

Principles of Robot Autonomy I

Course overview, intro to robotic systems and ROS

From automation...



...to autonomy

Waymo Self-Driving Car



Intuitive DaVinci Surgical Robot



Apollo Robot at MPI



Boston Dynamics – Spot Mini



Astrobee - NASA



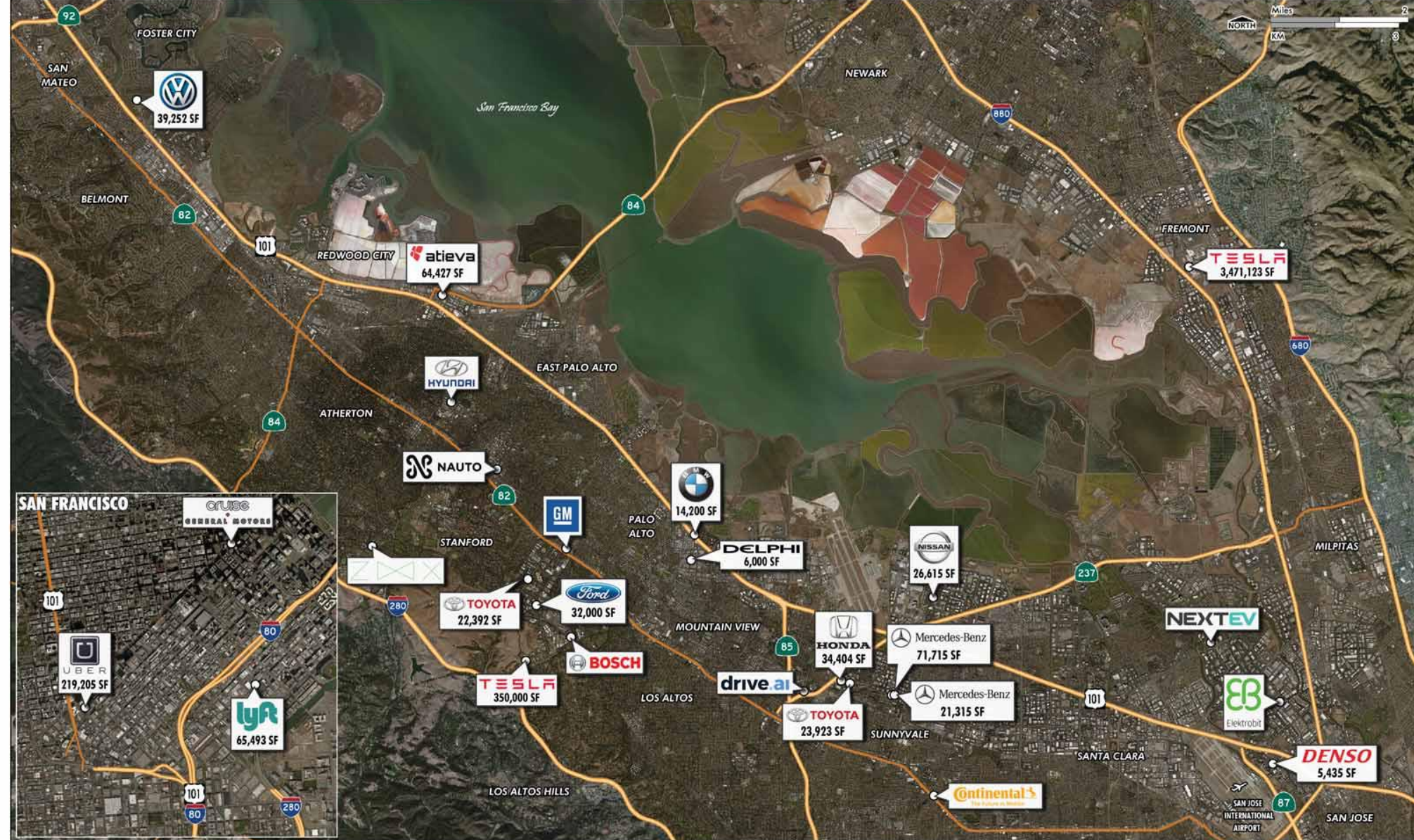
Zipline

Silicon Valley



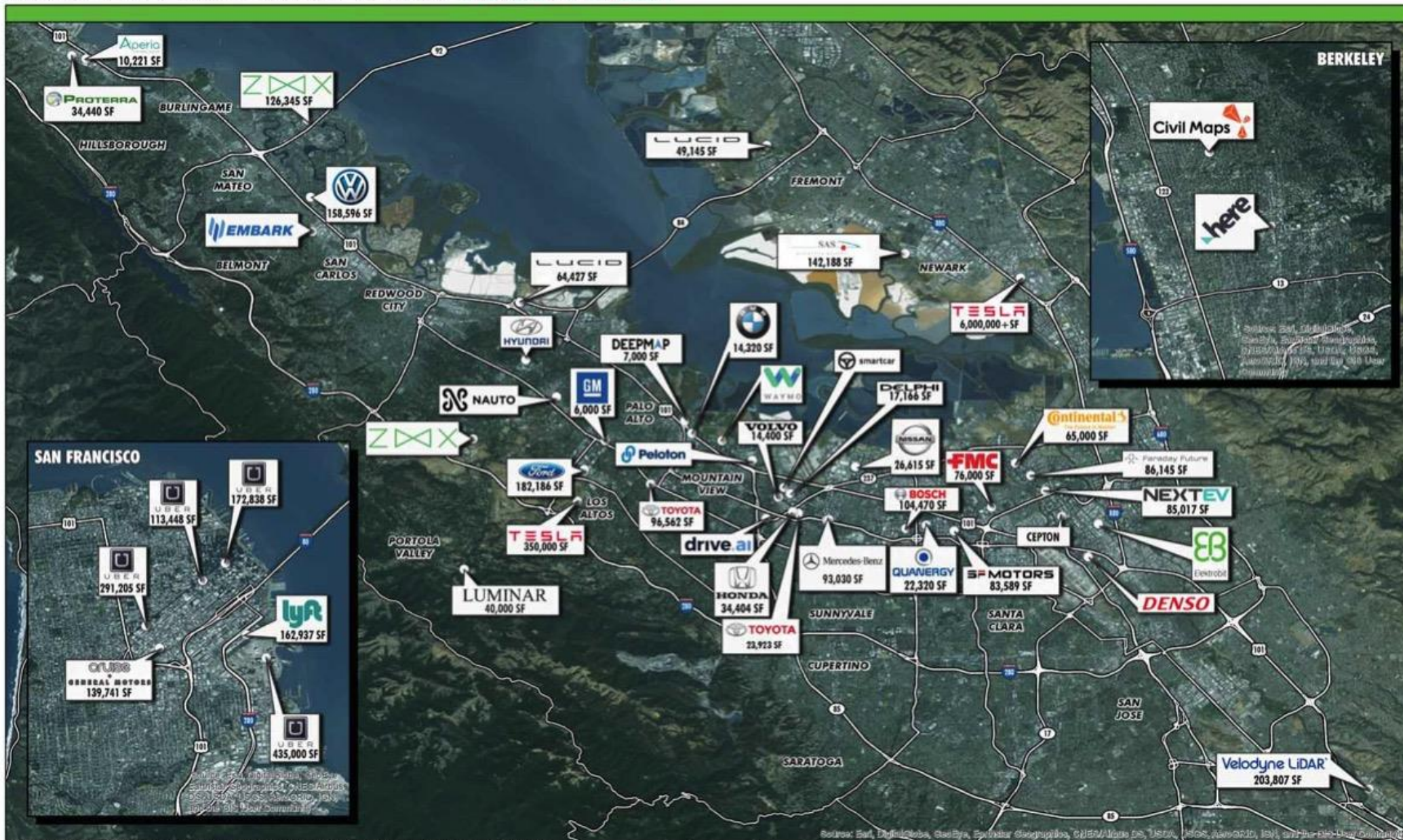
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Silicon Valley



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AUTO LAB MAP APRIL 2017 SILICON VALLEY



