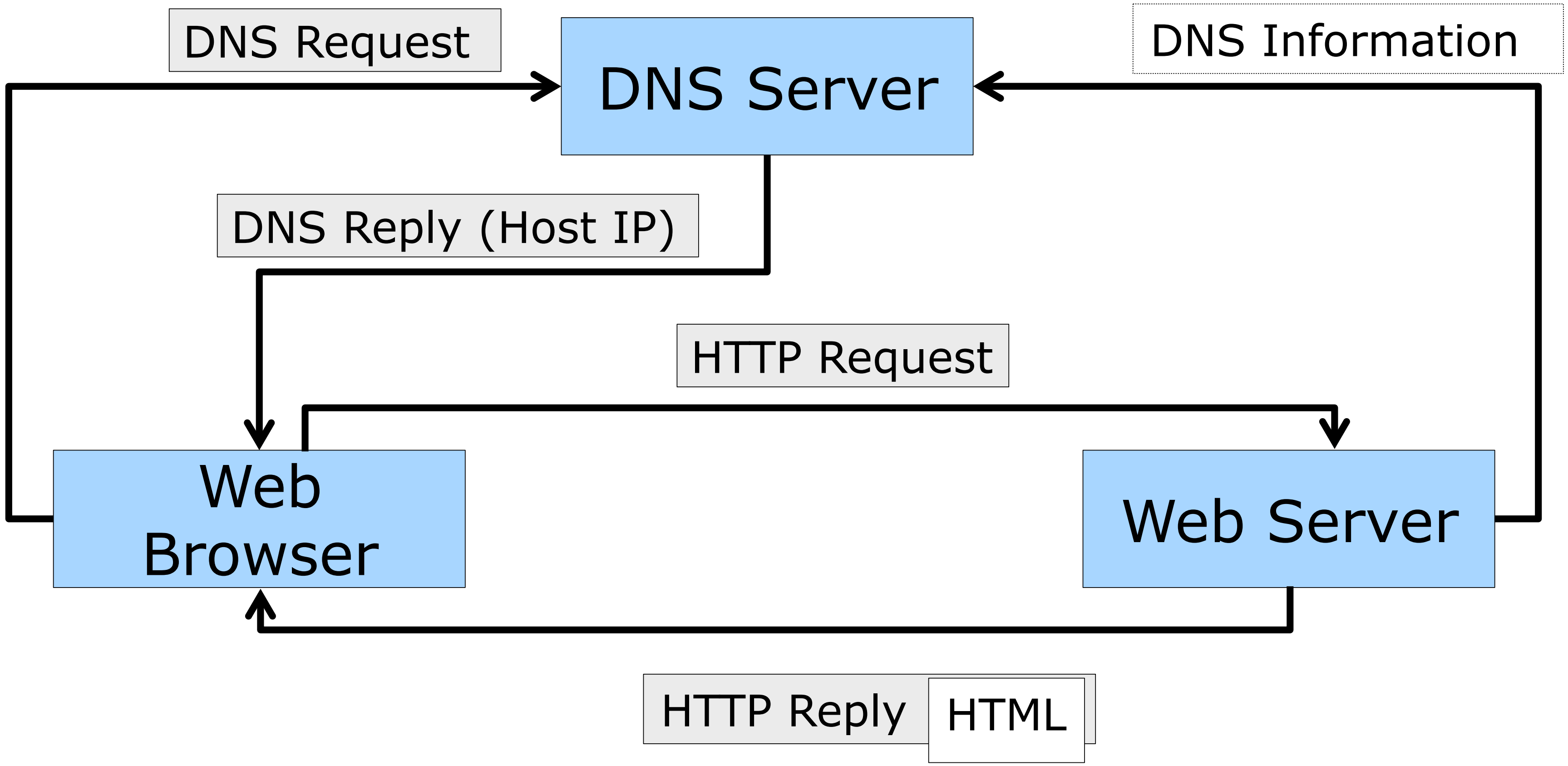
ROS - a Middleware for Robots

"Middleware is a software that connects software components or applications."

- Framework for interprocess communication
- Boosts modularization
- Enables transparent distribution of software in a network

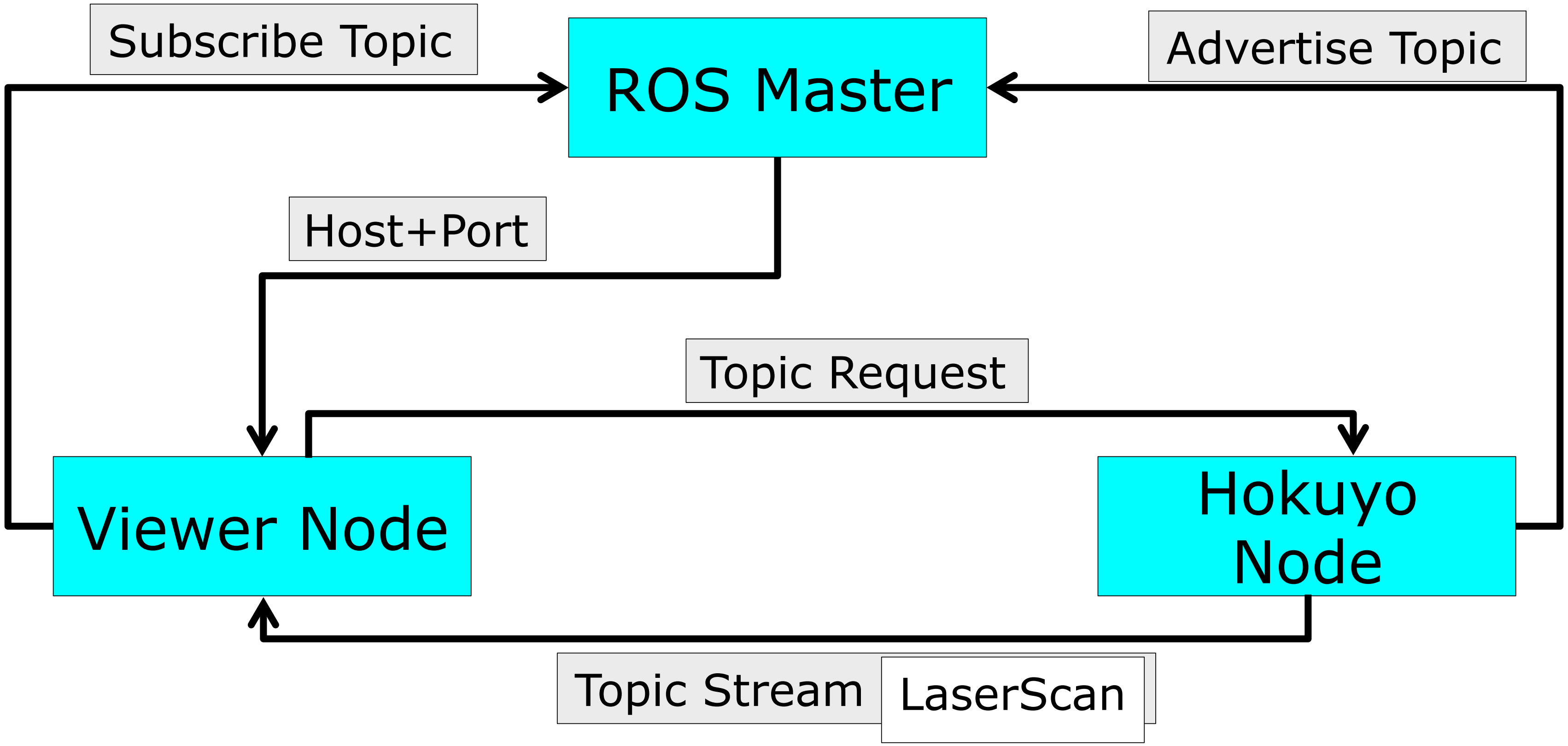
ROS - a Middleware for Robots

Example: Communication on the Internet



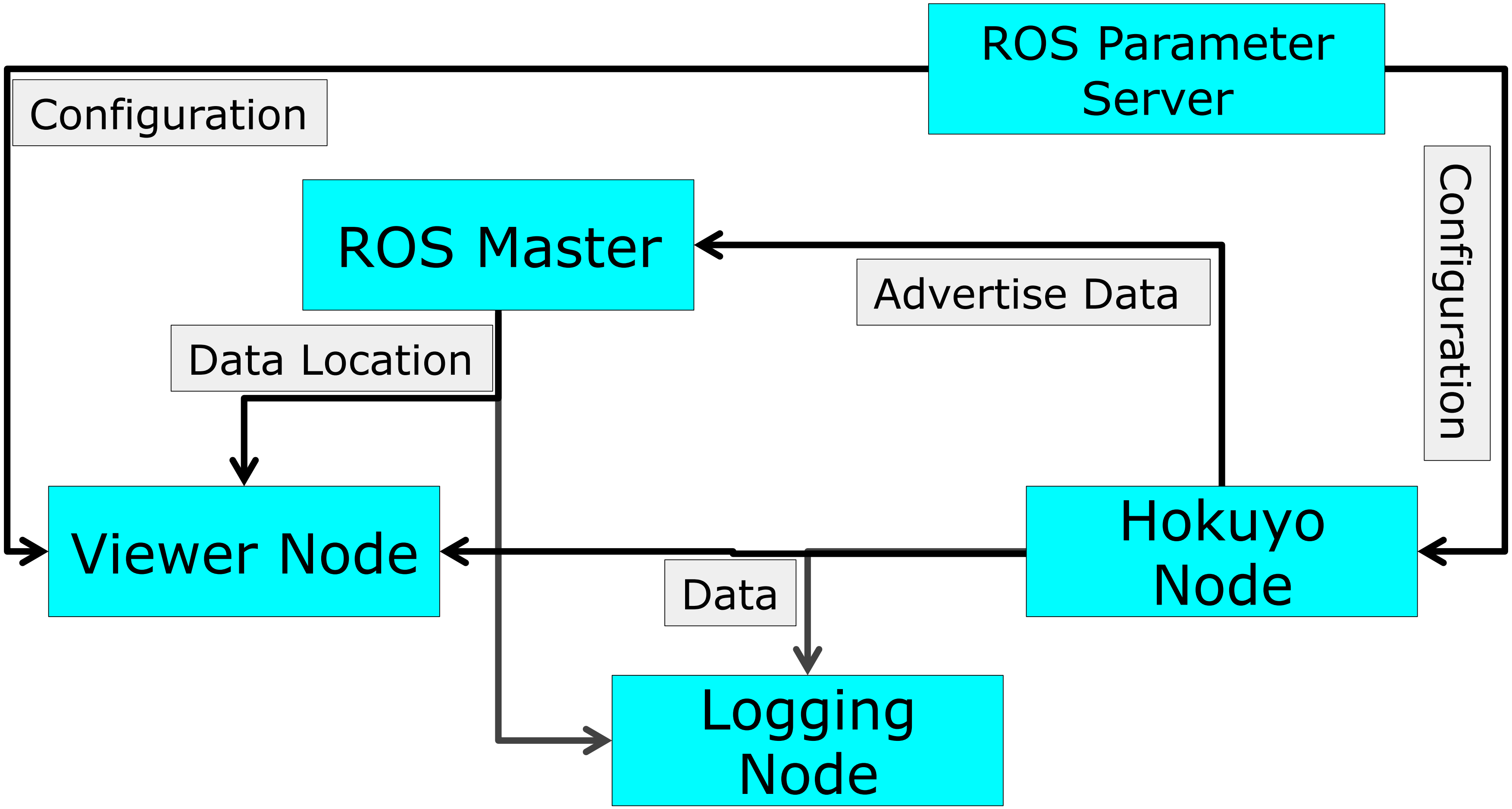
ROS - a Middleware for Robots

Interprocess Communication Using ROS

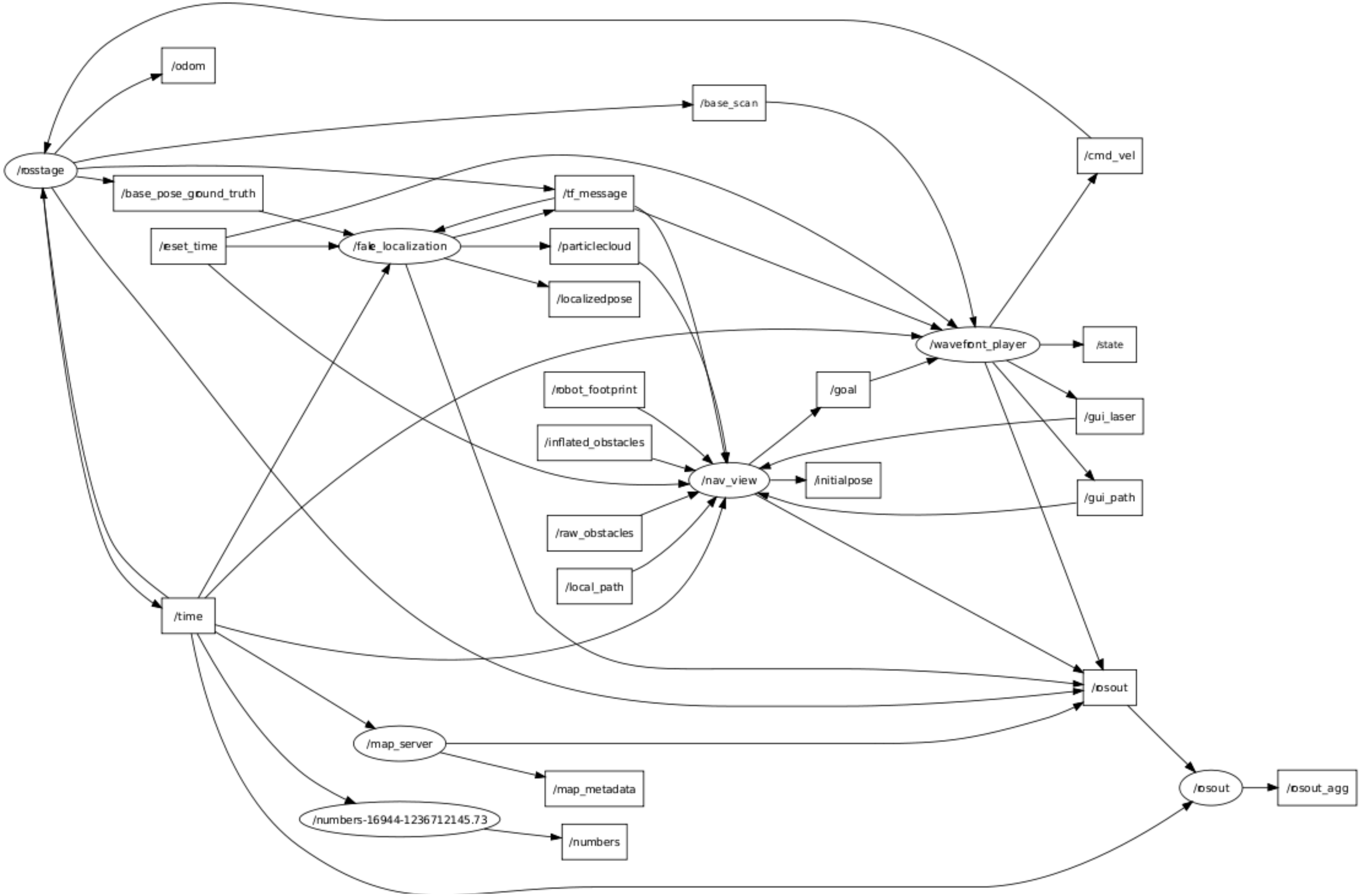


ROS - a Middleware for Robots

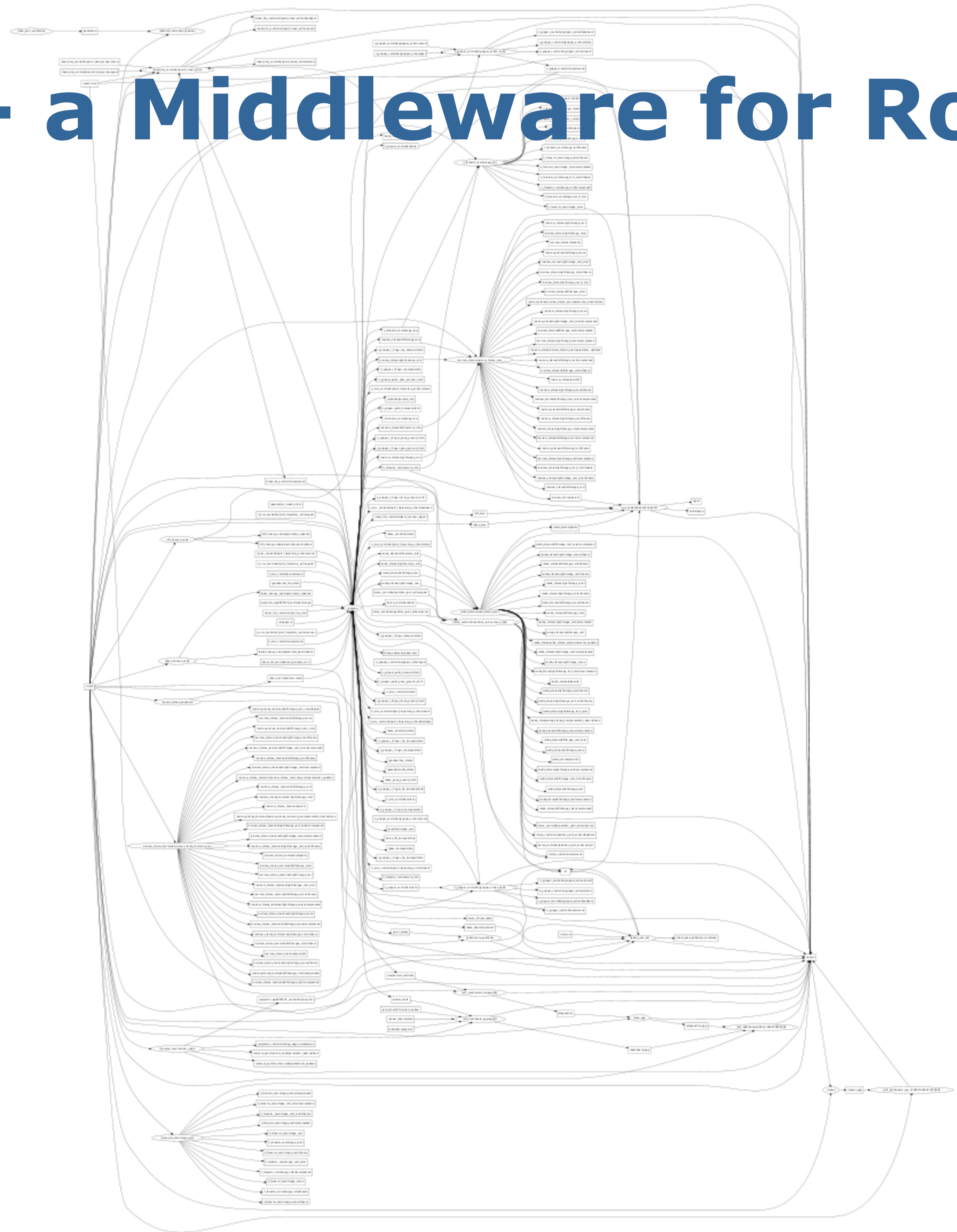
Interprocess Communication Using ROS



ROS - a Middleware for Robots



ROS - a Middleware for Robots



ROS - a Middleware for Robots

There is more to it...

