ELEC 3210
Introduction to Mobile Robotics
Lecture 6

(Machine Learning and Infomation Processing for Robotics)

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L5 Issue

- We rewrite the Frobenius norm using the trace of the matrix
$$\|\boldsymbol{Y}-\boldsymbol{RX}\|_F^2 = tr(\boldsymbol{Y}^T\boldsymbol{Y}) + tr(\boldsymbol{X}^T\boldsymbol{X}) - tr(\boldsymbol{Y}^T\boldsymbol{RX}) - tr\left(\boldsymbol{X}^{\boldsymbol{T}}\boldsymbol{R}^{\boldsymbol{T}}\boldsymbol{Y}\right)$$

- And observe that only the two last terms depend on the unknown $\boldsymbol{R}$ yielding a maximization problem.

- Even without using the properties of the trace we can see that both last terms are equal to
$$\sum_i^N \boldsymbol{R}(\boldsymbol{x}_i - \boldsymbol{x}_0)(\boldsymbol{y}_i - \boldsymbol{y}_0)^T = tr(\boldsymbol{RXY}^T)$$

- The 3D-3D pose problem reduced to
$$\max_{\boldsymbol{R}} \; tr(\boldsymbol{RXY}^T)$$

Courtesy: Shaojie Shen

L5 Issue

- If the SVD of $\boldsymbol{X}\boldsymbol{Y}^T$ is $\boldsymbol{U}\boldsymbol{S}\boldsymbol{V}^{\boldsymbol{T}}$ and let $\boldsymbol{Z} = \boldsymbol{V}^{\boldsymbol{T}}\boldsymbol{R}\boldsymbol{U}$

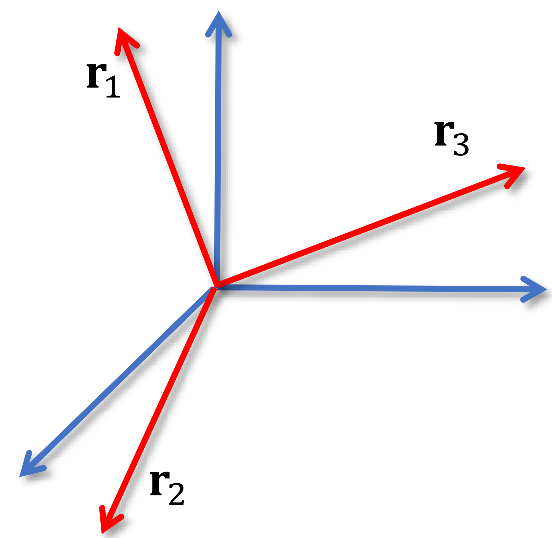
$$tr\left(\boldsymbol{R}\boldsymbol{X}\boldsymbol{Y}^{\boldsymbol{T}}\right) = tr\left(\boldsymbol{R}\boldsymbol{U}\boldsymbol{S}\boldsymbol{V}^{\boldsymbol{T}}\right) = tr(\boldsymbol{Z}\boldsymbol{S}) = \sum_{1}^{3} z_{ii}\sigma_i \leq \sum_{1}^{3} \sigma_i$$

- The upper bound is obtained by setting

$$\boldsymbol{R} = \boldsymbol{V}\boldsymbol{U}^{\boldsymbol{T}}$$

Courtesy: Shaojie Shen

L2 - Properties of a Rot. Mat.

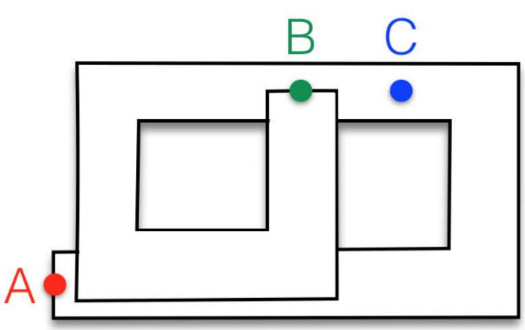


- Let $\mathbf{R} = [\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3]$ be a rotation matrix
- Orthogonal:
  - ${\mathbf{r}_i}^T \cdot \mathbf{r}_j = \begin{cases} 0 \text{ if } i \neq j \\ 1 \text{ if } i = j \end{cases}$
  - $\mathbf{R} \cdot \mathbf{R}^T = \mathbf{I}$
- Special orthogonal:
  - $\det\mathbf{R} = {\mathbf{r}_1}^T \cdot (\mathbf{r}_2 \times \mathbf{r}_3) = {\mathbf{r}_1}^T \cdot \mathbf{r}_1 = 1$
- The set of all rotations forms the Special Orthogonal Group
  - Special orthogonal group
  - 3D rotations: $SO(3)$
  - 2D rotations: $SO(2)$
  - $SO(n) = \{\mathbf{R} \in \mathbb{R}^{n \times n} | \mathbf{R} \cdot \mathbf{R}^T = \mathbf{I}, \det\mathbf{R} = 1\}$

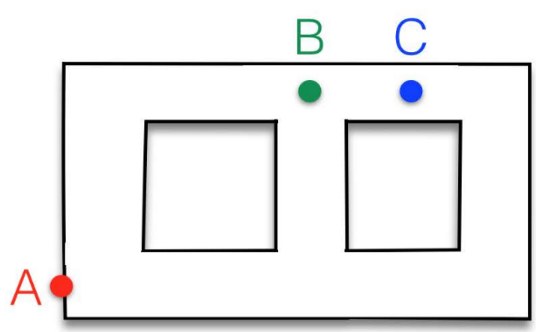
Map

Robot Localization

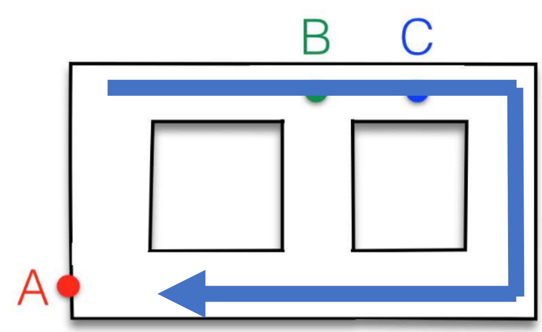
- **Odometry**
  - Wheel Odometry
  - Visual Odometry
  - LiDAR Odometry
  - etc