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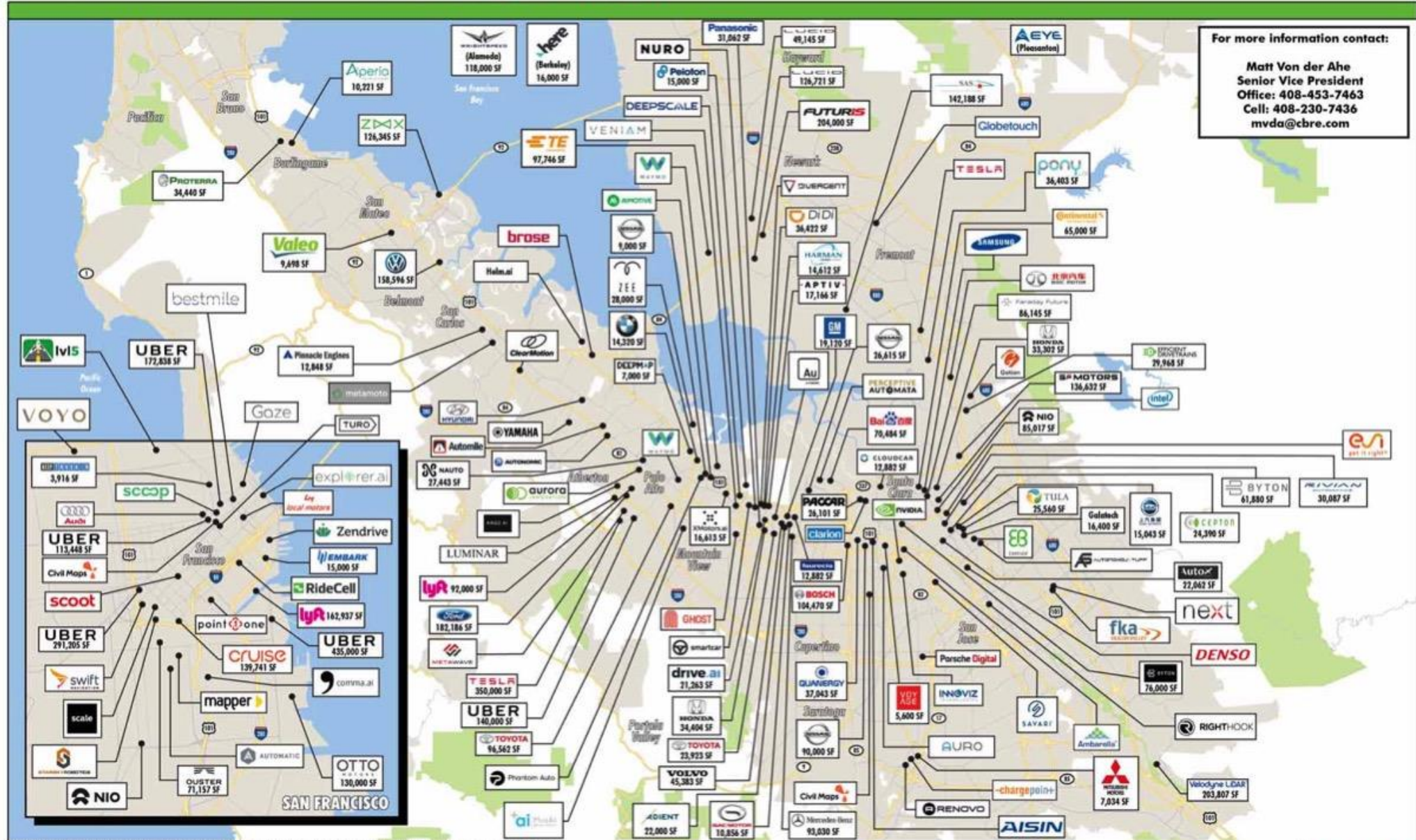
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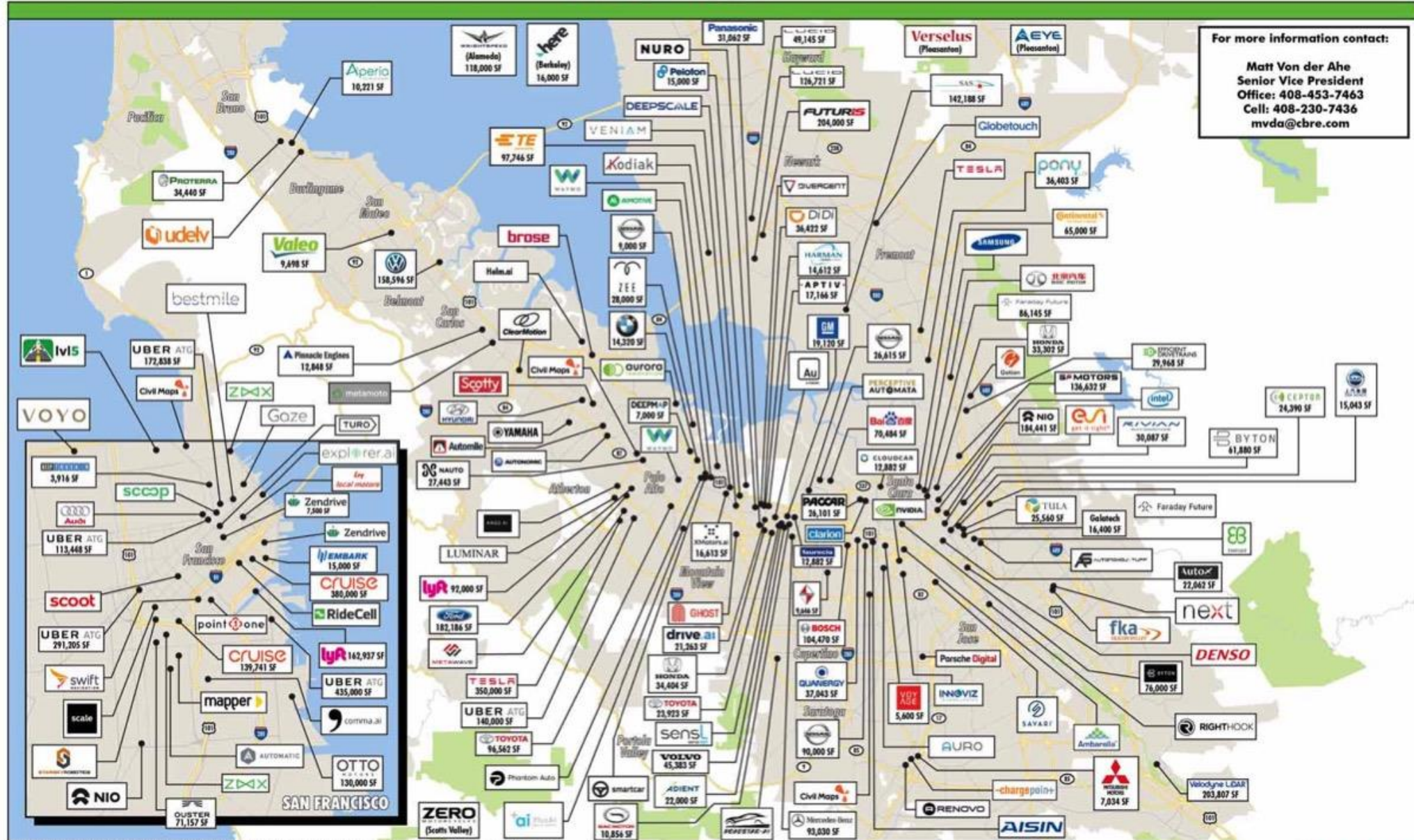
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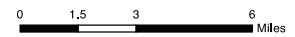
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SILICON VALLEY

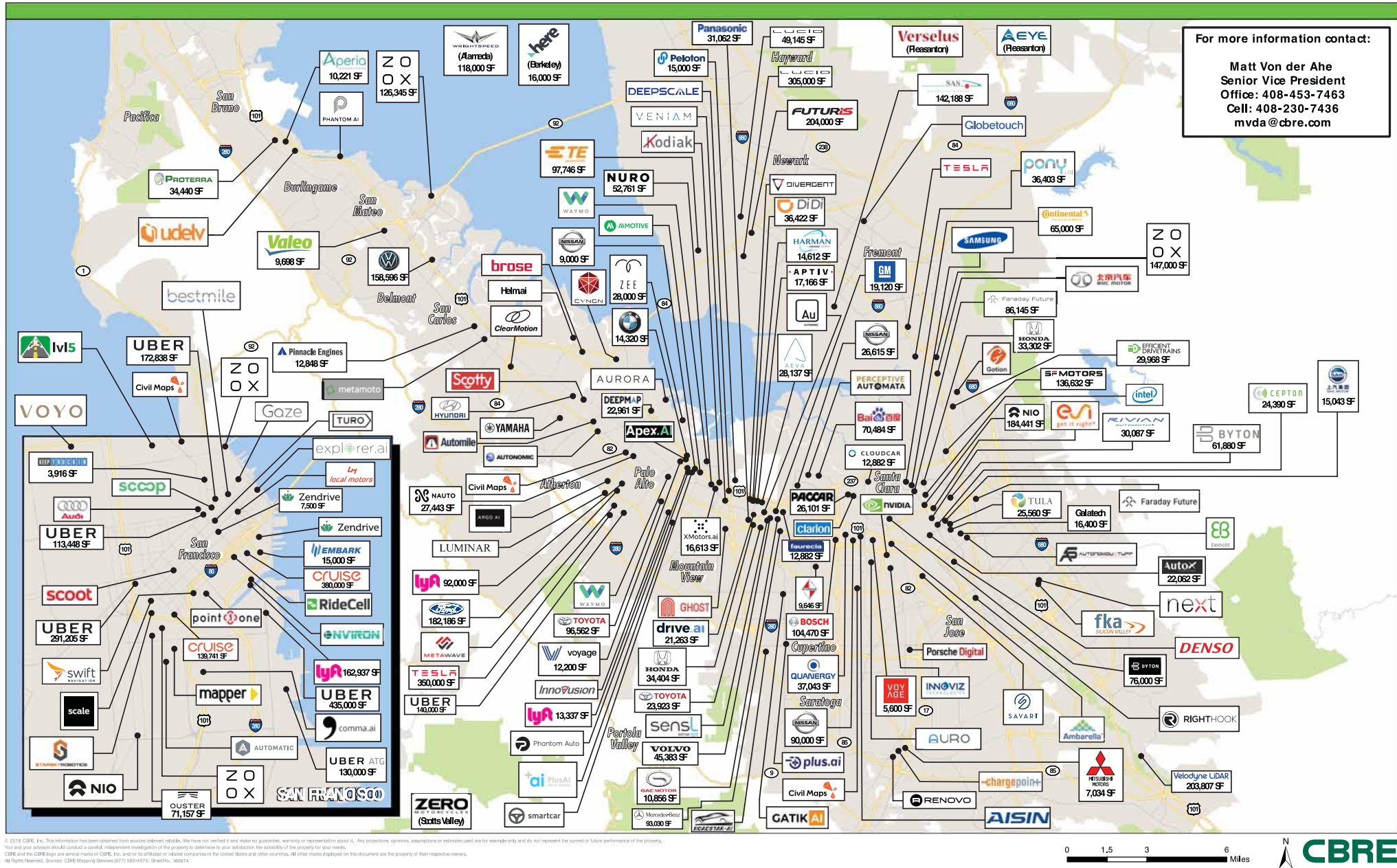


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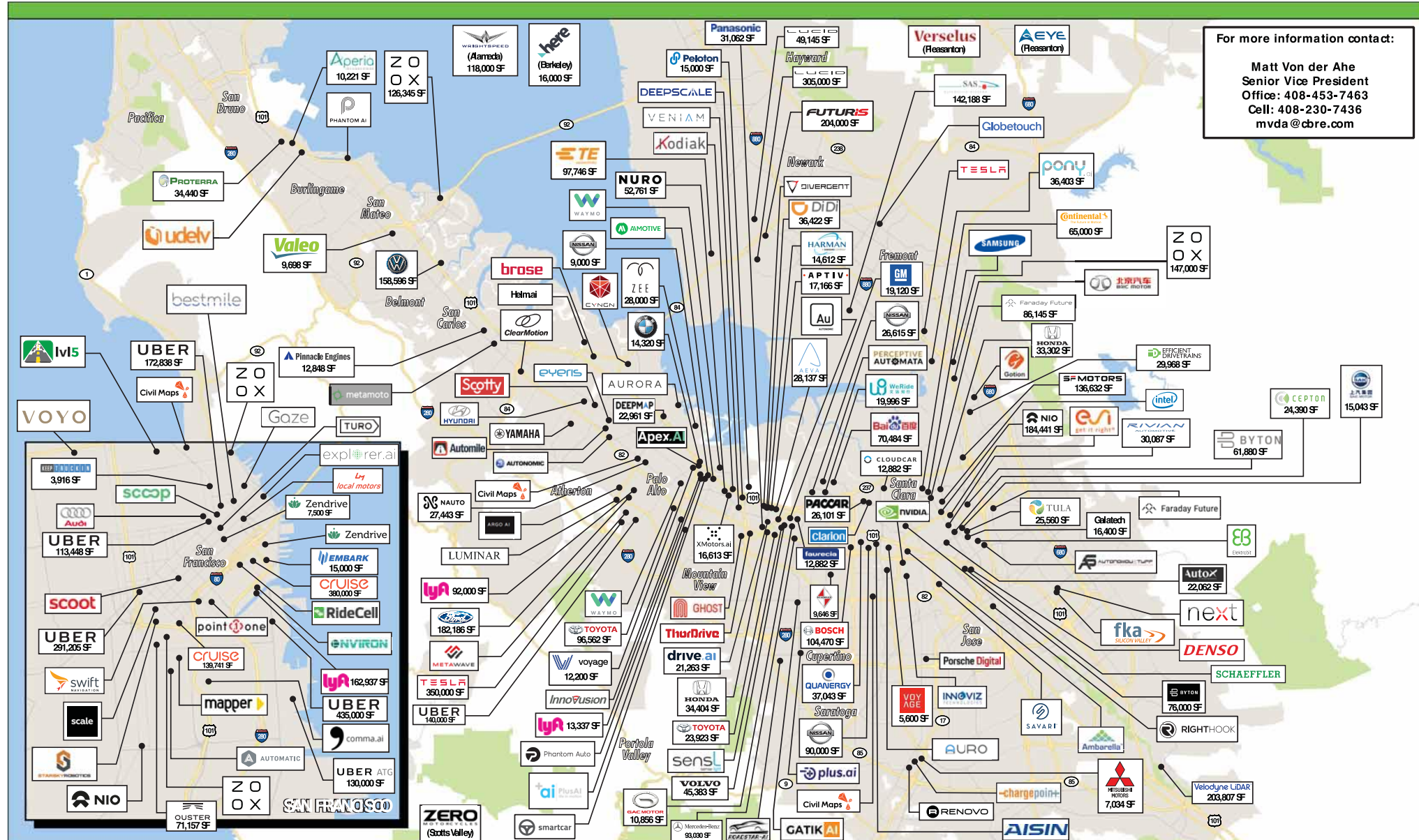
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SILICON VALLEY



