Vision Aided Navigation

67604

David Arnon

Topics

- Simultaneous Localization and Mapping
- Projective Geometry, Homogeneous Coordinates
- Camera Model
- Feature Matching
- Least Squares
- Triangulation
- 3D Registration
- Robust Optimization
- Bundle Adjustment
- Graph Based Optimization
- Covariance
- Pose Graph
- Loop Closure

In this Course

- Introduction to principles of SLAM
- Key techniques
- Hands on – On going project presented in 7-8 programming exercises
    - Extract geometric information from images
    - Initial motion estimation
    - Local motion estimation optimization
    - Large scale motion estimation
    - Loop Closure

Prerequisites

- Linear Algebra
- Probability
- Python Programming

Exercises

- Grade: 50% exercises, 50% final submission
- Submission in pairs
- Create a GitHub account with permissions to:
  - david.arnon@gmail.com
  - vivanti@gmail.com

Lecture

- Tuesdays 13-16

Forum

- https://moodle2.cs.huji.ac.il/nu21/course/view.php?id=67604

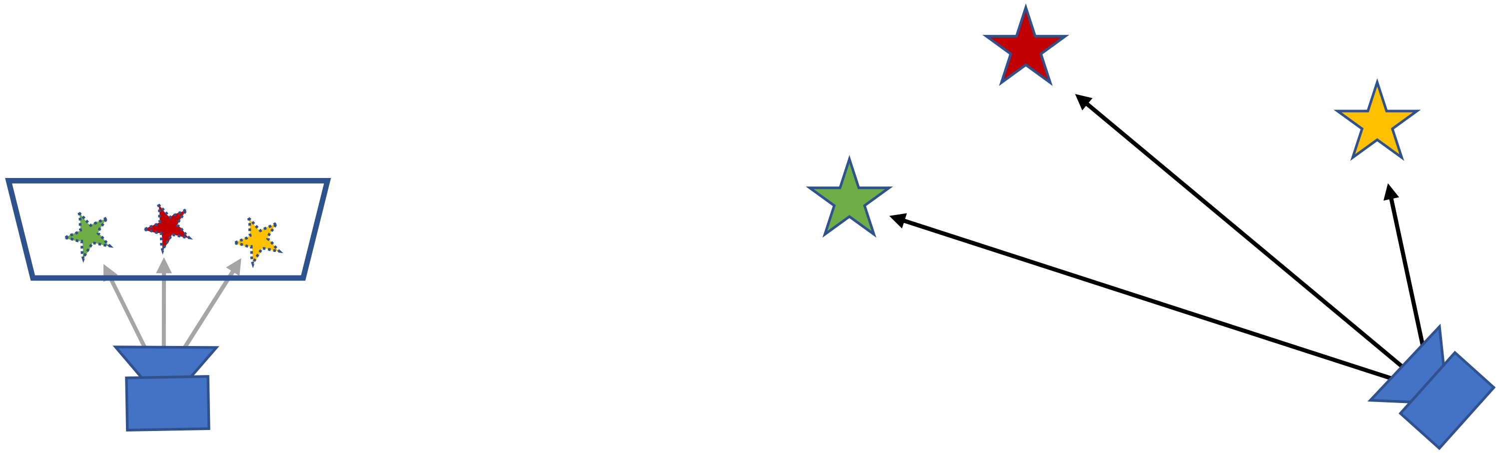
Feedback

Related Terms

- Navigation
- SfM – Structure from Motion
- Bundle Adjustment
- State Estimation
- SLAM - Simultaneous Localization and Mapping

Slam

- Localization – estimate the trajectory (poses)
- Mapping – build a map of the environment



Slam

- Localization – estimate the trajectory (poses)
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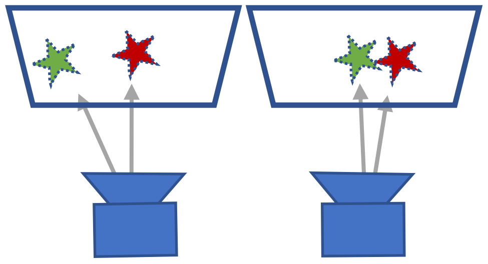
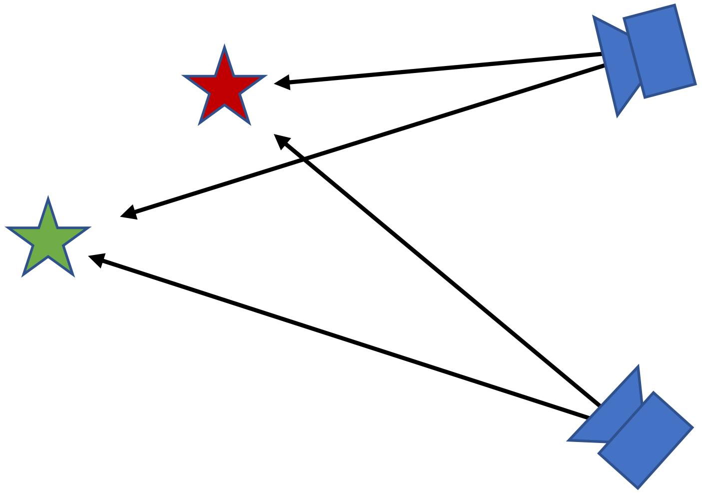




Slam

- **S**imultaneous **L**ocalization **A**nd **M**apping
  is the process of building a map of the environment while computing our location relative to it.

- Chicken and egg problem

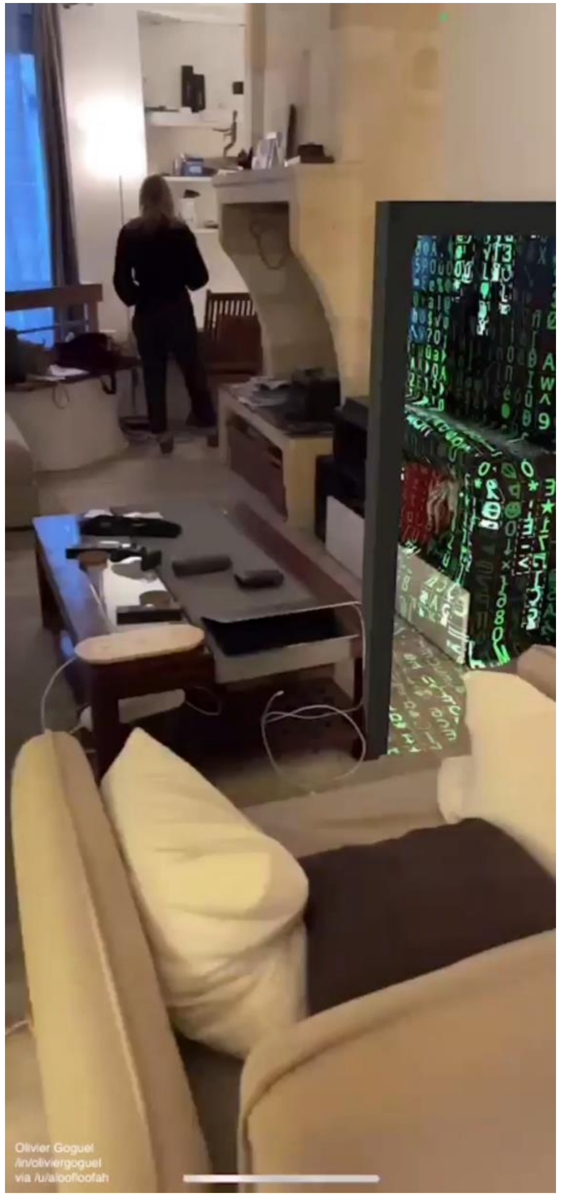
Slam

- Integral part in many navigation systems
- Examples:
  - Mars rover
  - Unmanned aerial delivery vehicles
  - Reef monitoring
  - Mine exploration
  - Augmented reality
  - Vacuum cleaner !
  - Autonomous vehicles

Applications

Georg Klein,
David Murray
Parallel Tracking and Mapping for Small AR Workspaces

Applications

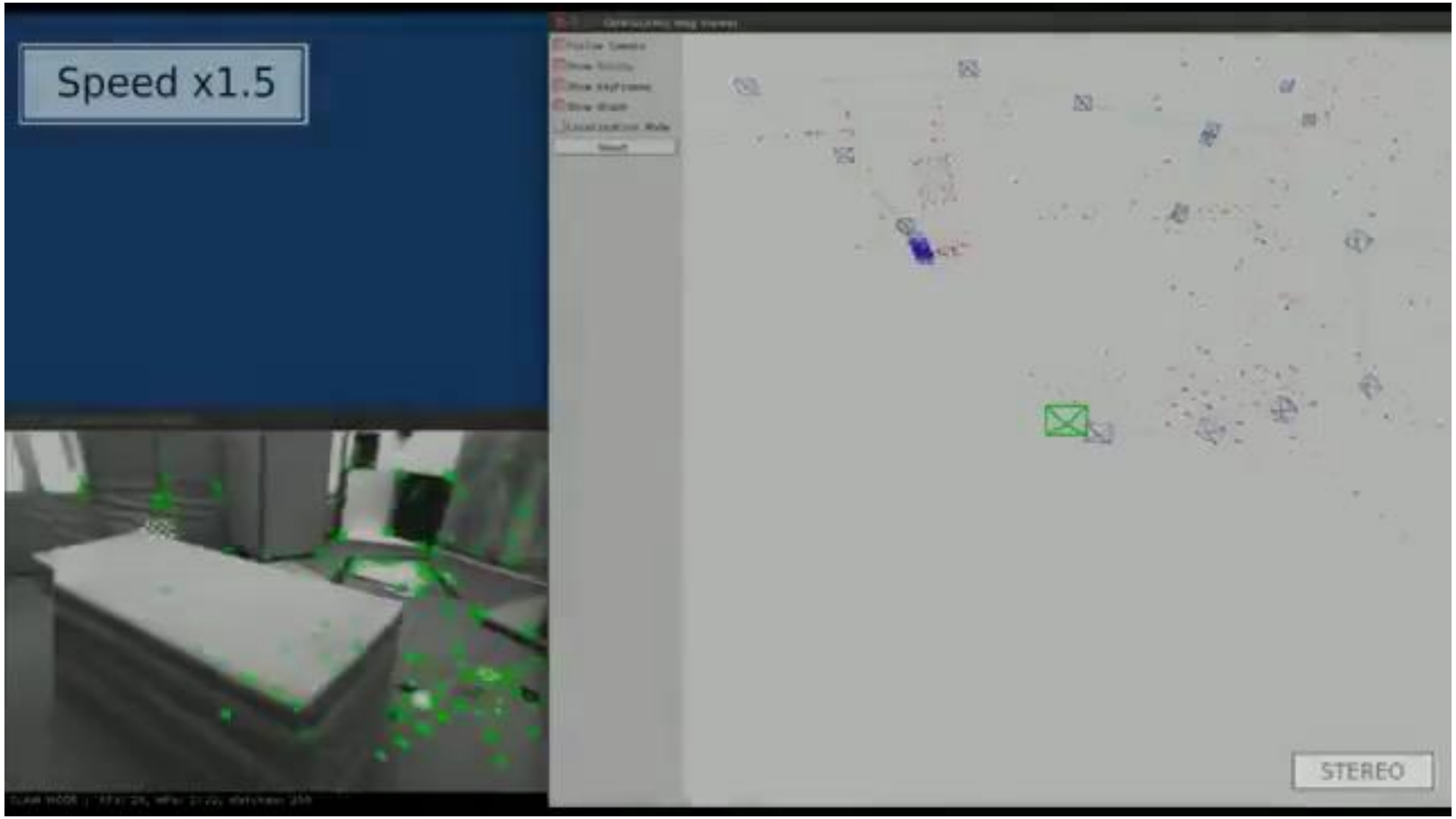


Olivier Goguel - Matrix effect with LIDAR, Unity, and ARKit

Applications

Magic Leap Demo

Applications



Raúl Mur-Artal, Juan D. Tardós. ORB-SLAM2: an Open-Source SLAM System for Monocular, Stereo and RGB-D Cameras

