

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

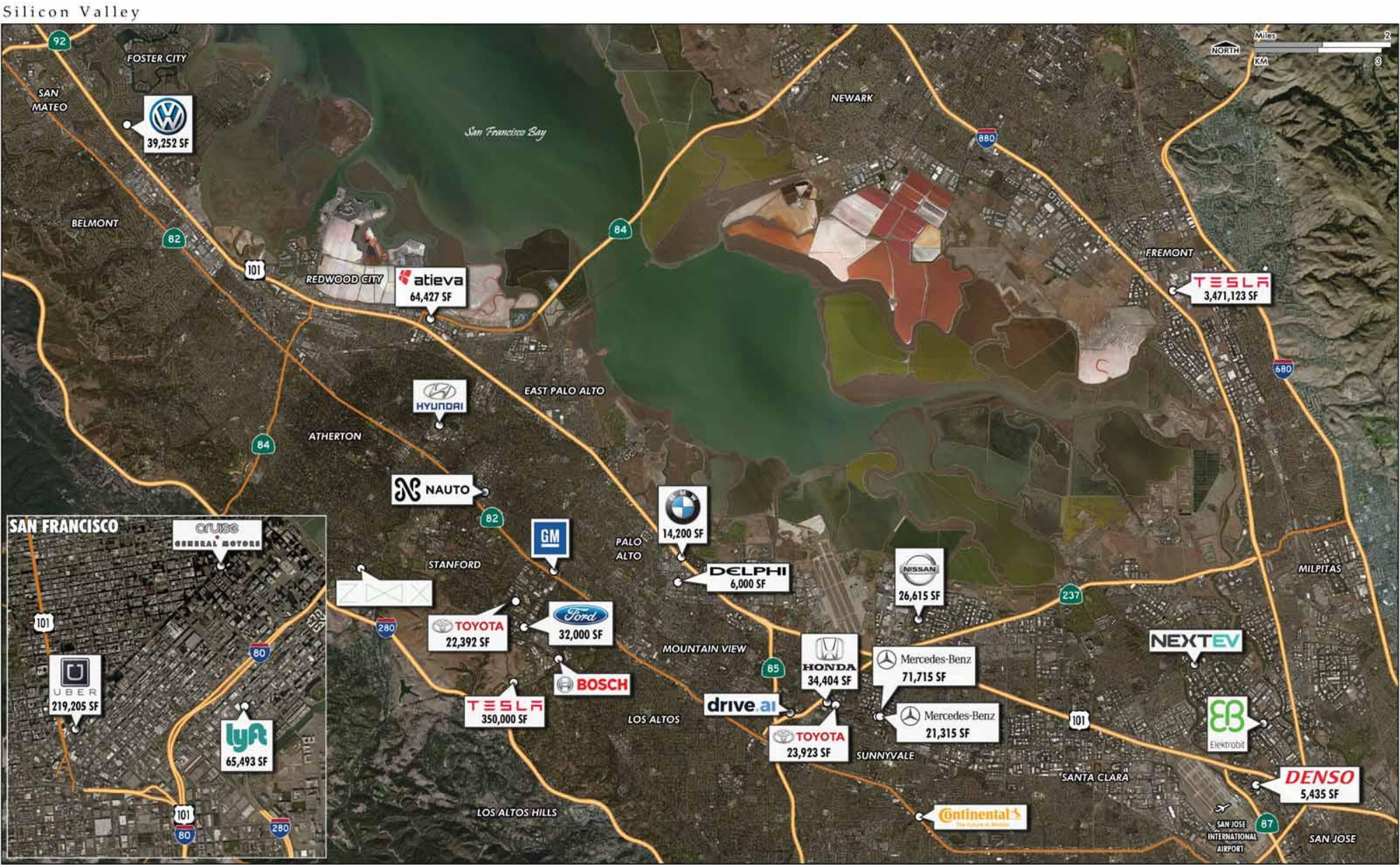


Zipline

Silicon Valley

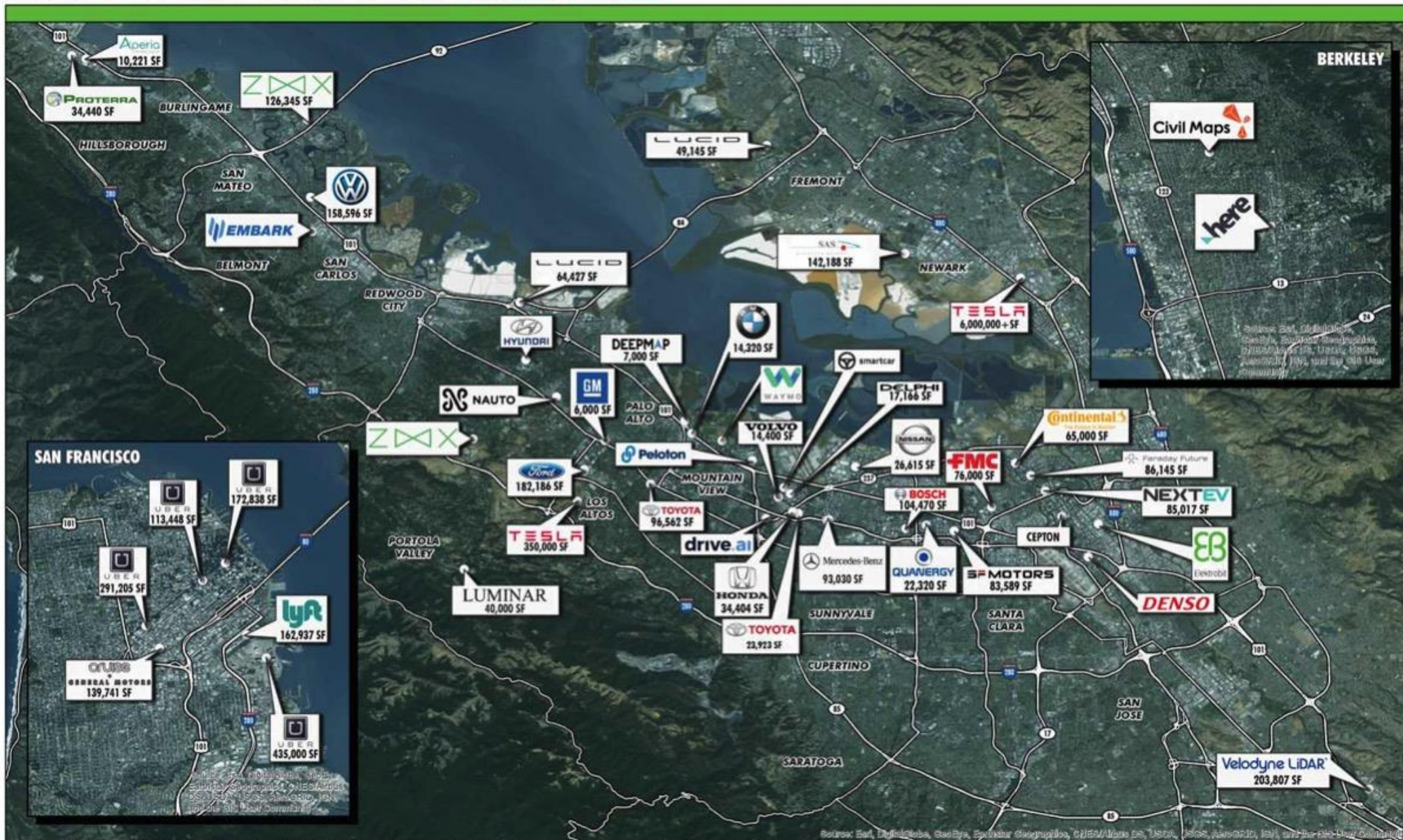


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AUTO