AUTO LAB MAP JANUARY 2019 SILICON VALLEY



Drone Platforms



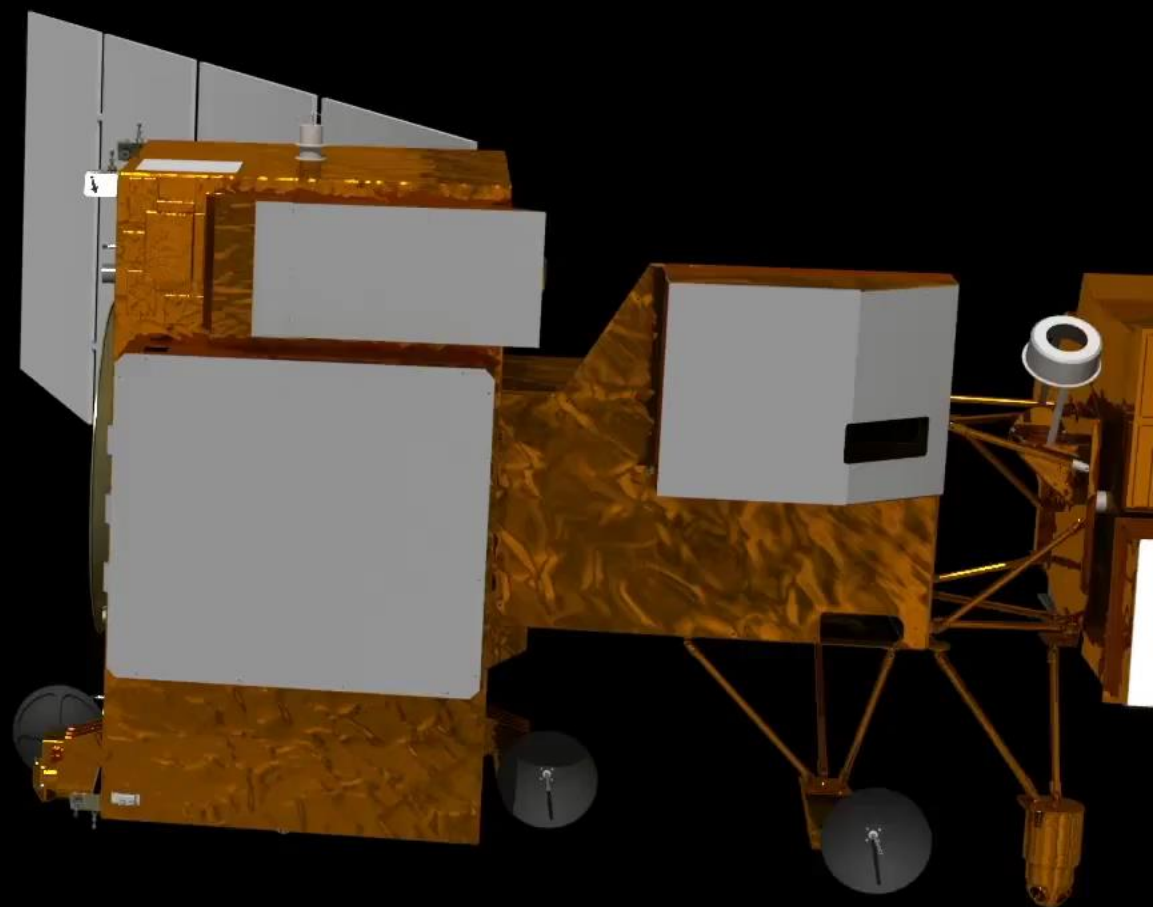
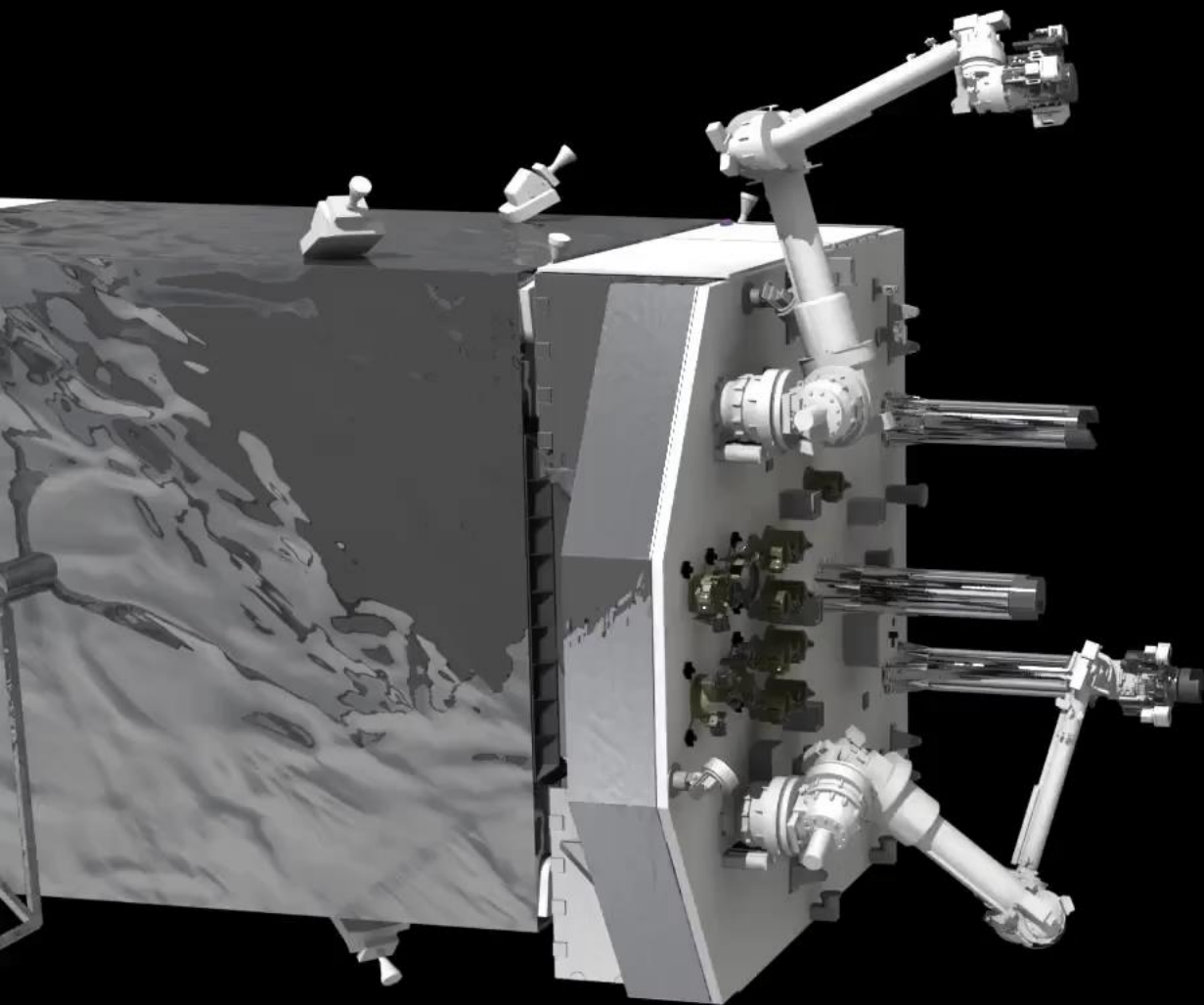
Test & Operation

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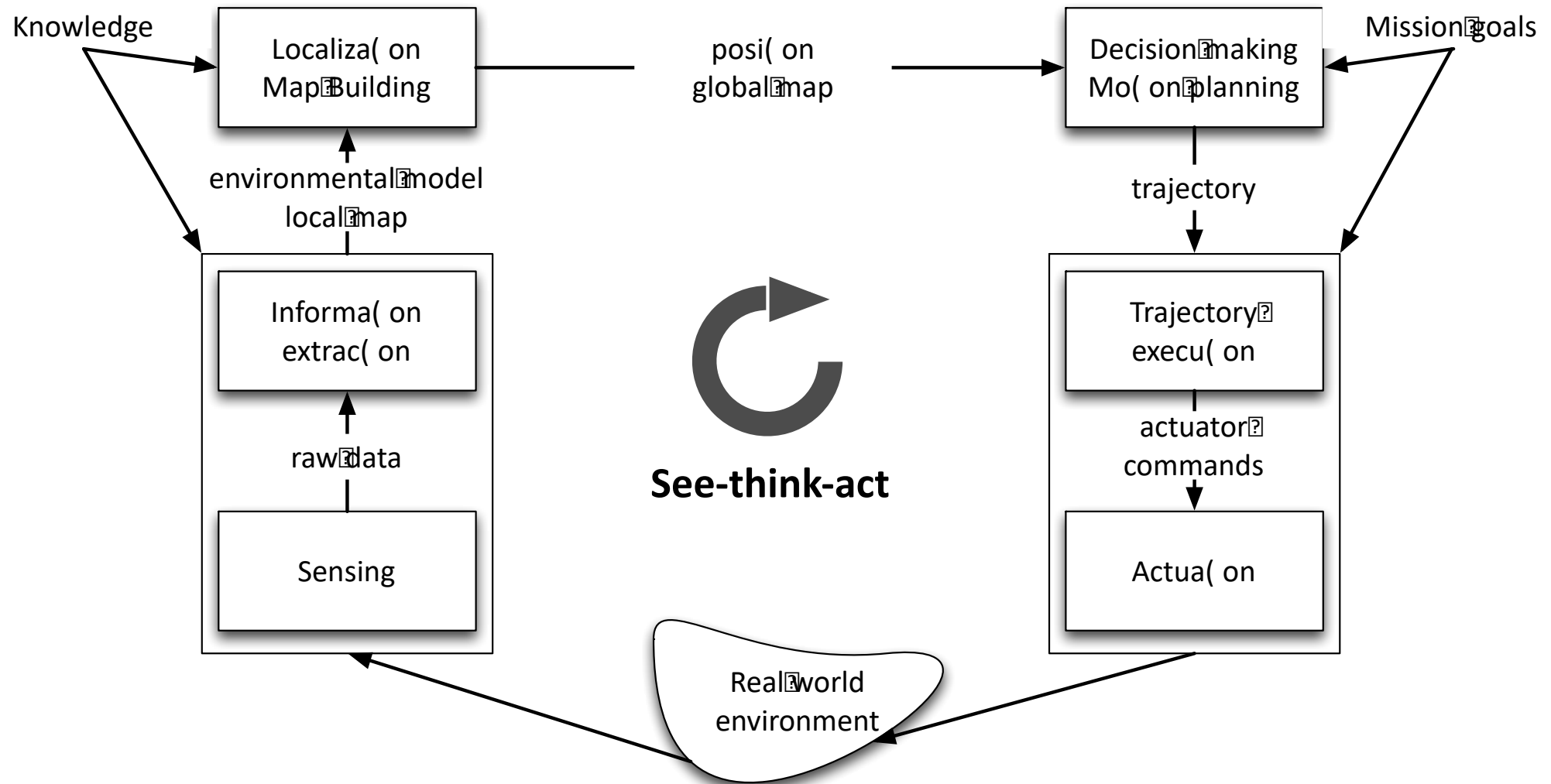




Course goals

- To learn the *theoretical*, *algorithmic*, and *implementation* aspects of main techniques for robot autonomy. Specifically, the student will
 1. Gain a fundamental knowledge of the “autonomy stack”
 2. Be able to apply such knowledge in applications using ROS