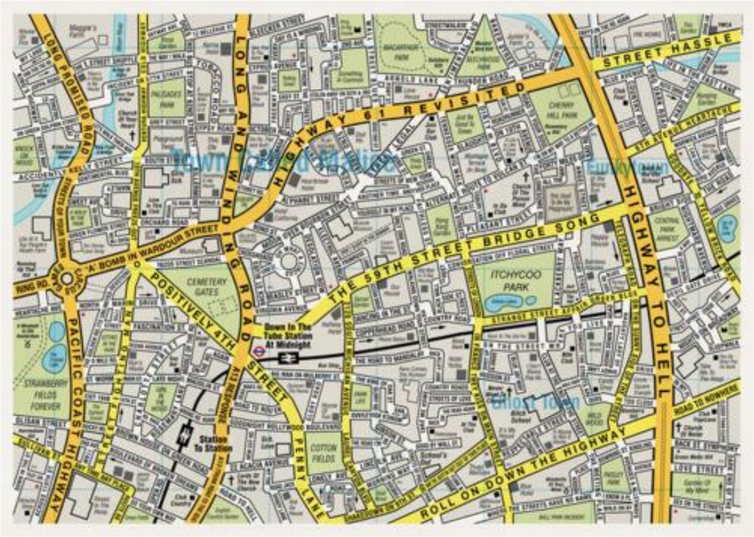
Slam

- “**Camera** with **wheels**”
  - Lidar
  - Sonar
  - Barometer
  - Radar
  - GPS
  - …
  - Wings
  - Rotor
  - Fins
  - …

- We estimate the pose of the camera (sensor)
  - Relevant with GPS?