LAB MAP APRIL 2017 SILICON VALLEY

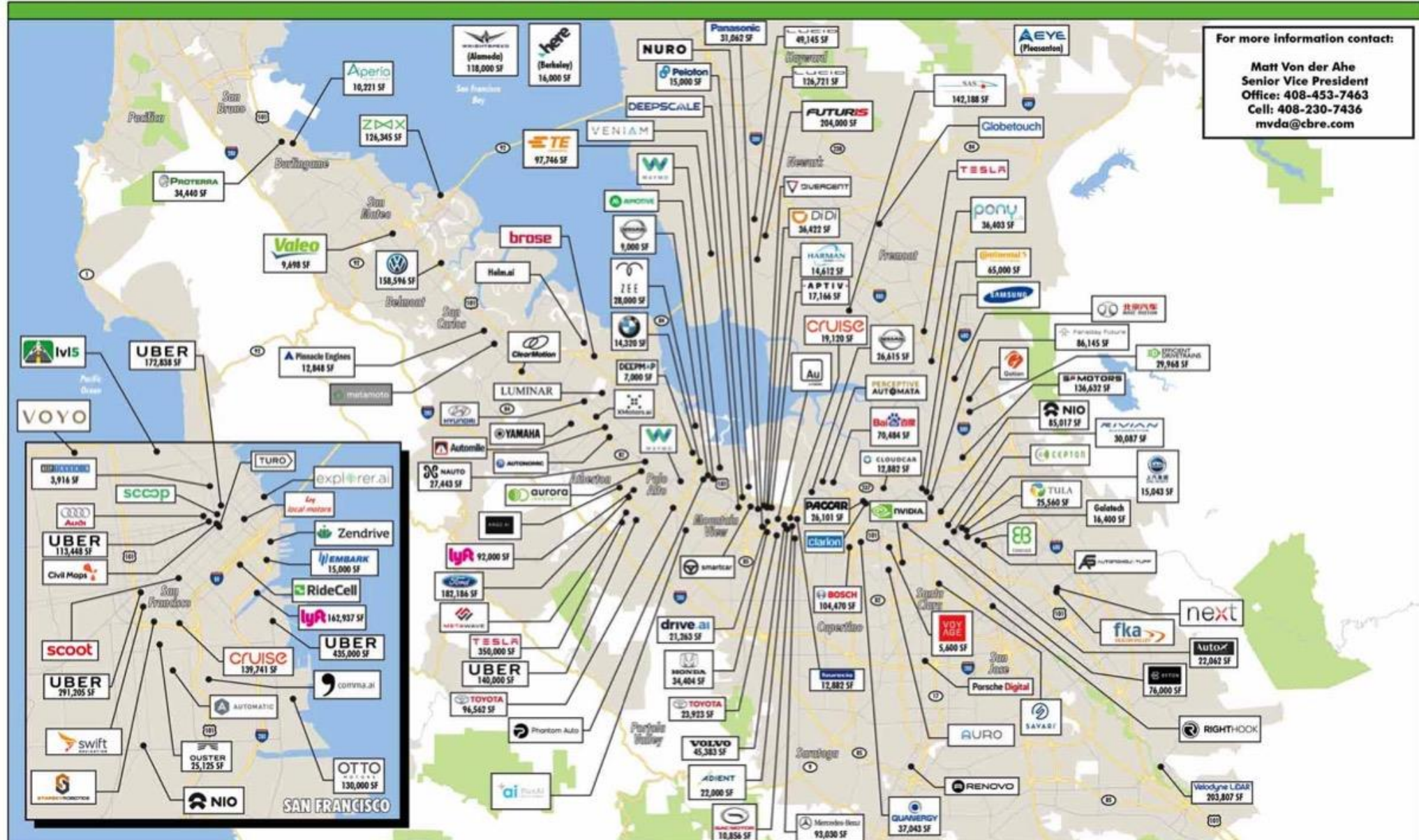


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AUTO LAB MAP MARCH 2018 SILICON VALLEY