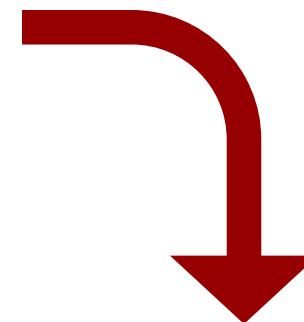
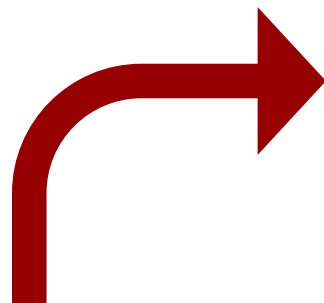
The see-think-act cycle



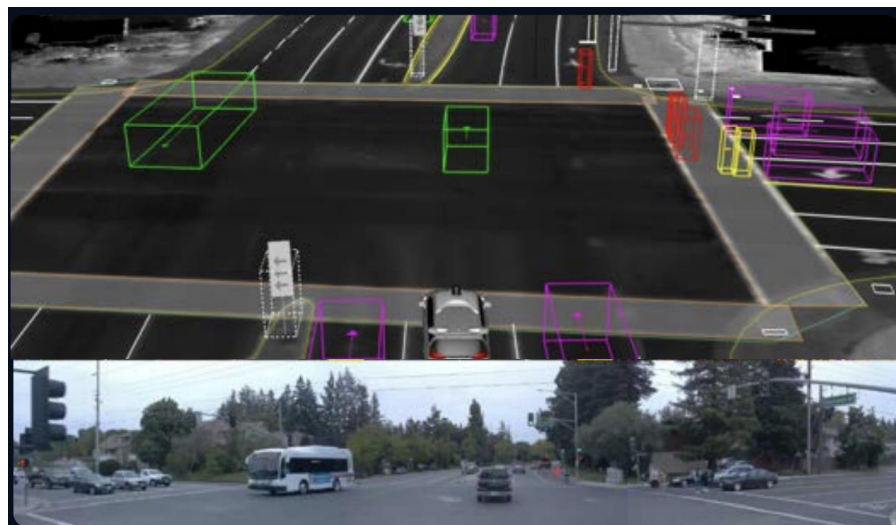
See-think-act cycle for AVs

Think

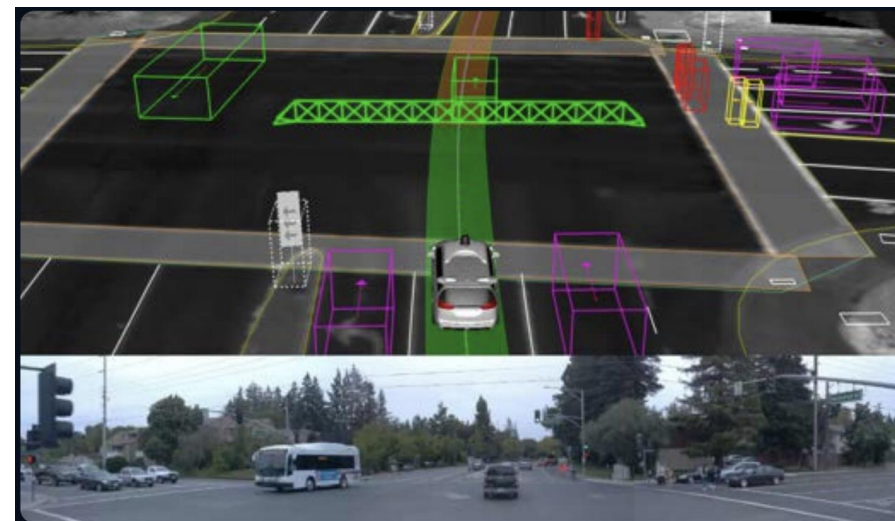
Note: other architectures are possible and subject of active R&D!



See



Act



Course structure

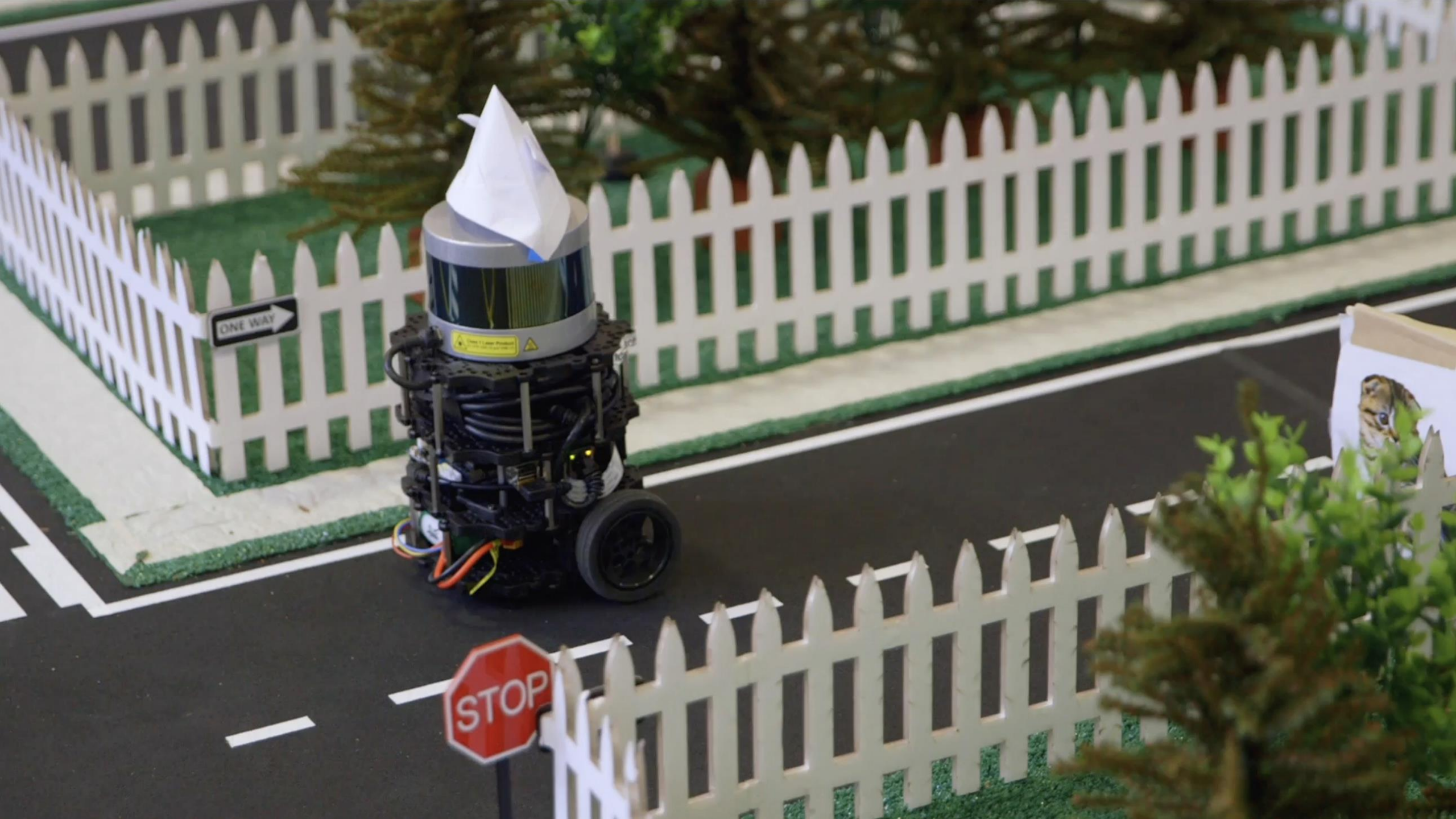
- Four main topics:
 1. Robot Operating System (week 1)
 2. Controls & Motion Planning (weeks 2-4) -- *act*
 3. Perception (weeks 5-8) -- *see*
 4. State Estimation, Localization & SLAM (weeks 8-11) -- *think*
- Extensive use of the Robot Operating System (ROS)
- Requirements
 - CS 106A or equivalent
 - CME 100 or equivalent (for calculus, linear algebra)
 - CME 102 or equivalent (for differential equations)
 - CME 106 or equivalent (for probability theory)
 - See also the [pre-knowledge quiz](#) on the course website

Logistics

- Lectures:
 - Tuesdays and Thursdays, 10:30am – 11:50am (CODAB60)
- Sections
 - 2-hour, once-a-week on Fridays
 - Hands-on exercises that complement the lecture material, build familiarity with ROS, and develop skills necessary for working with hardware
 - [Link](#) to the section sign-up sheet

Logistics

- Office hours:
 - Prof. Pavone: Tuesdays, 1:00 – 2:00pm (Durand 261), after class, and by appointment. Office hours will start during the week of Sep 29.
 - Course assistants: Wednesdays, 4:30 – 6:30pm (Durand 270), and Thursdays, 4:30 – 6:30pm (Durand 270)
- Course websites:
 - For course content: https://stanfordasl.github.io/PoRA-I/aa174a_aut2526/
 - For course announcements: <https://canvas.stanford.edu/courses/214652/>
 - For course-related questions: <https://edstem.org/us/courses/87236/discussion/>
 - For homework submissions: <https://www.gradescope.com/courses/1137718>
 - To contact the AA174A staff: aa174a-aut2526-staff@lists.stanford.edu



Team

Instructor



Marco Pavone
Associate Professor AA,
and CS/EE (by courtesy)