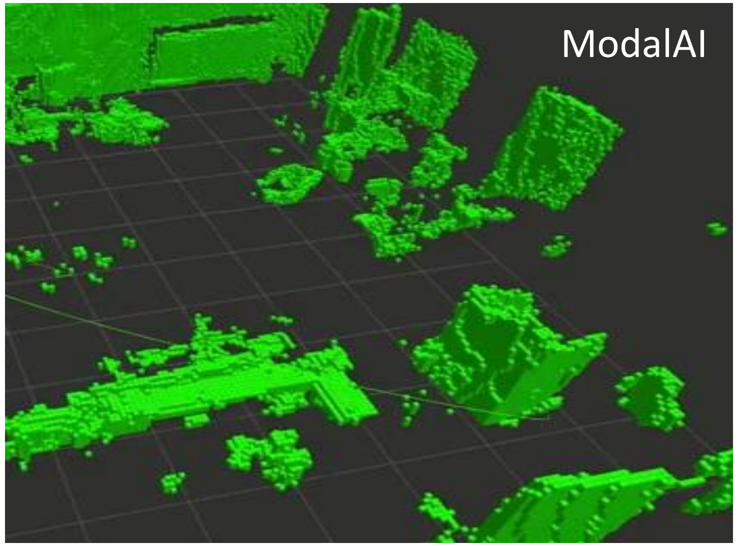
Slam

- Map

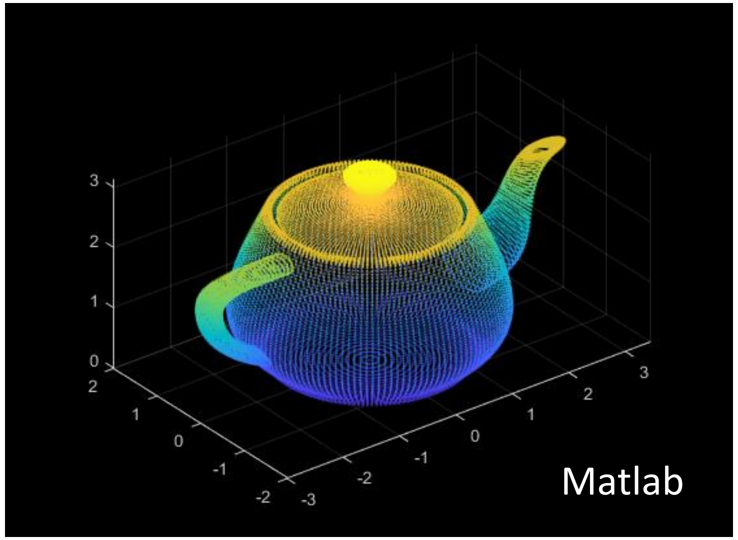


Geometric

Topologic

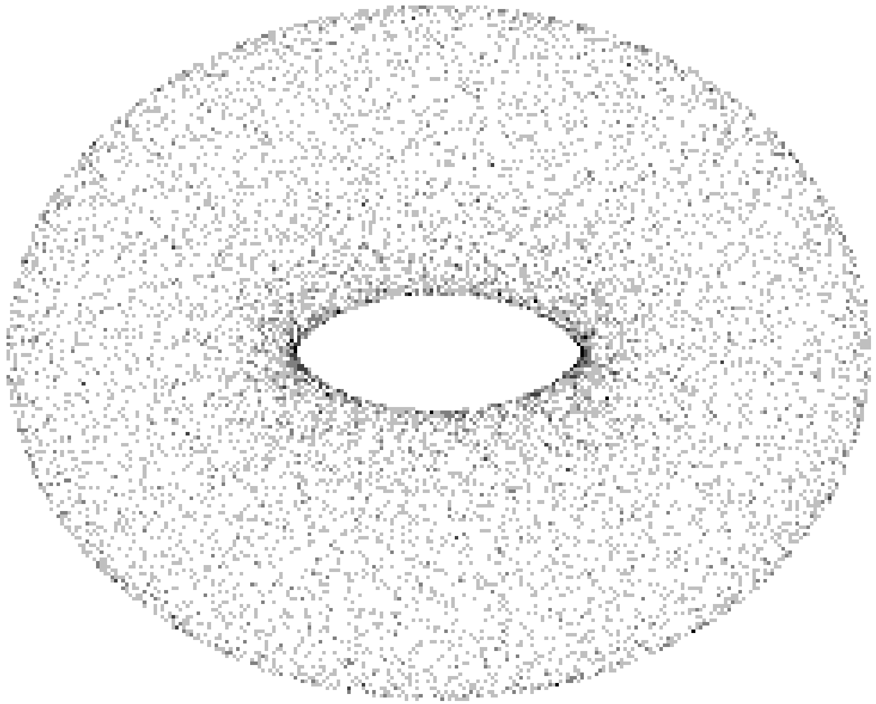


Volumetric

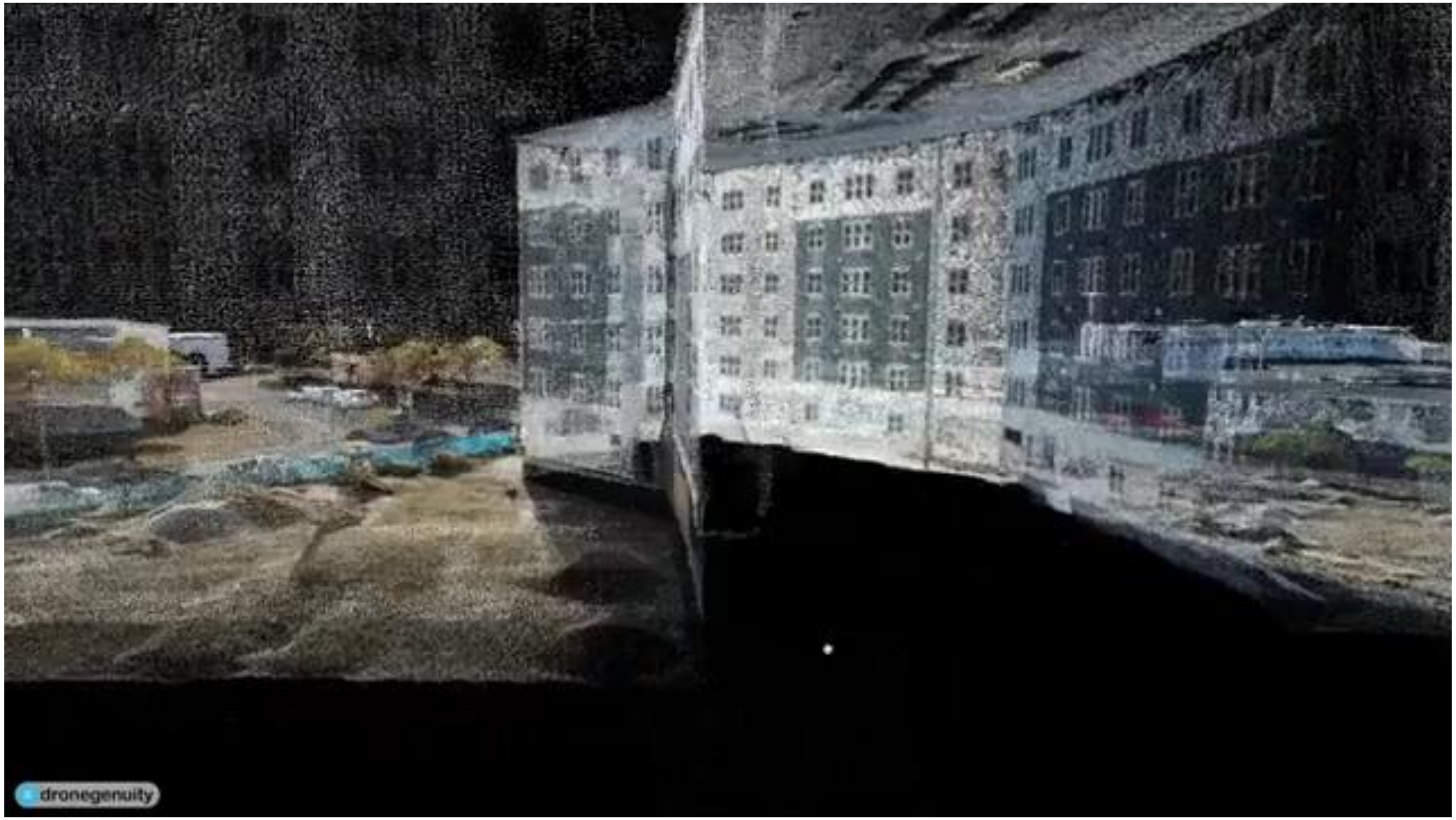


Point Cloud

Point Cloud



Point Cloud

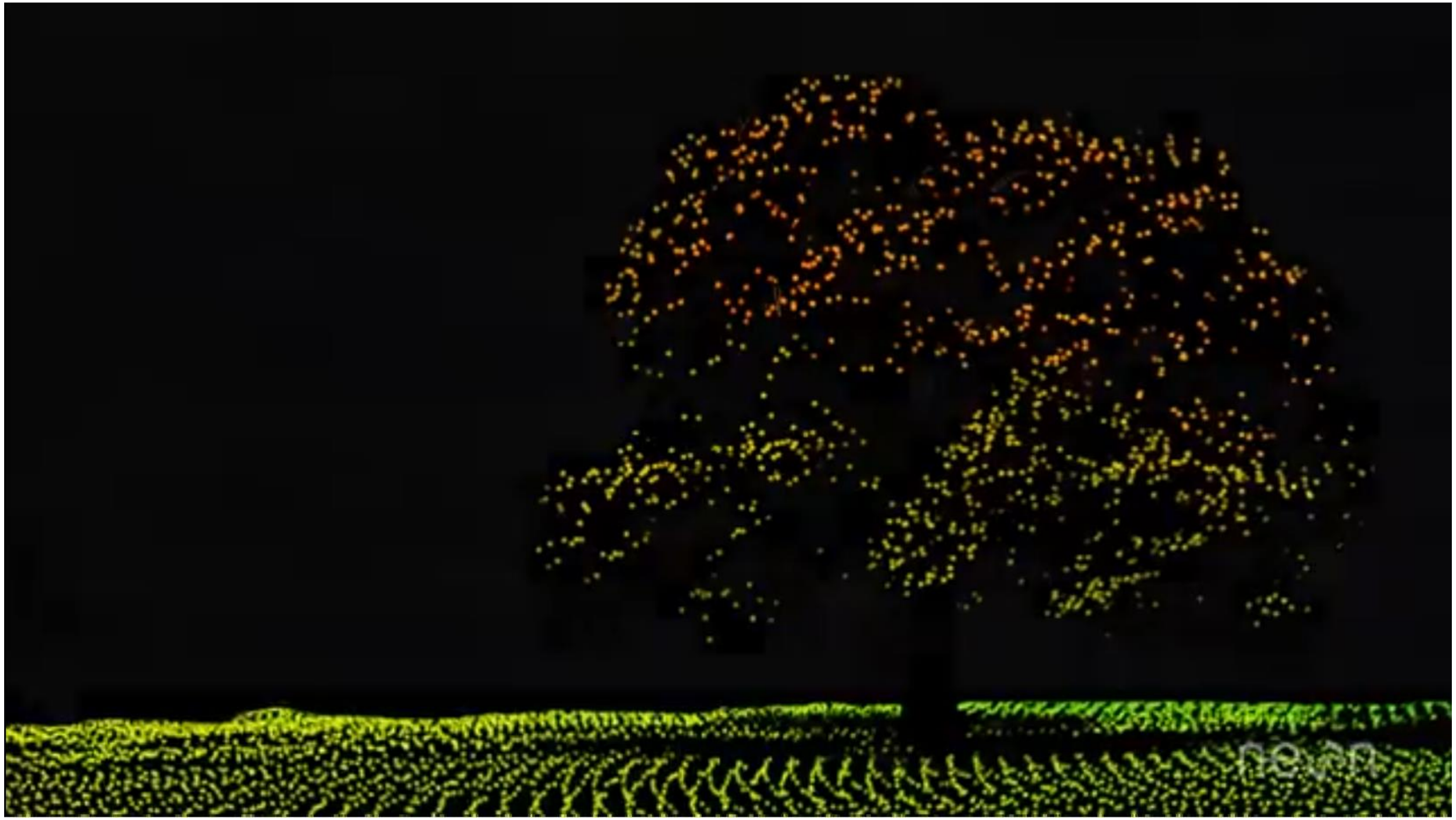


dronegenuity

Point Cloud

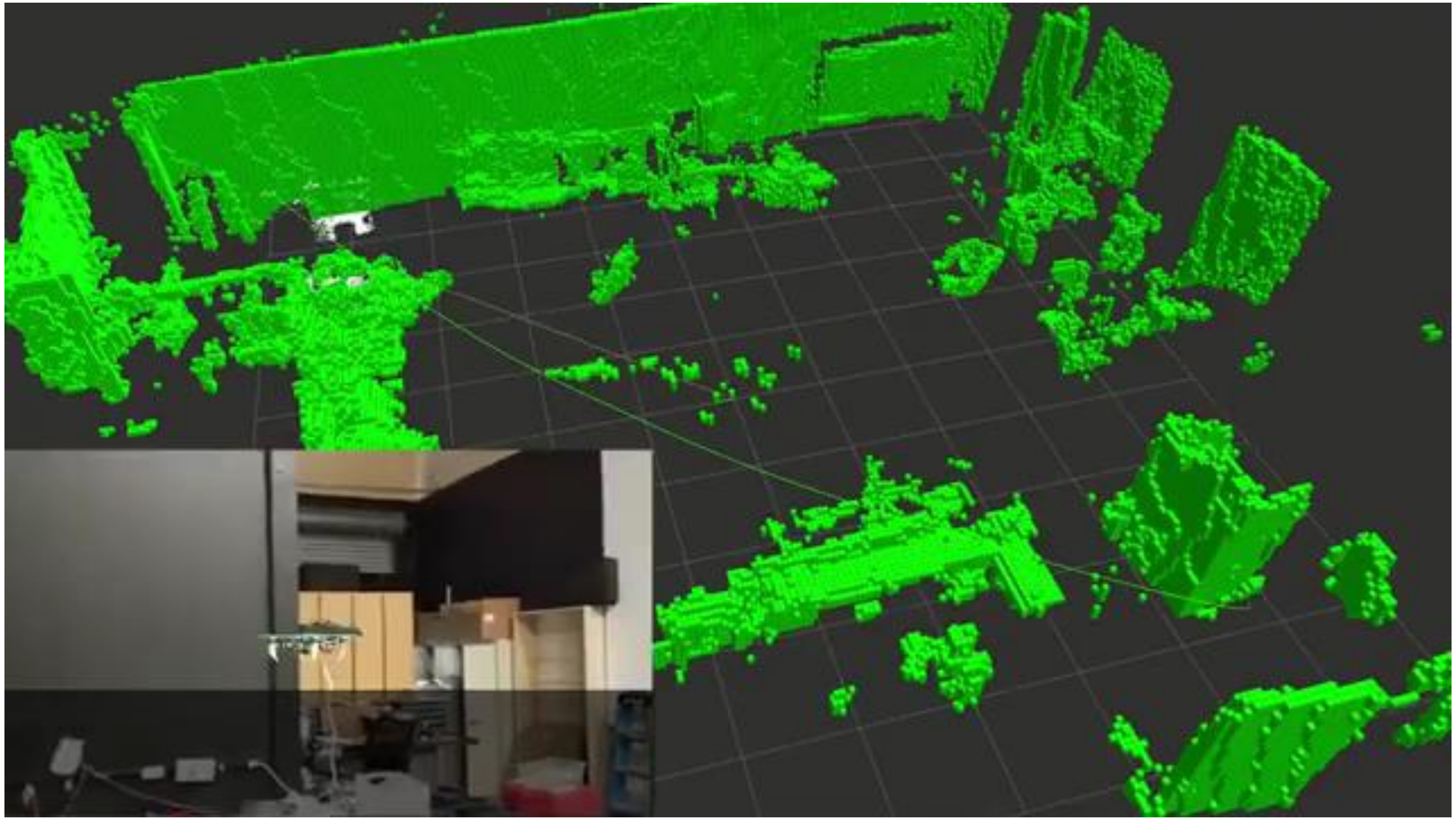
NEON Science

Point Cloud



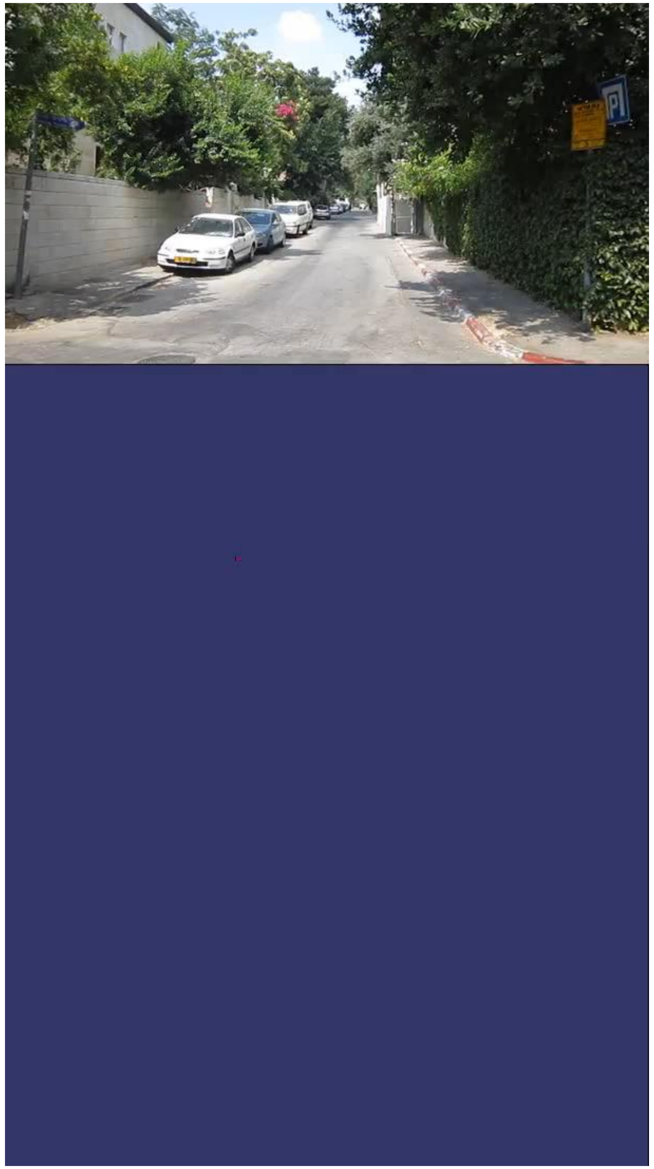
NEON Science

Applications



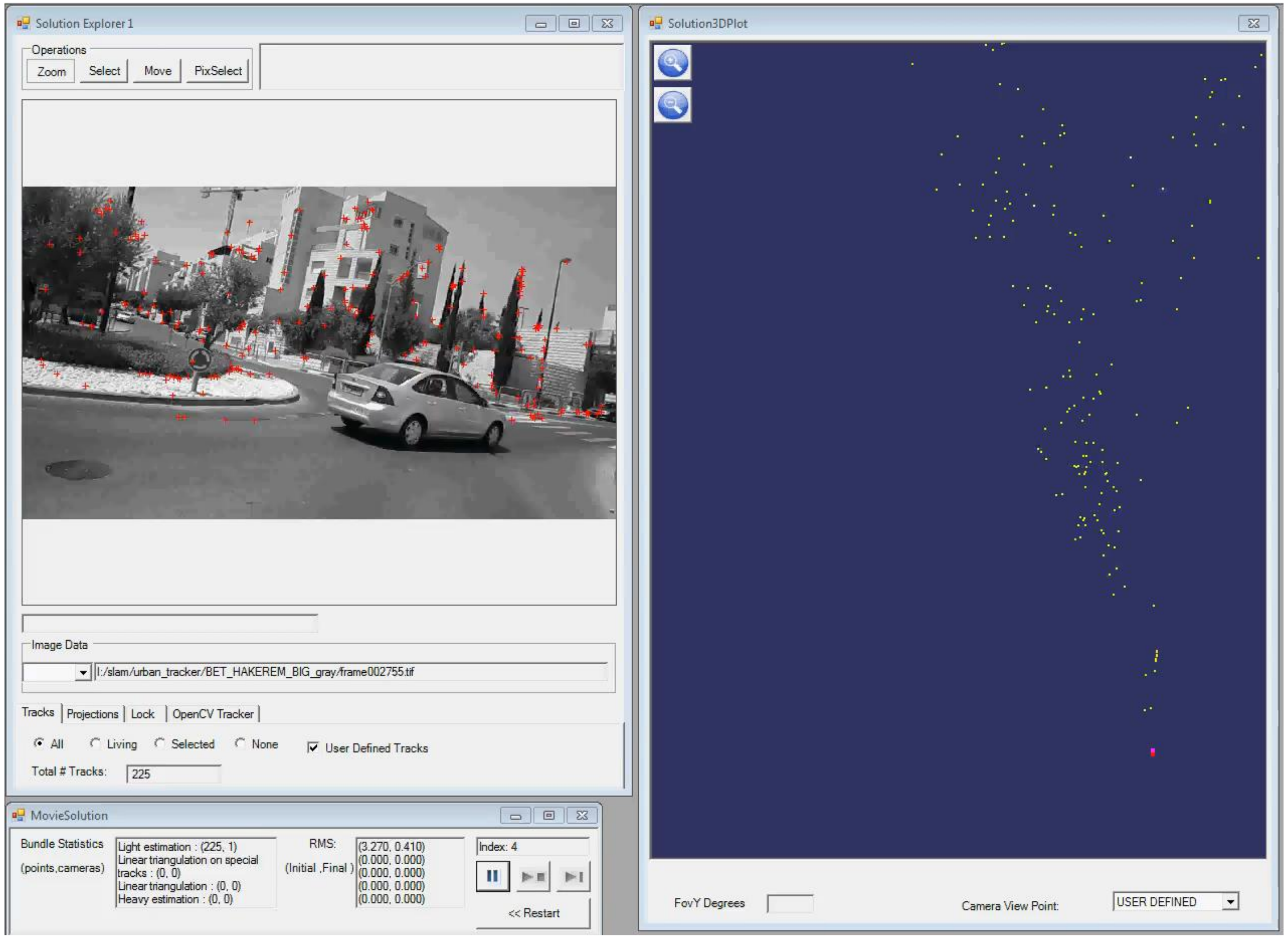
ModalAI sUAS

Applications



Rafael

Applications



Rafael

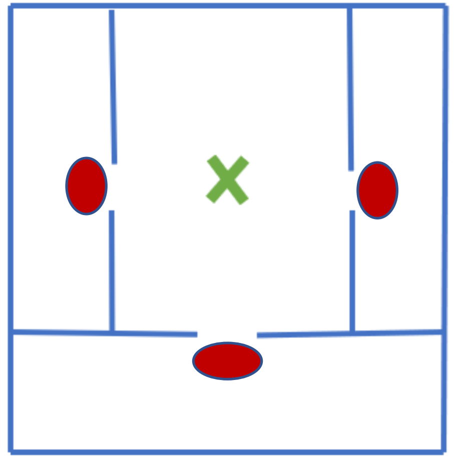
Slam Definition

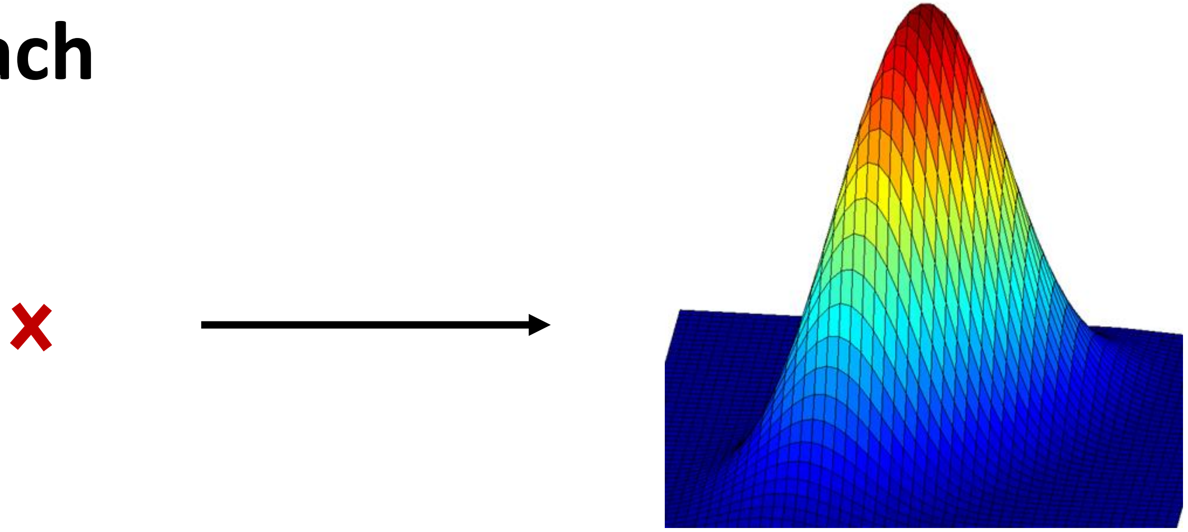