- **SLAM**
  - Simultaneous localization and **mapping**

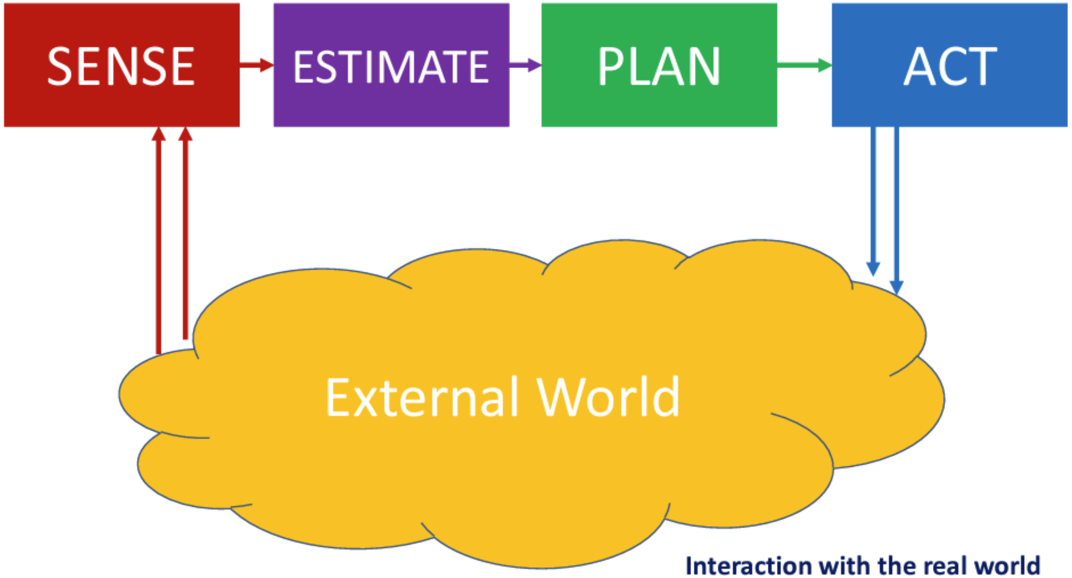


- **Map-based Localization**
  - Localize on a given **map**



Performance of Map

- Memory usage
- Load speed
- Maintainability (Easy to update)
- Usability with Estimation and Planning



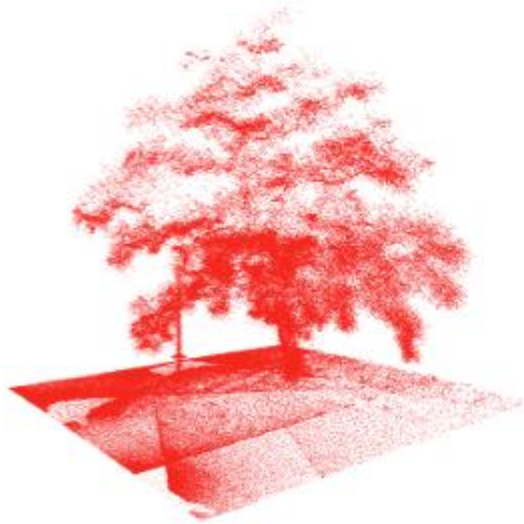
Interaction with the real world
introduces uncertainty!

Map

- Representations
  - Point Cloud
  - Grids
  - Octree
  - Elevation
  - Features
- Organization
  - Global
  - Topological

Point Cloud

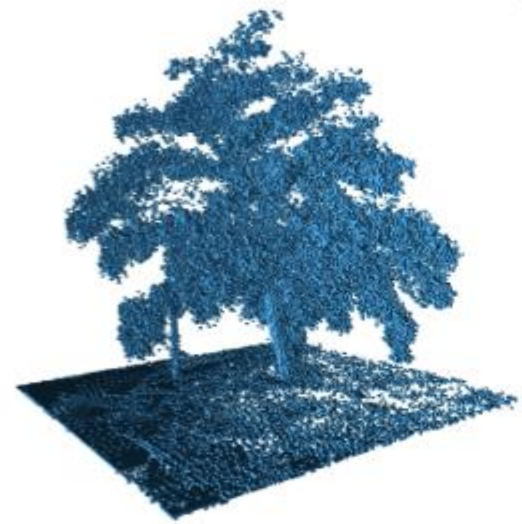
- Pros
  - No discretization of data
  - Mapped area not limited
- Cons
  - Unbounded memory usage
  - No direct representation of free
  or unknown space



Courtesy: Wolfram Burgard

Grid

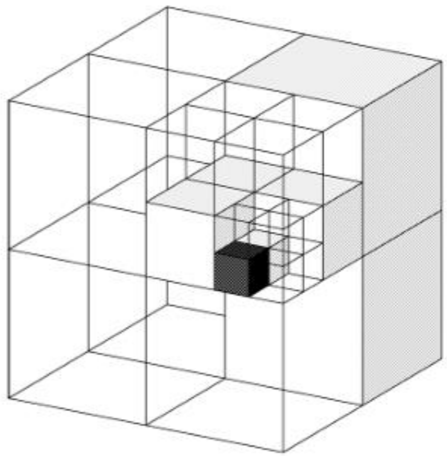
- Pros
  - Volumetric representation
  - Constant access time
  - Probabilistic update
  - Friendly to planning
- Cons
  - Memory requirement: Complete map is allocated in memory
  - Extent of the map has to be known/guessed

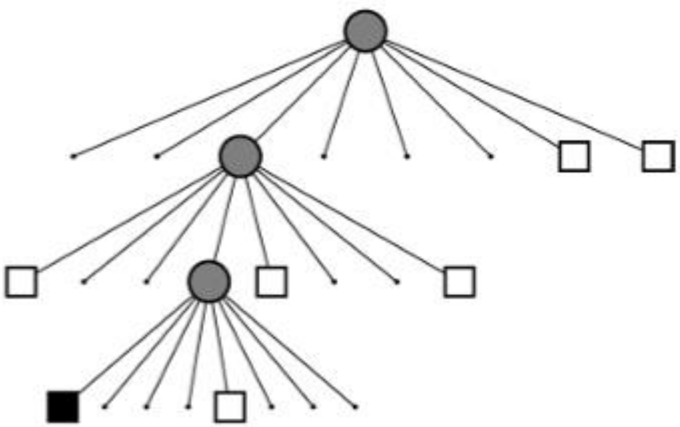


Courtesy: Wolfram Burgard

Octree

- Tree-based data structure
- Recursive subdivision of the space into octants
- Volumes allocated as needed
- “Smart 3D grid”

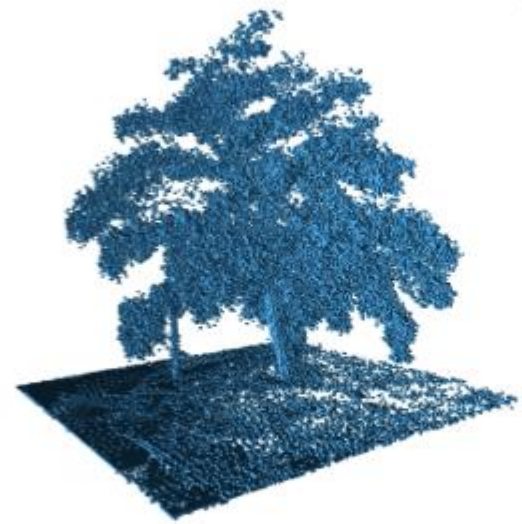




Courtesy: Wolfram Burgard

Octree

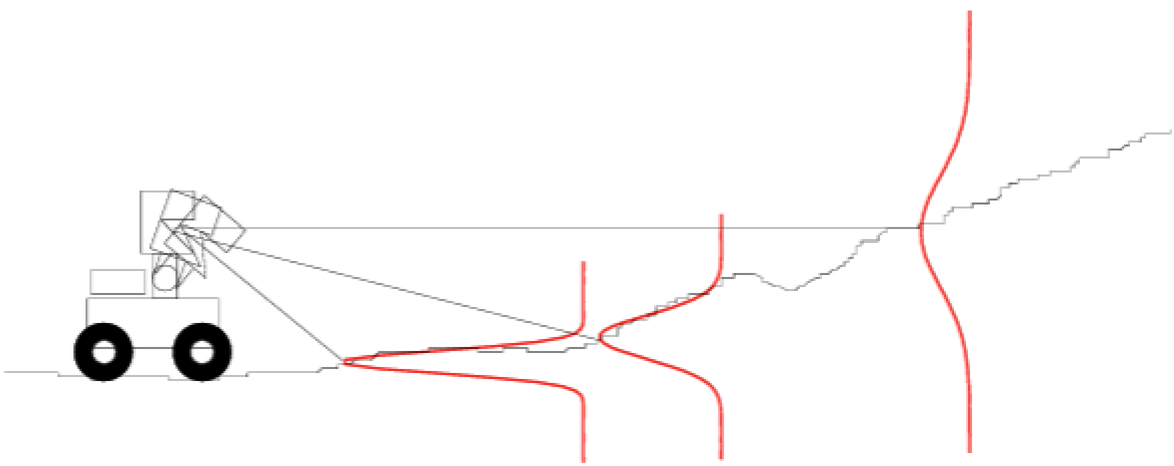
- Pros
  - Full 3D model
  - Probabilistic
  - Inherently multi-resolution
  - Memory efficient
- Cons
  - Implementation can be tricky (memory, update, map files, …)