Collaborators

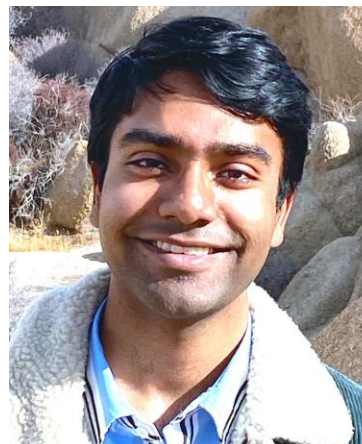
- Daniel Watzenig

Labs



CAs

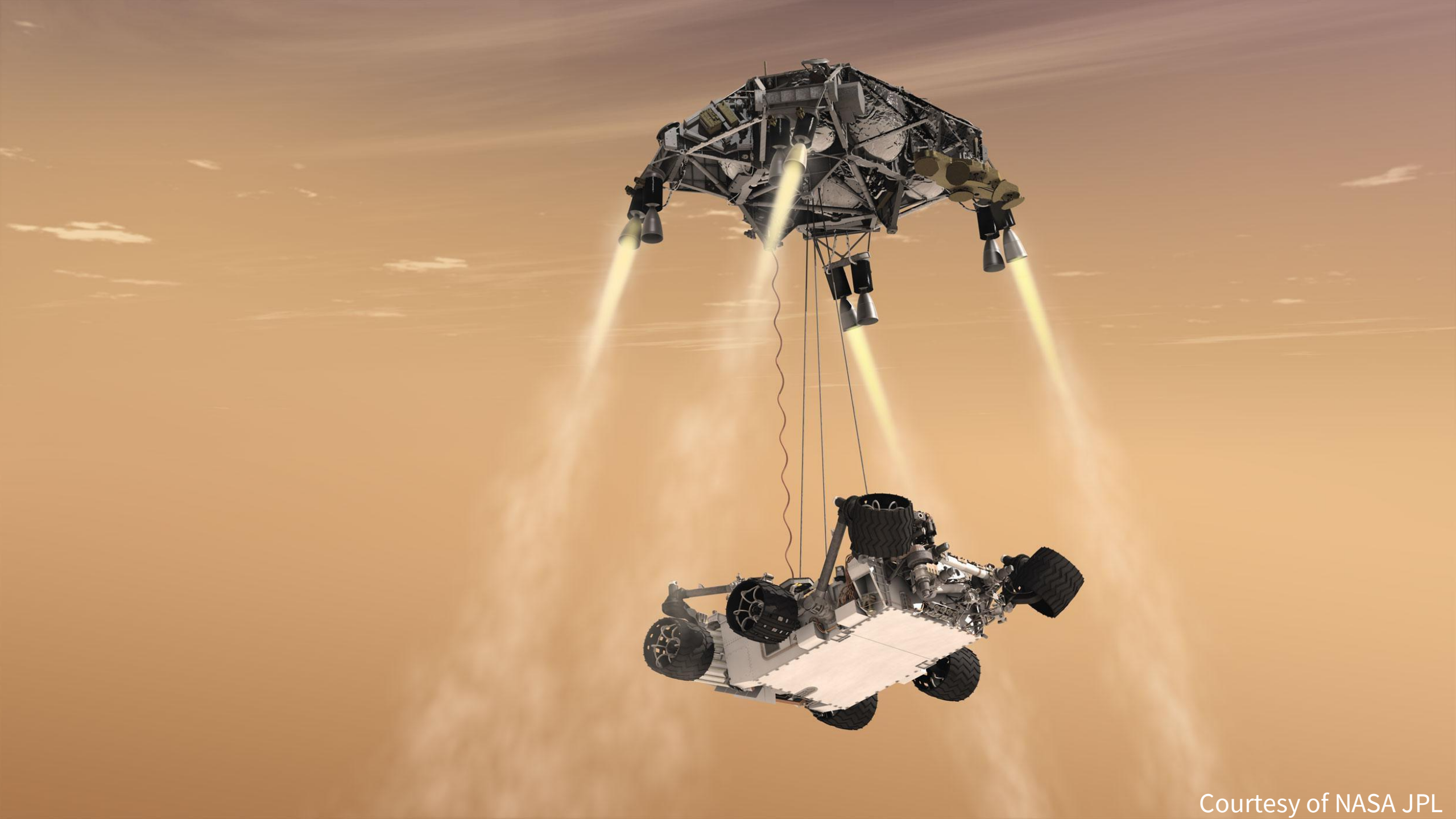
Milan Ganai



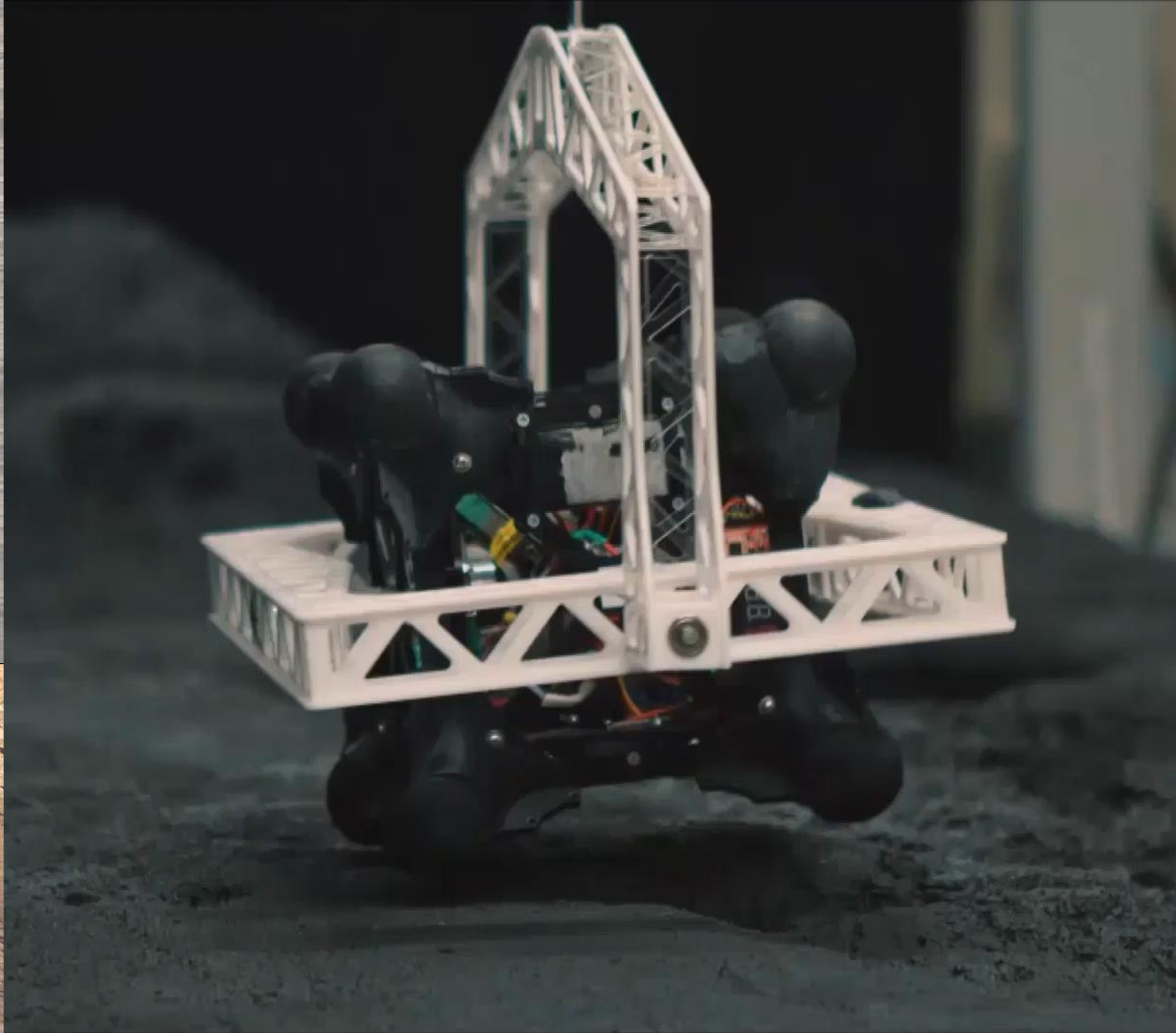
Yujung Jenny Kim

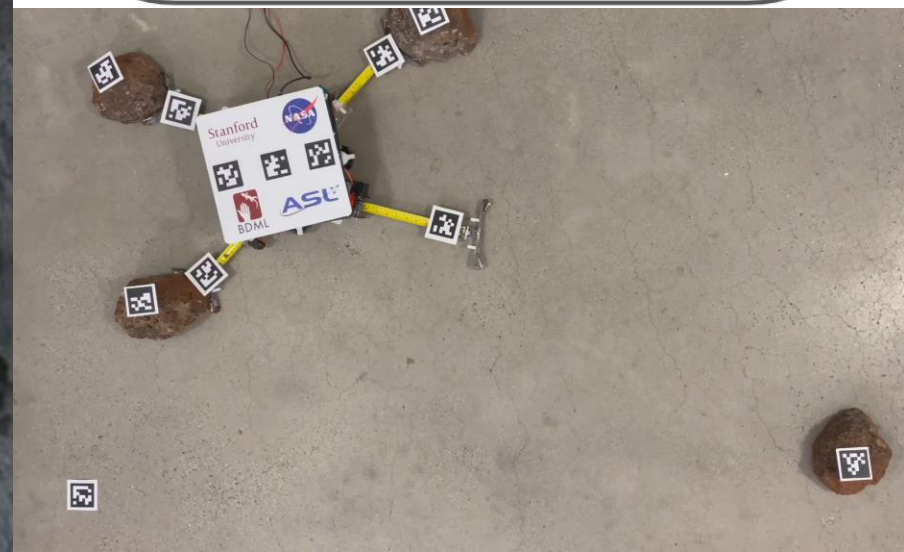
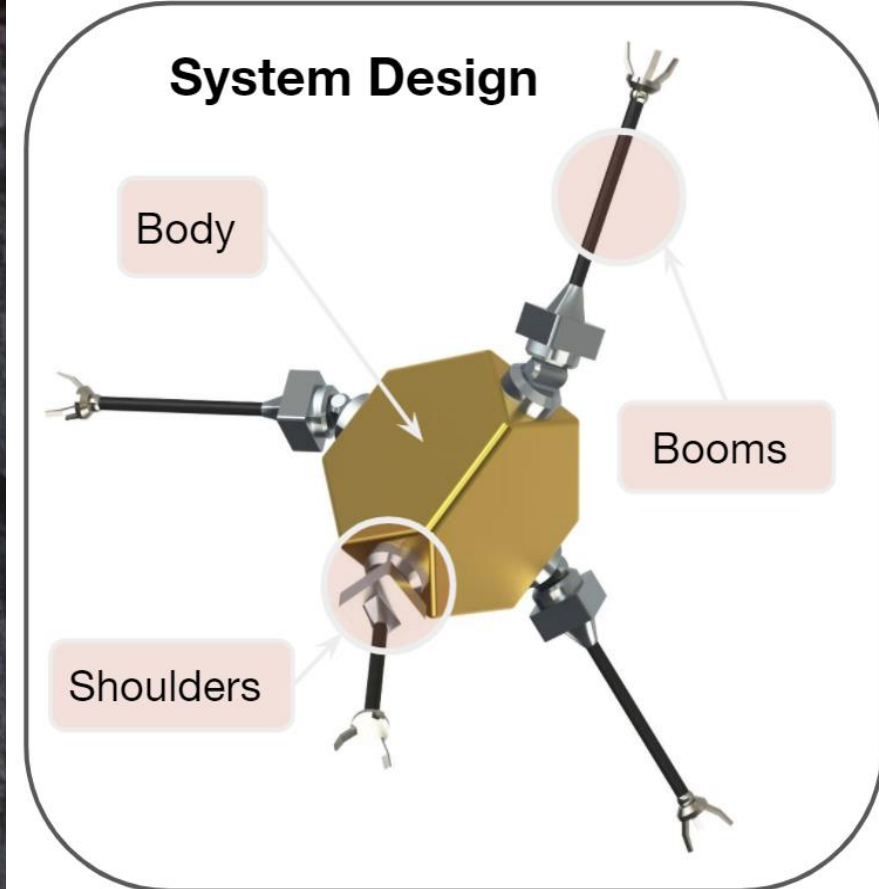


Jacky Kwok



Courtesy of NASA JPL









Center for Automotive Research at Stanford



<https://cars.stanford.edu/>

Autonomous Vehicle Research at NVIDIA



<https://research.nvidia.com/labs/avg>

Schedule

Date	Topic	Assignments
09/23	Course overview, intro to robotic systems and ROS	
09/25	Fundamentals of ROS & vectorized computation in Python	
09/26	★ Section 1 – UNIX, Git, and Python	HW1 out
09/30	State space dynamics – definitions and modeling	
10/02	State space dynamics – computation and simulation	
10/03	★ Section 2 – ROS, workspaces, packages, nodes	
10/07	Trajectory optimization	HW2 out
10/09	Trajectory tracking	
10/10	★ Section 3 – Launch files & RVIZ	HW1 due
10/14	Motion planning I: graph search algorithms	
10/16	Motion planning II: sampling-based methods	
10/17	★ Section 4 – Controller gain tuning in hardware	HW2 due
10/21	Robotic sensors & introduction to computer vision	HW3 out
10/23	Camera models and camera calibration	
10/24	★ Section 5 – Running a point-to-point navigator	
10/28	Image processing, feature detection, & feature description	
10/30	Information extraction	
10/31	★ Section 5 cont. & Section 6 head start	HW3 due, HW4 (part 1) out

11/04	No Lecture – Democracy Day	
11/06	<i>In-class midterm</i>	
11/07	★ No Section	
11/11	Deep learning for computer vision	
11/13	Intro to state estimation & filtering theory	
11/14	★ Section 6 – Object detection	HW4 (part 2) out
11/18	Parametric filtering (KF and EKF)	HW4 (part 1) due
11/20	Markov localization and EKF-localization	
11/21	★ Section 7 – Frontier exploration	
11/25		
11/27	<i>Thanksgiving</i>	
11/28		
12/02	Multi-sensor perception & sensor fusion	HW4 (part 2) due
12/04	Simultaneous localization and mapping (SLAM)	
12/05	★ Section 7 cont.	