- (De-)Serialization under the hood
- Central multi-level logging facilities
- Service calls, preemptible actions
- Central time
- Dynamic reconfiguration

ROS Overview

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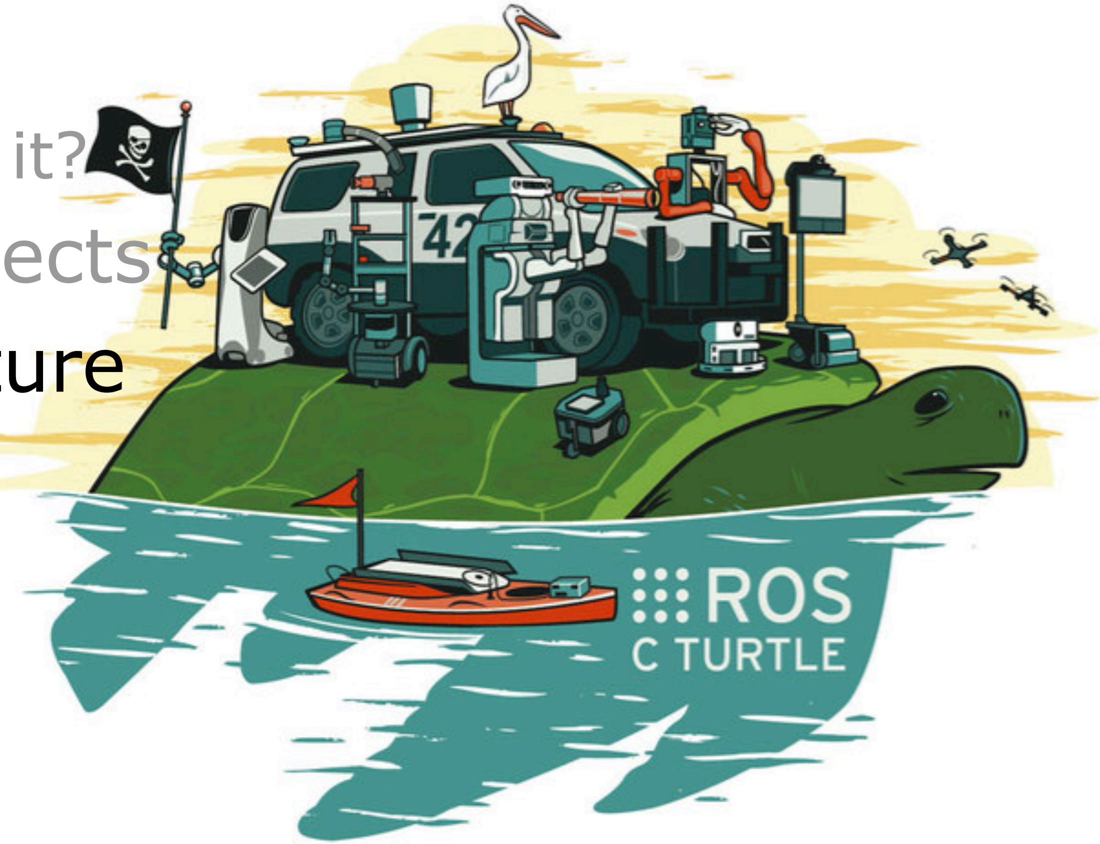


ROS – Software Distribution

Software Hierarchy

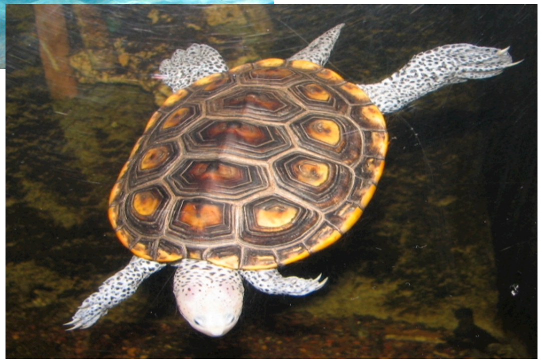
- **Release** – collection of stacks and packages
- **Stacks** – a full application suite
- **Package** – software (and interface definition) to solve a specific task
- **Node** – An executable with some useful functionality
- **Message/Service/Action** – Interface definitions

ROS – Software Distribution

Boxturtle
March 2010

C-Turtle
August 2010

Releases



Diamondback
March 2011

Electric Emys
November 2011

ROS – Software Distribution

ROS.org

About | Mailing Lists | code.ros.org

Documentation Browse Software News

packages ~3150 repositories ~270 stacks ~500

Name	Packages	Description
2dmapping_pr2_app	1	A 2D mapping application for the PR2 robot platform.
2dnav_pr2_app	1	A 2D navigation application for the PR2 robot platform.
arm_navigation	4	arm_navigation
articulation	5	Kinematic models for articulated objects (cabinet doors fitting, model selection and visualization.
art_vehicle	10	ART autonomous vehicle support
asctec_drivers	6	asctec_drivers
au_automow_common	5	Auburn University Autonomous Lawnmower - Common
au_automow_drivers	3	au_automow_drivers
au_automow_simulation	0	au_automow_simulation
bag_experimental	0	bag_experimental
billiards	17	billiards

ROS – Software Distribution

- Binary distribution via debian package management
- Source distribution via version control systems
- Tools for dependency resolution
  - Fetch binaries from apt-repository
  - Fetch source code from version control
  - Recursively build dependencies
- Central documentation wiki: ros.org/wiki

Installation instructions & download mirror:

http://ros.informatik.uni-freiburg.de

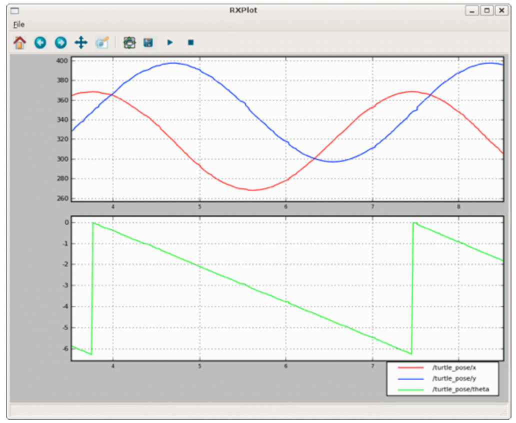
ROS – Client Libraries

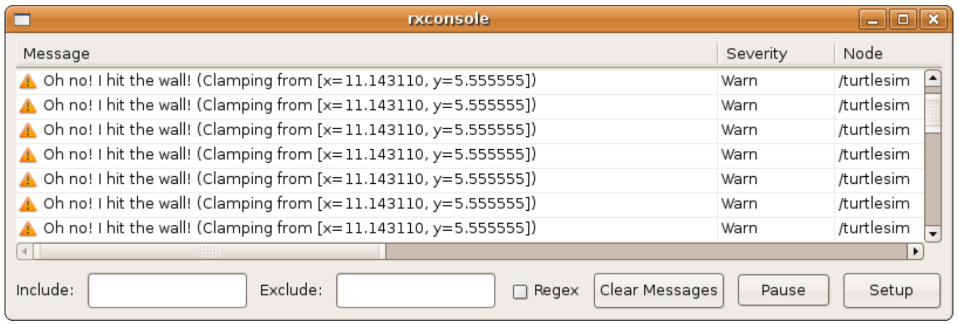
- What makes a program a ROS node?
- → Usage of a client library
  - C++ and Python
  - Octave/Matlab, Lisp, Java and Lua (experimental)
  - You can implement your own
- A client library embeds a program in the ROS interprocess communication network (i.e. attaches it to the middleware)

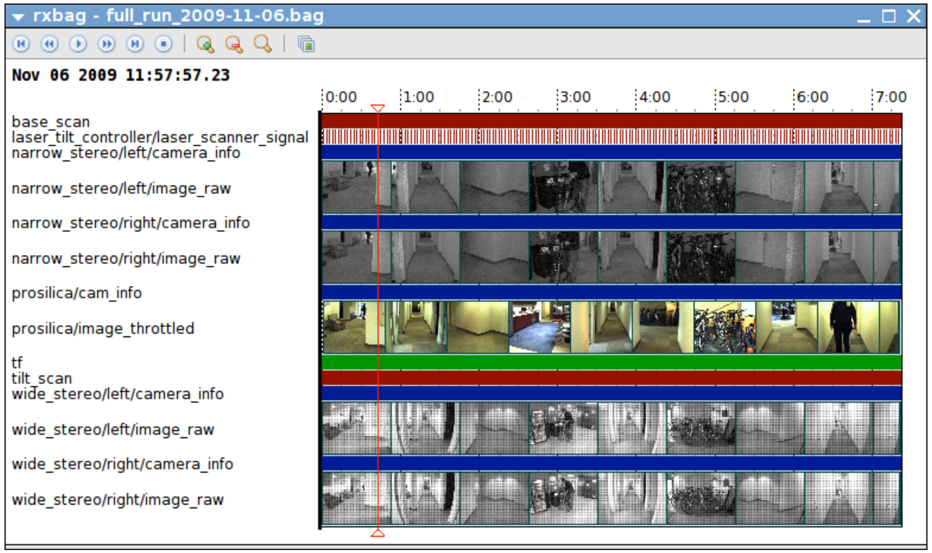
ROS – Tool Ecosystem

There is more to it...

- Tools for analysis, debugging
- and visualization of IPC
- Live message view
- Recording and playback
- Many more...







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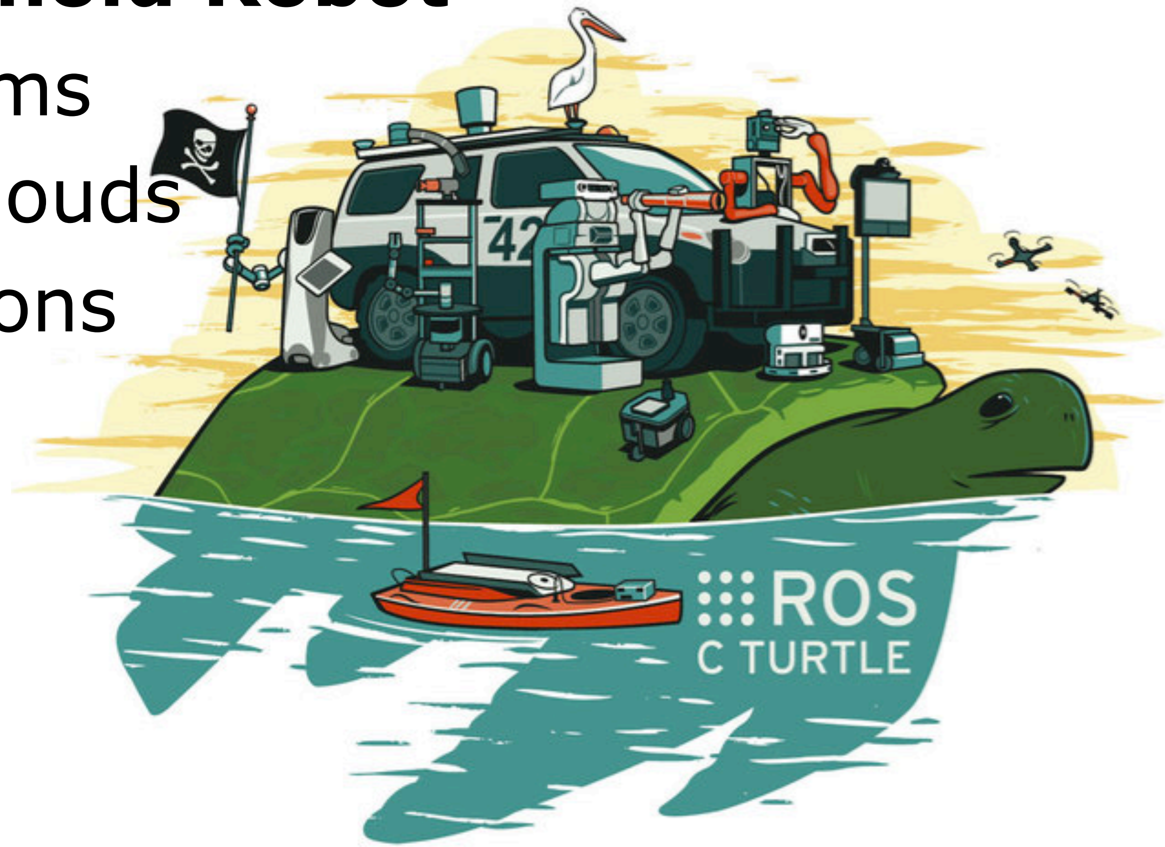
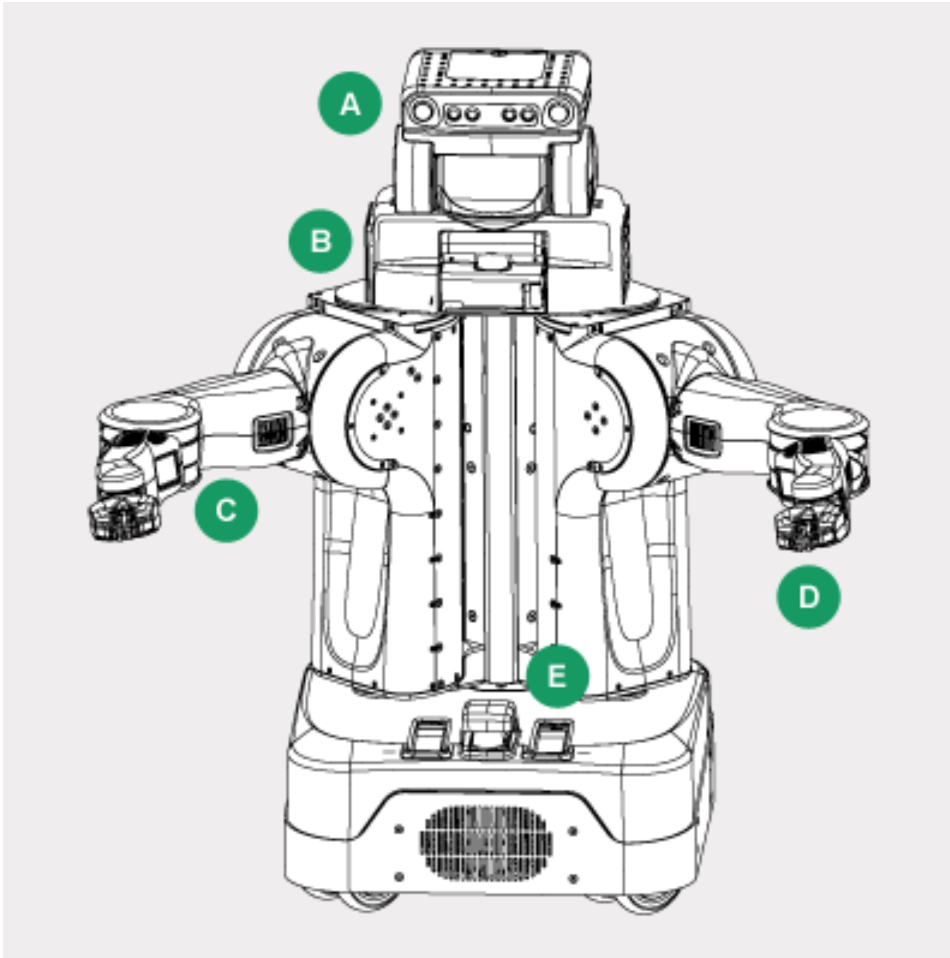
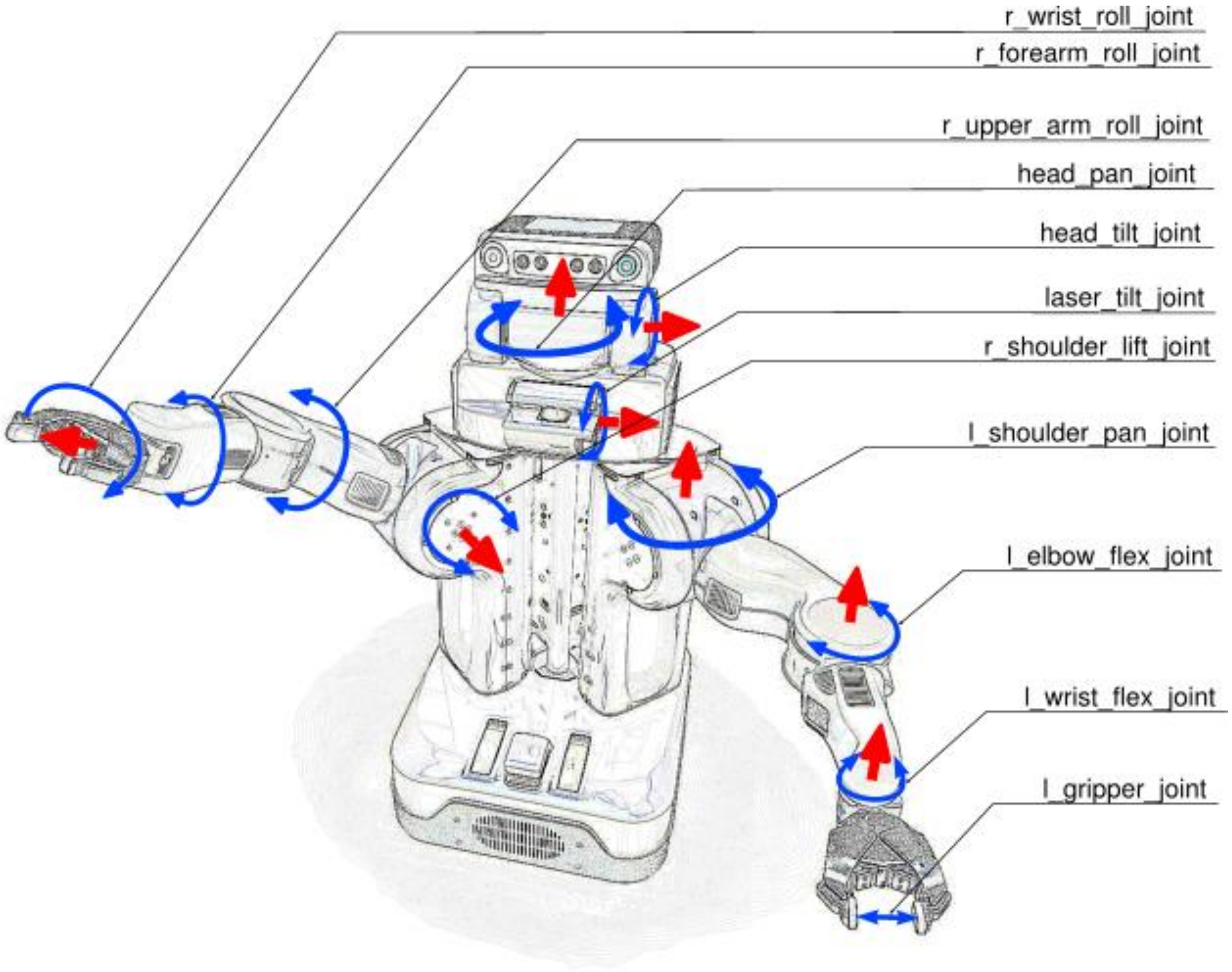