Courtesy: Wolfram Burgard

Elevation

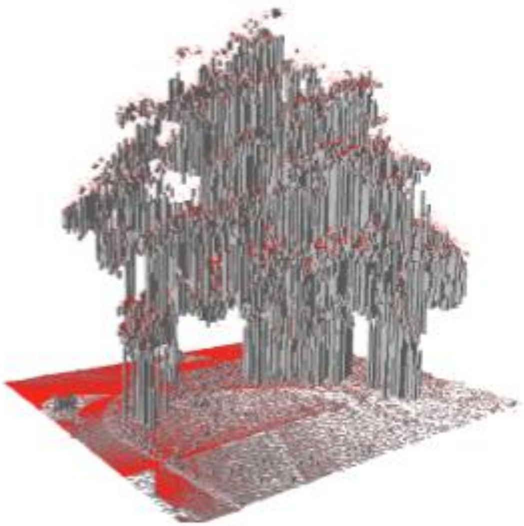
- 2D grid that stores an estimated height (elevation) for each cell
- Uncertainty increases with measured distance
- The elevation cam be updated



Courtesy: Wolfram Burgard

Elevation - 2.5D Height

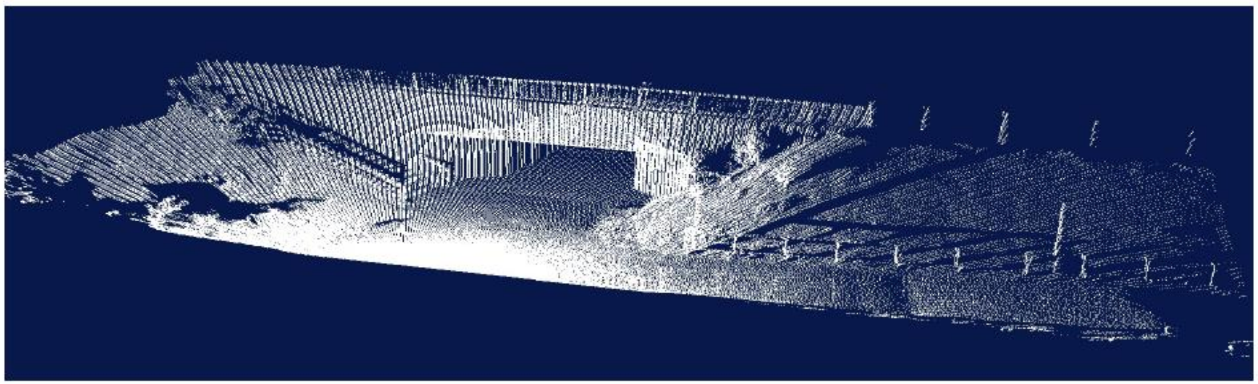
- Pro:
  - 2.5D representation (vs. full 3D grid)
  - Constant time access
  - Probabilistic estimate about the height
- Cons:
  - No vertical objects
  - Only one level is represented

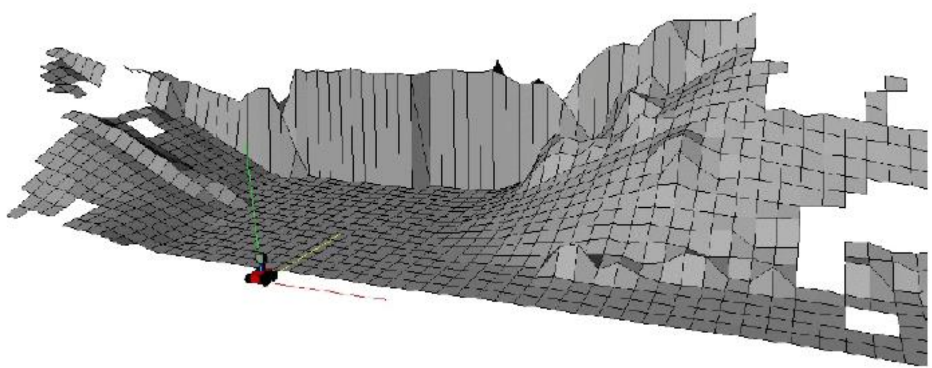


Courtesy: Wolfram Burgard

Standard Elevation Map

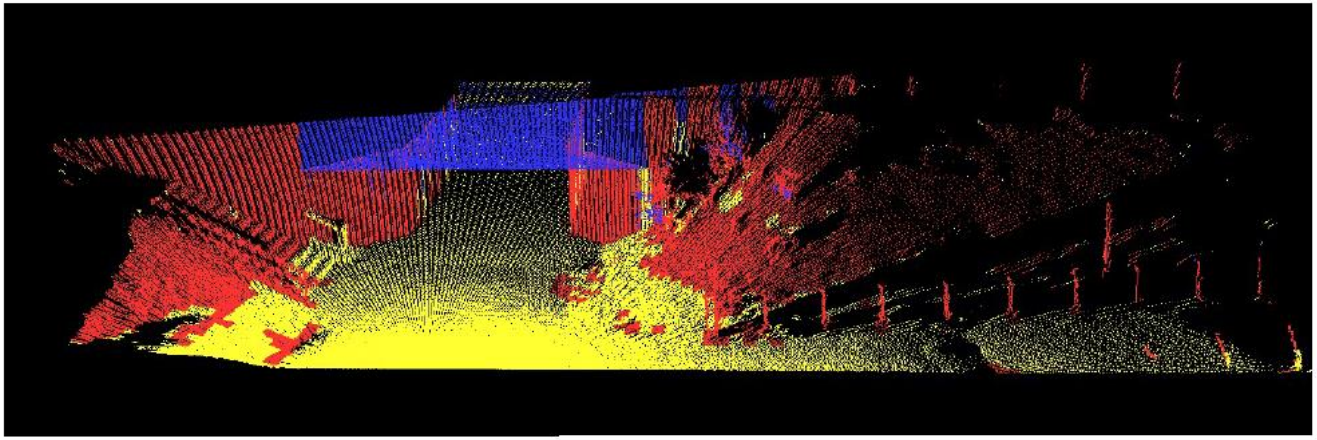
- Problem of basic elevation map
- Need check scheme for “large gap” of cells