[Turtlebot3](#)



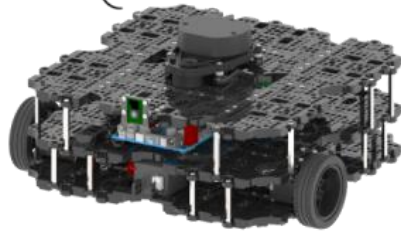
TurtleBot3
Burger



TurtleBot3
Waffle



TurtleBot3
Waffle Pi



[Velodyne LiDAR](#)

- Imagine you have a robot with sensors, motors, and AI.
- How do you make all the pieces talk to each other - reliably, in real time, and in a way others can build on?
- That's where ROS comes in!

Quadrotor



Manipulation



TurtleBot



The Challenge of Building Robots

- Robots are complex systems
 - Hardware
 - Sensors (IMU, velocity, LiDAR, Camera, Microphone, ...)
 - Actuators (wheels, joints, grippers, valves, ...)
 - Structures (Links, frame, ...)
 - Software
 - Control
 - Trajectory planning
 - Object detection
 - Localization
 - ...

What would we do without ROS?

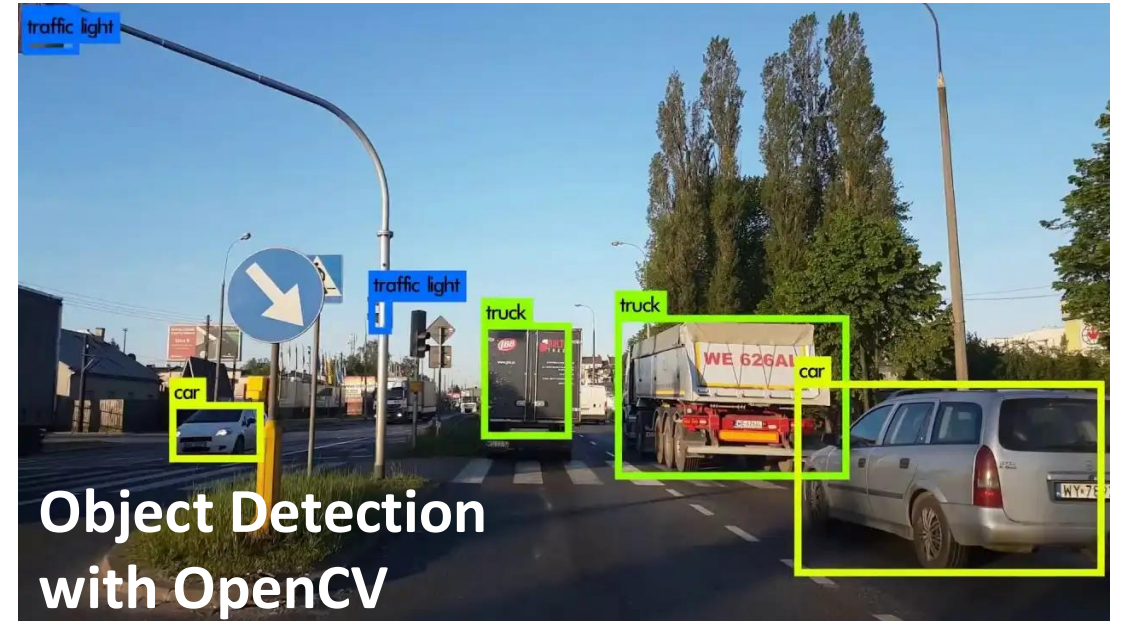
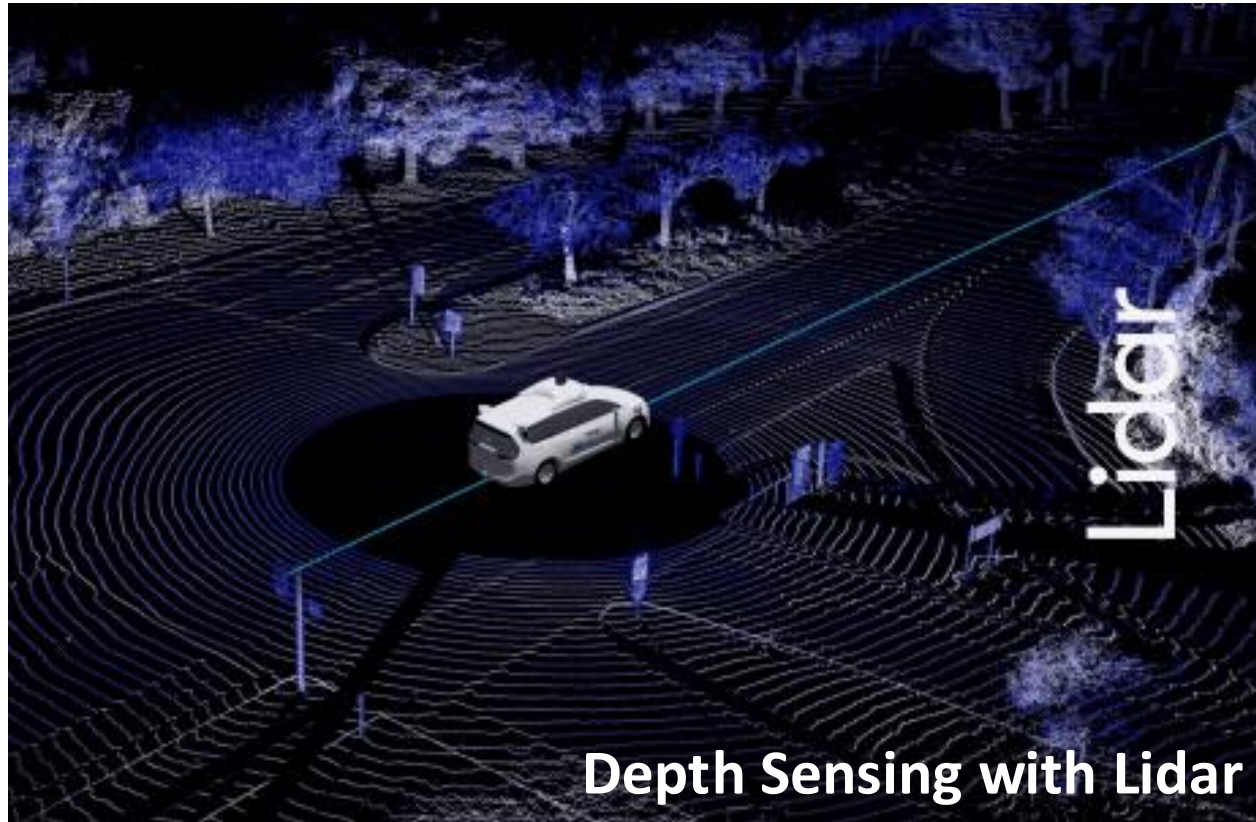
- Write custom code to connect sensors and actuators.
- Reinvent tools for visualization, debugging, and simulation.
- Struggle with versioning, testing, and sharing code.

What is ROS?

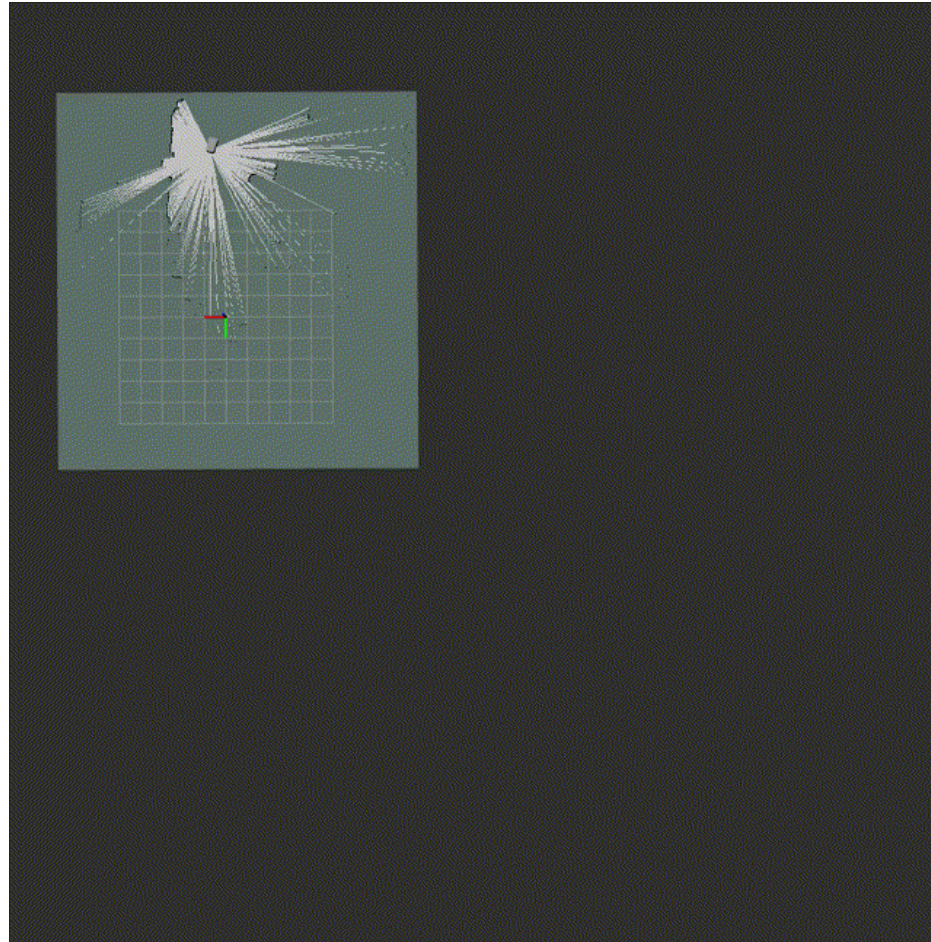


- Middleware (Not an operating system)
- ROS provides:
 - Launching different components
 - Communication between components → Publish/subscribe messaging system.
 - Reusable components → Packages for navigation, vision, motion planning
 - Tools for visualization & debugging → RViz, Gazebo, rqt.
 - Community & ecosystem → Thousands of open-source packages.

Perception



Localization and Mapping



Navigation



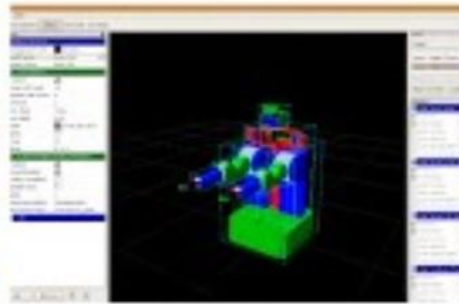
Manipulation



Simulation and Visualization



Gazebo



Rviz



RQT

ROS2 Simulation and Visualization Tools

Multidisciplinary Collaboration

- All disciplines come together
 - Mechanical engineers: Design the robot body and actuators
 - Electrical engineers: Design actuators, sensors, and control
 - Computer scientists / AI researchers: Implement perception and planning
 - Design experts: Build human-robot interfaces via ROS APIs.