Sensors



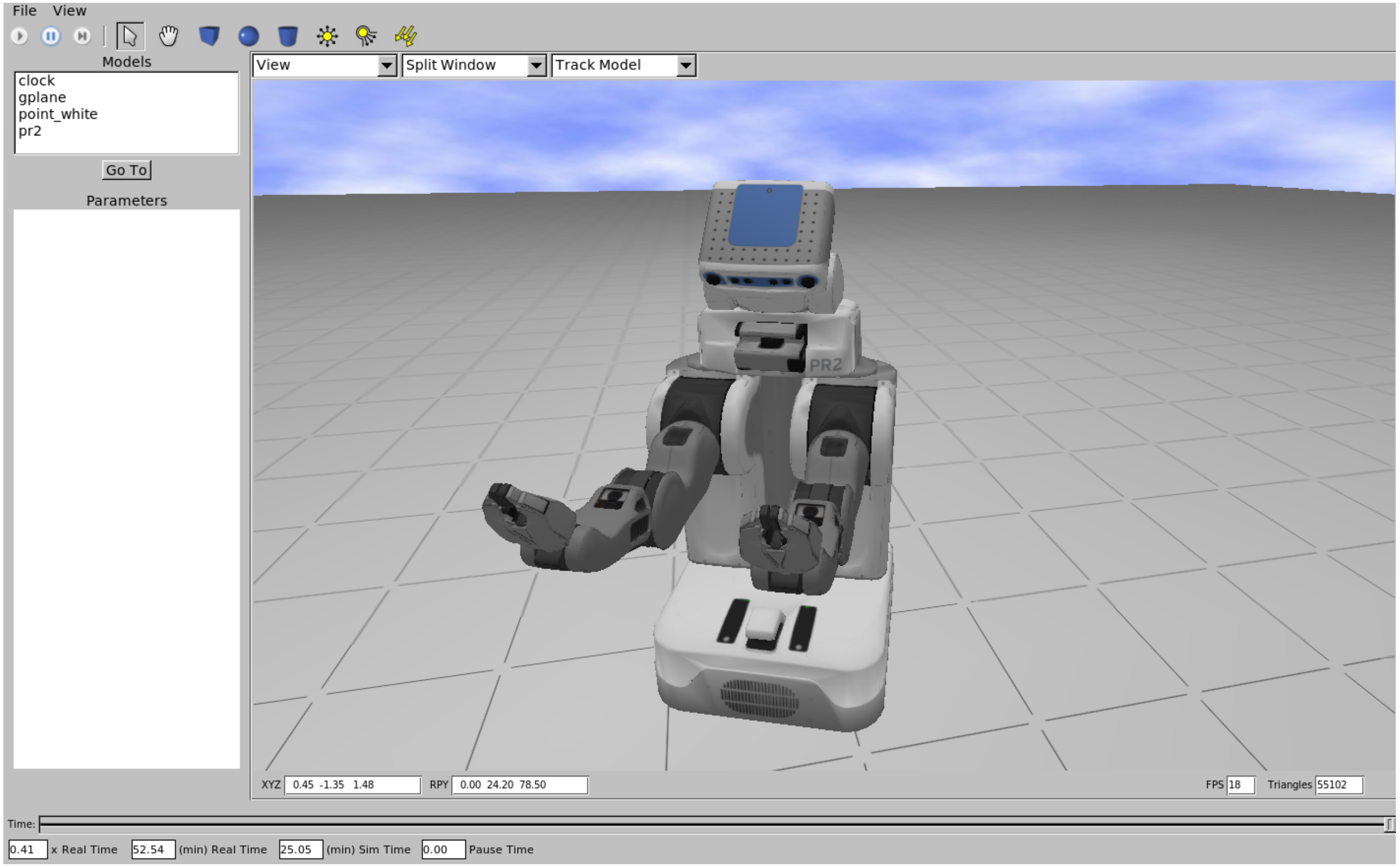
Joints


r_wrist_roll_joint
r_forearm_roll_joint
r_upper_arm_roll_joint
head_pan_joint
head_tilt_joint
laser_tilt_joint
r_shoulder_lift_joint
l_shoulder_pan_joint
l_elbow_flex_joint
l_wrist_flex_joint
l_gripper_joint

PC Hardware

- 2x Onboard servers
  - Processors : Two Quad-Core i7 Xeon
  - Memory : 24 GB
- Internal hard drive: 500 GB
- Removable hard drive:: 1.5 TB

PR2 Simulation



PR2 Simulation

- Motivation:
  - Regression testing
  - Visualization
  - Design, optimization
  - Multiple developers, single robot

- Based on Open Source project Gazebo
- Uses Open Dynamics and Physics Engine
- Uses Ogre for rendering

PR2 Simulation

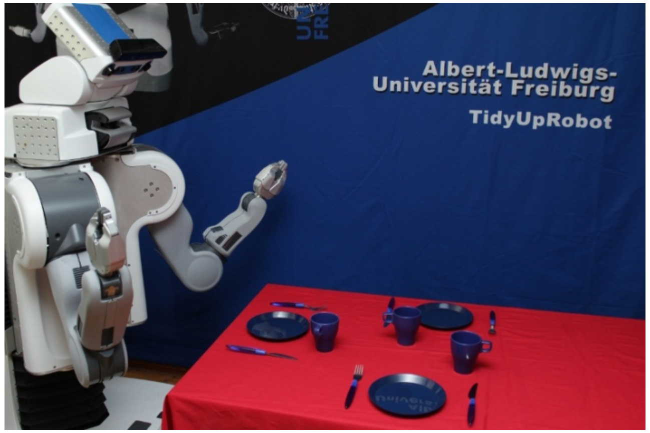
- Requirements:
  - Graphics card with 3D acceleration (Nvidia, ATI)
  - Linux supported driver
  - Core2Duo processor
  - > 2GB Ram

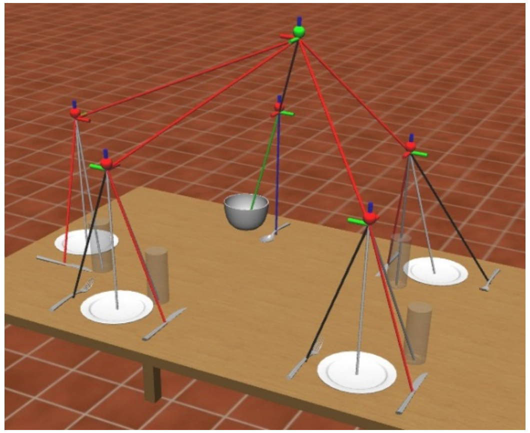
Simulation Fidelity

- Manipulation:
  - Simulated real-time PR2 etherCAT node communicates actuator states (motor efforts and position)
- Perception:
  - Simulated sensor nodes for cameras, lasers and imu
  - Stream data as well as services provided
- Self collision checks are disabled
- Anti-gravity arms
- No laser scan duration

Learning to Set a Table

- Observe example scenes of breakfast tables
- Learn a hierarchical scene model
  - Level 1: physical objects (segmented point clouds)
  - Level 2: covers (constellations of physical objects)
  - Level 3: table scenes (constellations of covers)
- Sample from the model to generate new scenes

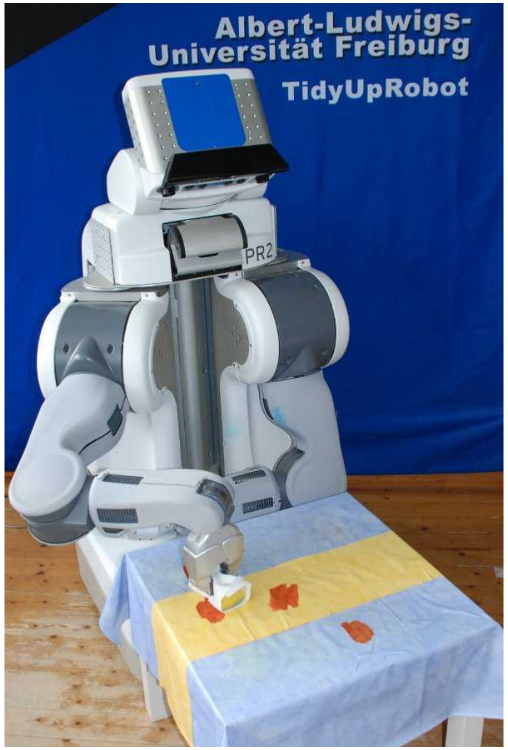




Learning to Clean a Table

- Uncertainty about how the dirt looks like
- Idea: "Dirt is that what we can remove"

1. Cluster image into color classes
2. Observe table state
3. Try wiping each class
4. Updating belief about the expected
5. Clean the entire table
6. Observe again



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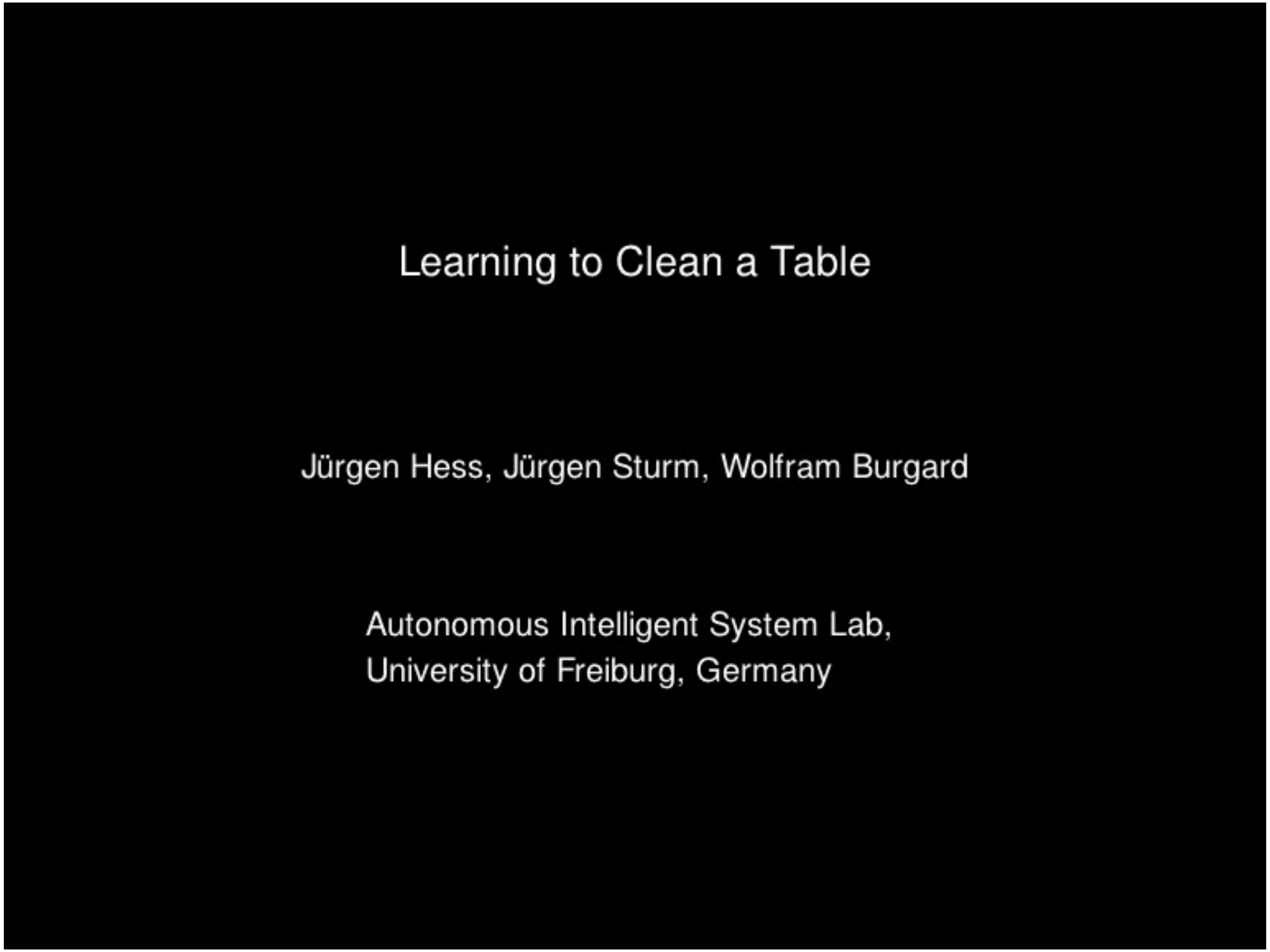
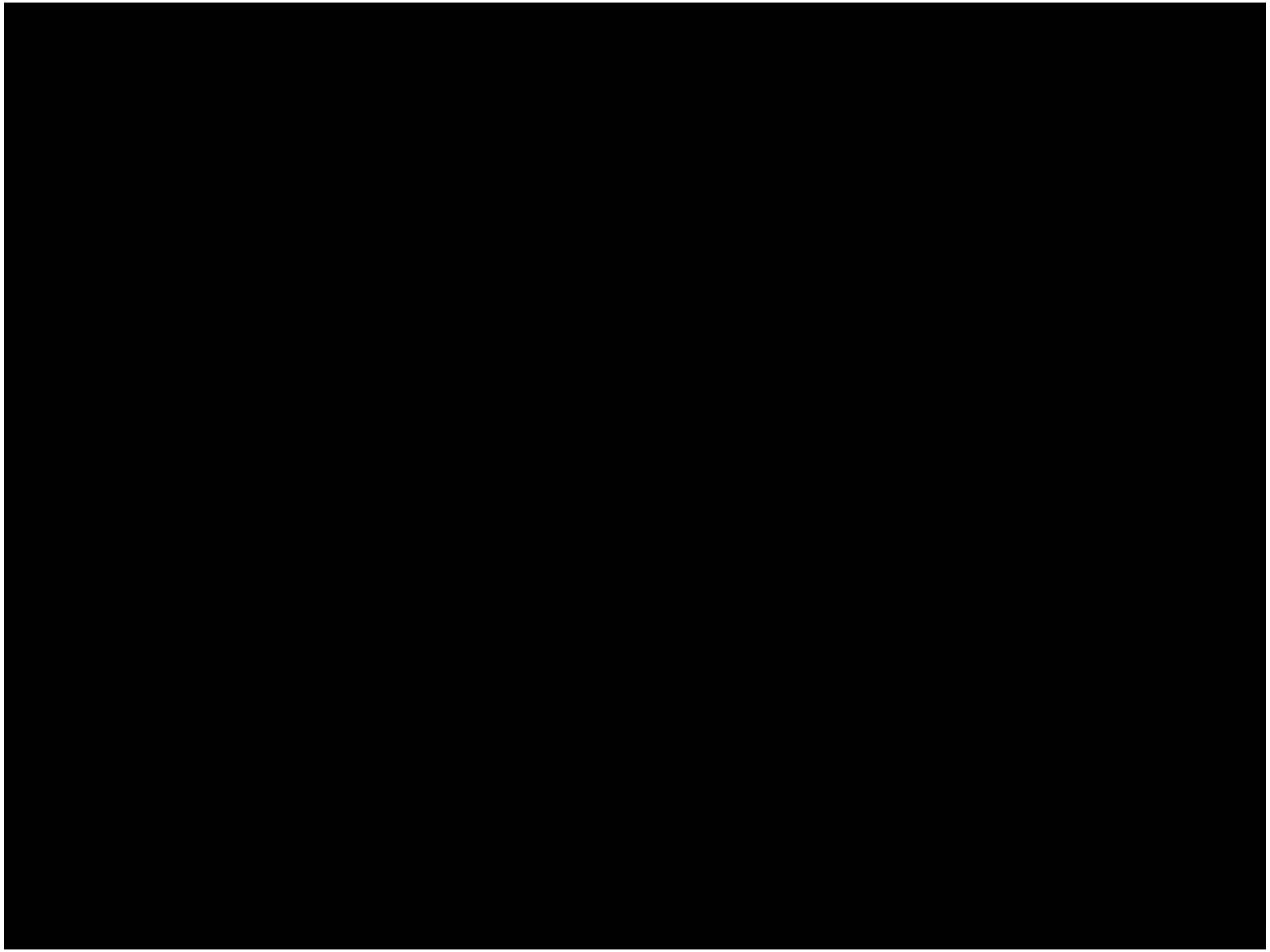


Student Projects

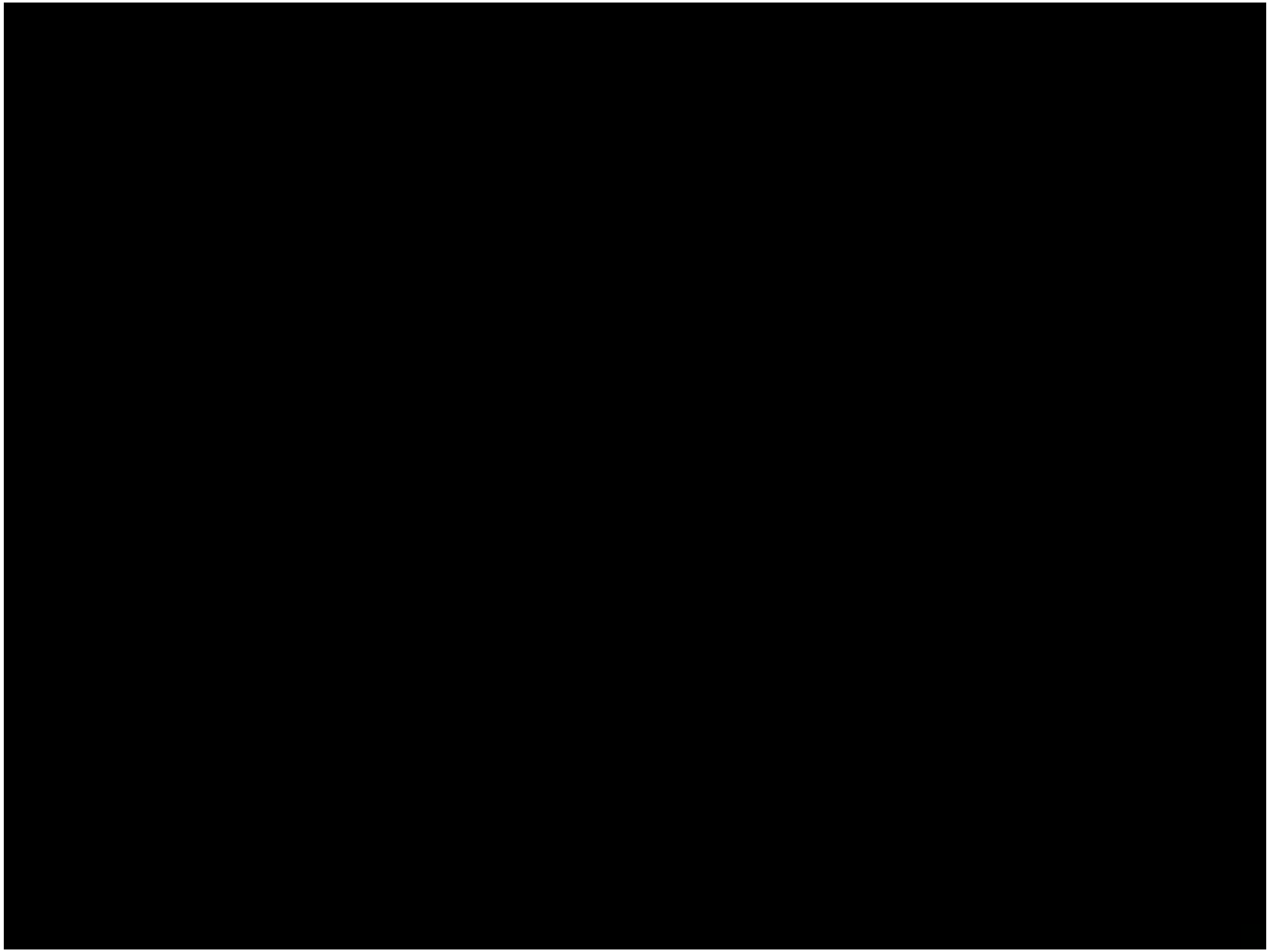
- Portrait Bot:
  - Recognize faces in camera images
  - Extract edges
  - Draw edge image onto a whiteboard
  - Available in May