- Given
  - Controls
    - $u_{1:N} = \{u_1, u_2, \dots, u_N\}$
  - Measurements
    - $z_{0:N} = \{z_0, z_1, z_2, \dots, z_N\}$

- Wanted
  - Trajectory
    - $x_{0:N} = \{x_0, x_1, x_2, \dots, x_N\}$
  - Environment map
    - m

Slam Definition

Probabilistic approach





$$p(x_{0:N}, m \mid u_{1:N}, z_{0:N})$$

trajectory map controls observations

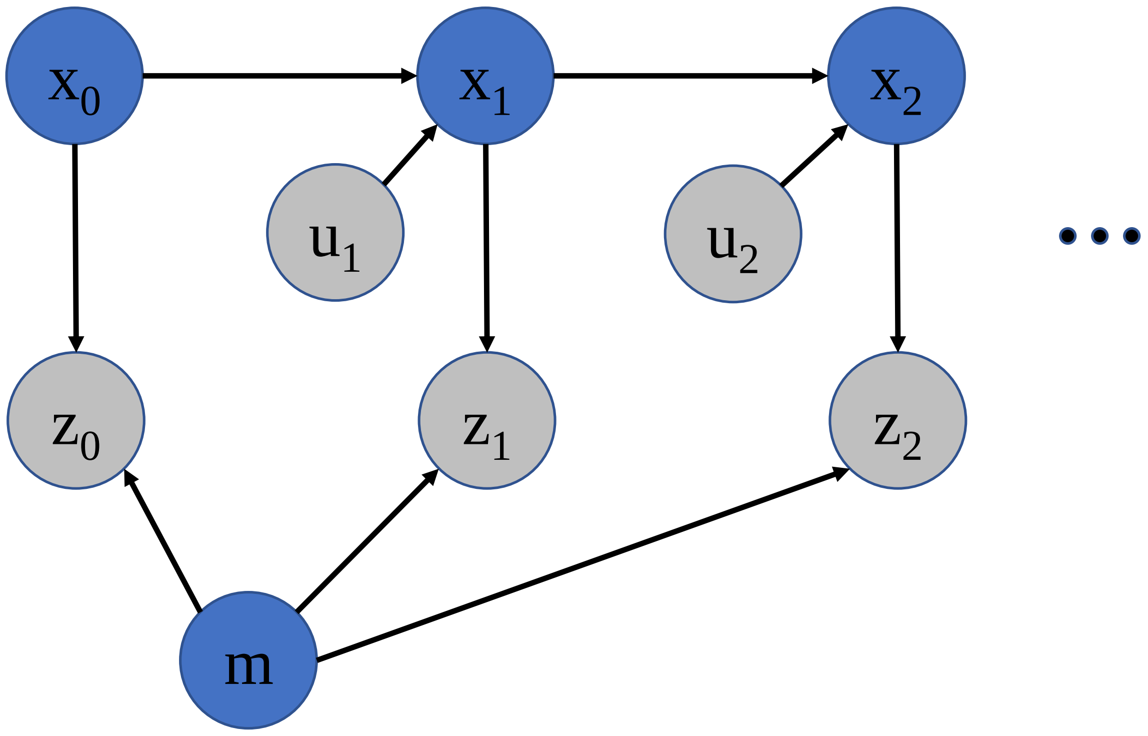
Slam

- In the course we present one approach for solution
- Many other approaches
  - EKF – Extended Kalman Filter
    - UKF
    - EIF
  - Particle Filter
  - …
  - See Cyrill Stachniss courses
    - https://www.youtube.com/channel/UCi1TC2fLRvgBQNe-T4dp8Eg