Robot Operating System – History

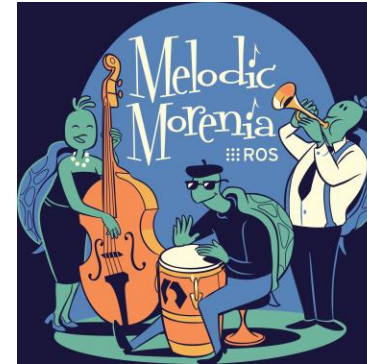
ROS 1



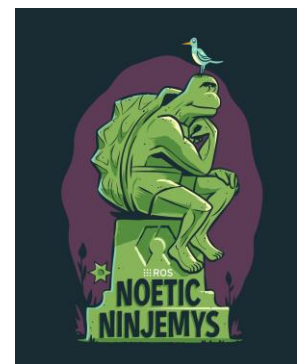
2014 - 2019



2016 - 2021



2018 - 2023



2020 - 2025

ROS 2



2019 - 2021



2020 - 2023



2022 - 2027



2017 - Present

Key takeaways



- ROS is a **framework** that connects all parts of a robot.
- It saves time, encourages collaboration, and accelerates innovation.
- ROS brings robot autonomy to reality.
- The ROS ecosystem is vast and growing.
- Next lecture: *How ROS actually works* — topics, nodes, packages, ...



Backup

Robot Operating System – History

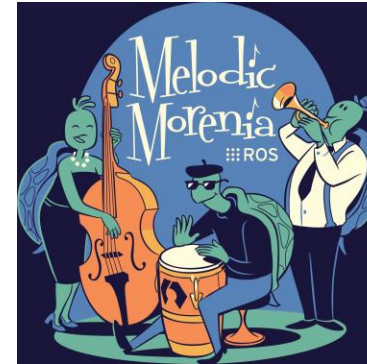
ROS 1



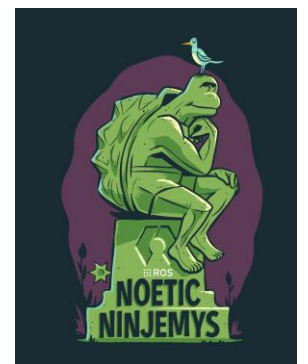
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Robot Operating System – History

ROS 1

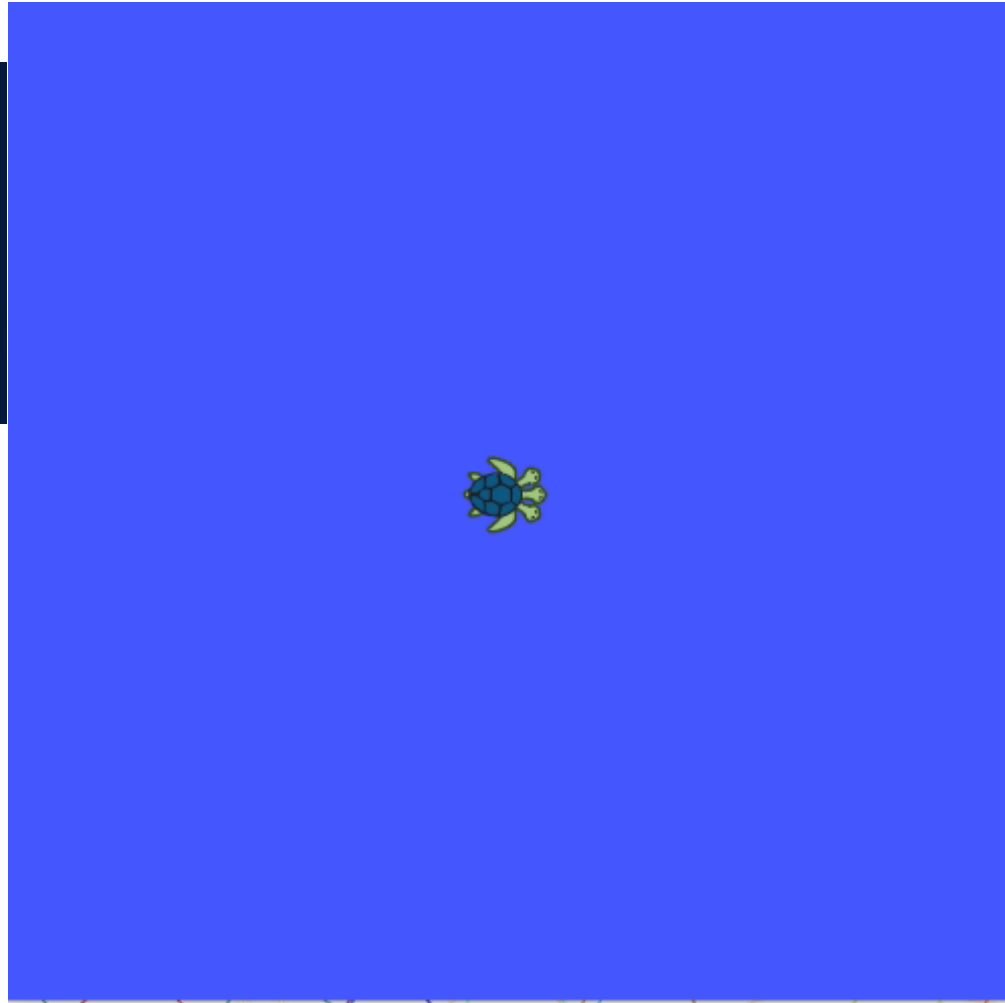


2014 - 2019

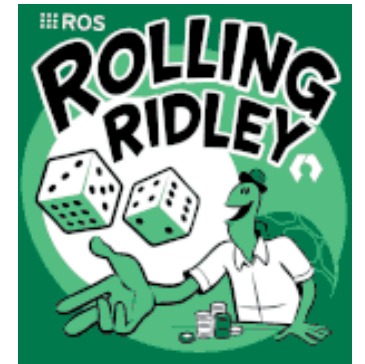
ROS 2



2019 - 2021



2020 - 2025



2017 - Present

Robot Operating System – History

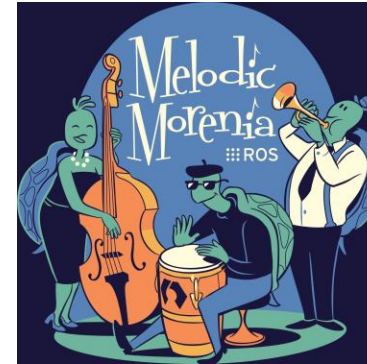
ROS 1



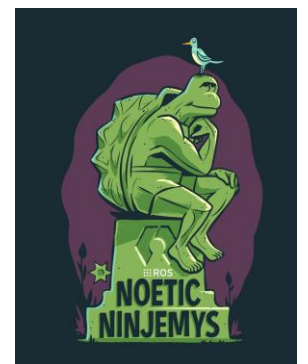
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ROS 2



2019 - 2021



2020 - 2023



2022 - 2027



2017 - Present

Why is ROS popular in academia?

- Not reinventing the wheel is generally good
- Robotics is hard! It's great to offload some of the work to smart people
- ROS is now 12 years old and still going strong



Robot Operating System – Overview

- Community & Ecosystem
 - Hardware Drivers
 - Software
- Tooling
 - Visualization
 - Debugging
- Asynchronous Programming Model

Robot Operating System – ROS2

- Community & Ecosystem
 - Hardware Drivers
 - Software

Robot Operating System – ROS2

- Community & Ecosystem
 - Hardware Drivers
 - Software



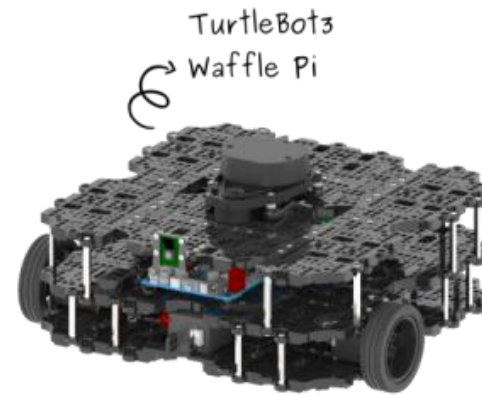
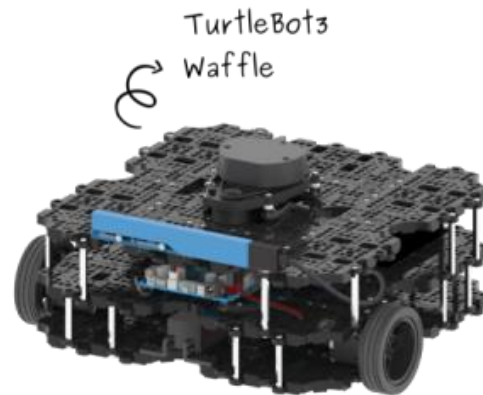
TURTLEBOT3



[Crazyflie](#)



[Joysticks](#)



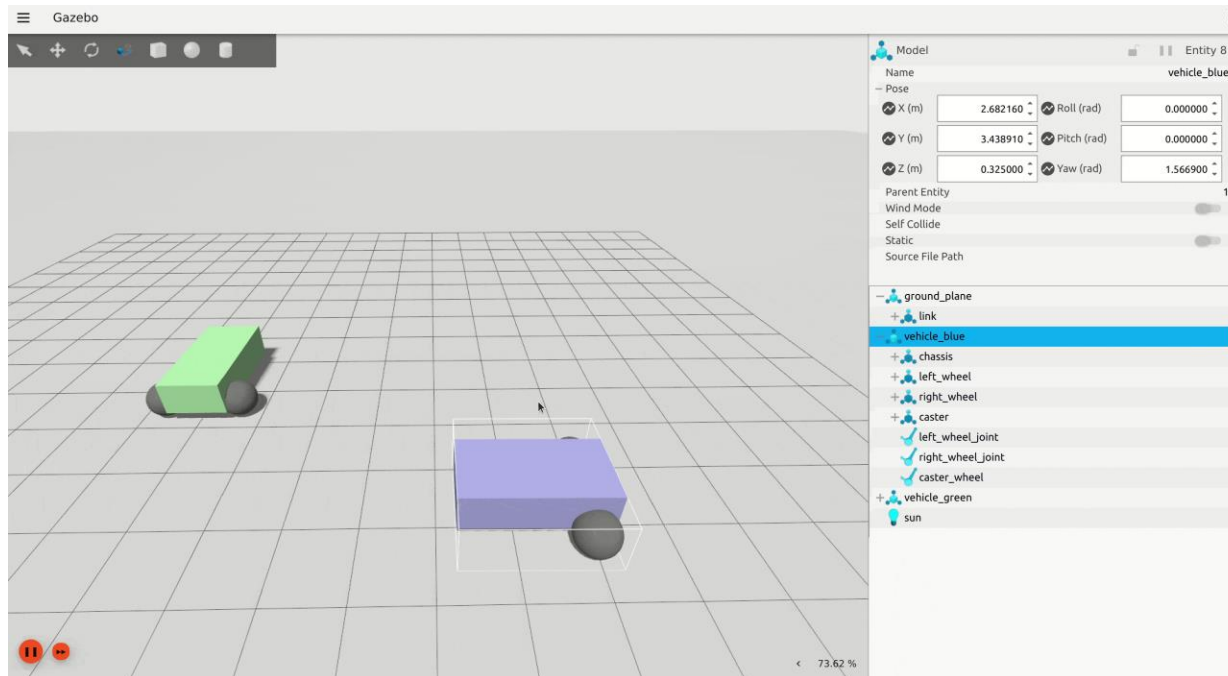
[Turtlebot3](#)