- Two-handed cleaning with a broom:
  - Objective: adapting coverage plan to using a broom (e.g. different poses/pattern for sweeping in corners or under a table)

Student Project: Portrait Bot



Student Project: Sweeping



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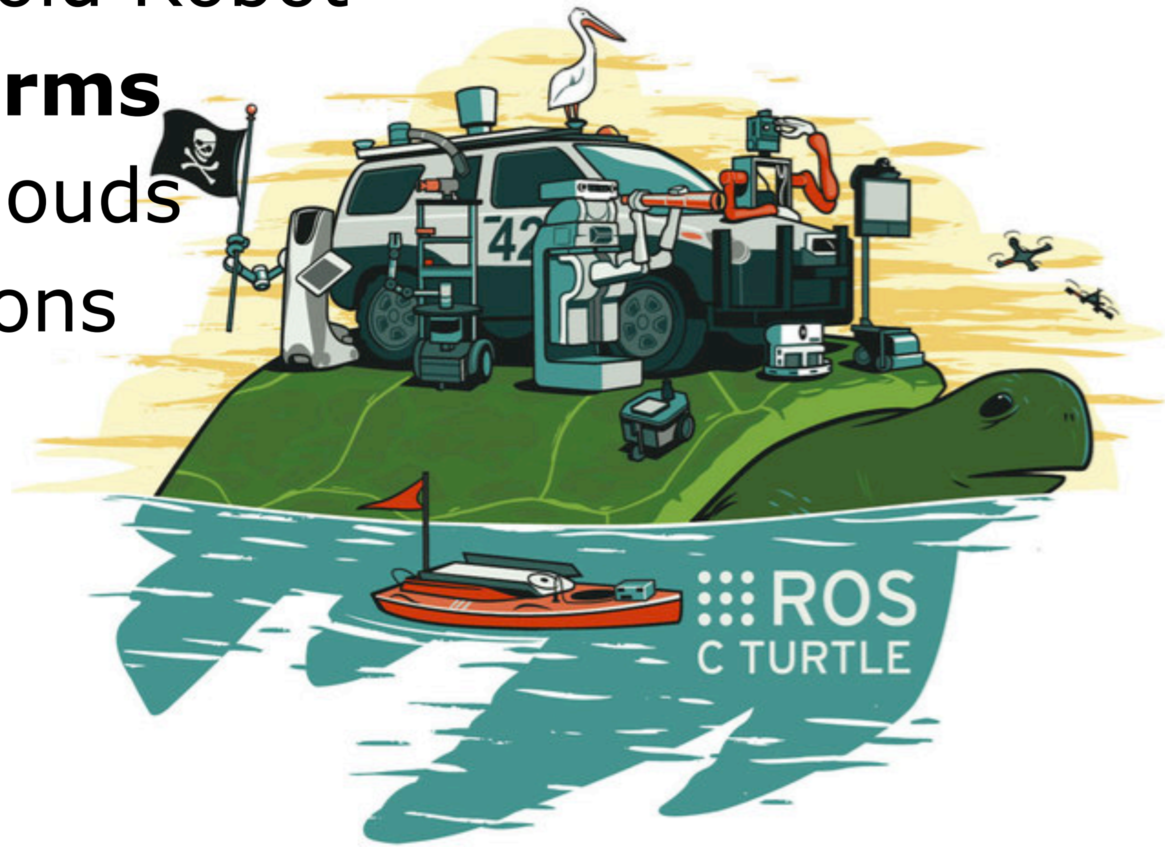
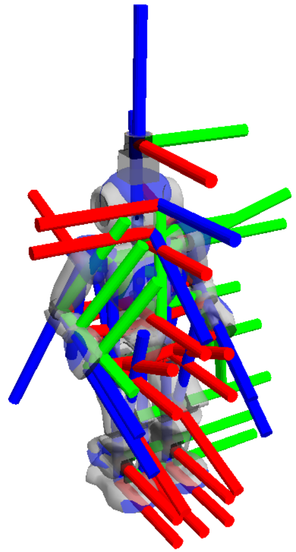
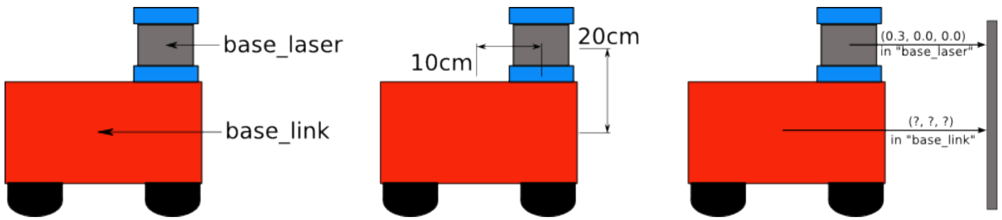


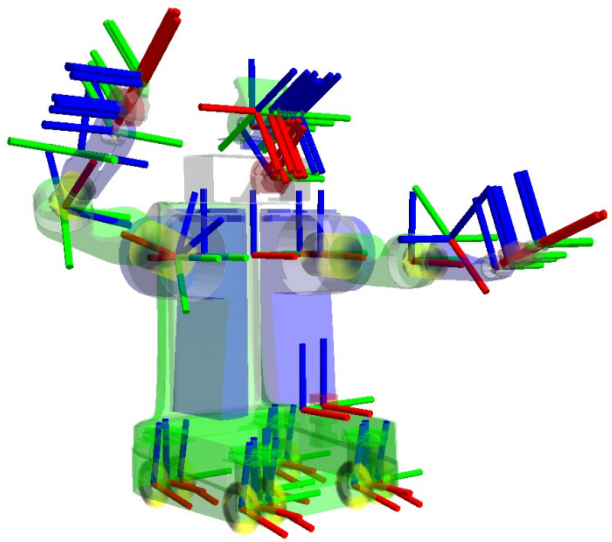
Motivation

- Multiple sensors and actuators on robots
- Robot and sensors not static
- Multi-robot cooperation

➡ **Where is this object relative to my gripper? Where is my arm in the world?**







What is tf?

A coordinate frame tracking system

- Standardized protocol for publishing transform data to a distributed system
- Helper classes and methods for:
  - Publishing coordinate frame data: *TransformBroadcaster*
  - Collecting transform data and using it to manipulate data: *Transformer, TransformListener, tf::MessageFilter, ...*
- Currently: Only tree(s) of transformations, but any robot(s) / sensor layout
- Conversion functions, mathematical operations on 3D poses

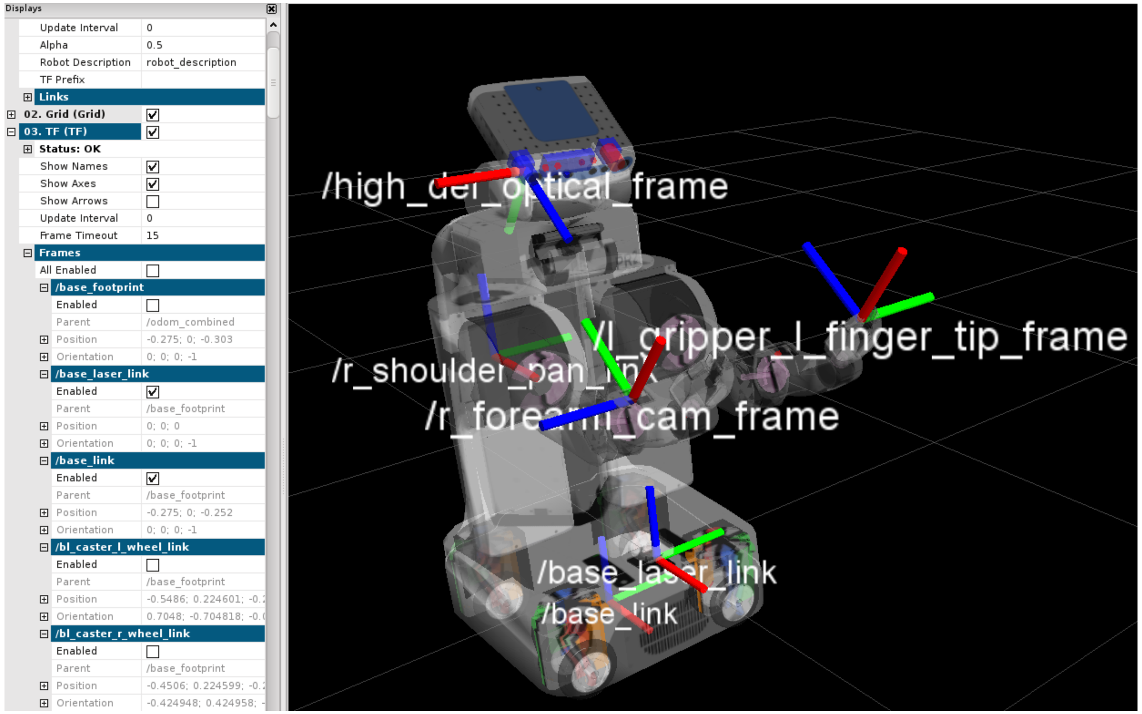
tf is Distributed!

- Two types of tf nodes: Publishers & Listeners
- Listeners: Listen to /tf and cache all data heard up to cache limit (10 sec default)
- Publishers: Publish transforms between coordinate frames on /tf
- No central source of tf information, or history before a node was started

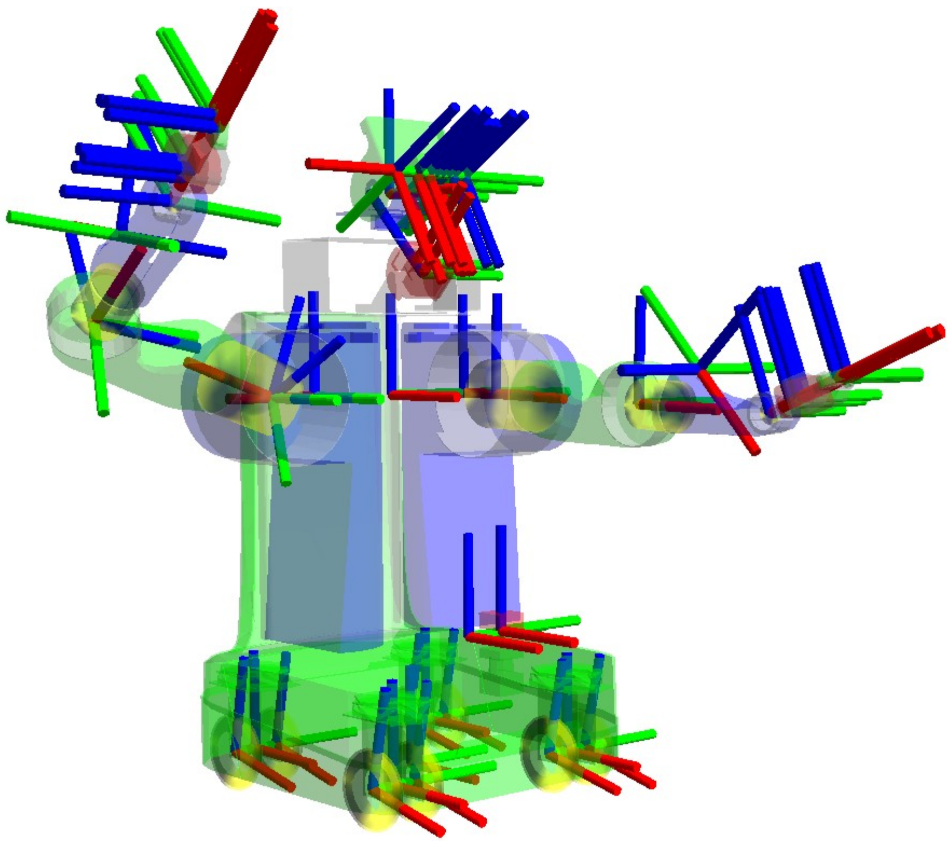
Debugging Tools

- Command Line Tools
  - tf_echo: Print a specific transform to the screen
  - tf_monitor: Display statistics about transforms
  - roswtf: Debug common tf configuration errors

- Visualizations
  - Rviz tf plugin
  - view_frames



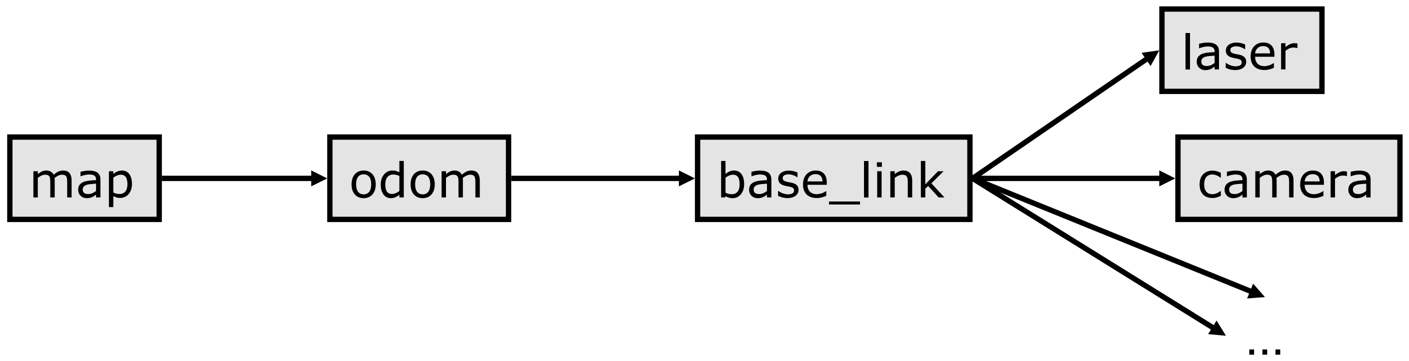
Coordinate Frames on the PR2



- Coordinate frames for every link and sensor of the robot
- Each sensor publishes data in its own coordinate frame

Common Setup for Mobile Robots

- odom -> base_link provided by robot odometry
- map -> odom provided by localization method (e.g. *amcl* in ROS)
  - How to transform odom link in map frame so that base_link is “correct”?



Sources of Transformations

- URDF file defines robot “body layout”
  - Joints, links, sensor positions, visualization

- tf for all robot links automatically published
- Static transforms published from command line
- In your own node (e.g. localization)

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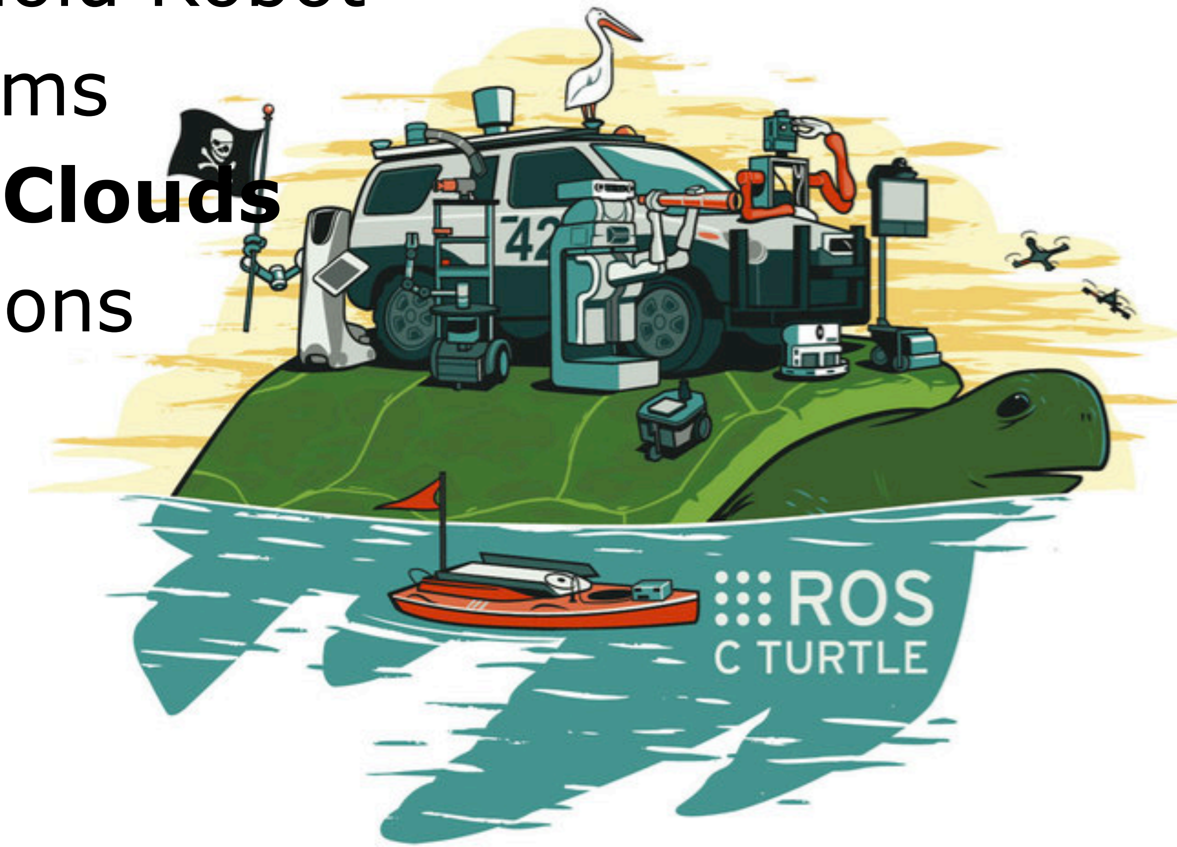
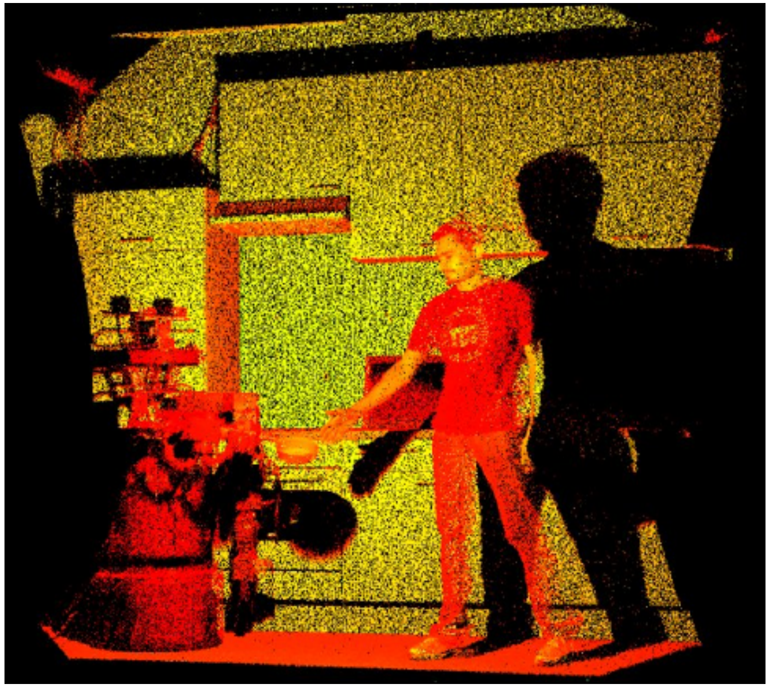
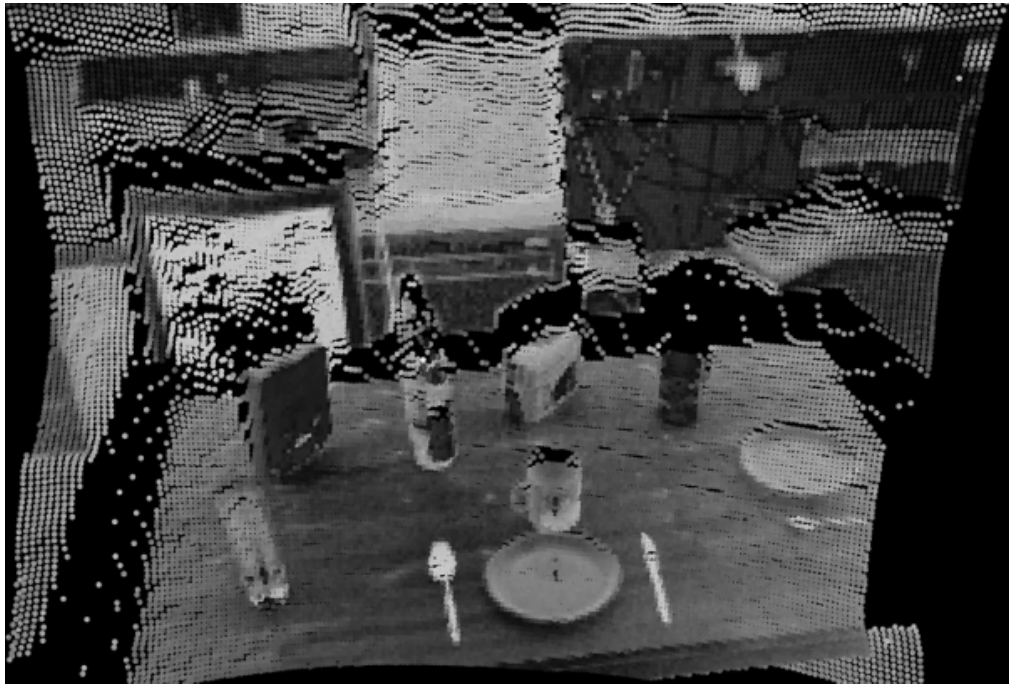