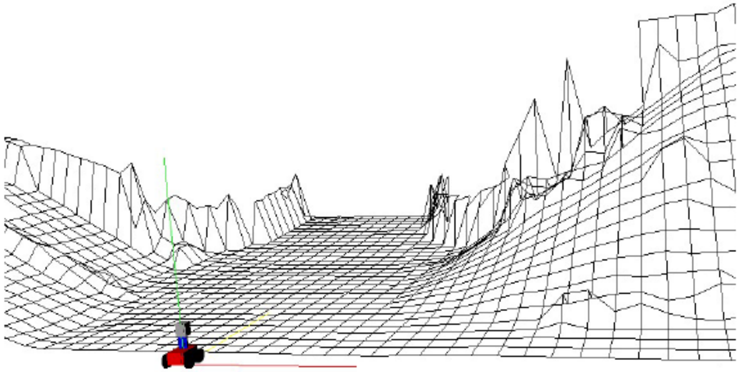




Extended Elevation Map

- Red: cells with vertical objects; Blue: data points above a big vertical gap; Yellow: cells seen from above
- Traversability estimation using gap cells

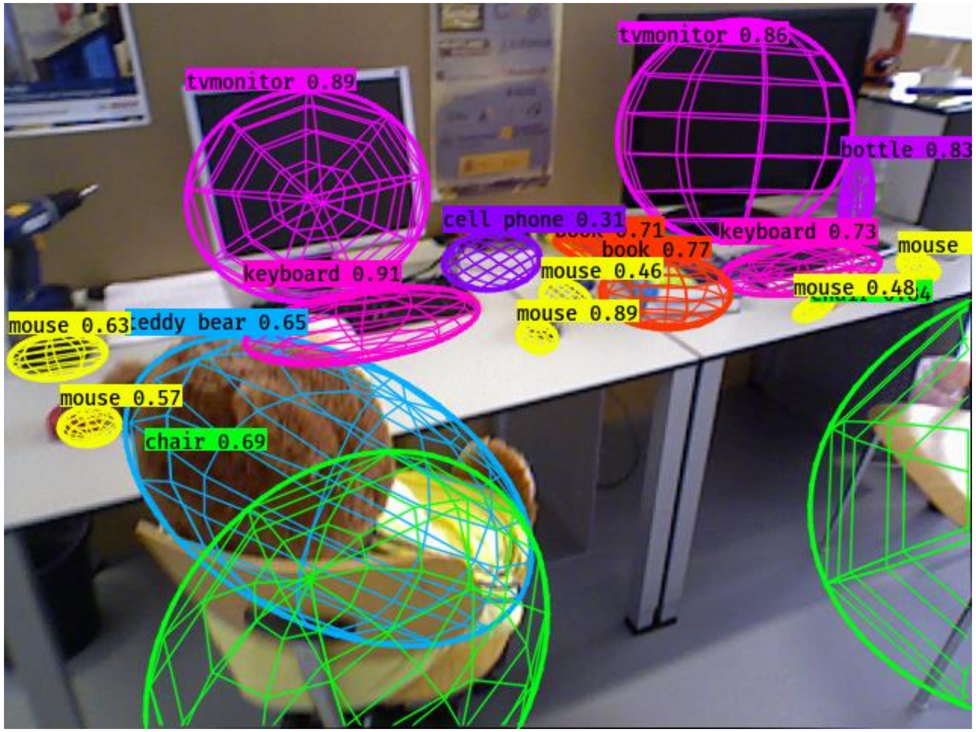




Courtesy: Wolfram Burgard

Features

- A broad concept that includes landmark, line, curve, objects, point with descriptors and others



Obejct SLAM

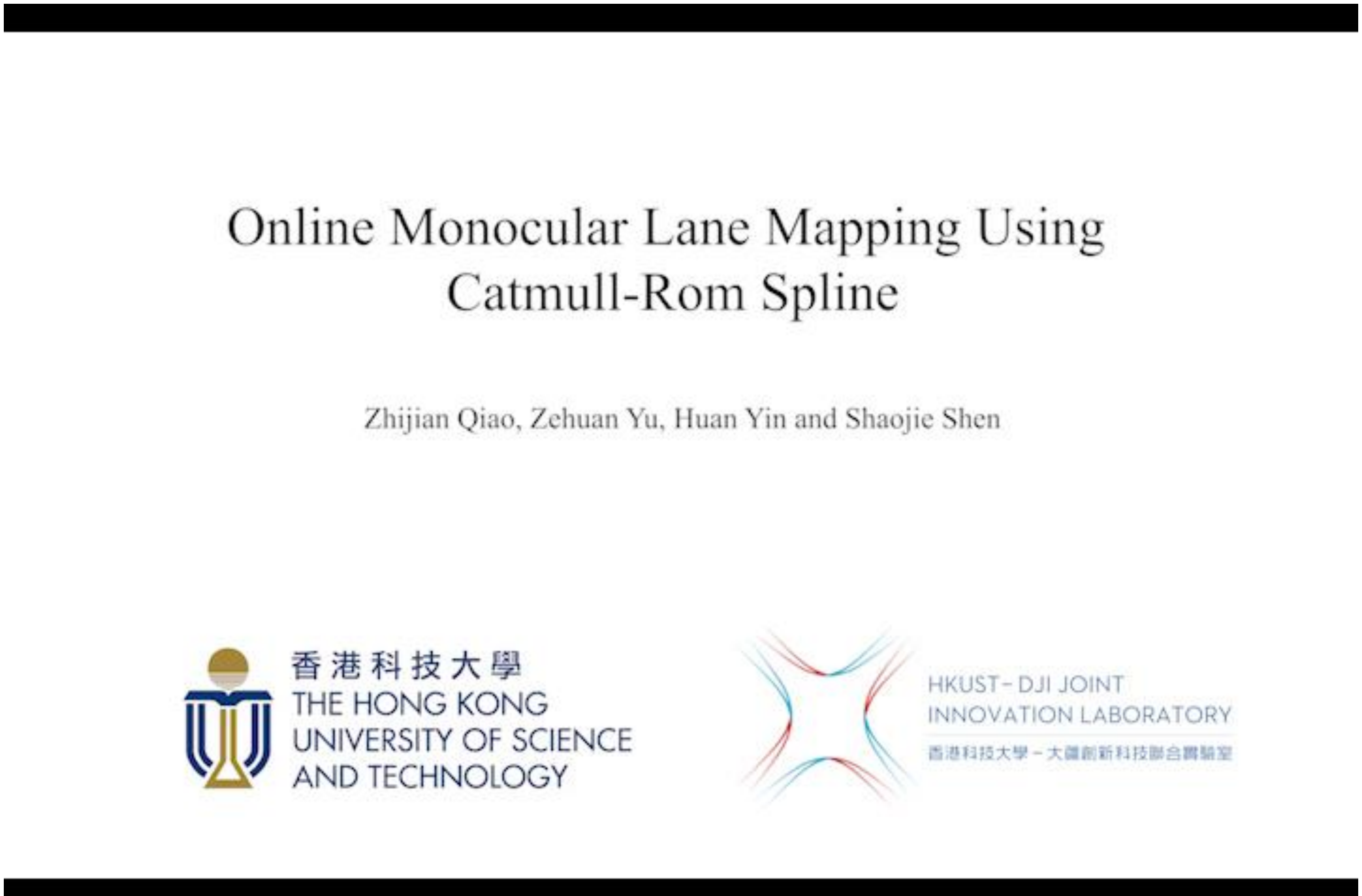
LandMark as Features

- Victoria dataset, Sydney, AU
- Use tree trunks as landmarks for SLAM (EKF SLAM)

2002 (maybe)