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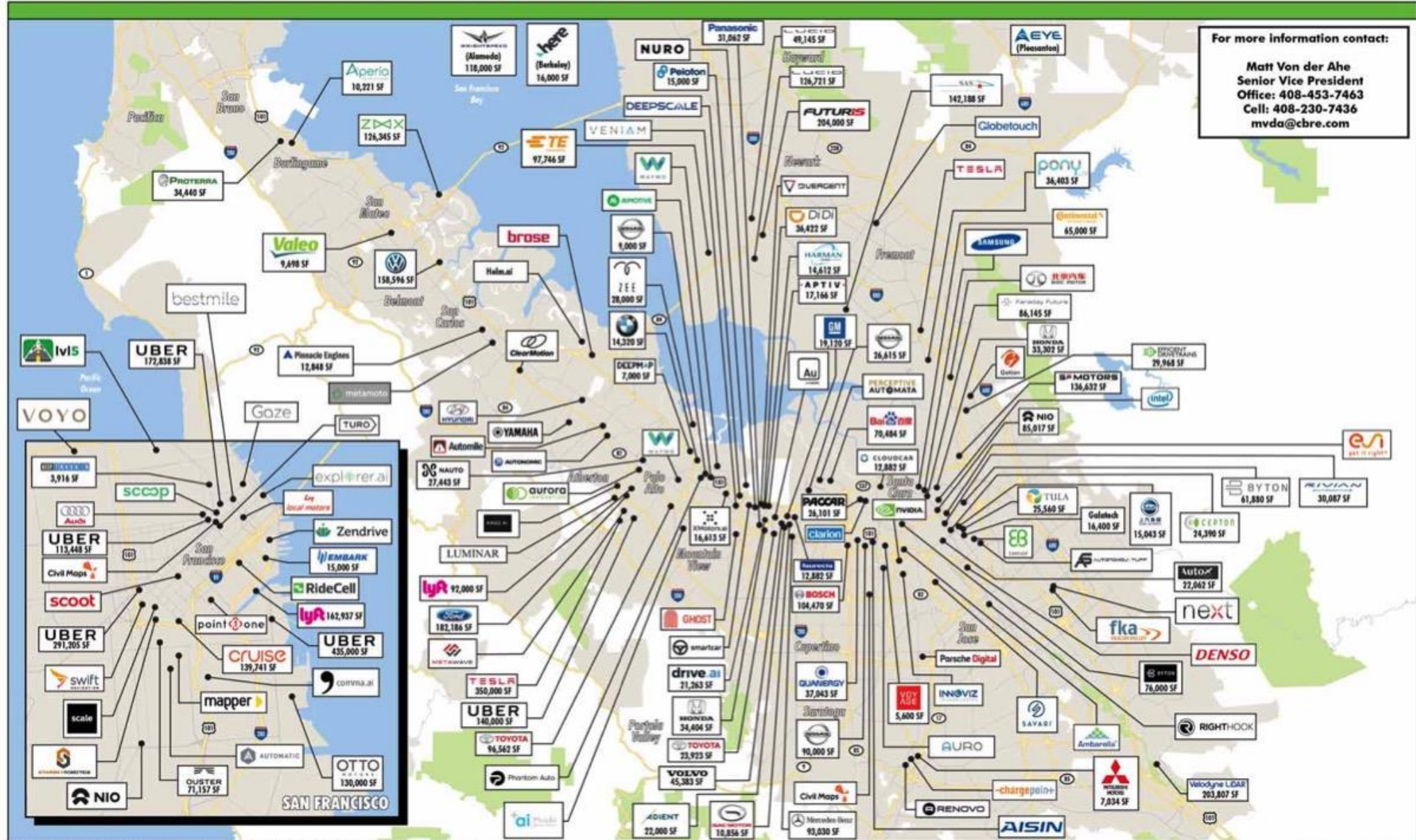
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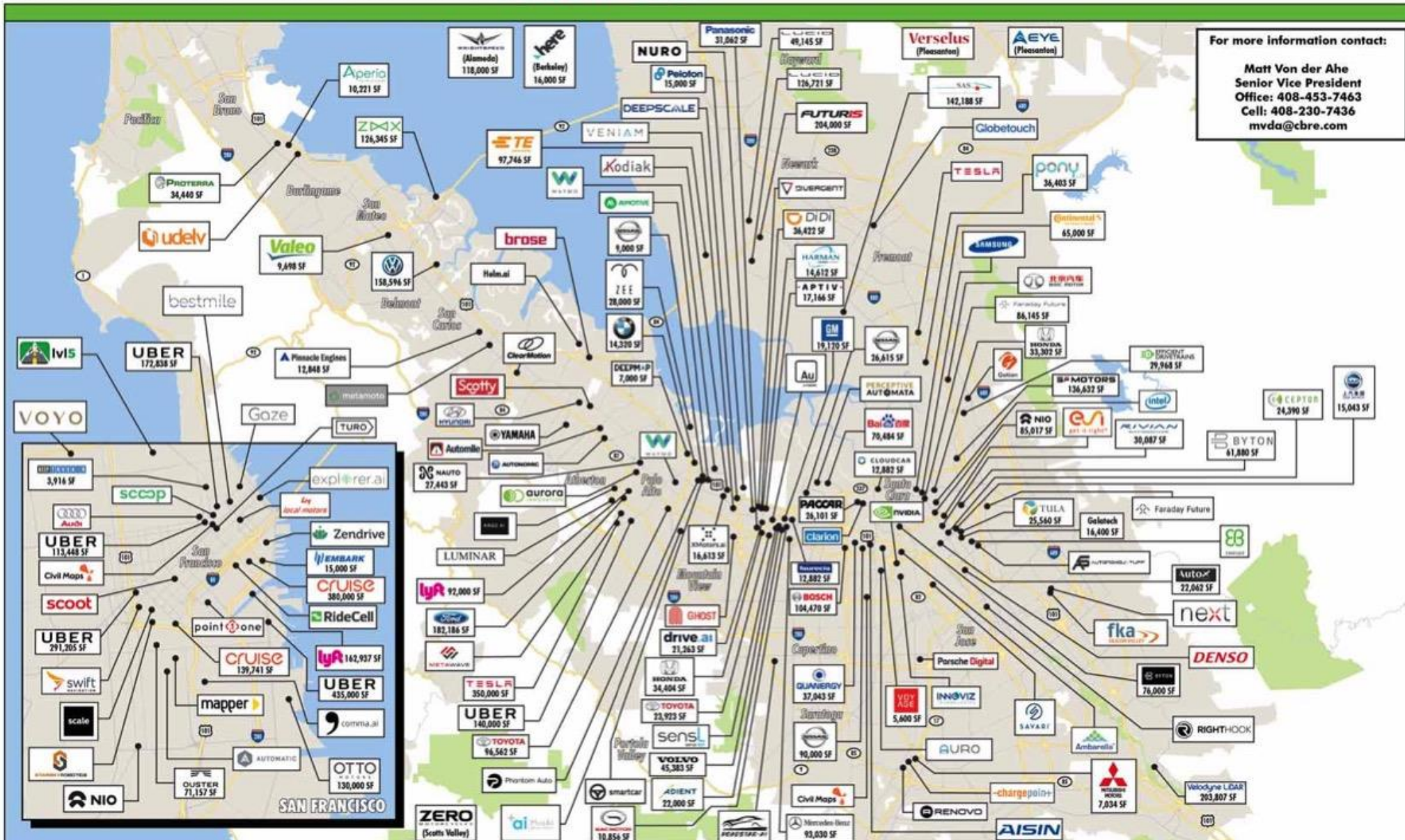