What are Point Clouds



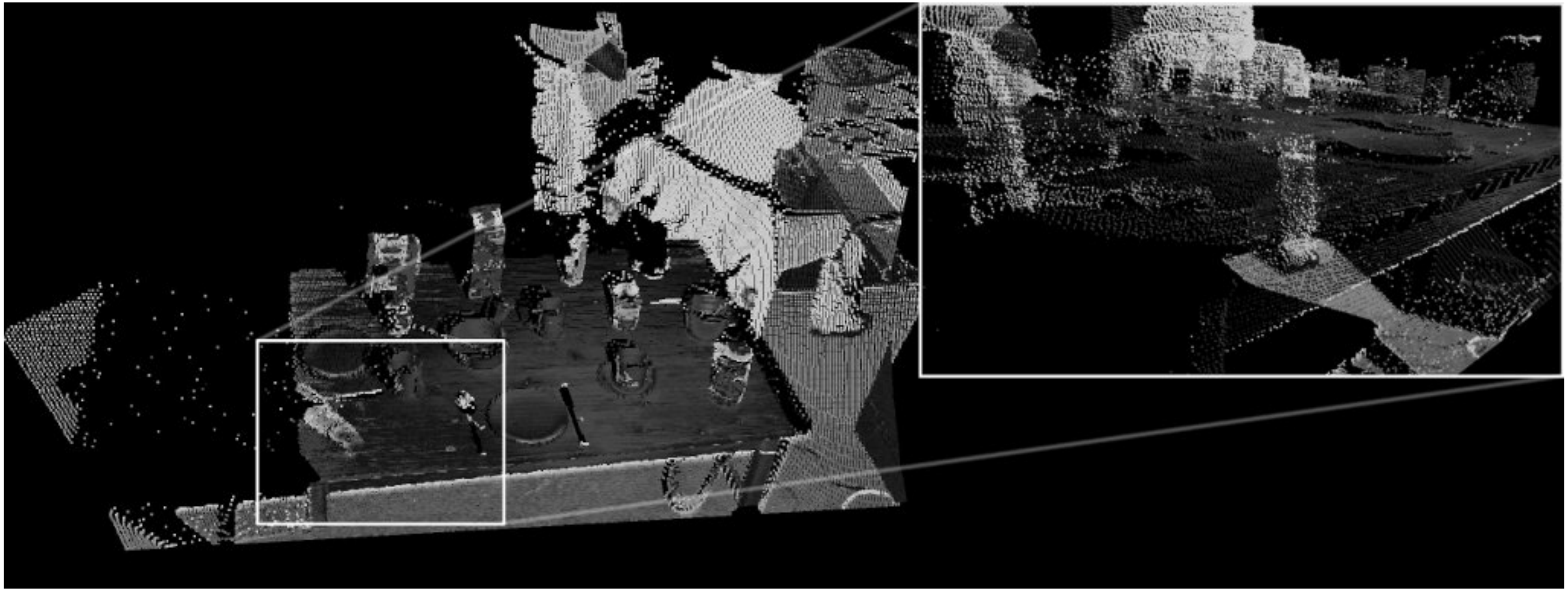


- Point Cloud = a "cloud" (i.e., collection) of nD points (usually n = 3)
- $\mathbf{p}_i = \{x_i, y_i, z_i\} \longrightarrow \mathcal{P} = \{\mathbf{p}_1, \mathbf{p}_2, \ldots, \mathbf{p}_i, \ldots, \mathbf{p}_n\}$
- used to represent 3D information about the world

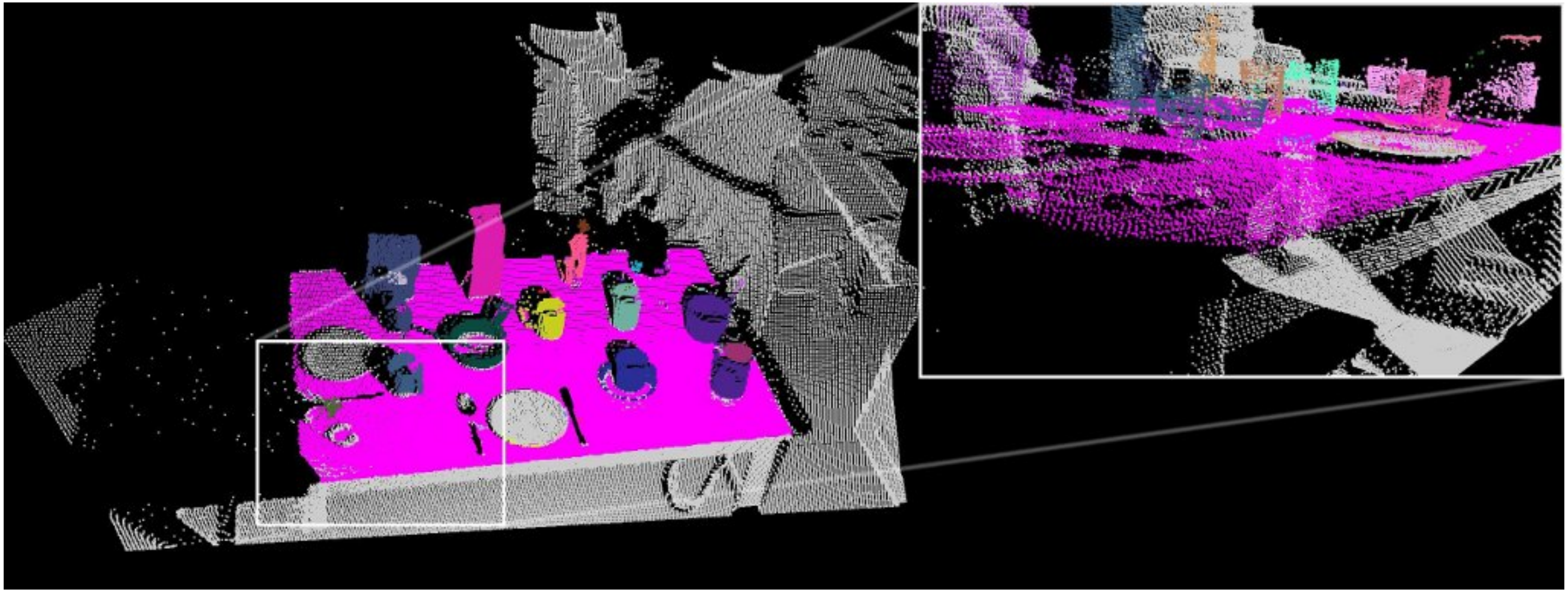
What are Point Clouds

- besides XYZ data, each point $\mathbf{p}$ can hold additional information
- examples include: RGB colors, intensity values, distances, segmentation results, etc…

What are Point Clouds



What are Point Clouds

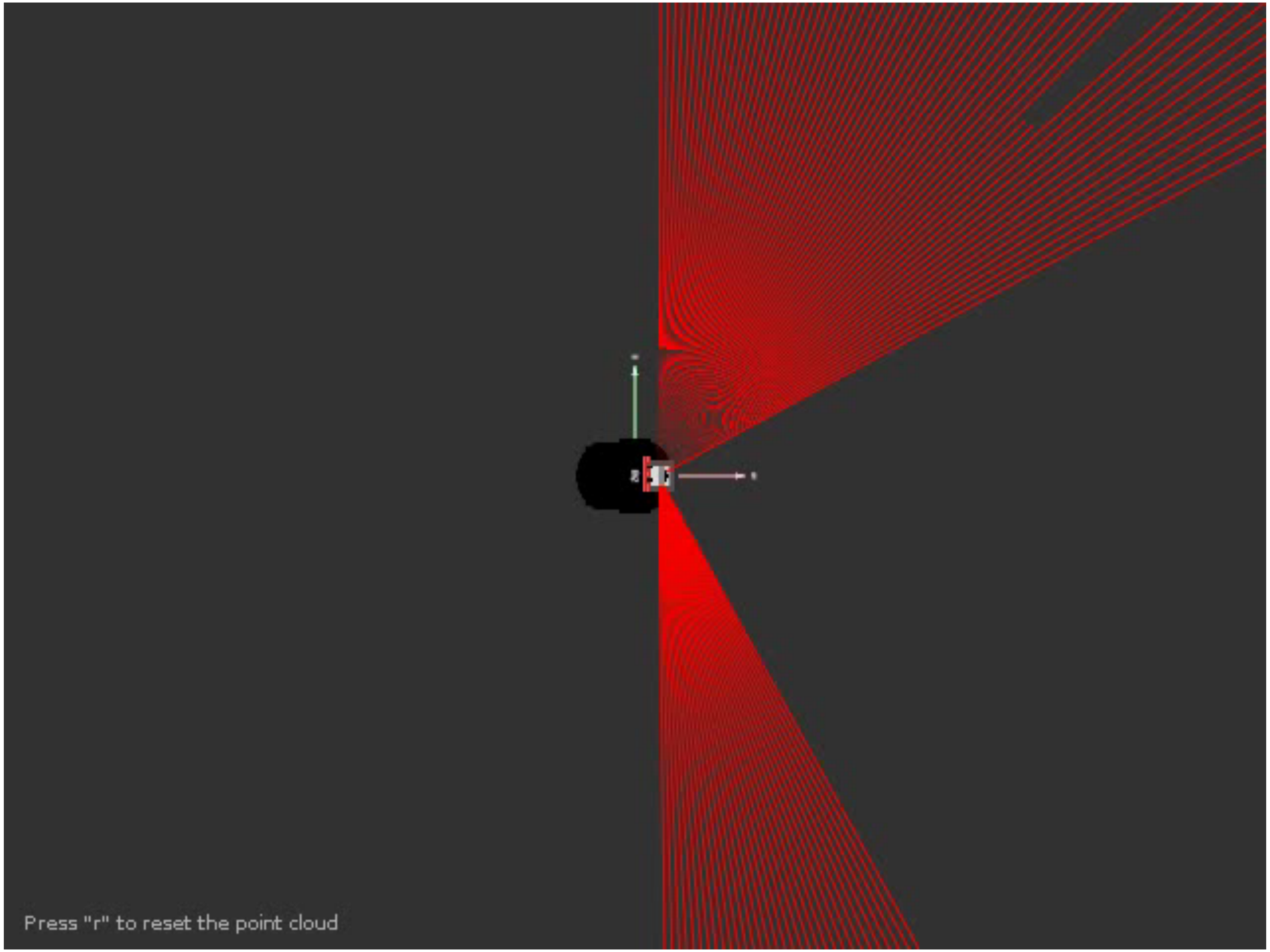


Where do they come from?

- Laser scans (high quality)
- Stereo cameras (passive & fast but dependent on texture)
- Time of flight cameras (fast but not as accurate/robust)
- Kinect-Style Sensors
- Simulation
- …

Tilting Laser Scanner

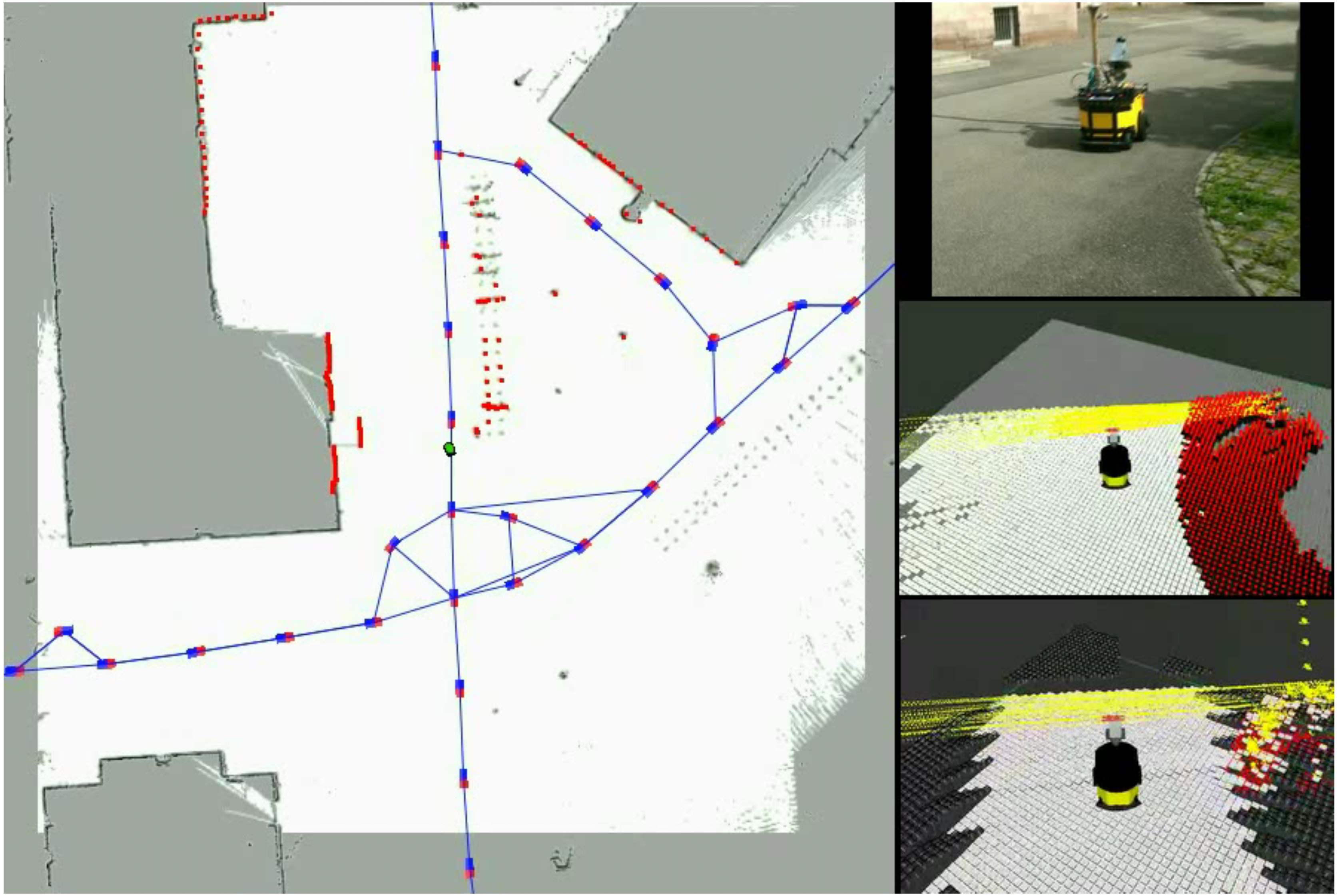
Tilting Scanner on Moving Robot



For what!?

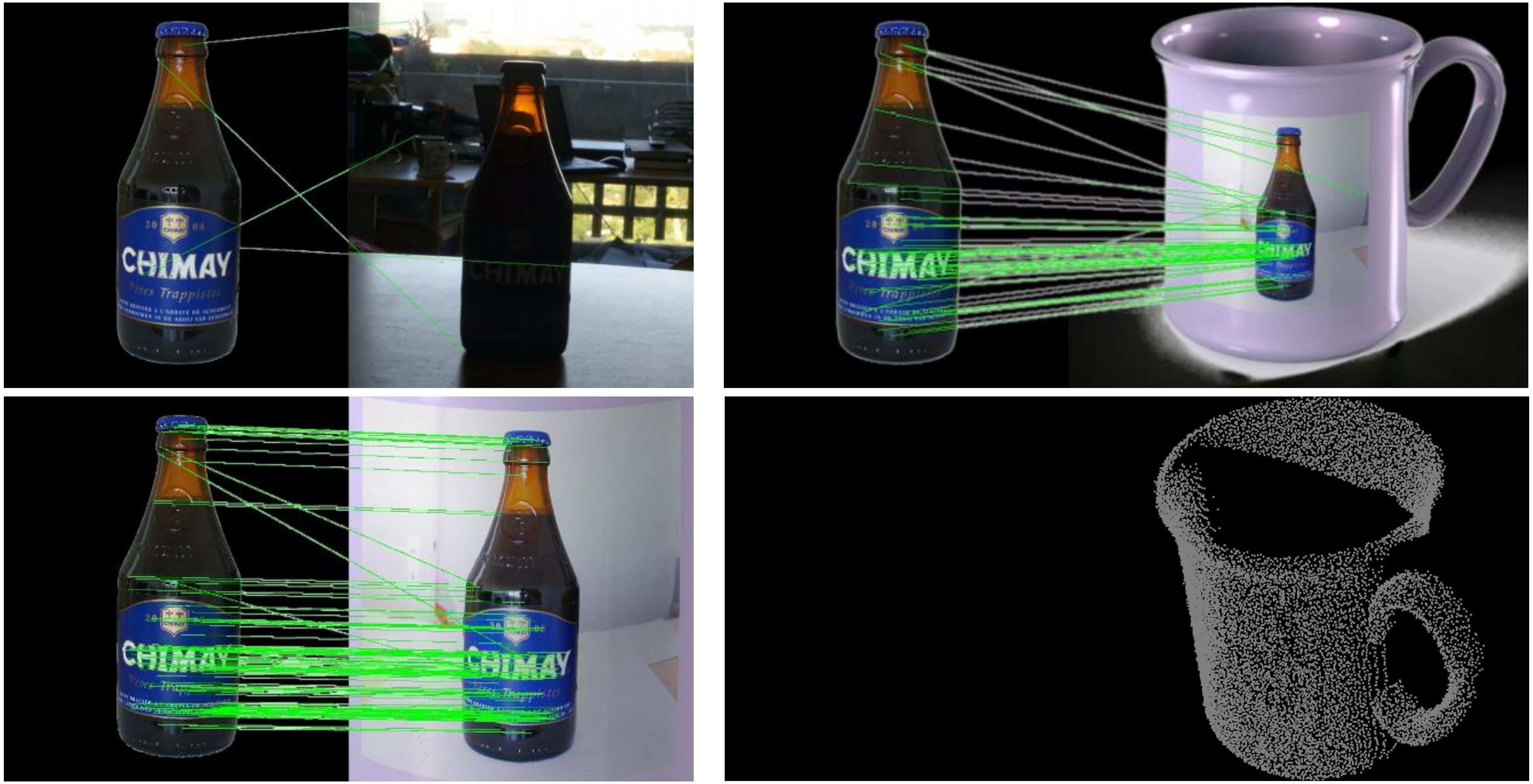
- Spatial information of the environment has many important applications
  - Navigation / Obstacle avoidance
  - Object recognition
  - Grasping
  - …

Obstacle & Terrain Detection



Object Recognition

Point Clouds can complement and supersede images when they are ambiguous.