  - Deep Learning

Slam

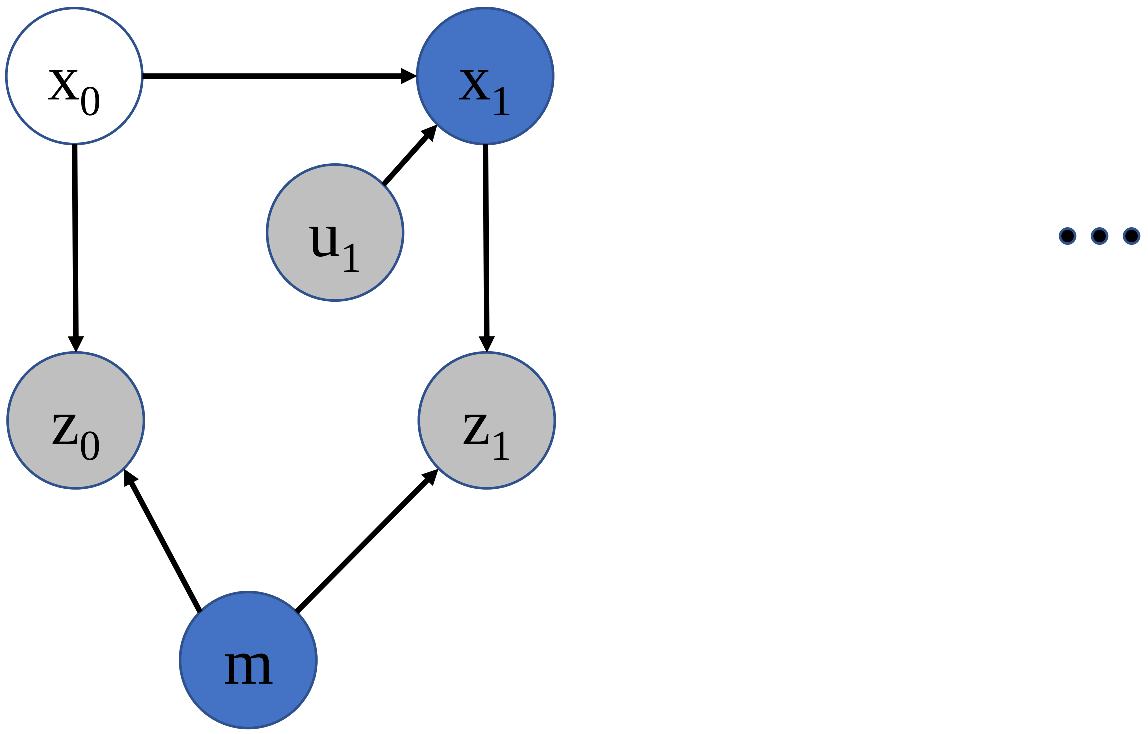
- Graphical Model



$$p(x_{0:2}, m \mid u_{1:2}, z_{0:2})$$

Online Slam

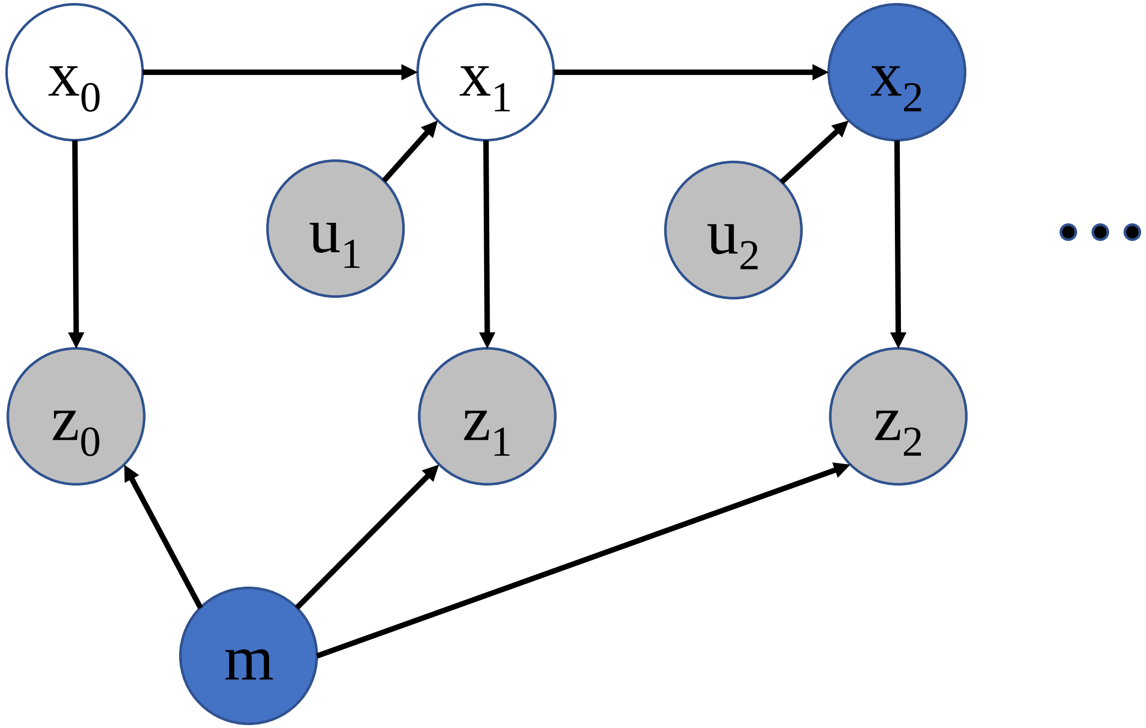
- Graphical Model



$$p(x_1, m \mid u_1, z_{0:1})$$

Online Slam

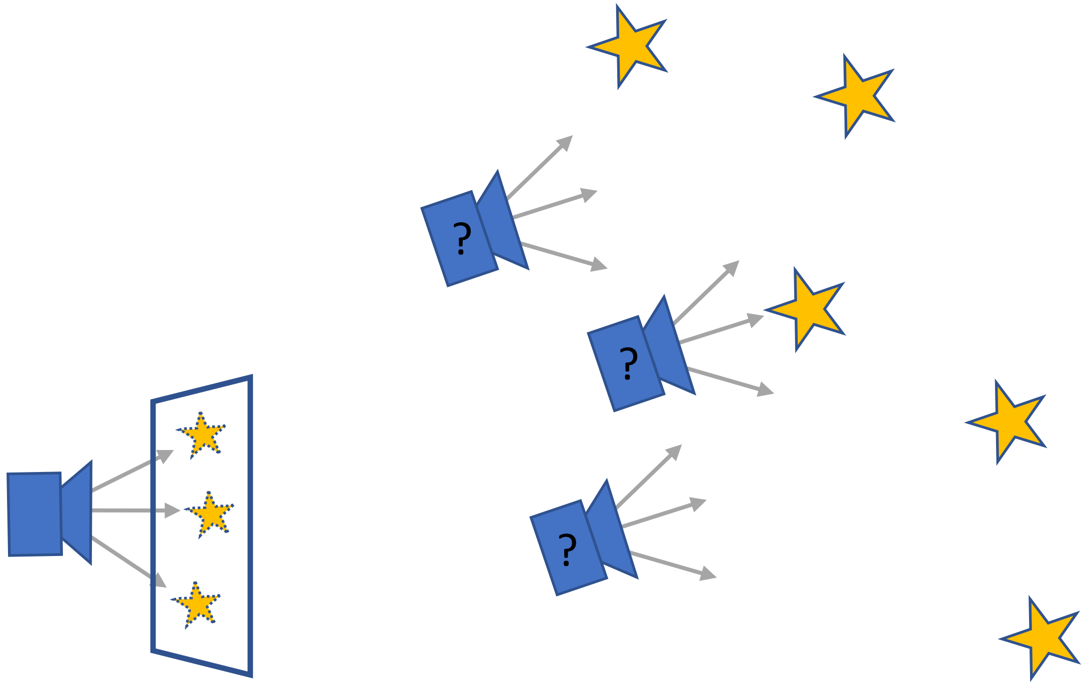
- Graphical Model

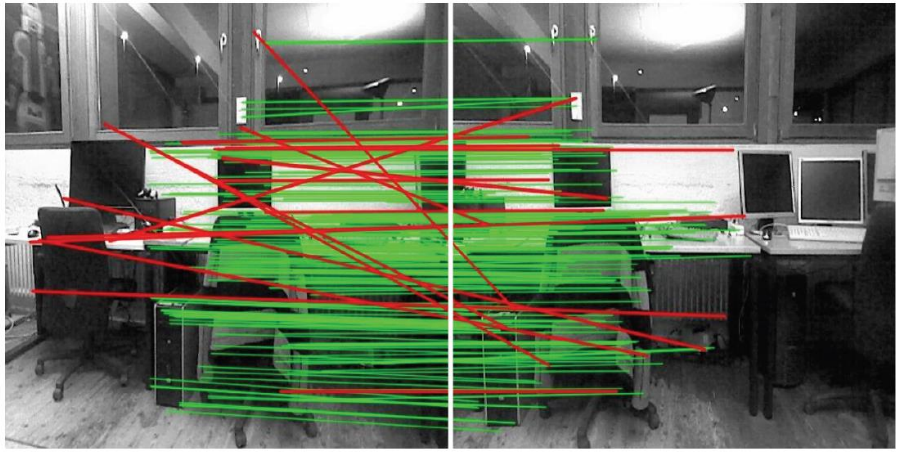


$$p(x_2, m | u_{1:2}, z_{0:2}) = \int_{x_0} \int_{x_1} p(x_{0:2}, m | u_{1:2}, z_{0:2}) dx_1 dx_0$$

Challenges

- Both map and trajectory are unknown and highly correlated
- Data Association mistakes are critical!





Slam

- Static / Dynamic
- Time / Space constraints
- Small / large uncertainty
- Single / Multi platform

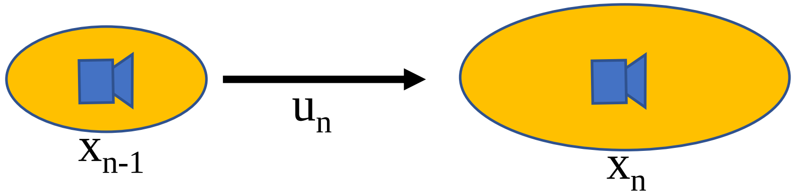
History

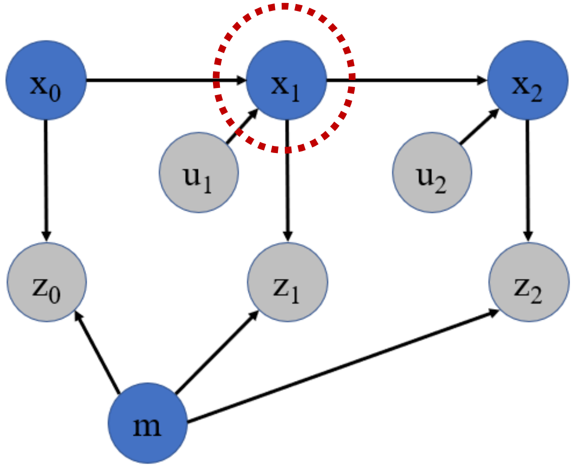
- Roots in photogrammetry in the 1950’s
- 1987-8: key papers by Smith, Self and Cheeseman
- 1990-5: Kalman filter approaches
- 1995: SLAM acronym
- 2007-9: PTAM Klein, Murray
- 2008: FrameSLAM Konolige, Agrawal
- 2010: Why Filter? Strasdat, Montiel, Davison
- 2011-present: G^2O Kümmerle, Grisetti, Strasdat, Konolige, Burgard
  GTSAM Dellaert, …
- 2015: PoseNet Kendall, Grimes, Cipolla

Motion Model

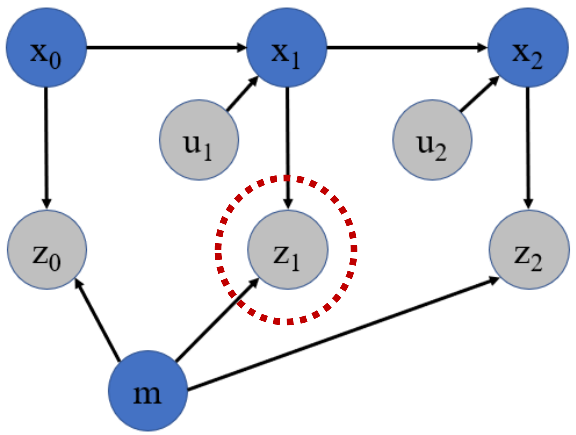
$$p(x_n | x_{n-1}, u_n)$$

- Gaussian model



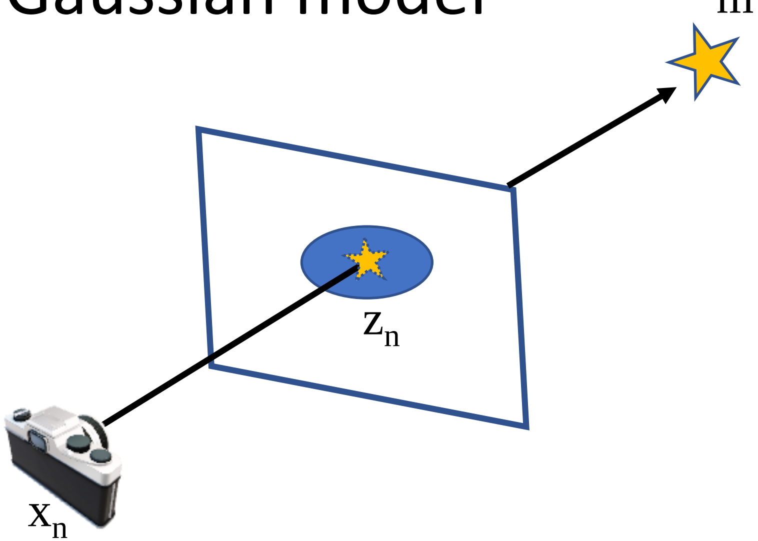


Measurement Model

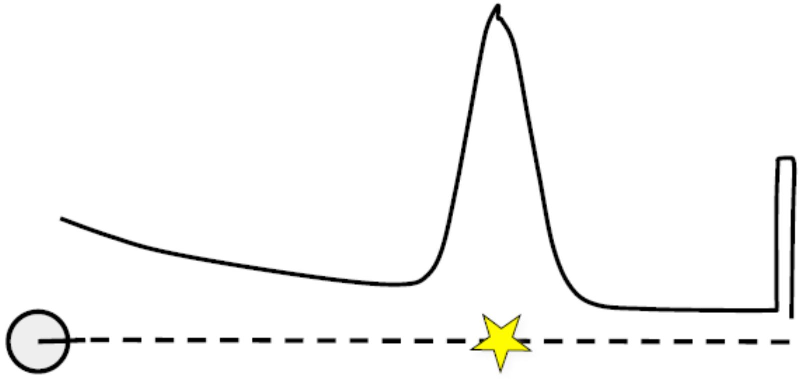


$$p(z_n | x_n, m)$$

- Gaussian model



- Non-Gaussian



Courtesy of Cyrill Stachniss

Summary

- Simultaneous Localization and Mapping
  is the process of building a map of the environment while computing our pose relative to it.