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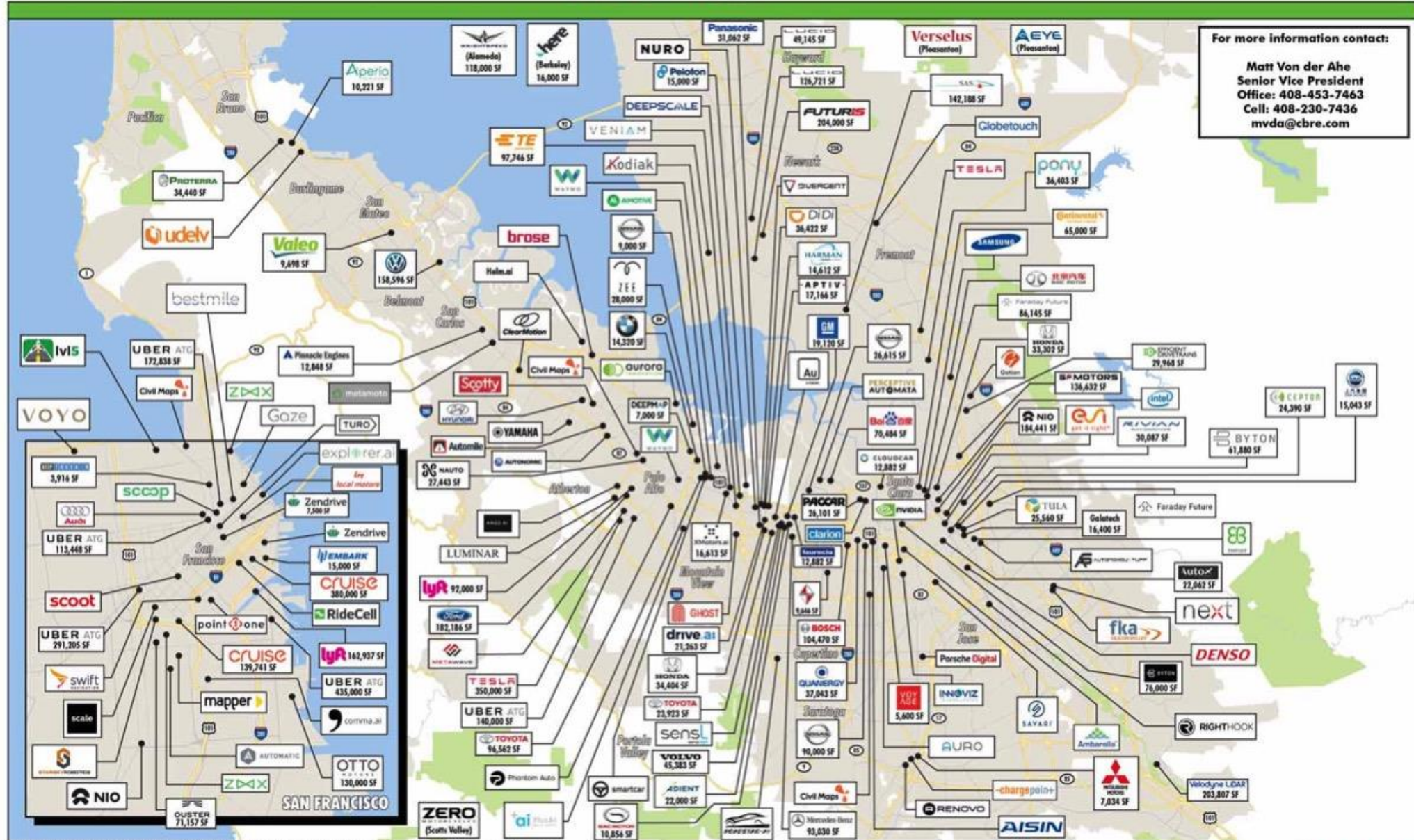
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SILICON VALLEY