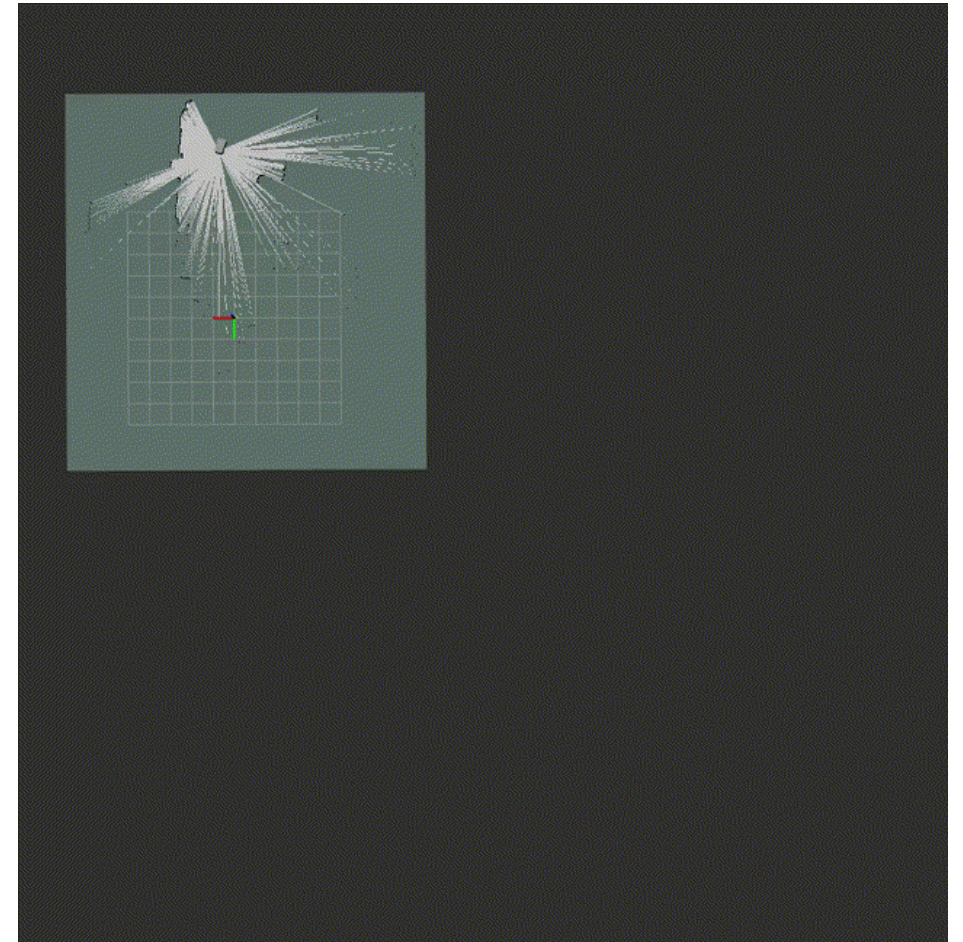
[Velodyne LiDAR](#)

Robot Operating System – ROS2

- Community & Ecosystem
 - Hardware Drivers
 - Software



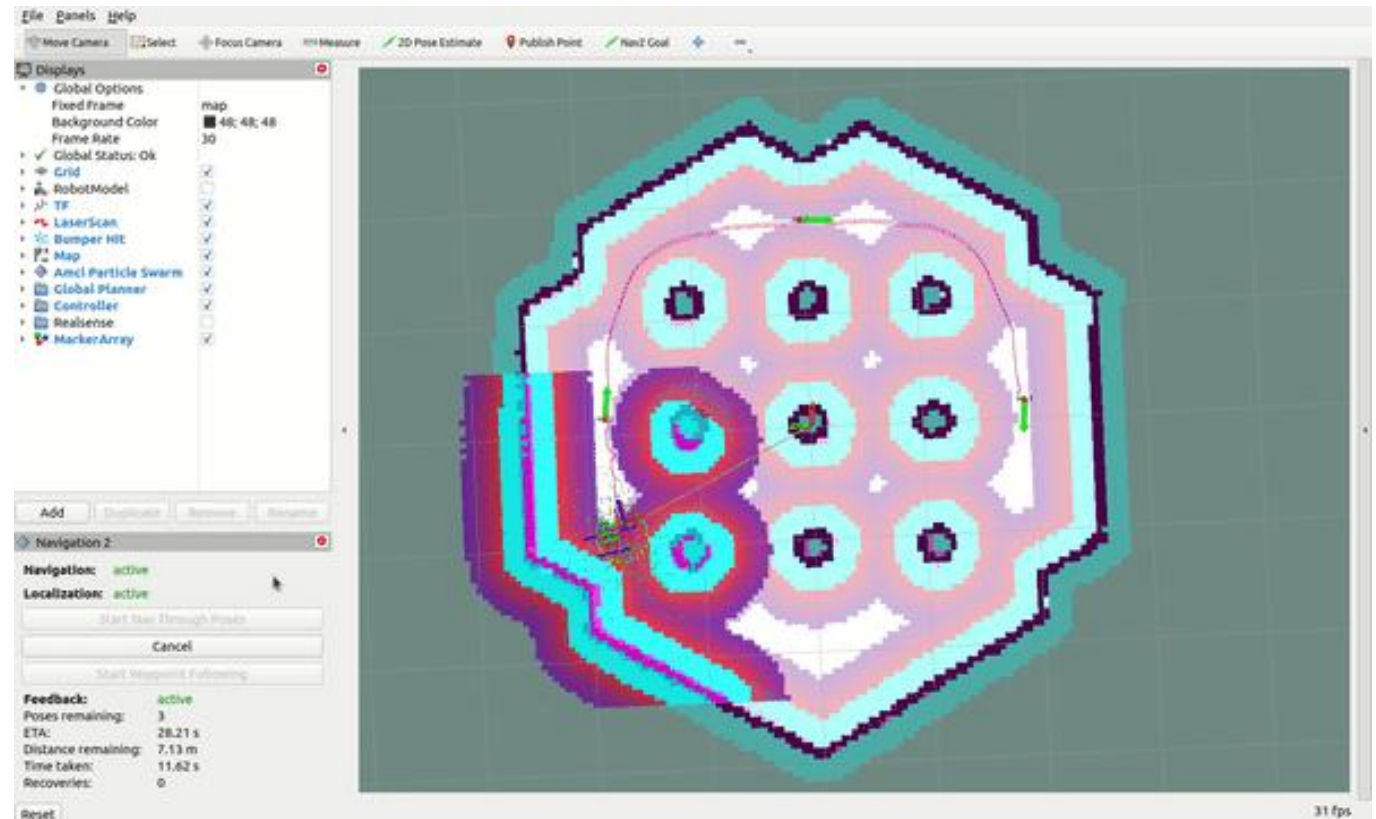
[Gazebo Sim](#)



[SLAM Toolbox](#)

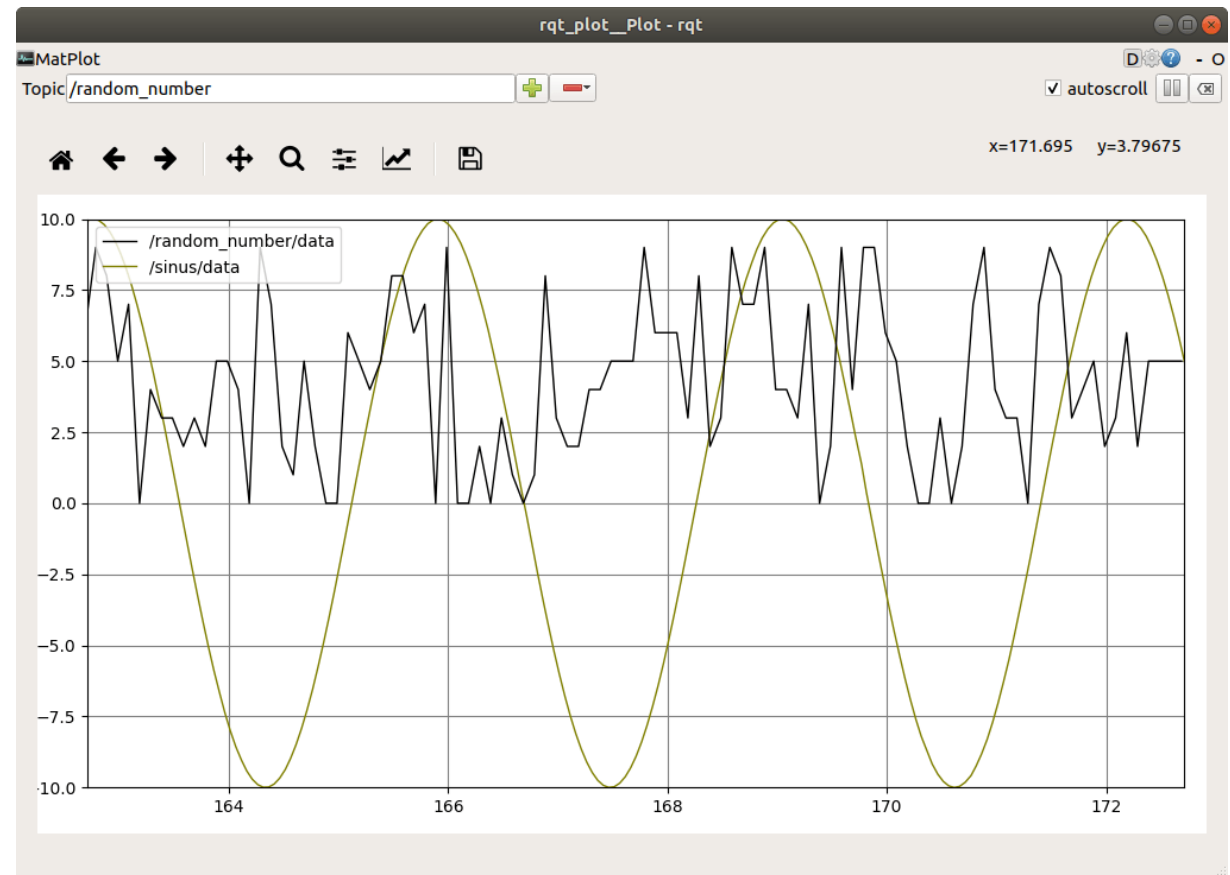
Robot Operating System – ROS2

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See-think-act

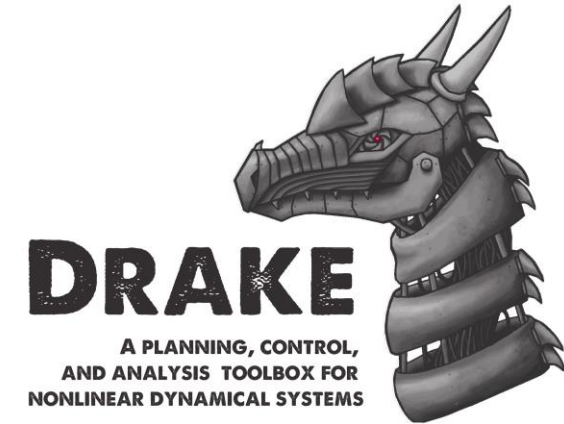
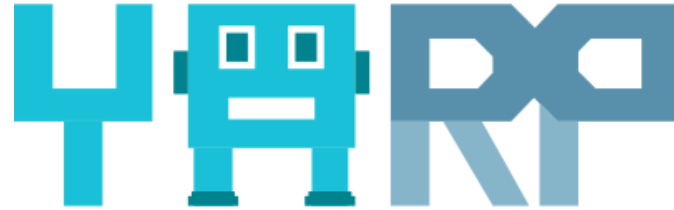
Robot Operating System – ROS2

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- Asynchronous Programming Model

Let's write some code!

Are there “Alternatives” to ROS?

- LCM
- Drake
- Player
- YARP
- Orocos
- MRPT
- And many others!



Next time: fundamentals of ROS



Robot Operating System