Willow Garage

- Founded by Scott Hasan
- 2006 -2014
- DARPA challenge
- “No more reinventing the wheel”
- More than 400 papers

BUSINESS INSIDER

TECH | FINANCE | POLITICS | STRATEGY | LIFE | ALL

Hassan met Page and Sergey Brin while working on an Integrated Digital Libraries project at Stanford. He ended up programming much of the original search engine that eventually became Google.

He also decided to invest $800 in the company 12 days after Page and Brin officially formed it 1998. He then founded his own company: An email-list service called eGroups.com that Yahoo bought for about $432 million in 2000.

Willow Garage

Willow Garage

From Wikipedia, the free encyclopedia

Coordinates: 37°27′08″N 122°09′58″W

Willow Garage was a robotics research lab and technology incubator devoted to developing hardware and open source software for personal robotics applications.[2] The company was probably best known for its open source software suite ROS (Robot Operating System), which has been rapidly and widely becoming a common, standard tool among robotics researchers and industry, since its initial release in 2010.[3] It was started in late 2006 by Scott Hassan, who had worked with Larry Page and Sergey Brin to develop the technology that was the predecessor to the Google search engine.[4] Steve Cousins was the president and CEO. Willow Garage was located in Menlo Park, California.[5]

Willow Garage shut down in early 2014. Most employees were retained by Suitable Technologies, Inc, while the support and services responsibilities were transferred to Clearpath Robotics.[6][7]

Willow Garage

Industry	Robotics
Founded	2006
Headquarters	Menlo Park, California
Key people	Scott Hassan (Founder) Steve Cousins (CEO) Eric Berger (Co-Director, Personal Robotics Program)

Open source software [edit]

Willow Garage was maintaining ROS (Robot Operating System),[32][33] the OpenCV computer vision library,[34] and PCL (Point Cloud Library).[35] These projects all use the BSD license, an open source software license.

ROS development is now overseen by Open Robotics.

Robots [edit]

Willow Garage's first major robot is called PR2. It is of a size similar to a human. PR2 is designed as a common hardware and software platform for robot researchers. PR2 is a spinoff of PR1, a robotics platform being developed at Stanford University. *PR* stands for "personal robot".[36][37]

The PR2 has two 7-DOF arms with a payload of 1.8 kilograms (4.0 lb). Sensors include a 5-megapixel camera, a tilting laser range finder, and an inertial measurement unit. The "texture projector" projects a pattern on the environment to create 3D information for capture by the cameras. Willow Garage calls this "textured light", but this approach is better known as structured light.[38] The head-mounted laser scanner measures distance by time-of-flight. The two computers located in the base of the robot are 8-core servers, each of which has 24 Gigabytes of RAM, for a total of 48 GB. The battery system consists of 16 laptop batteries.[39]

On May 26, 2010, Willow Garage [40] held a graduation party in which the 11 PR2s were introduced. Some PR2s "danced" with humans while being led by their grippers. At least one party-goer attended by telepresence using the Willow Garage Texai remote presence device.[41][42] Jonathan Knowles of Autodesk attended an XPrize cocktail party using a Texai to hobnob with

The PR2 robot

Software »

ROS

Open source libraries and tools for building robotics applications.

Learn More »

OpenCV

pcl

Open source computer vision libraries for real-time perception.

Texai/Beam »

Highest quality remote presence for the enterprise and home.

FrameSLAM

FrameSLAM: From Bundle Adjustment to Real-Time Visual Mapping

Kurt Konolige and Motilal Agrawal

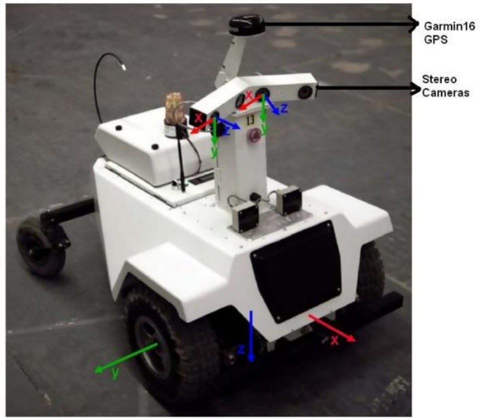


Figure 1. Stereo and GPS Sensors on our Robot

Kurt Konolige received the Ph.D. degree in computer science from Stanford University, Stanford, CA, in 1984.

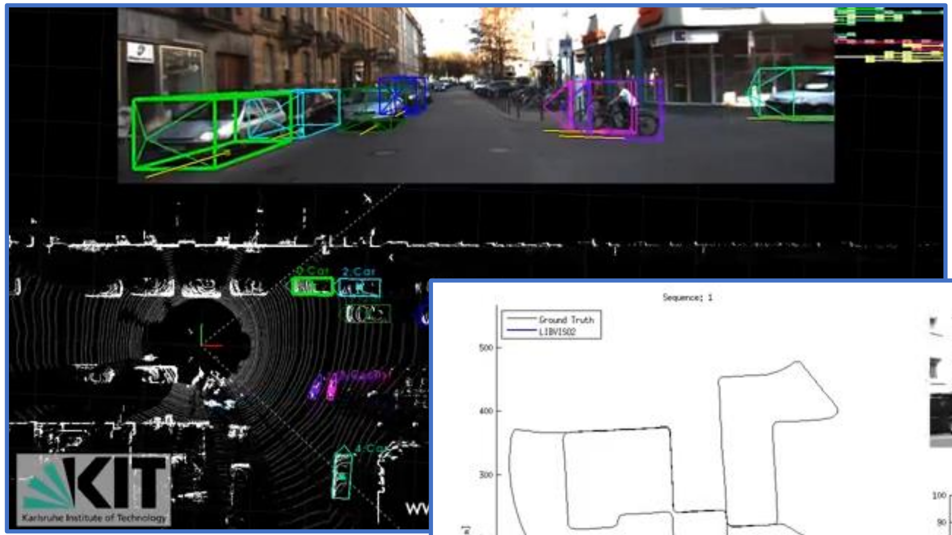
He is currently a Senior Researcher at Willow Garage, Menlo Park CA. He is also a Consulting Professor of computer science at Stanford University, where he teaches a course in mobile robotics. He is the Co-Developer of the Pioneer and AmigoBot robot line and the Saphira robot control architecture. His current research interests include real-time perception, navigation for mobile robots, visual perception, mapping, and navigation using probabilistic techniques.

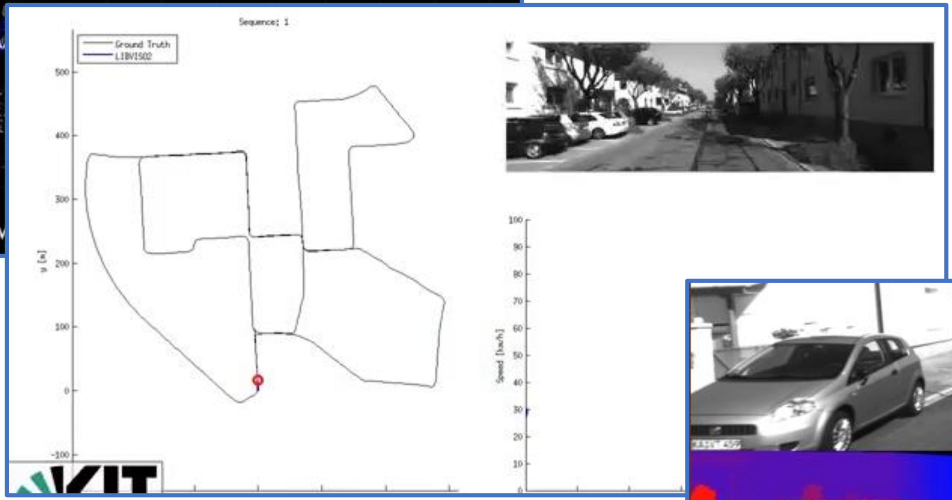
Dr. Konolige is a Fellow of Association for the Advancement of Artificial Intelligence (AAAI).

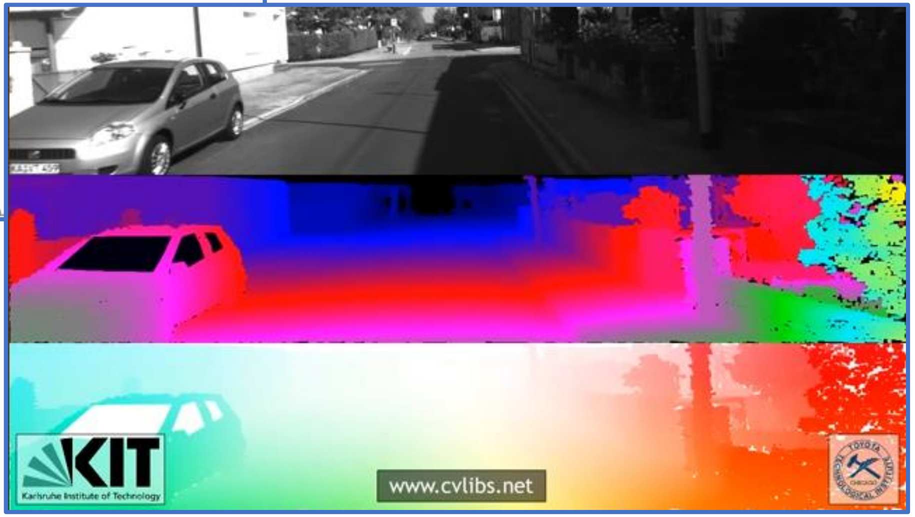
Motilal Agrawal received the B.Tech. degree in computer science from the Indian Institute of Technology, Delhi, India, in 1998 and the Ph.D. degree in computer vision from the University of Maryland, Baltimore, in 2002.

In January 2003, he joined the Artificial Intelligence Center, SRI International, Menlo Park, CA, where he is currently a Senior Computer Scientist with the Perception Program. He has organized two workshops at the Computer Vision and Pattern Recognition (CVPR) and Intelligent Robots Systems (IROS) Conferences. His current research interests include real-time perception and navigation for mobile robots and novel algorithms for real-time visual localization. He is the author or coauthor of several papers published in prominent computer vision and robotics conferences.