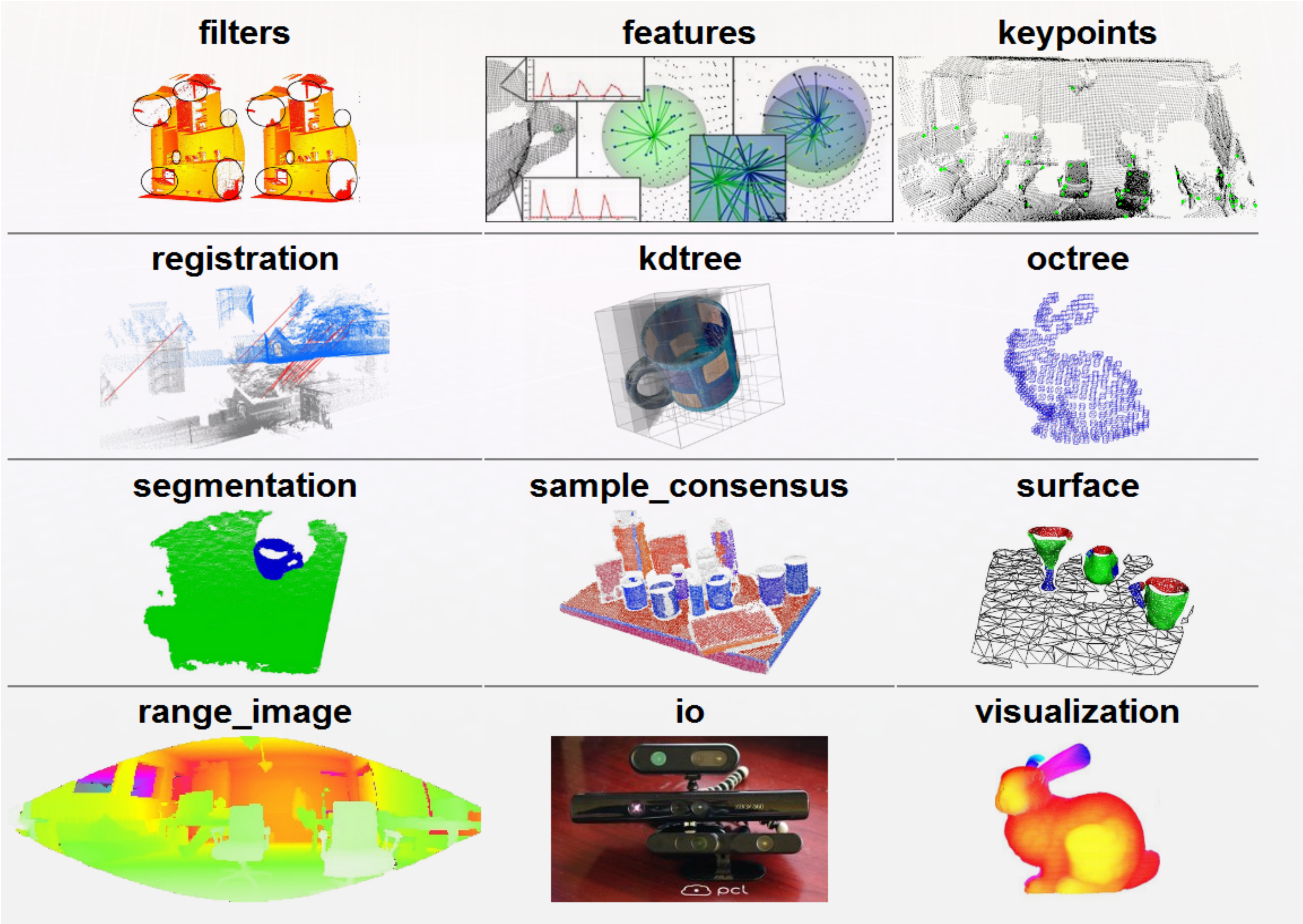


What is PCL?

PCL

- is a fully templated modern C++ library for 3D point cloud processing
- uses SSE optimizations (Eigen backend) for fast computations on modern CPUs
- uses OpenMP and Intel TBB for parallelization
- passes data between modules (e.g., algorithms) using Boost shared pointers
- will be made independent from ROS in one of the next releases

PCL Modules


filters
features
keypoints
registration
kdtree
octree
segmentation
sample_consensus
surface
range_image
io
visualization
pcl

Data Representation

- PointCloud class (templated over the point type):

```
template <typename PointT>
class PointCloud;
```

- Important members:

```
std::vector<PointT> points; // the data
uint32_t width, height; // scan structure?
```

Point Types

- Examples of PointT:

```
struct PointXYZ
{
  float x;
  float y;
  float z;
}
```

or

```
struct Normal
{
  float normal[3];
  float curvature;
}
```

See pcl/include/pcl/point_types.h for more examples.

PointCloud2 Message

- We distinguish between two data formats for the point clouds:
  - PointCloud<PointType> with a specific data type (for actual usage in the code)
  - PointCloud2 as a general representation containing a header defining the point cloud structure (for loading, saving or sending as a ROS message)

Conversion between the two is easy:

`pcl::fromROSMsg` and `pcl::toROSMsg`

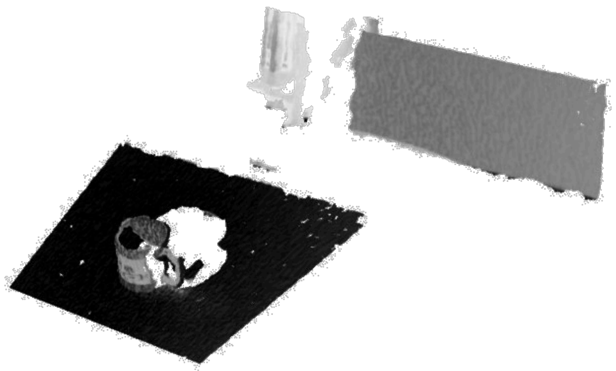
Basic Interface

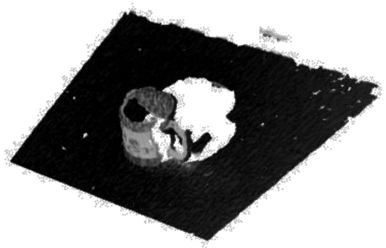
Filters, Features, Segmentation all use the same basic usage interface:

- Create the object
- use `setInputCloud` to give the input
- set some parameters
- call `compute` to get the output

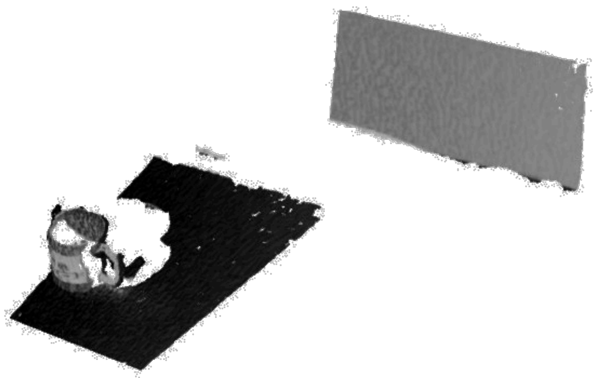
Filter Example 1

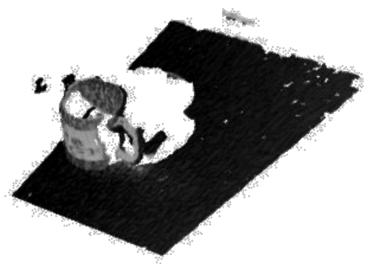
```
pcl::PassThrough<T> p;
p.setInputCloud (data);
p.FilterLimits (0.0, 0.5);
p.SetFilterFieldName ("z");
```





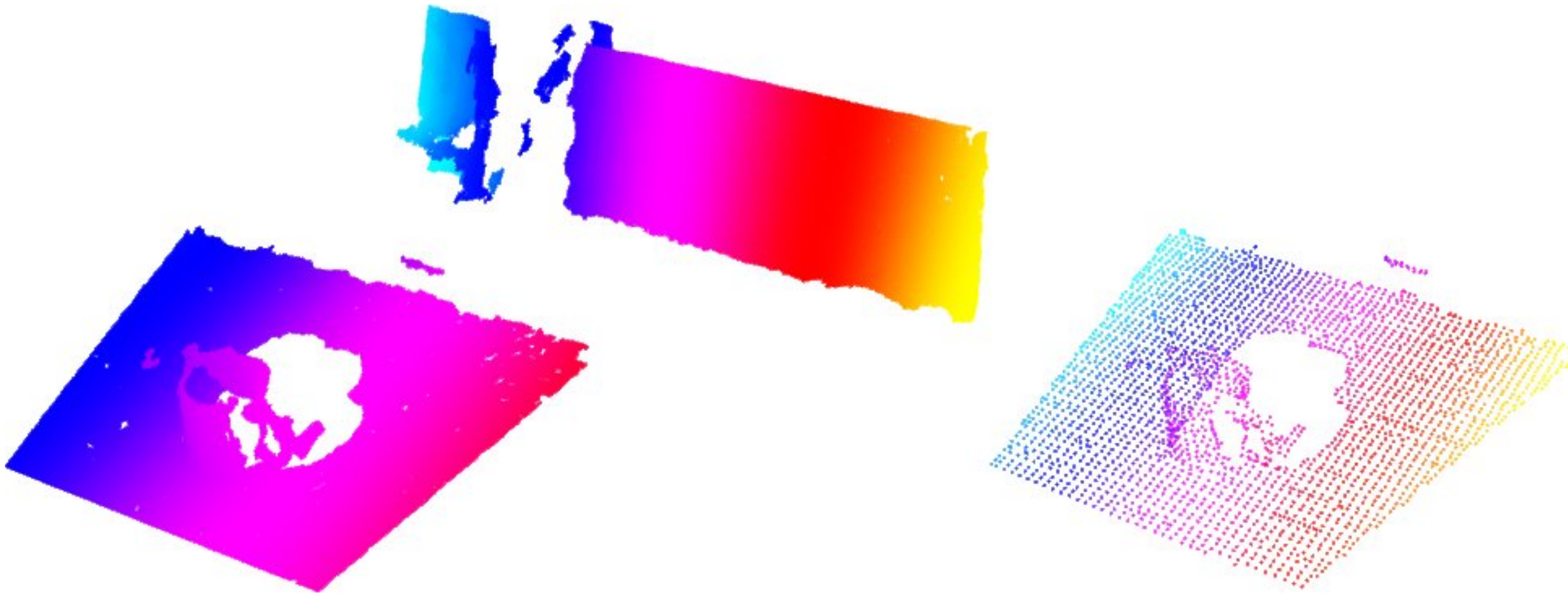
```
filter_field_name = "x"; | filter_field_name = "xz";
```





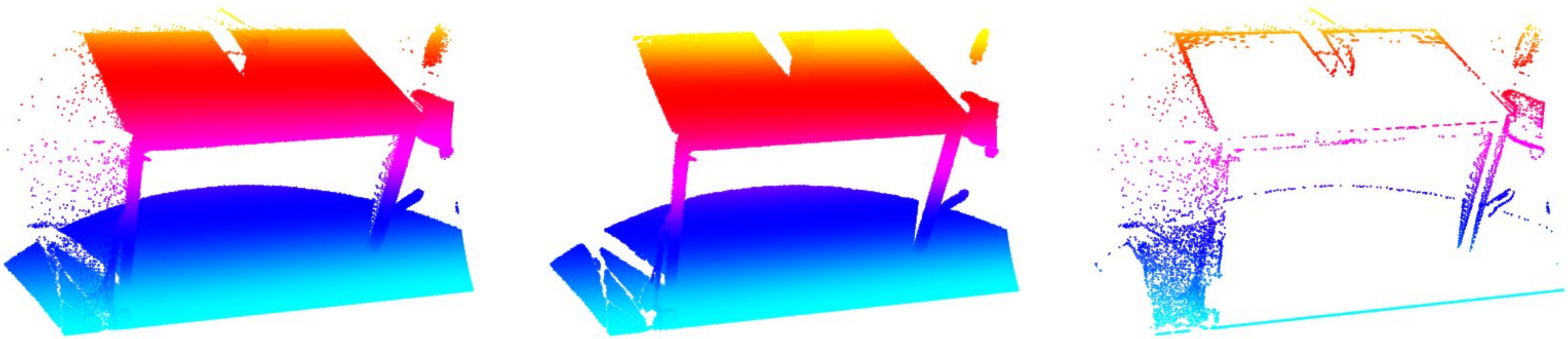
Filter Example 2

```
pcl::VoxelGrid<T> p;
p.setInputCloud (data);
p.FilterLimits (0.0, 0.5);
p.SetFilterFieldName ("z");
p.setLeafSize (0.01, 0.01, 0.01);
```



Filter Example 3

```
pcl::StatisticalOutlierRemoval<T> p;
p.setInputCloud (data);
p.setMeanK (50);
p.setStddevMulThresh (1.0);
```

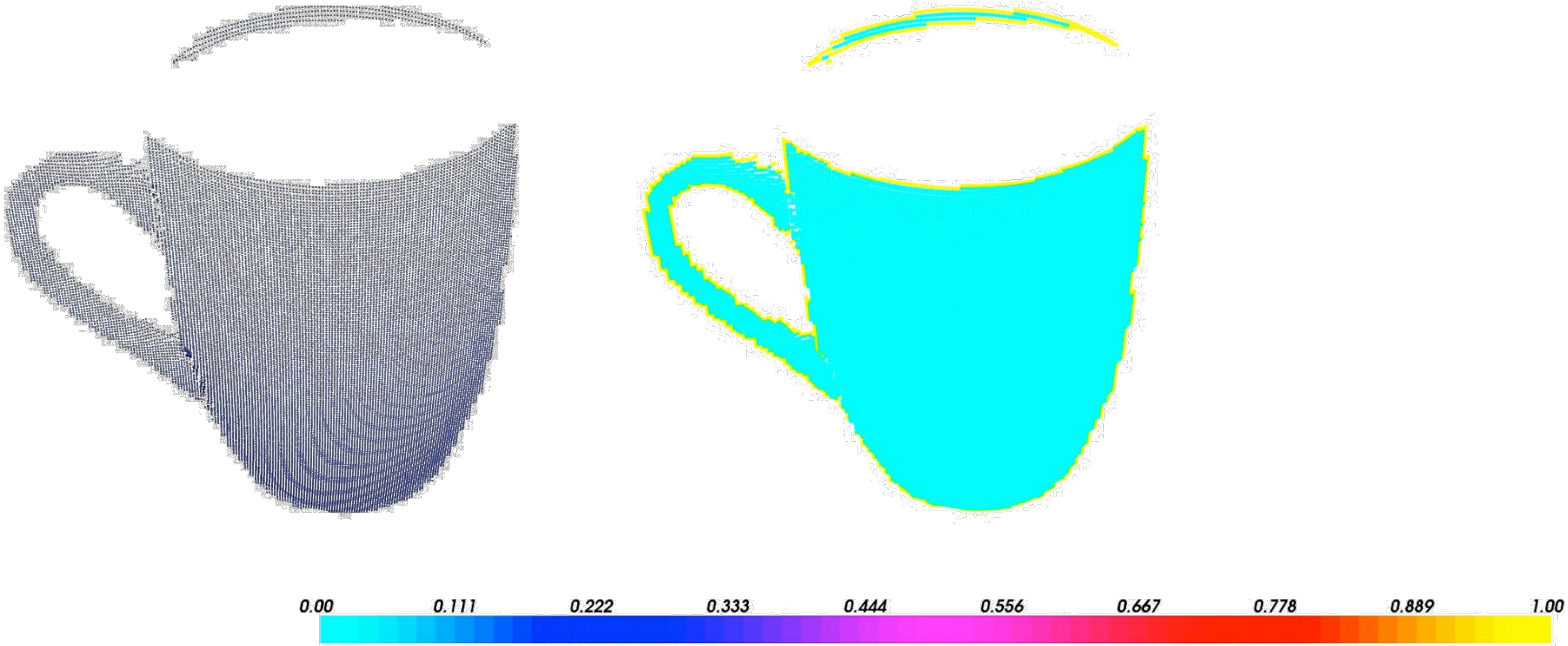


Features Example 1

```
pcl::NormalEstimation<T> p;
p.setInputCloud (data);
p.SetRadiusSearch (0.01);
```

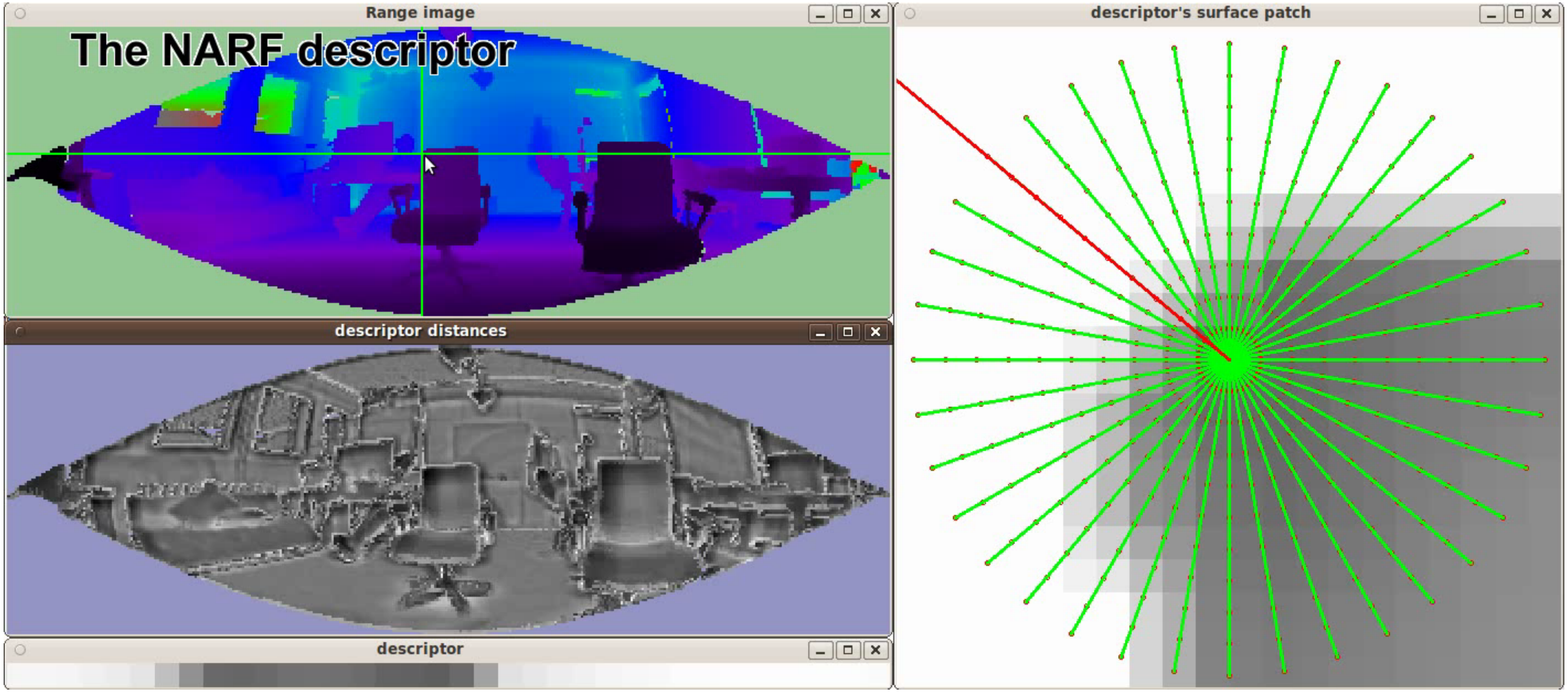
Features Example 2

```
pcl::BoundaryEstimation<T,N> p;
p.setInputCloud (data);
p.setInputNormals (normals);
p.SetRadiusSearch (0.01);
```