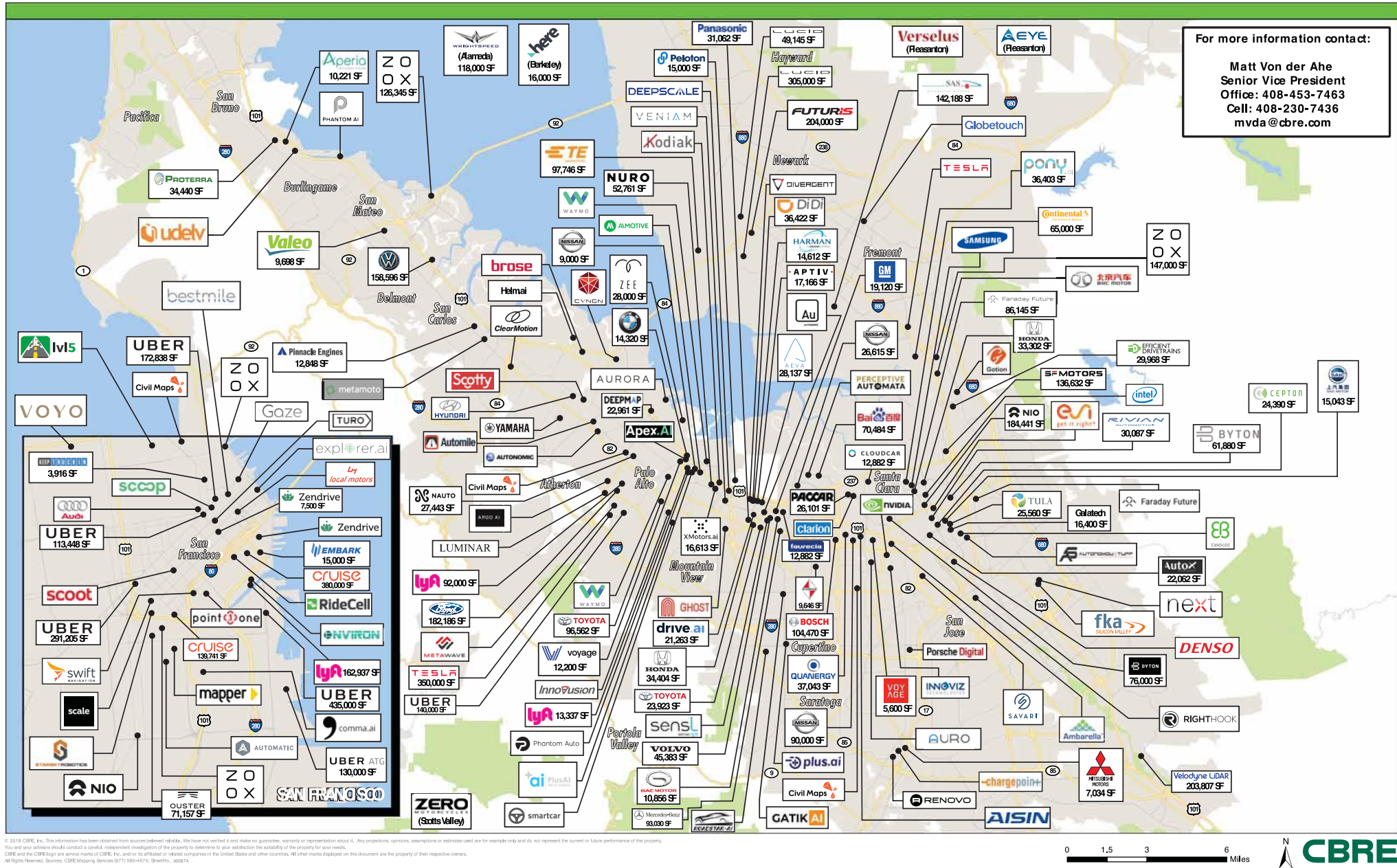


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