Project - Kitty





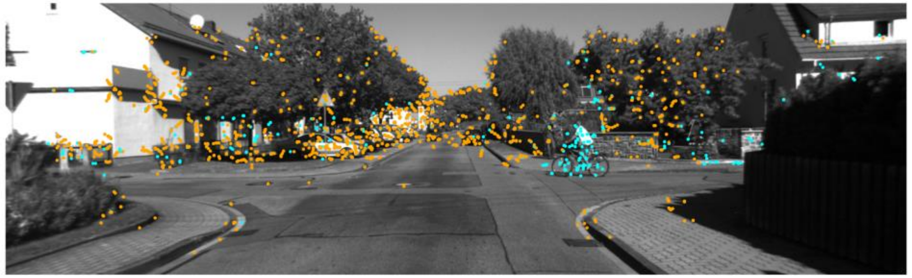


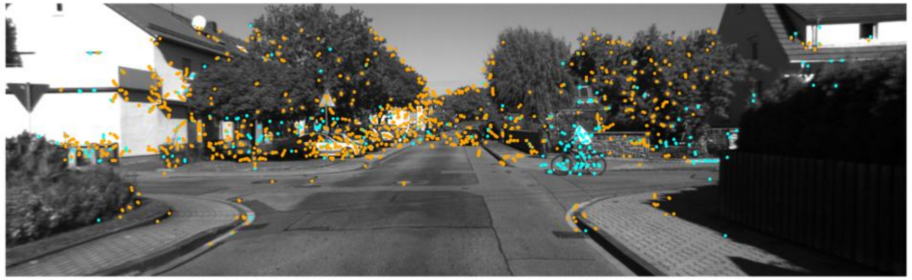
Project - Kitty

Project - Kitty

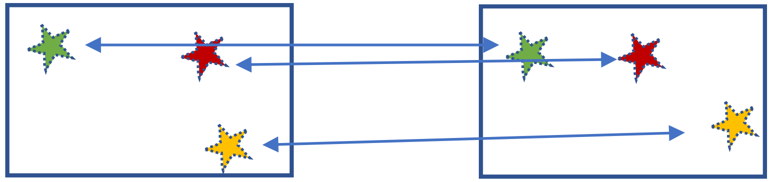
Project - Kitty

Project – Phase 1

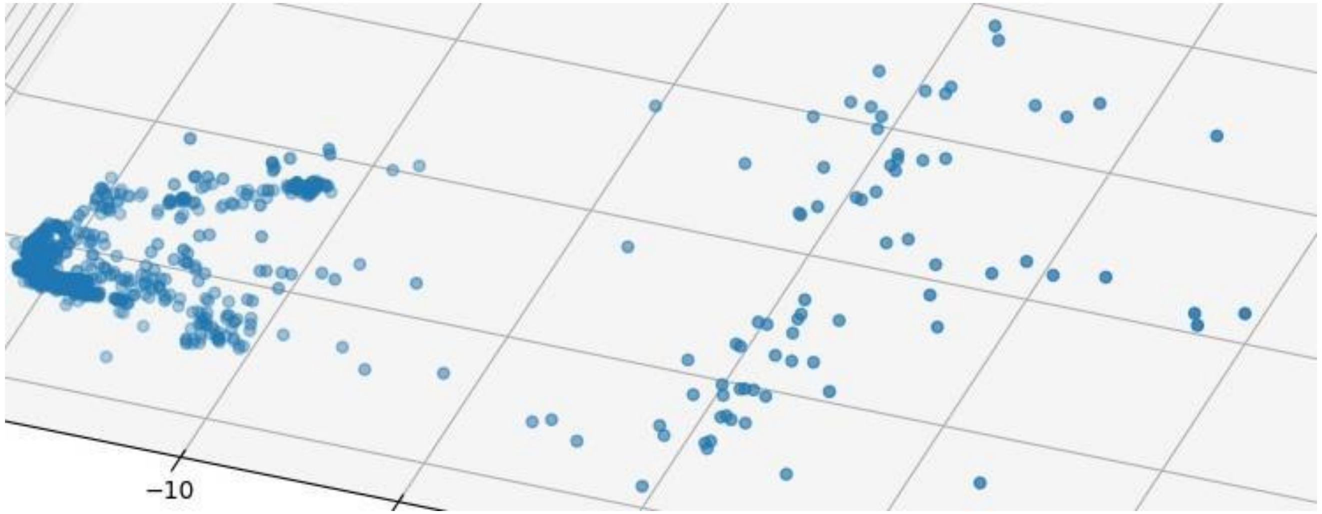




- Extract geometric information
- Stereo matching

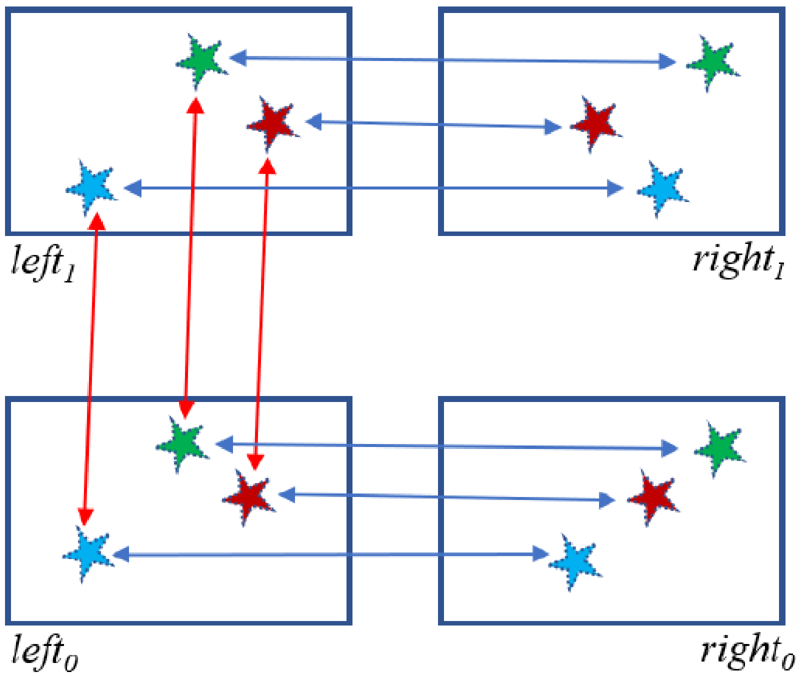


- Triangulation



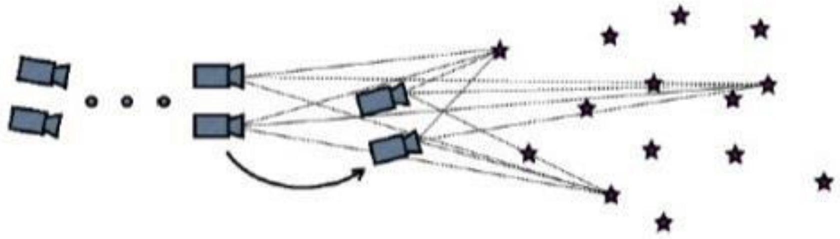
Project – Phase 2

- Initial motion estimation



- Consensus matching
  - No outliers

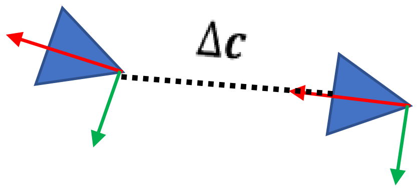
- PnP

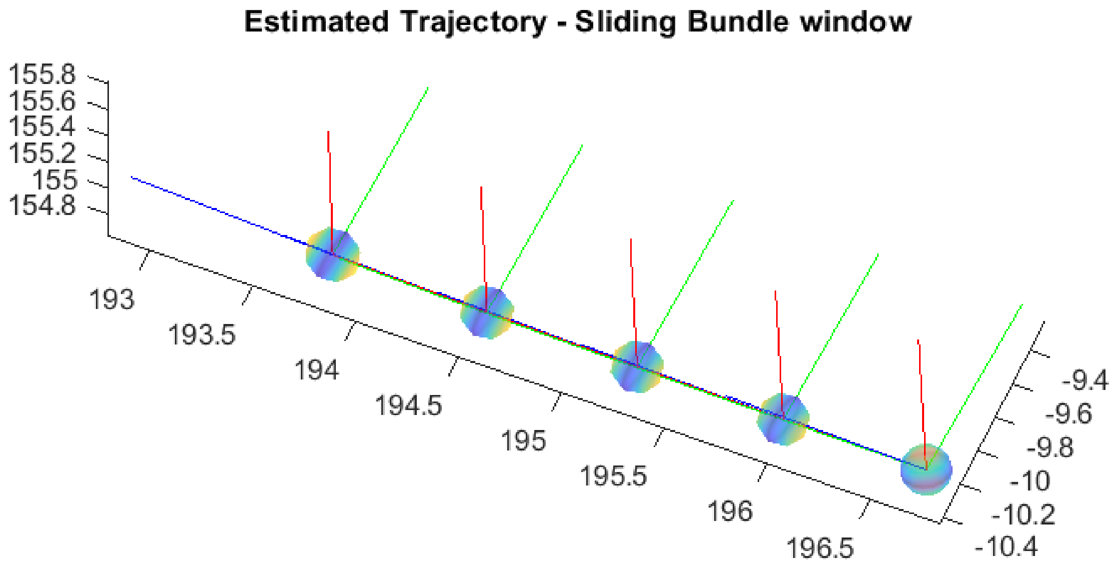


FrameSLAM Konolige, Agrawal

Project – Phase 3

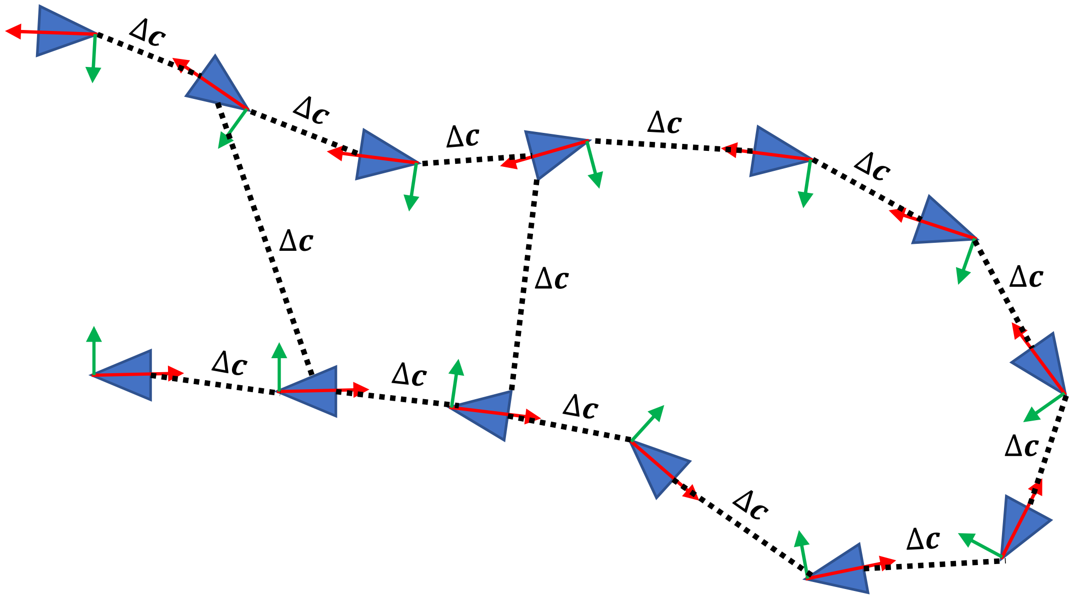
- Bundle Adjustment - Motion estimation optimization
- Visual Odometry