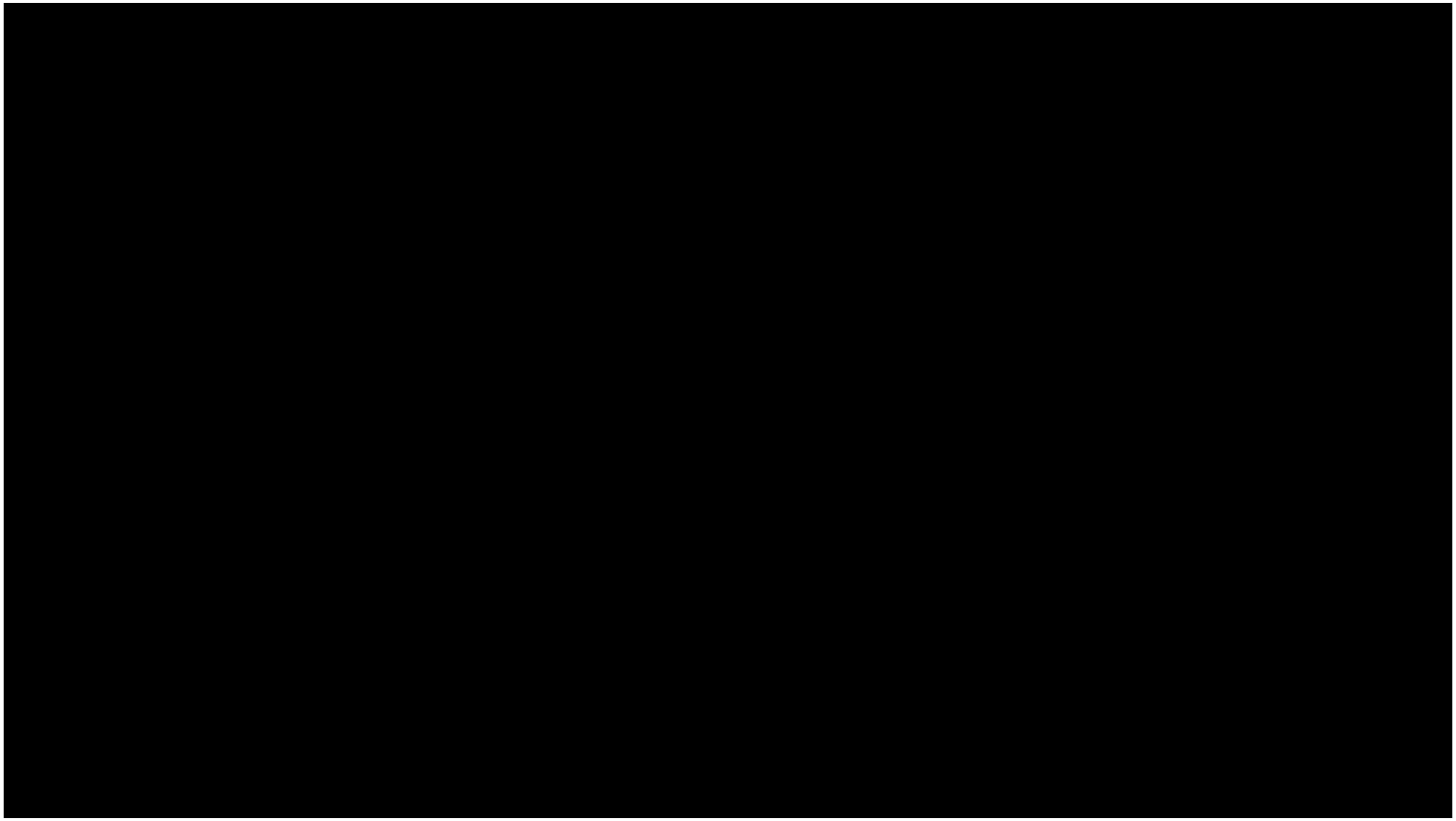
Spline as Features

- Lane Mapping



Visual Features

- Tesla Bot Update Video (2023 May)



Courtesy: Tesla

Obejcts as Features

- Quadric SLAM by Nicholson et al.

AUSTRALIAN CENTRE FOR ROBOTIC VISION

QUT Robots for the real world

QuadricSLAM: Constrained Dual Quadrics from Object Detections as Landmarks in Object-oriented SLAM

Lachlan Nicholson, Michael Milford, Niko Sünderhauf

ARC Centre of Excellence for Robotic Vision

Features

- Pros
  - Compact, less memory cost
  - Close to human perception of environments
  - Can support localization
- Cons
  - Unable to represent complex environments
  - Not planning-oriented

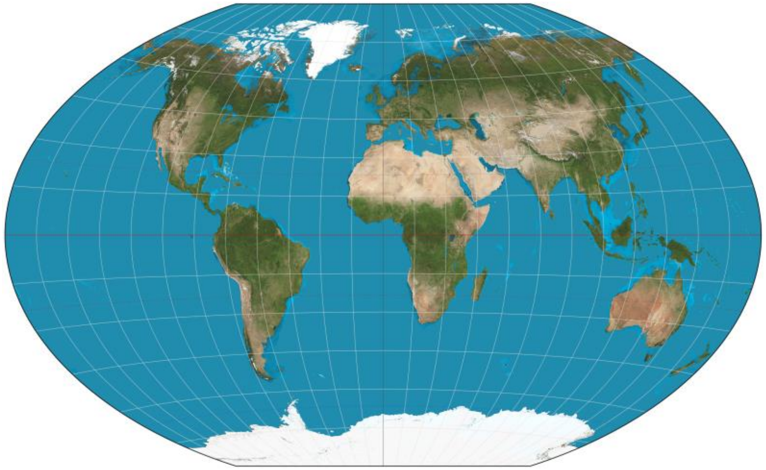
Tunnels

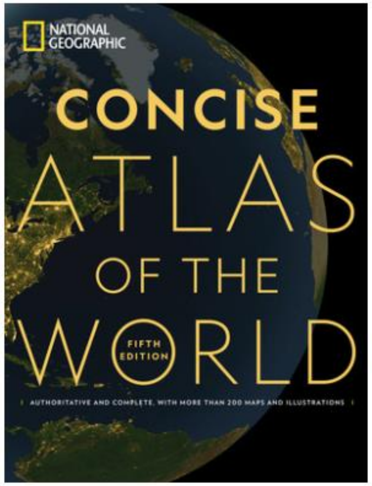
Map

- Representations ☑
  - Point Cloud
  - Grids
  - Octree
  - Elevation
  - Features
- Organization
  - Global
  - Topological

Global vs Topological

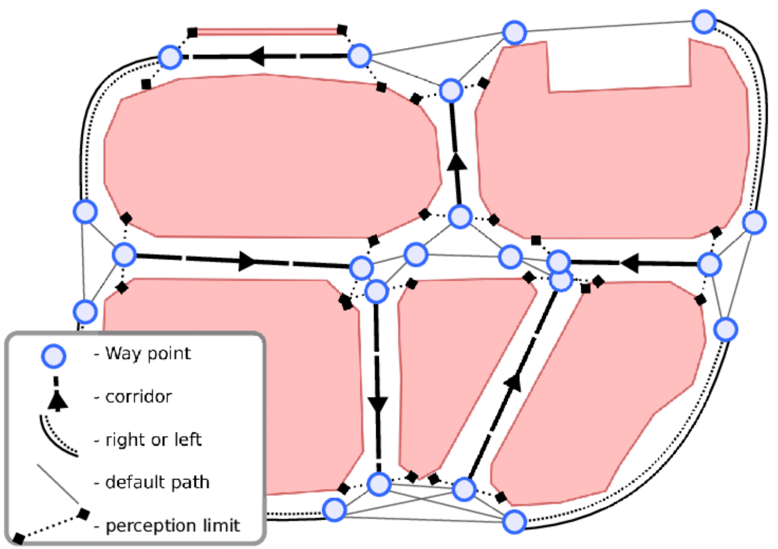
- Global map is okay for small-area navigation
- Topological-based is close to human-level