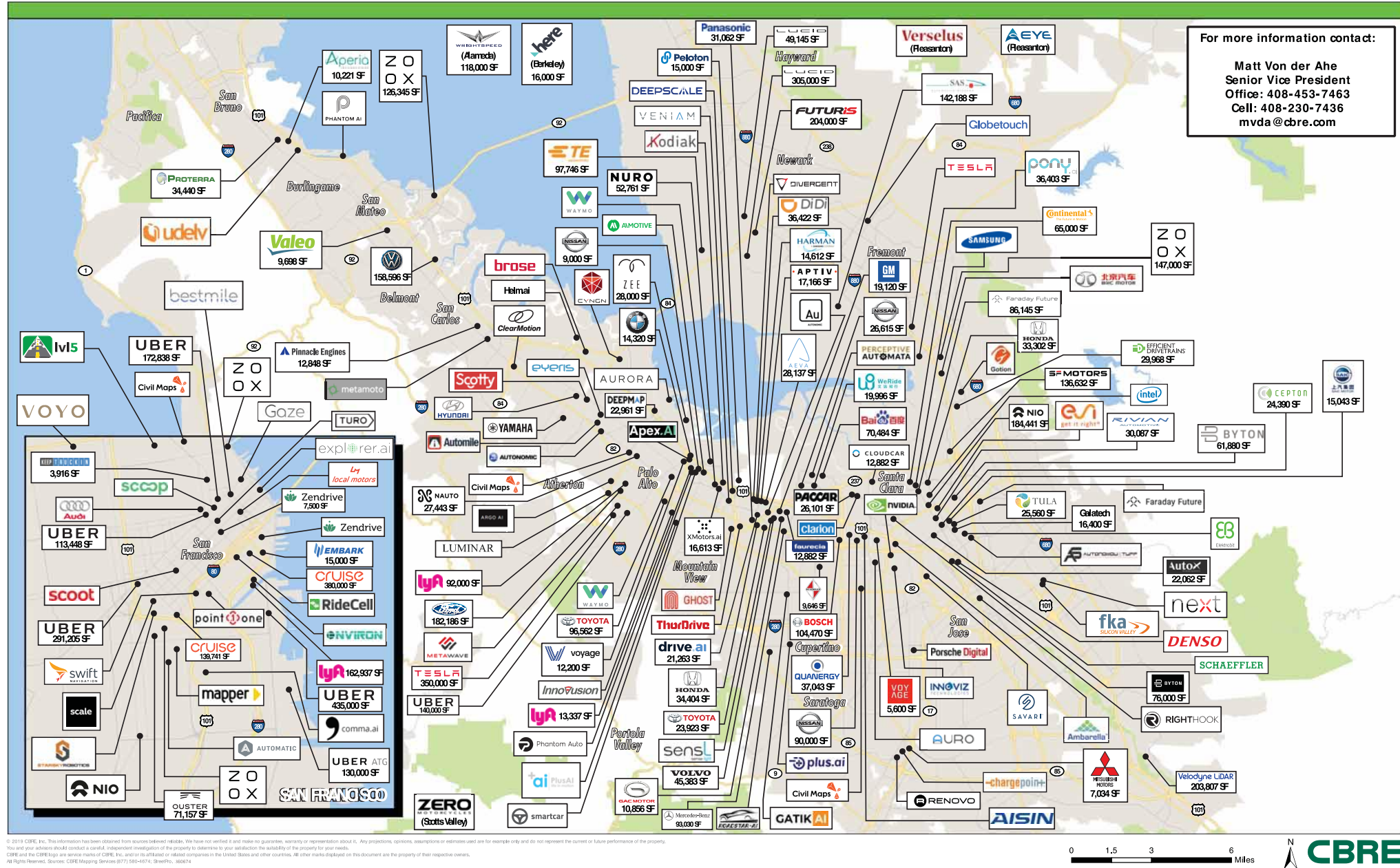
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Drone Platforms