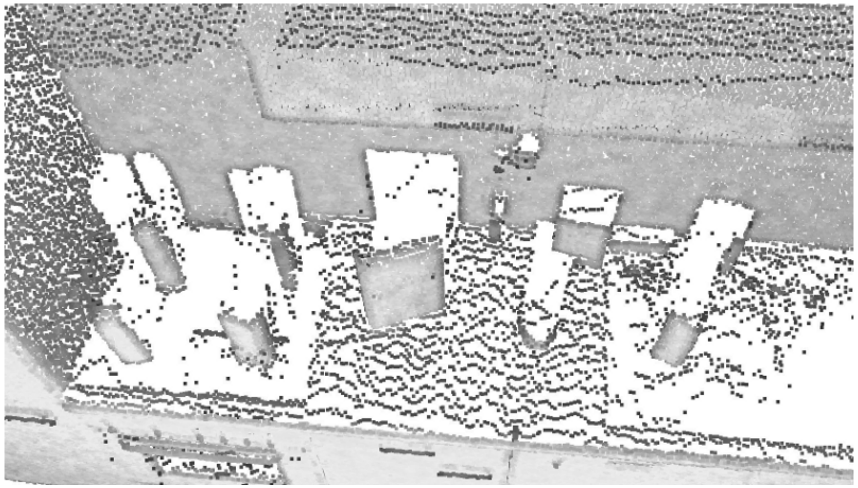
Features Example 3

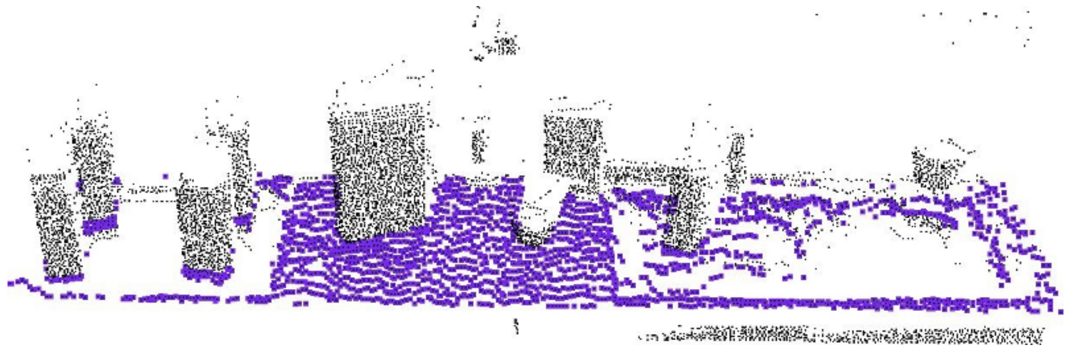
```
NarfDescriptor narf_descriptor(&range_image);
narf_descriptor.getParameters().support_size = 0.3;
narf_descriptor.getParameters().rotation_invariant = false;
PointCloud<Narf36> narf_descriptors;
narf_descriptor.compute(narf_descriptors);
```



Segmentation Example 1

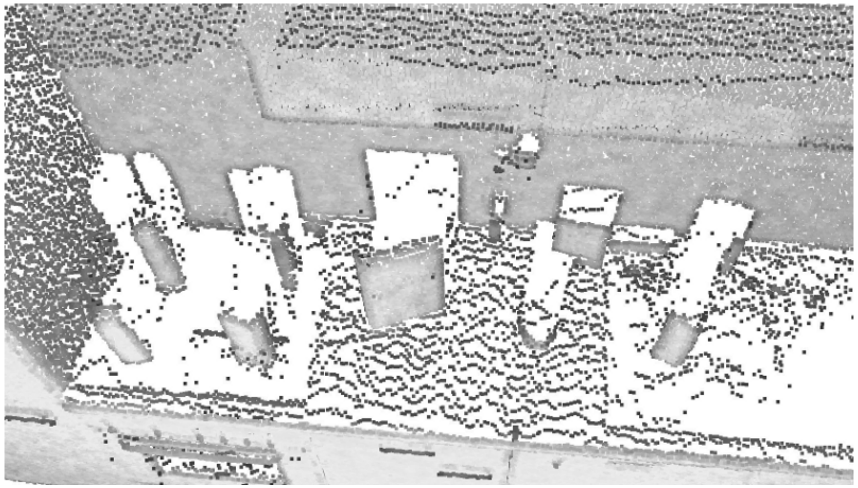
```
pcl::SACSegmentation<T> p;
p.setInputCloud (data);
p.setModelType (pcl::SACMODEL_PLANE);
p.setMethodType (pcl::SAC_RANSAC);
p.setDistanceThreshold (0.01);
```





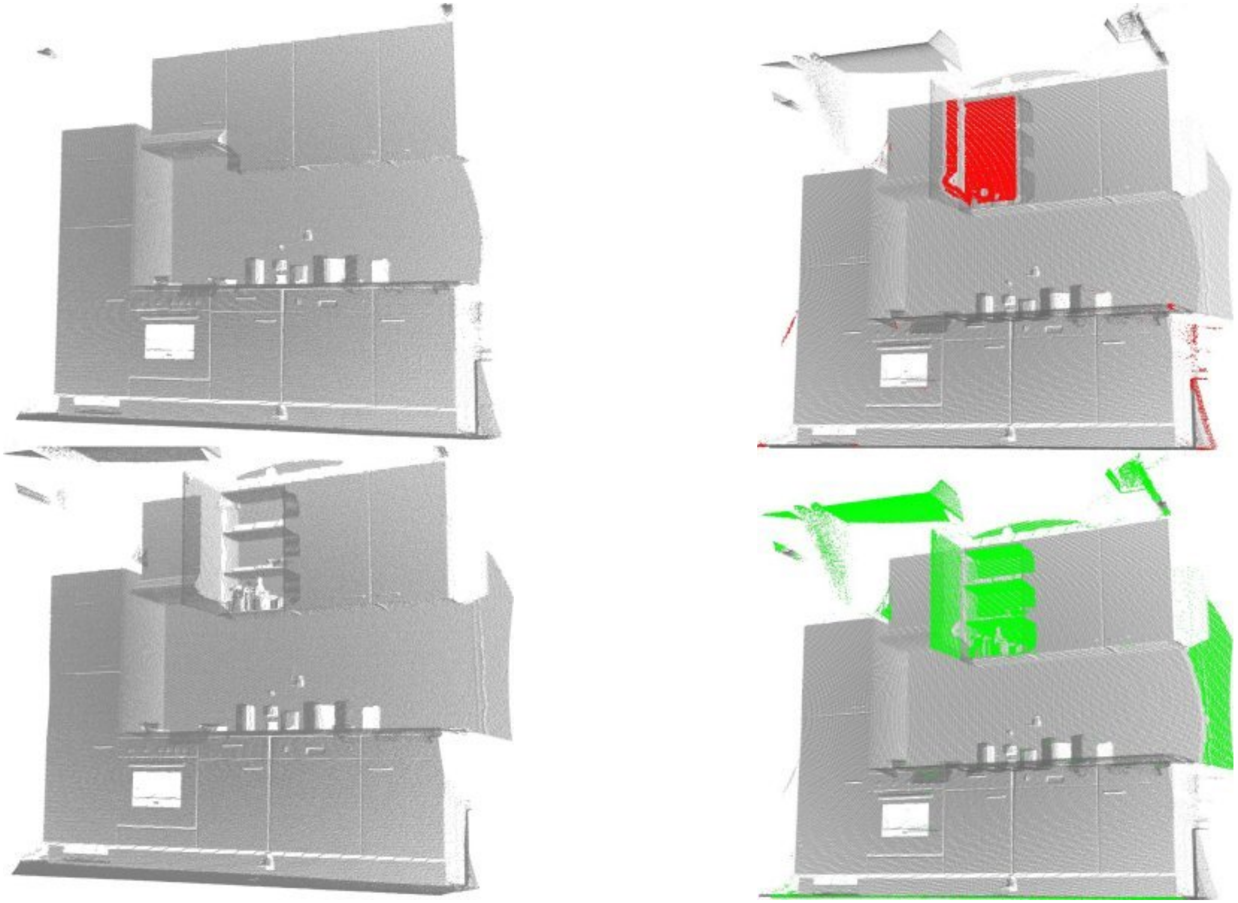
Segmentation Example 2

```
pcl::EuclideanClusterExtraction<T> p;
p.setInputCloud (data);
p.setClusterTolerance (0.05);
p.setMinClusterSize (1);
```



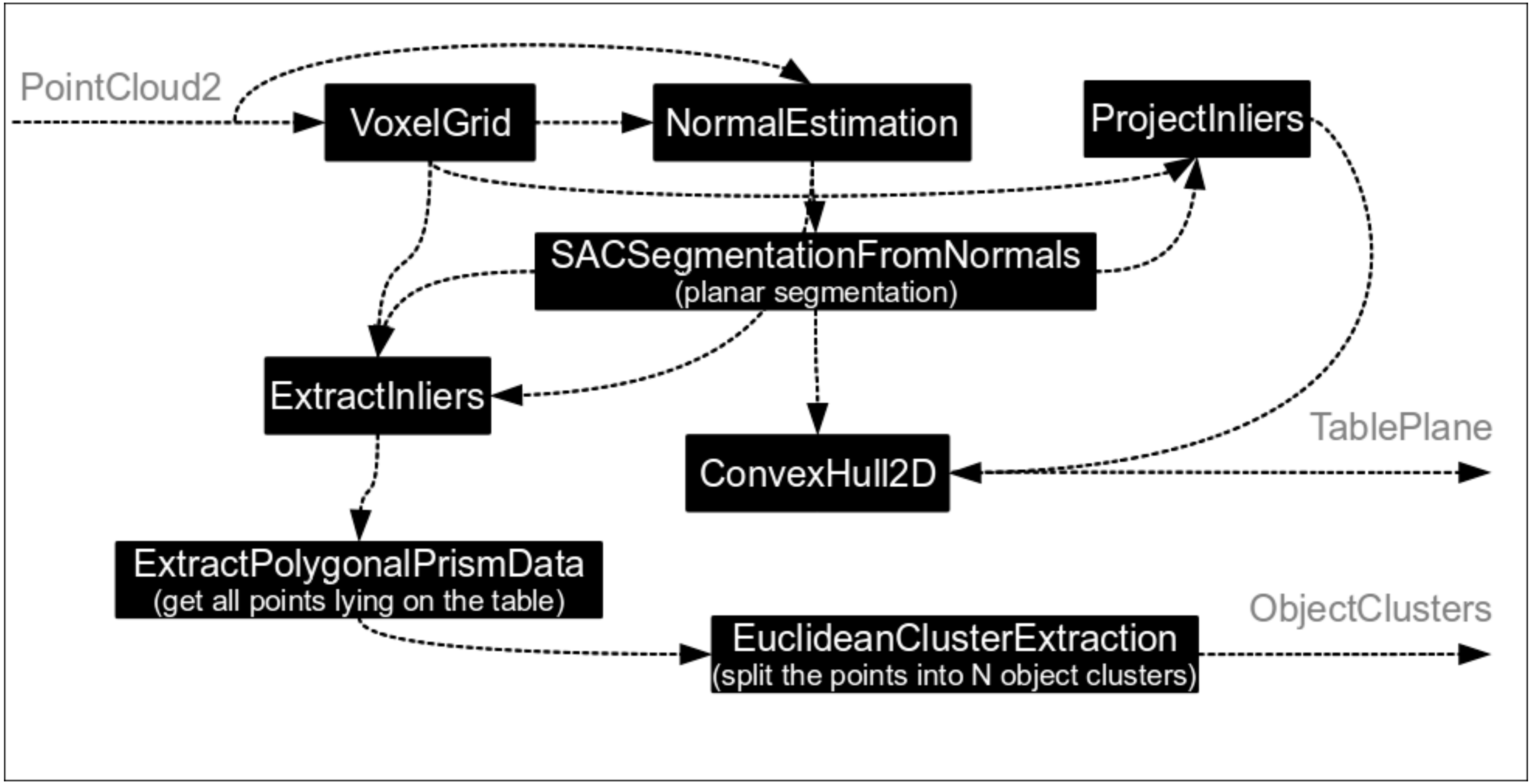
Segmentation Example 3

```
pcl::SegmentDifferences<T> p;
p.setInputCloud (source);
p.setTargetCloud (target);
p.setDistanceThreshold (0.001);
```



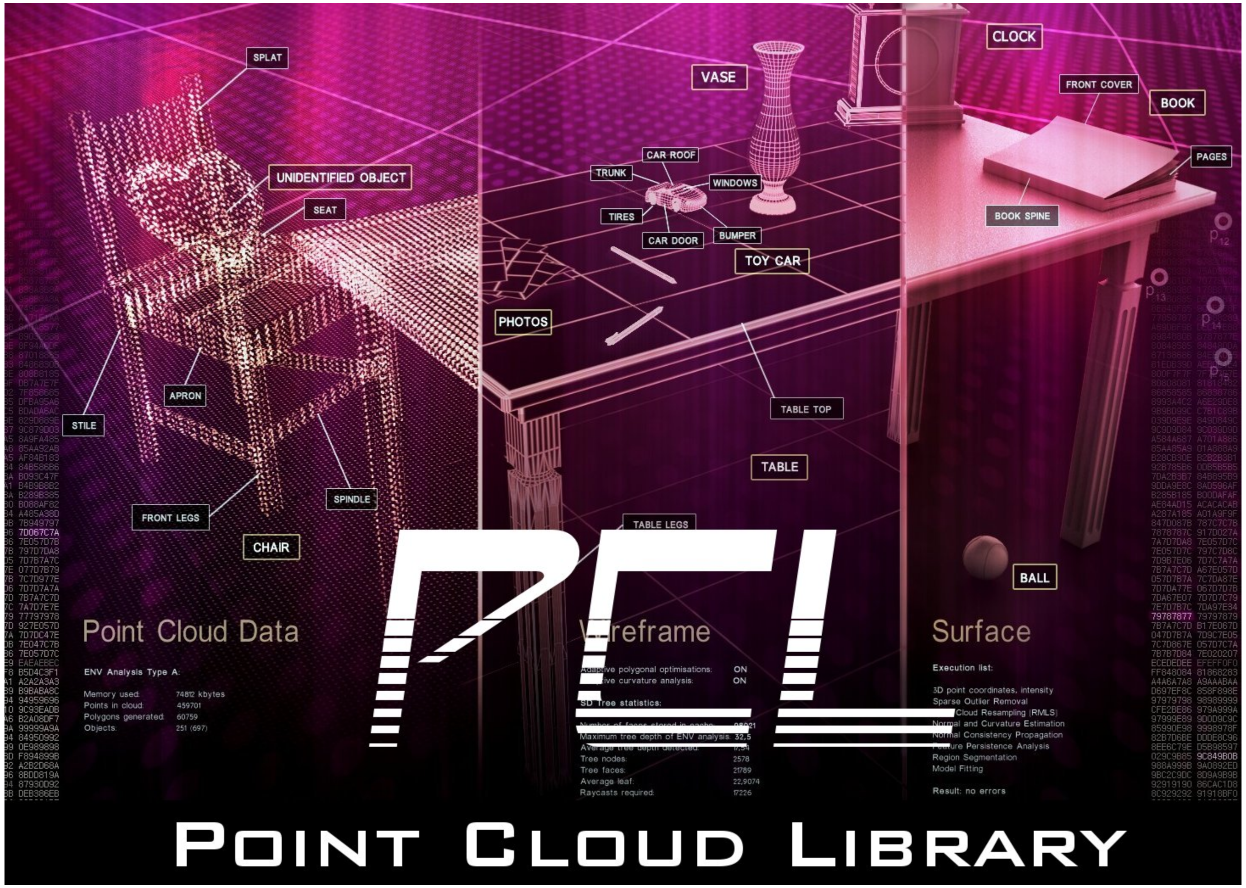
Higher level example

How to extract a table plane and the objects on it?