Topological Map

- Node (Pose) + Edge
- In each submap
  - Pose
  - Map representations or raw data, e.g, laser scans and images
- Criteria for “ map split”
  - distance traveled or rotated angle
  - memory limit of submap



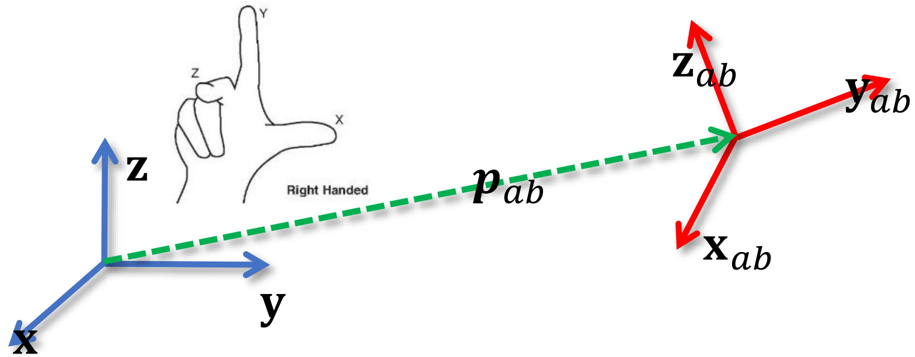
Courtesy: Lozenguez

Summary

- Different 3D map representations exist
  - Why and How
  - Pros and Cons
- Conclusion
  - Octomap is currently a popular tool for LiDAR point clouds
  - Hybrid representations (like multi-sensor fusion)
    - Sparse features for localization, Dense grids for planning

Robot Operating System (ROS)

From Concept/Math to Program



How to install Ubuntu & ROS?

- Canvas PDF File
  - EnvSetup.pdf

Env Setup

1 / 19

Introduction

What is ROS?

- **ROS: Robot Operating System**
  - a flexible framework for writing robot software
  - a collection of tools, libraries, and convention
  - across a wide variety of robotic platforms

Courtesy: ROS

ROS

- Programming Language

- Tools and Libraries

C++ in ROS

Simple C++ Program

```
#include <iostream>

int main(int argc, char* argv[])
{



    std::cout << "Hello World!";

    return 0;
}
```

Simple C++ ROS Node

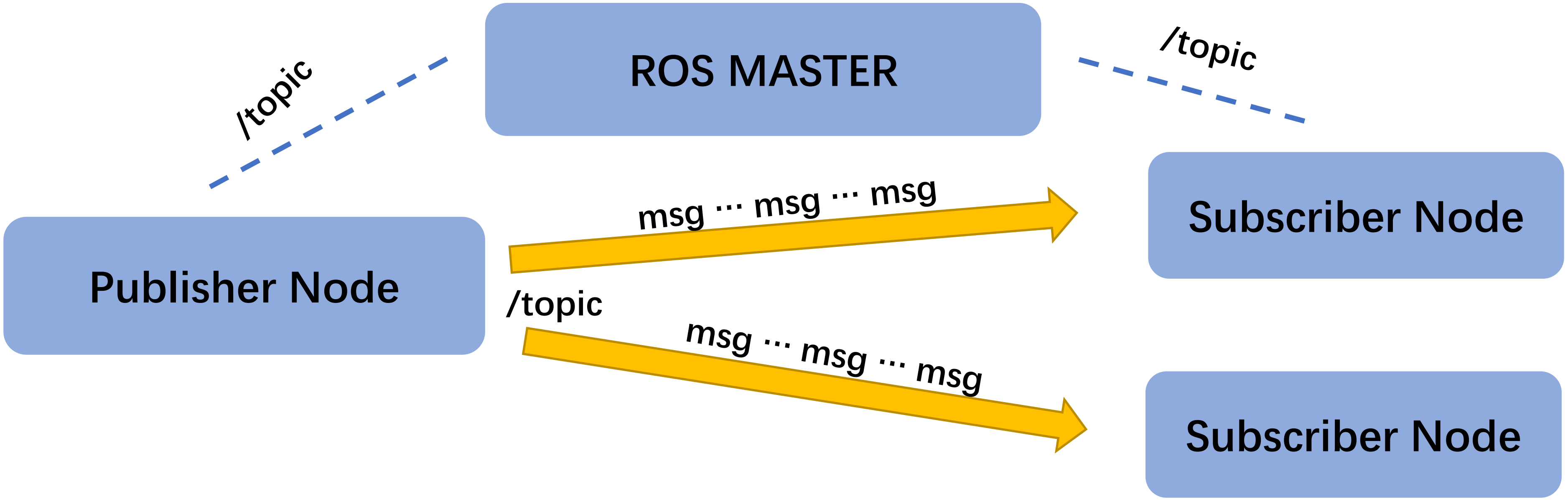
```
#include <ros/ros.h>

int main(int argc, char* argv[])
{
    ros::init(argc, argv, “hello”);
    ros::NodeHandle node;

    ROS_INFO_STREAM("Hello World!“);

    return 0;
}
```

ROS Master and Node

- **ROS Master**
  - As a parameter server
  - Enabling different nodes to find each other
  - One system, one master

- **ROS Node**
  - Must have unique names
  - Different functionalities in different nodes
  - Communicate with other nodes through topics, services, or actions
  - Different nodes can run on different devices and hosts, and communicate via Ethernet (Distributed System)

ROS as Glue



ROS MASTER
/topic
/topic
Publisher Node
msg ··· msg ··· msg
/topic
msg ··· msg ··· msg
Subscriber Node
Subscriber Node