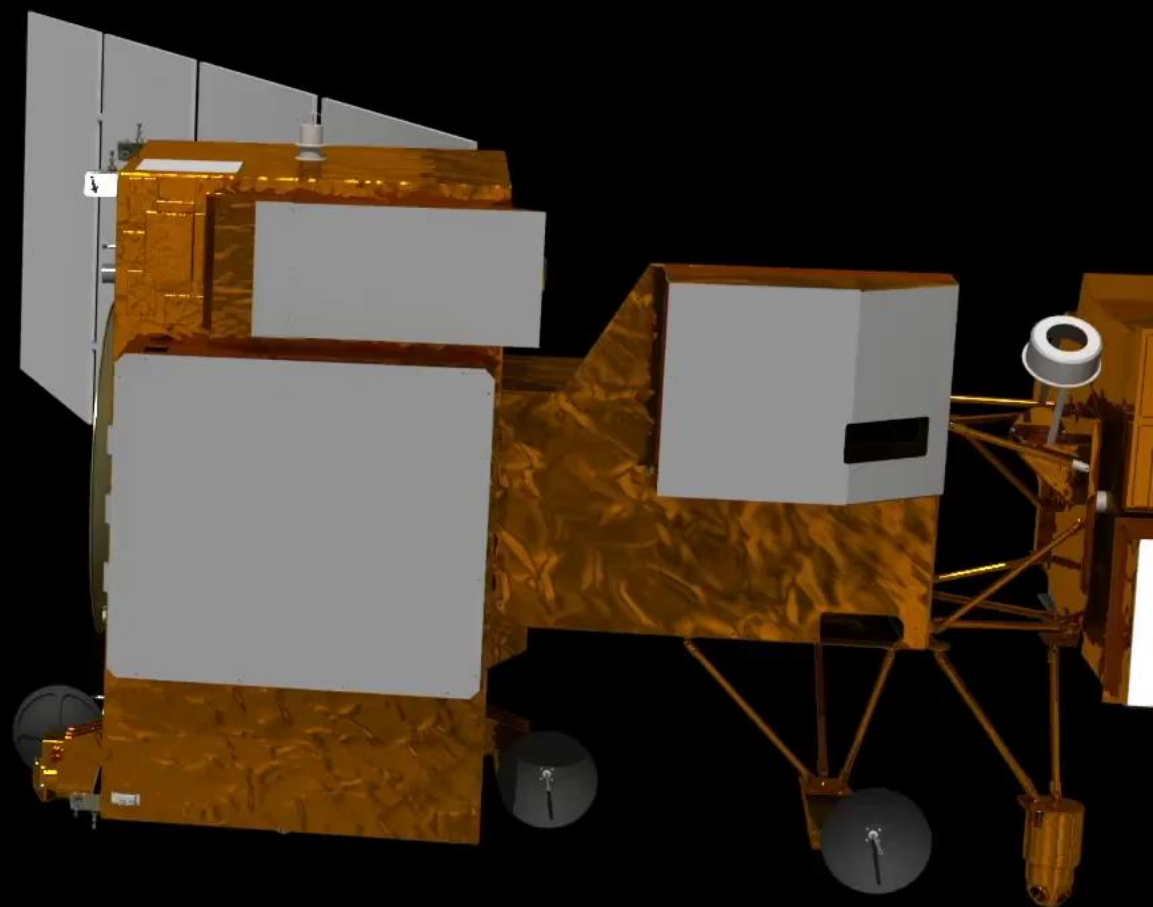
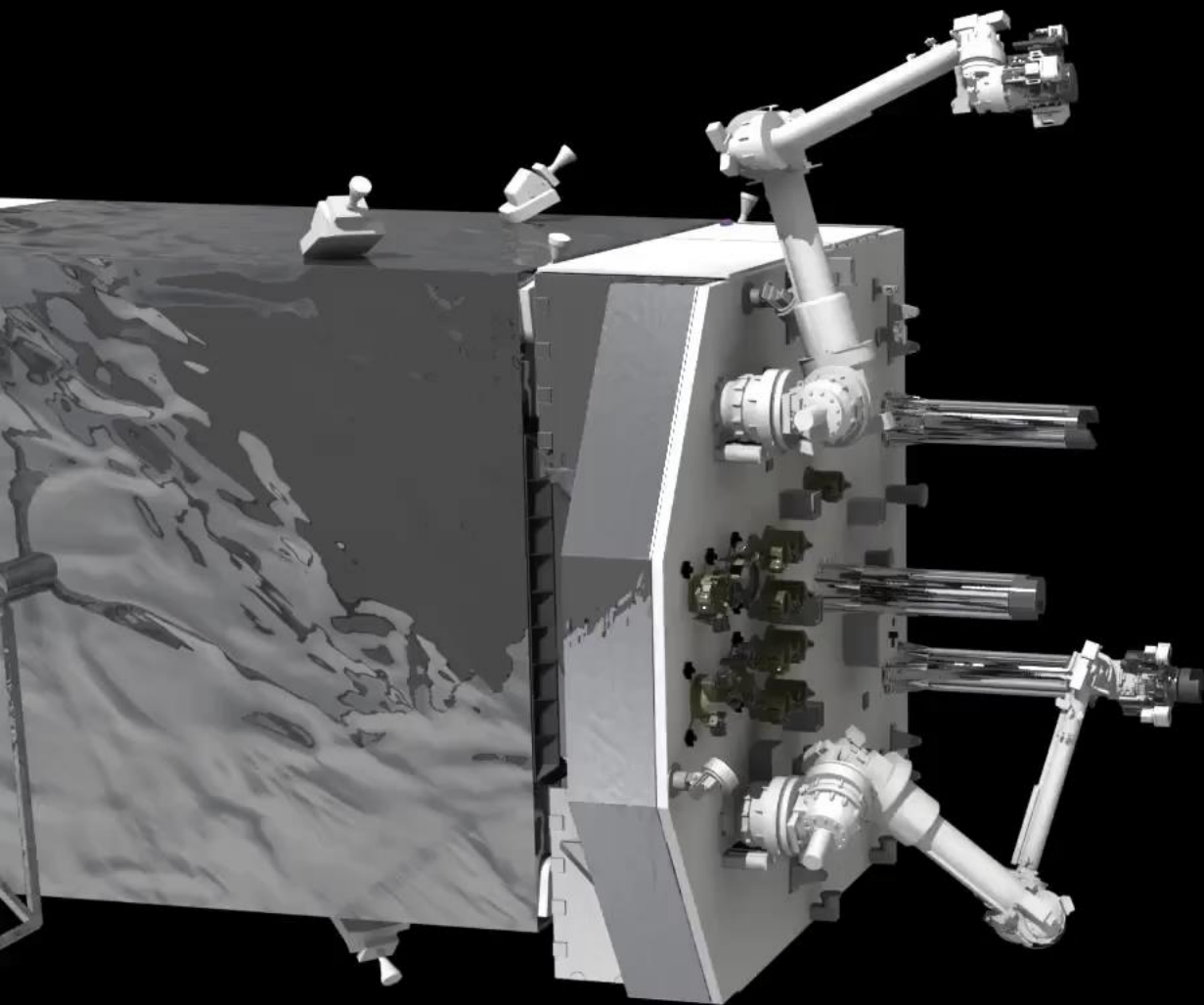
Test & Operation