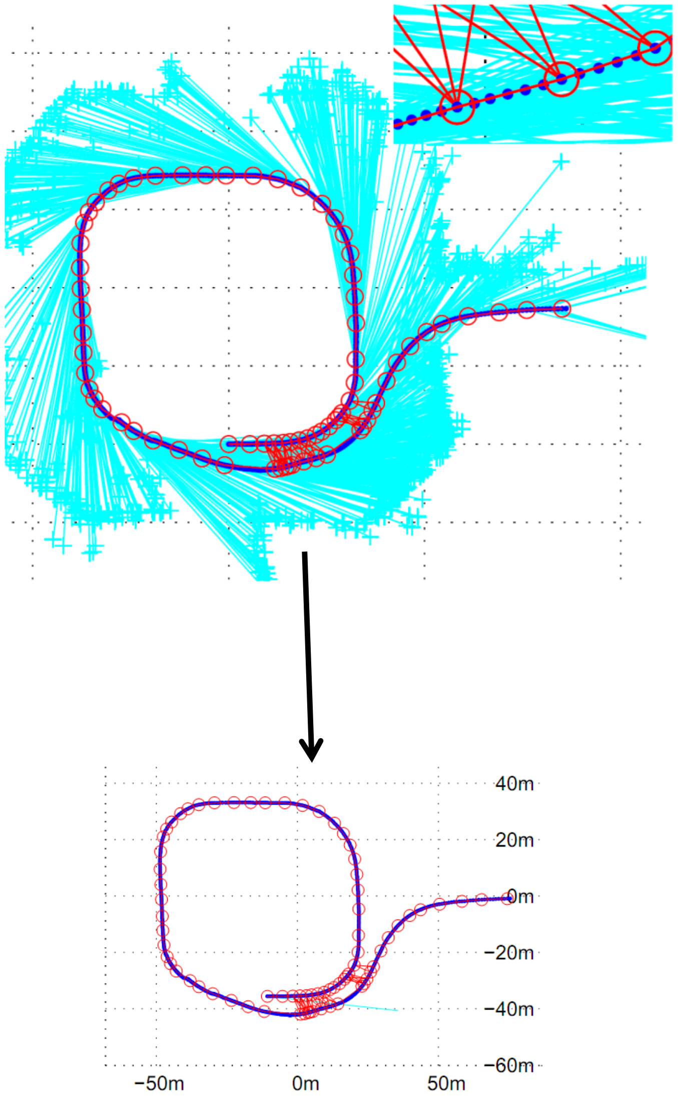




Project – Phase 4

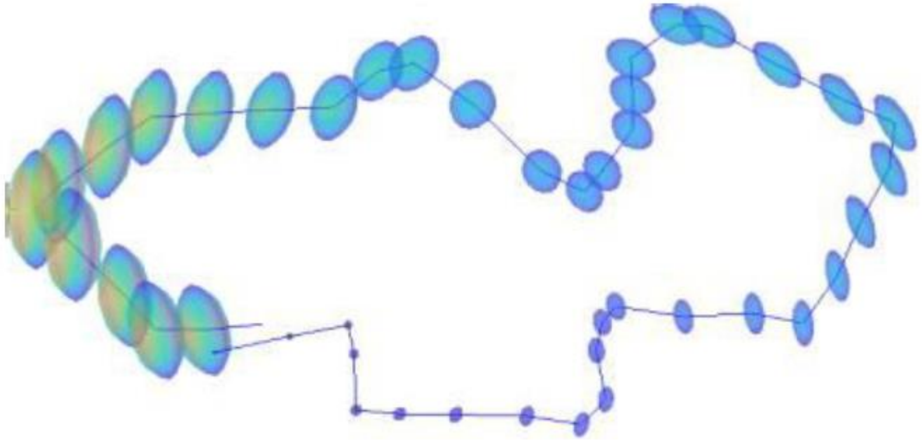
- Pose Graph - Large scale motion estimation

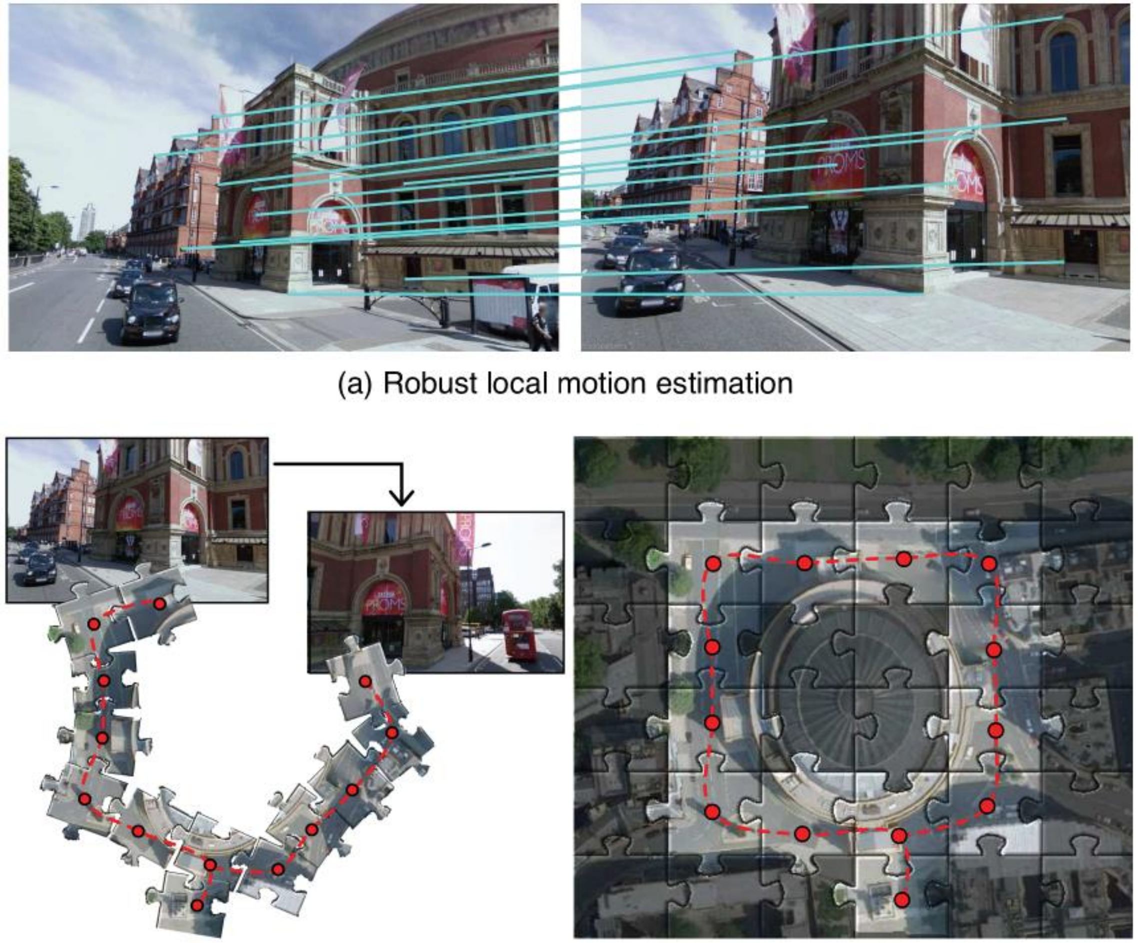




Project – Phase 5

- Loop Closure





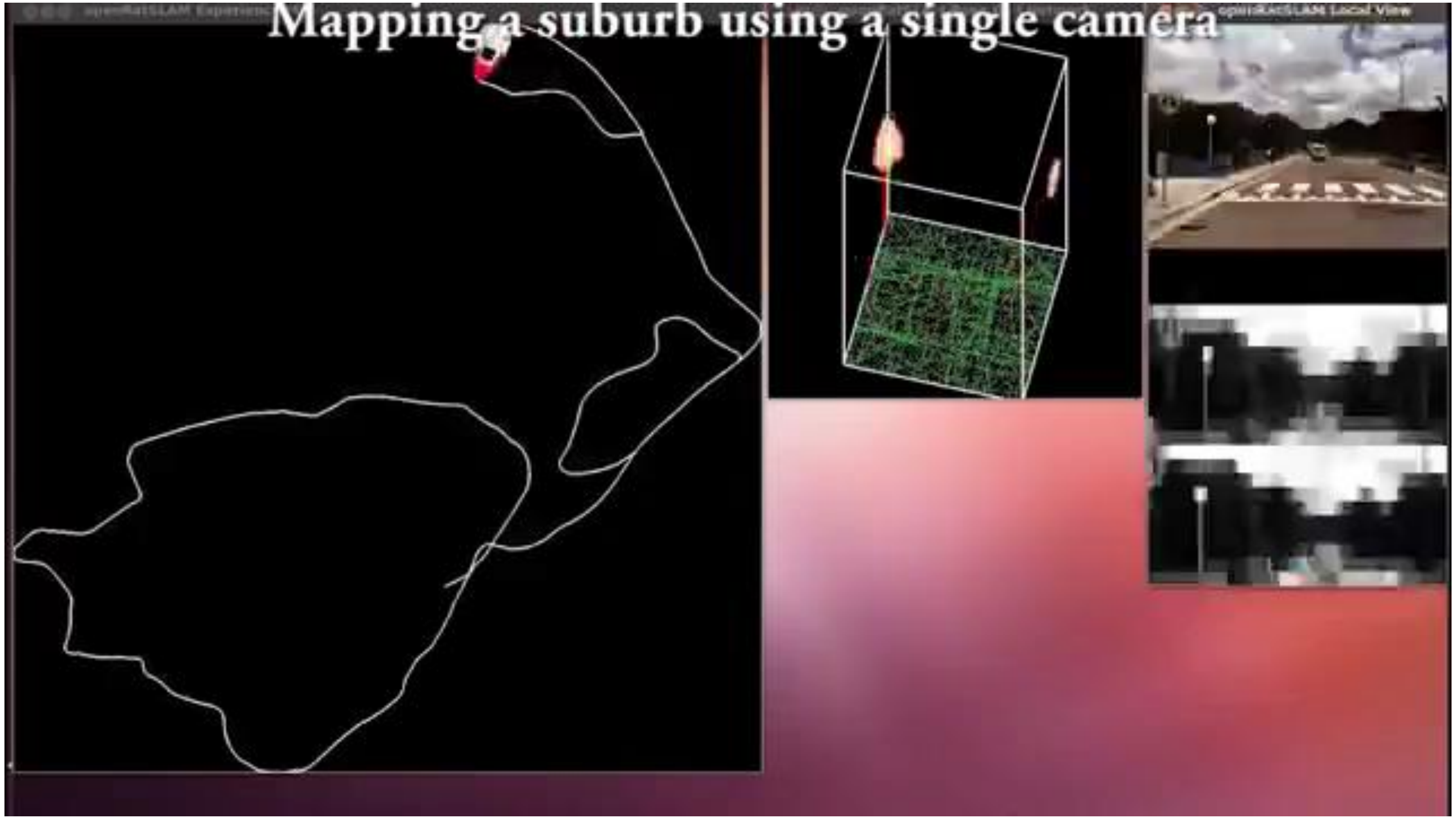
(a) Robust local motion estimation

(b) Mapping and loop-closure detection

(c) Global optimisation

Applying Information Theory to Efficient SLAM – M.Chli

Applications – Loop Closure



Ball, Heath, Wiles, Wyeth, Corke, Milford OpenRatSLAM: an open source brain-based SLAM system