ROS as Glue

ROS MASTER

/topic

/topic

Camera Node

msg ··· msg ··· msg

msg ··· msg ··· msg

msg ··· msg ··· msg

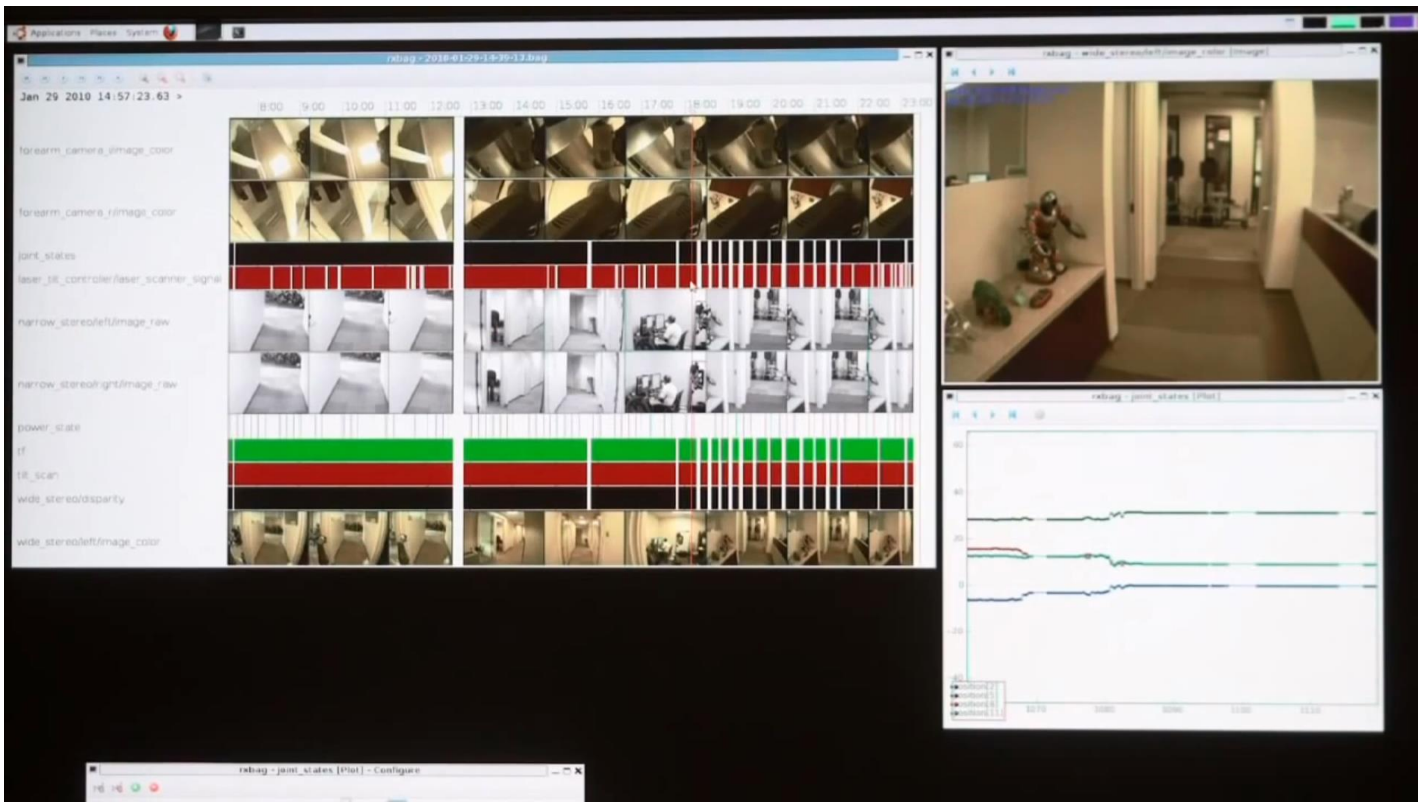
Image Processing Node

Data Recording Node

Visualization Node

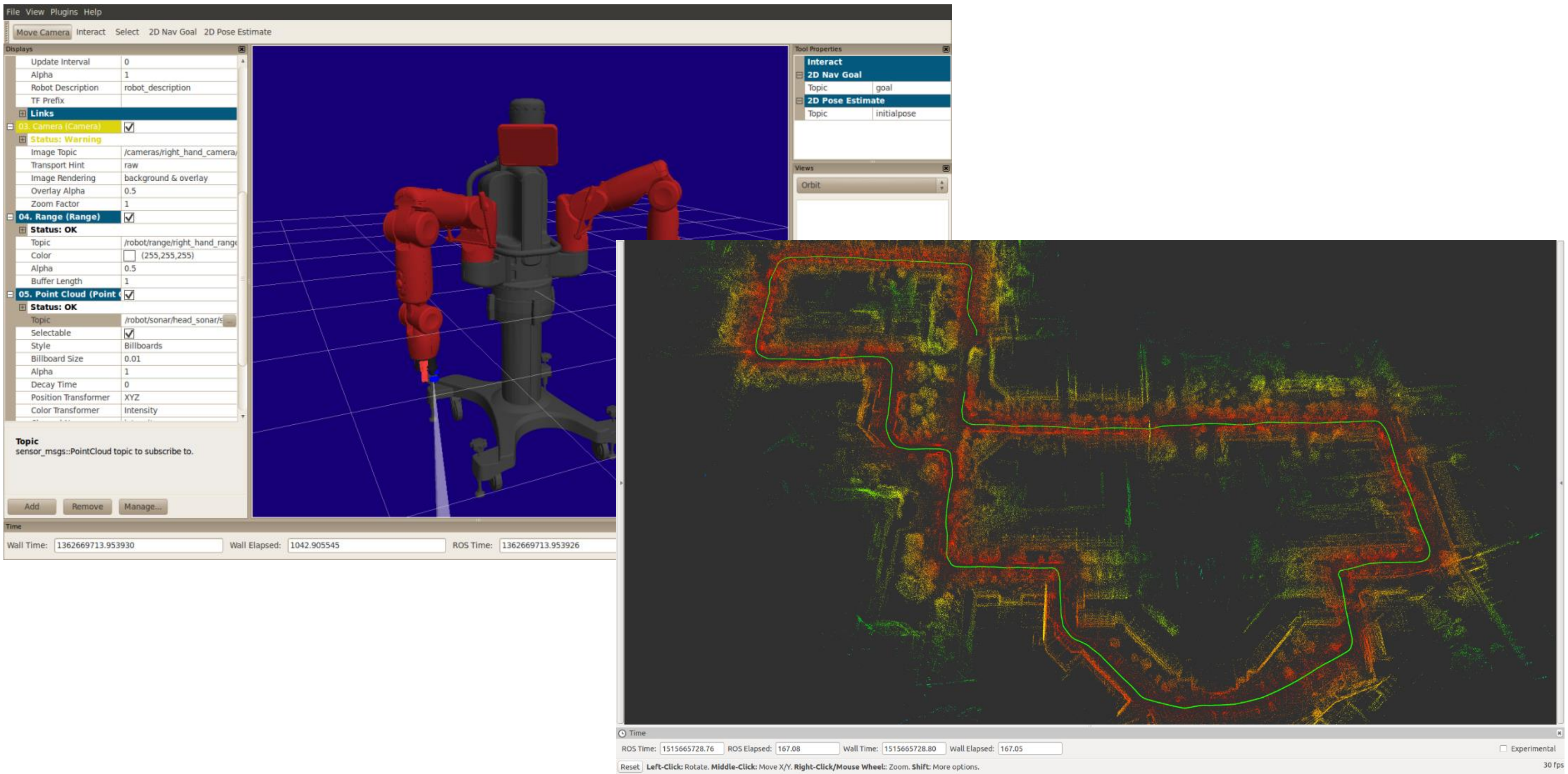
Rosbag

- Recorded Data
- Easy to debug offline



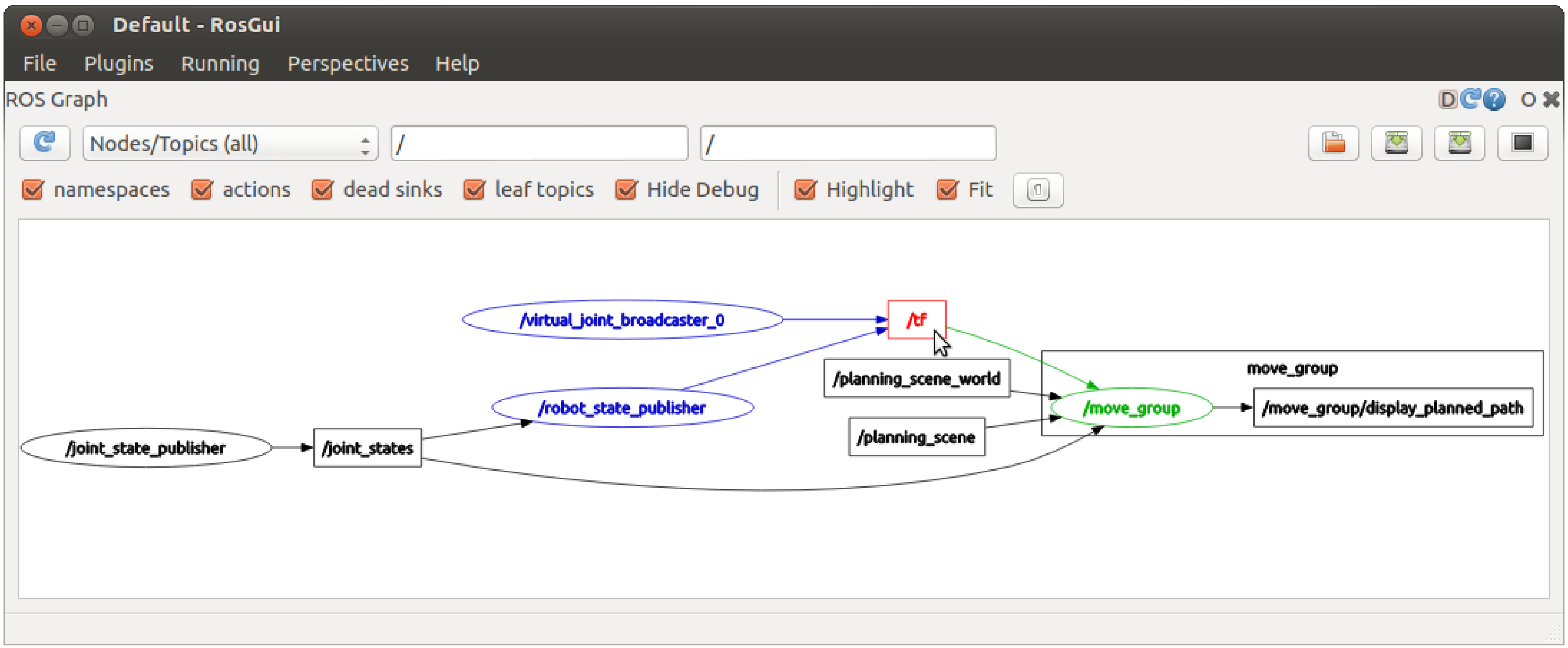
Rviz

- Visualization



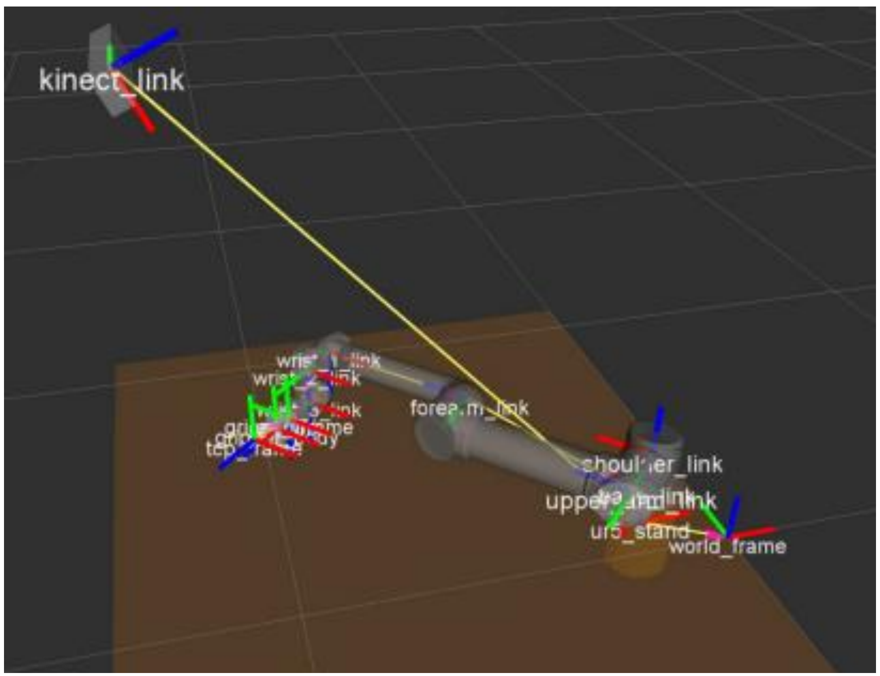
rqt_graph

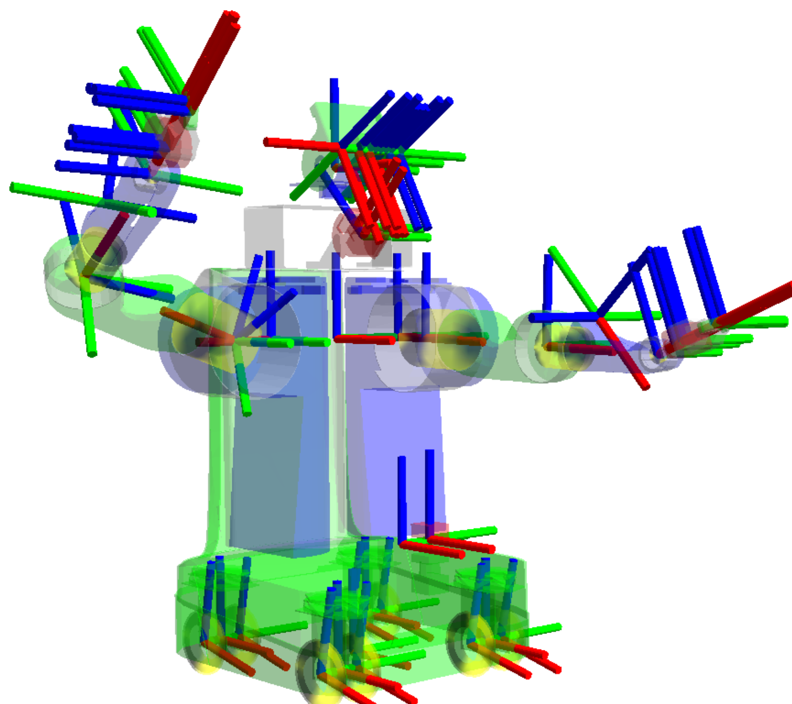
- Visualization for ROS nodes



TF

- Transformation / Pose





Documents of Pose

- https://docs.ros.org/en/noetic/api/geometry_msgs/html/index-msg.html

geometry_msgs Msg/Srv Documentation

See also:

- Website
- Code API Documentation

Message types

- Accel
- AccelStamped
- AccelWithCovariance
- AccelWithCovarianceStamped
- Inertia
- InertiaStamped
- Point
- Point32
- PointStamped
- Polygon
- PolygonStamped
- Pose
- Pose2D
- PoseArray
- PoseStamped
- PoseWithCovariance
- PoseWithCovarianceStamped
- Quaternion
- QuaternionStamped
- Transform

Courtesy: ROS Documents

Other Concepts and Tools

- Package
- Launch File
- rqt_plot

…

Check when you need!

http://wiki.ros.org/ROS/Tutorials

https://docs.ros.org/

Next Lecture

- Bayes Theorem
- Gaussian Distribution