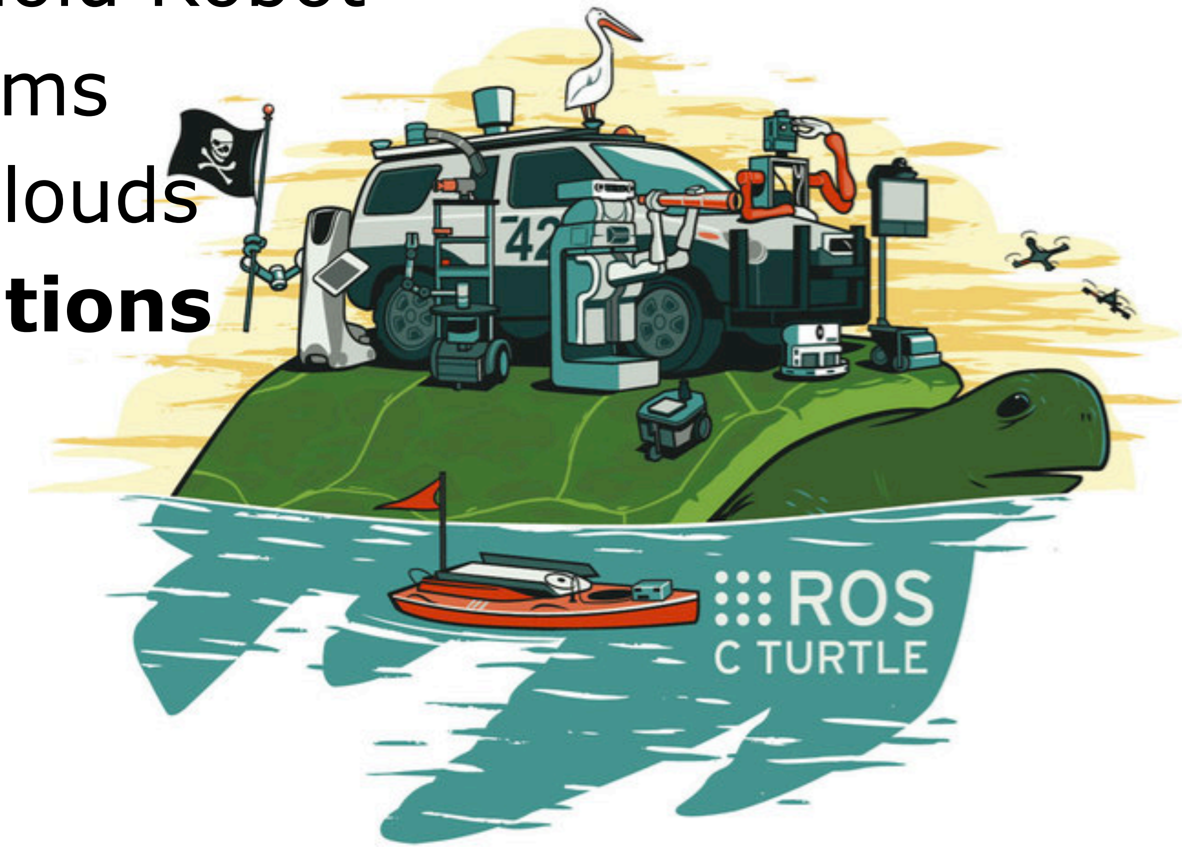
More details

- See http://www.ros.org/wiki/pcl
  and http://www.pointclouds.org



Today's Lecture

- ROS – Robot Operating System
- PR2 – Humanoid Robot
- TF – Transforms
- PCL – Point Clouds
- **ROS Applications**

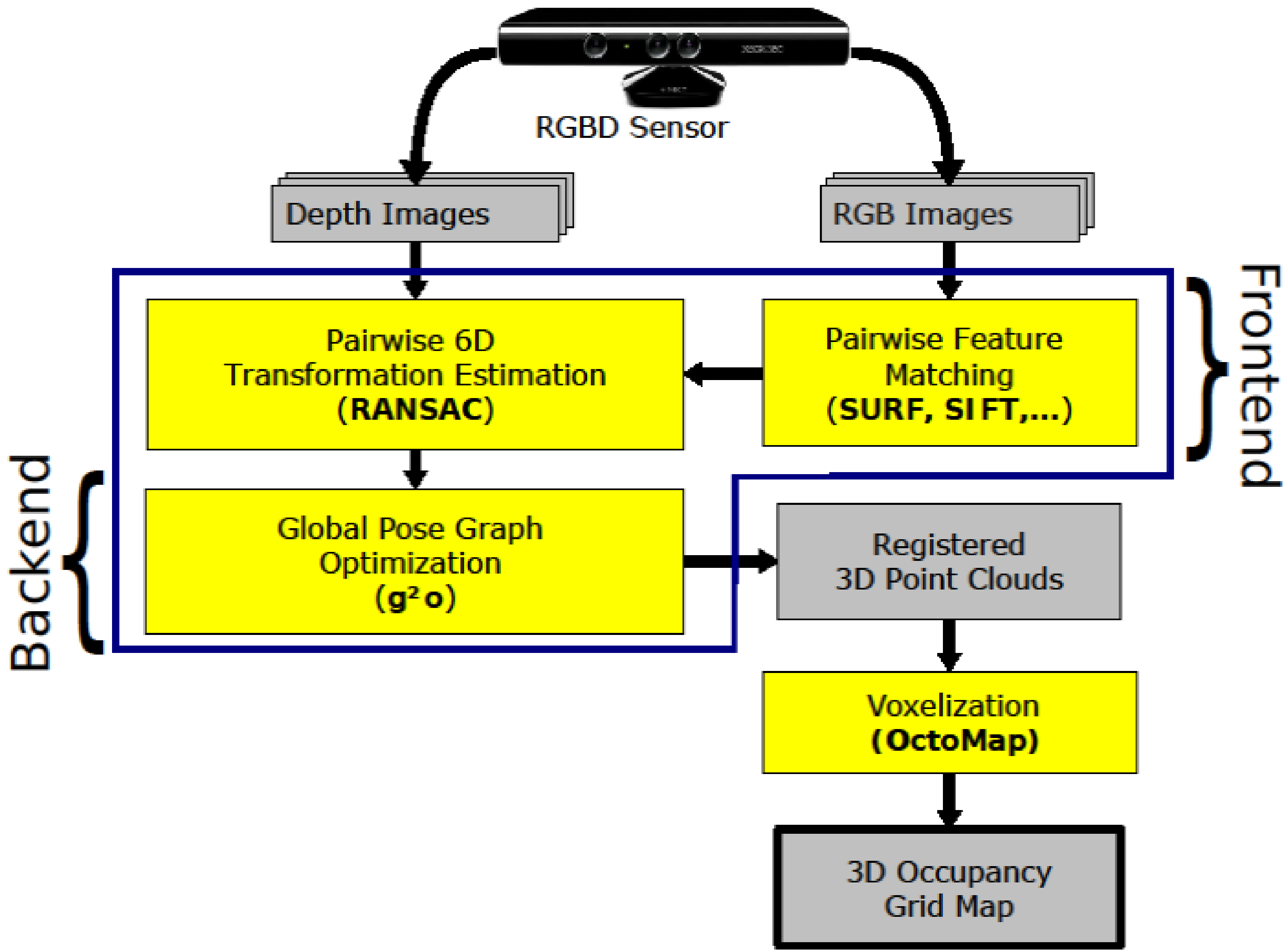


SLAM on Dense Colored Clouds

- Our goal: SLAM systems for RGB-D sensors
  - 3D environment representation
  - 6DOF trajectory estimation
  - Online Operation
  - No dependency on further sensors (e.g. Odometry, Laser)

- New kinect-style sensors provide:
  - Dense RGB-D data
  - High framerate (30 Hz)
  - Low weight (440g)
  - Low-cost (~100€)

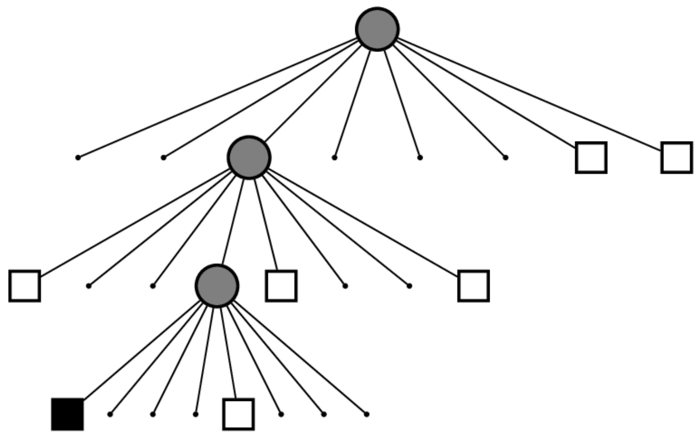
Approach Overview

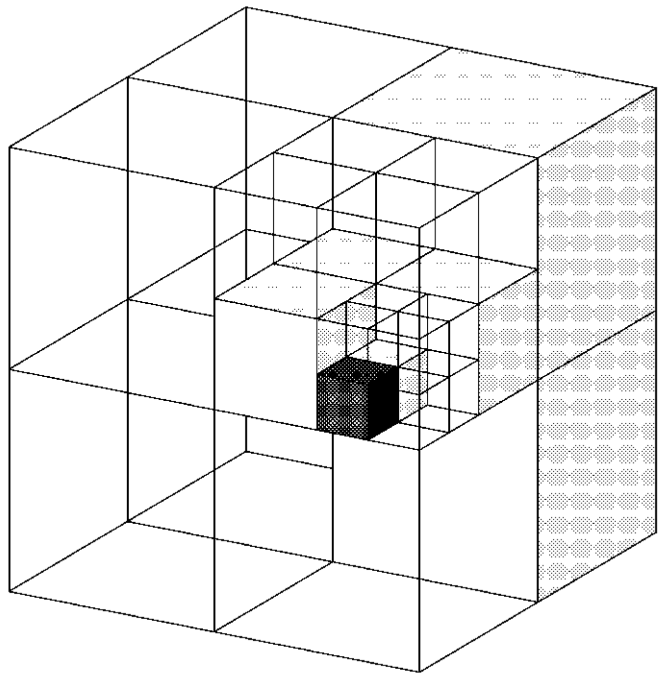


Map Representation

- Point clouds are inefficient for applications such as collision detection and navigation
- We use the OctoMap framework
  - Octree-based data structure
  - Recursive subdivision of space into octants
  - Volumes allocated as needed

➡ Smart 3D grid





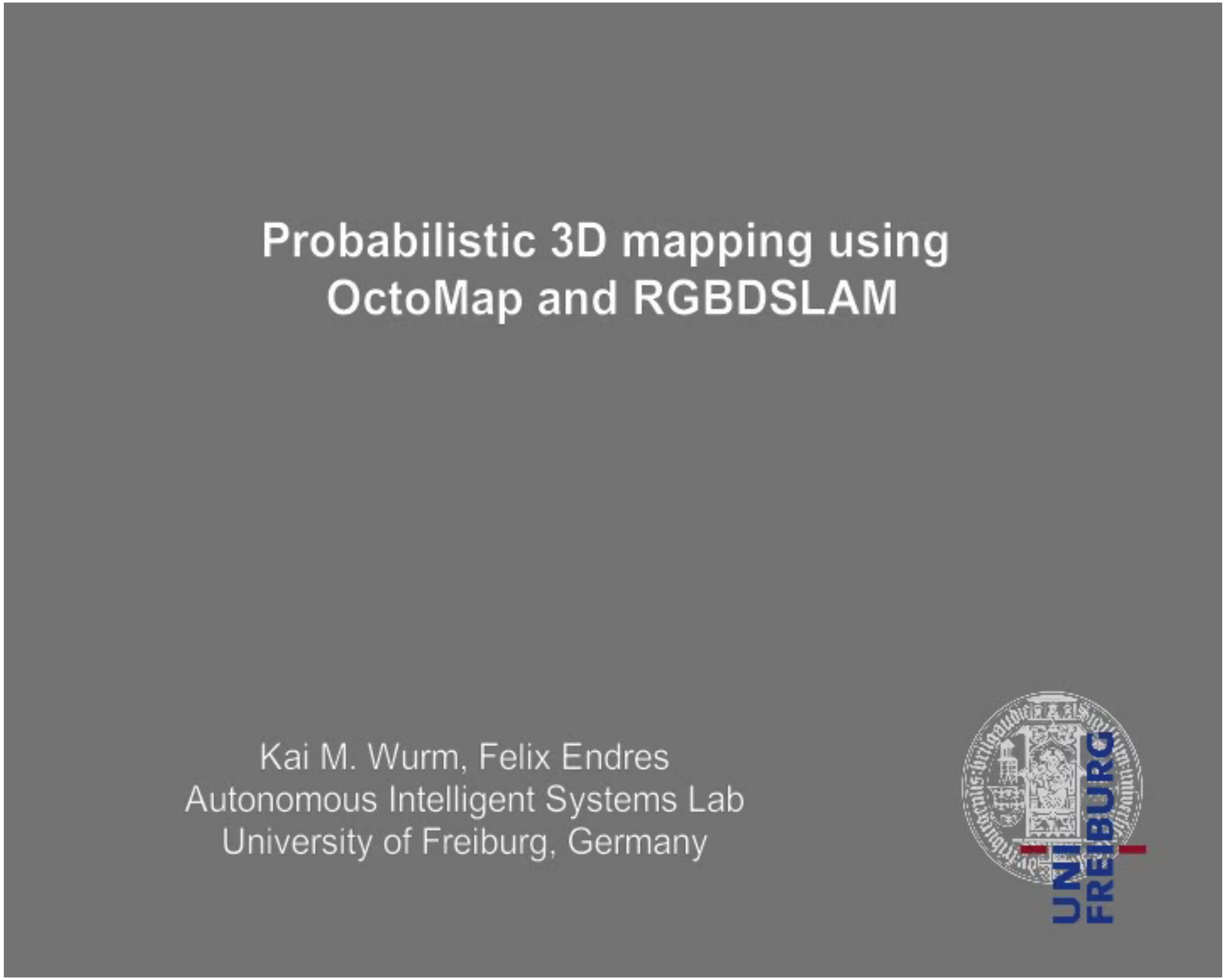
OctoMap Framework

Probabilistic Update of Voxels

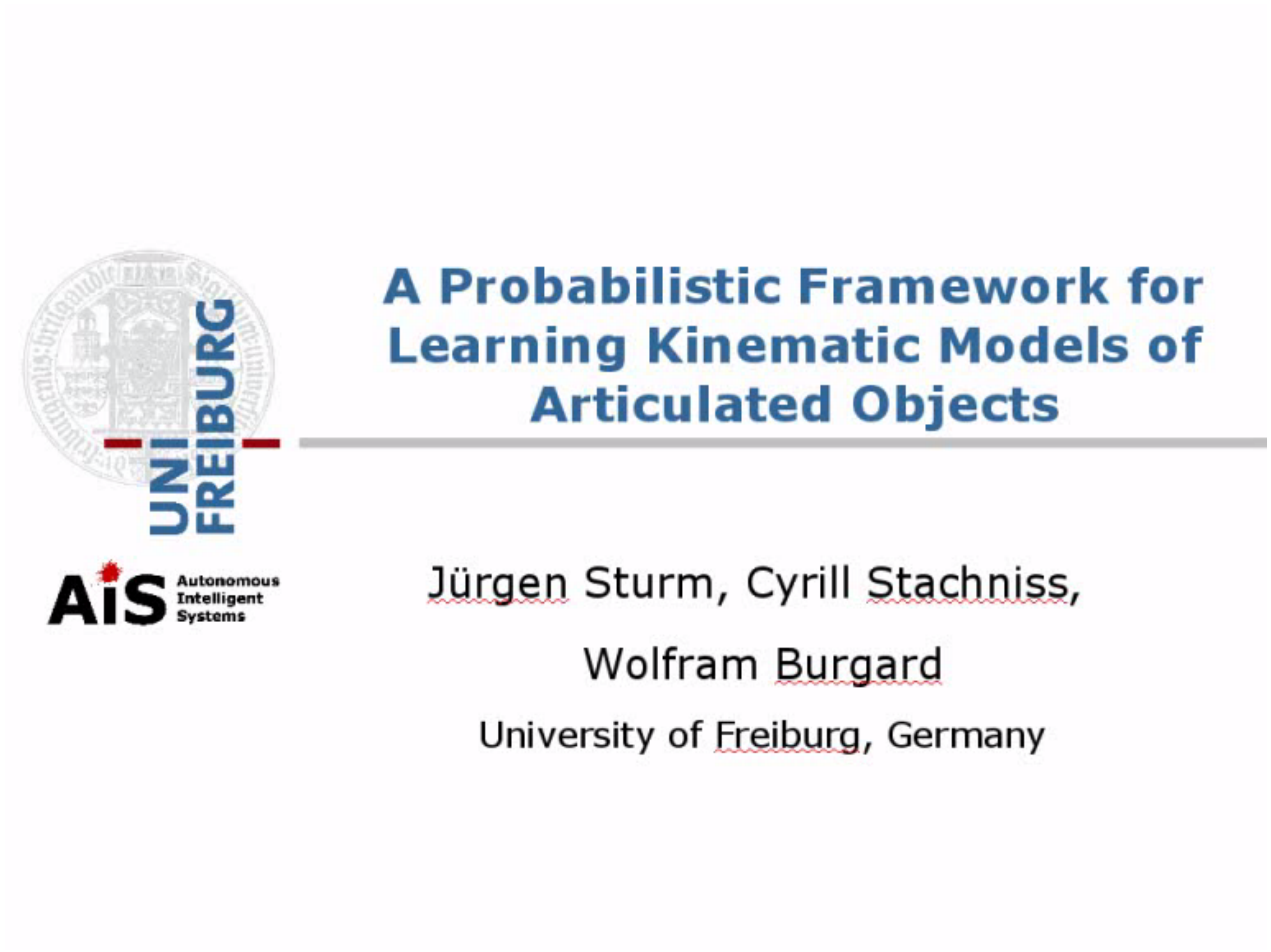
- Full 3D model
- Probabilistic
- Multi-resolution
- Memory efficient

- Available from octomap.sf.net

Octomap with Per-Voxel Colors

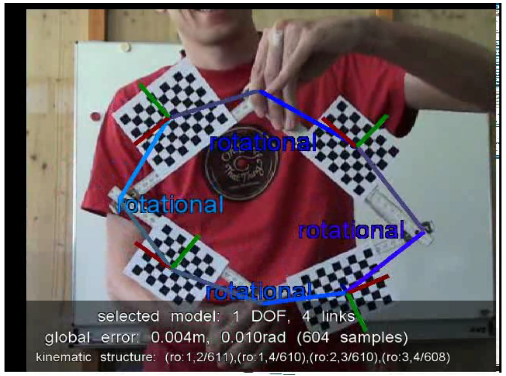


Kinematic Models



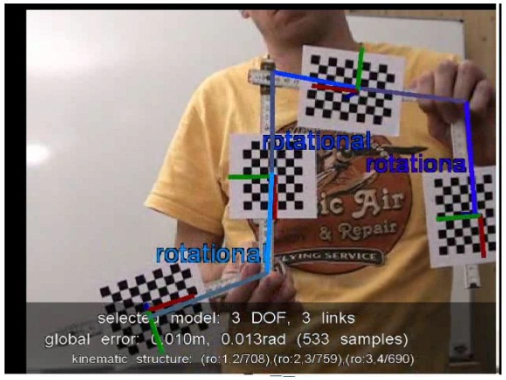
Kinematic Models

- Fit and select appropriate models for observed motion trajectories of articulated objects
- Estimate structure and DOFs of articulated objects with n>2 object parts



1-DOF closed chain

3-DOF open chain

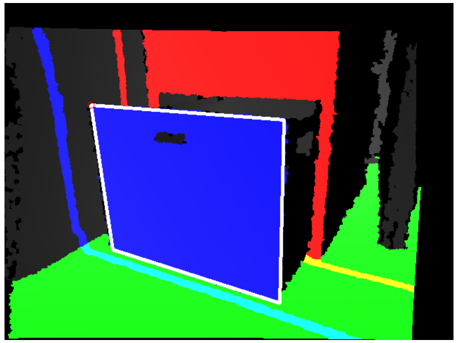


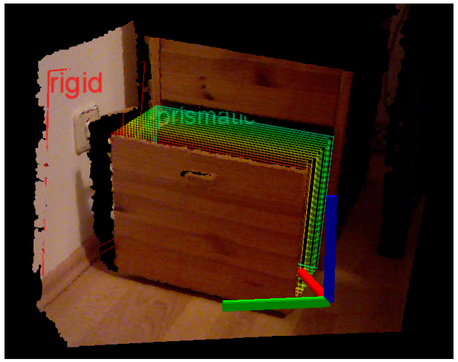
Kinematic Models

- Marker-less perception:

  Detect and track articulated objects in depth images and learn their kinematic models

- Approach:
  - Segment planes
  - Fit pose candidates and filter
  - Learn kinematic models





A Probabilistic Framework for Learning Kinematic Models of Articulated Objects

Jürgen Sturm, Cyrill Stachniss,

Wolfram Burgard

University of Freiburg, Germany

Thank You...

...for your attention