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Pay-as-a-Service F

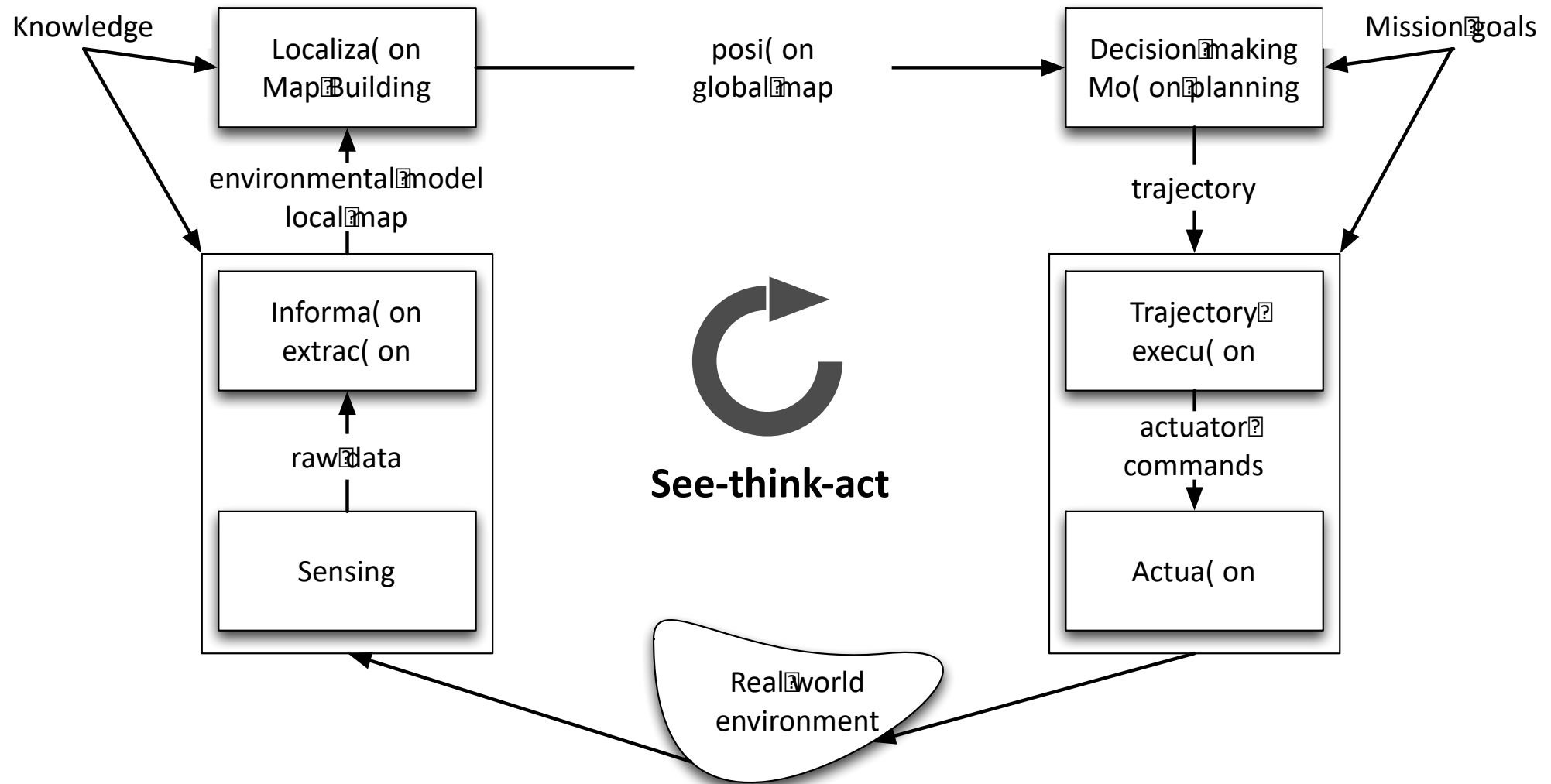




Course goals

- 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

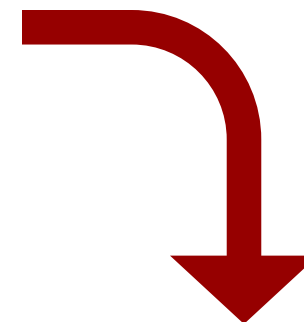
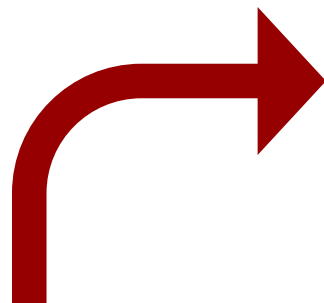
The see-think-act cycle



See-think-act cycle for AVs

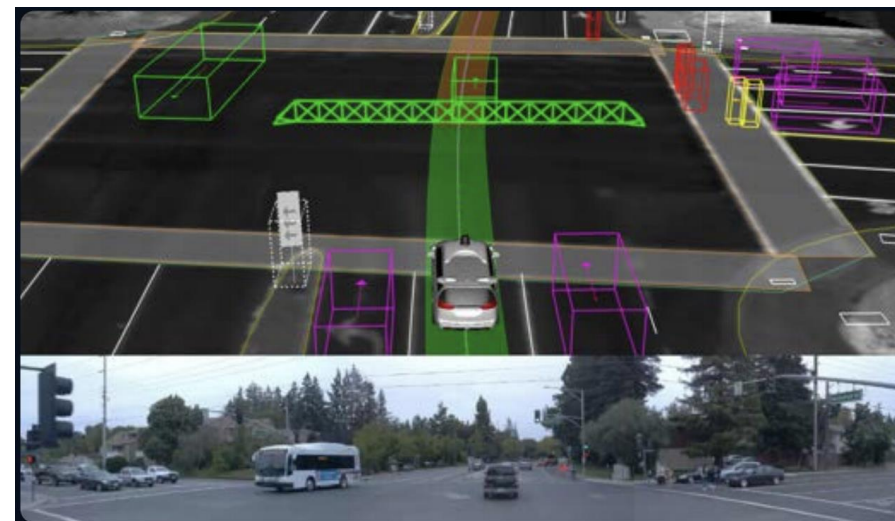
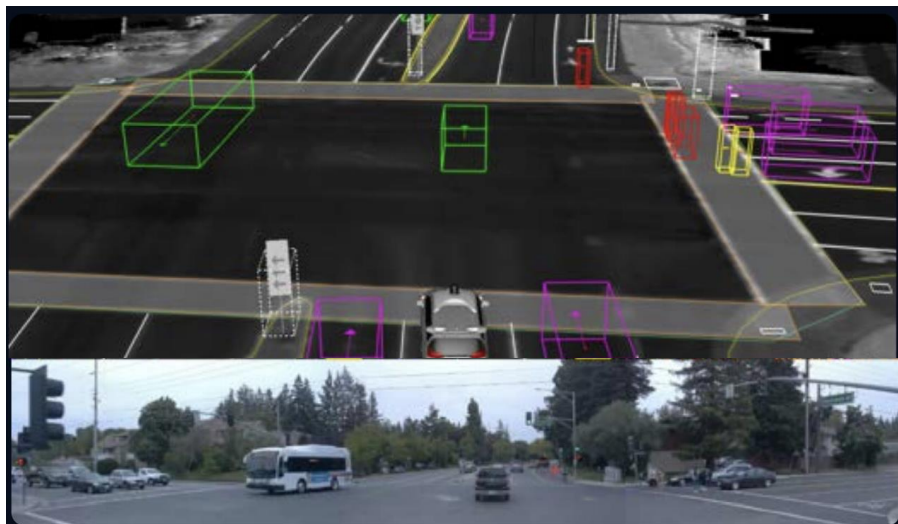
Think

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



Act

See



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 (Lathrop 018)
- 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
 - [Link](#) to hazard acknowledgement and Skilling lab policy

Logistics

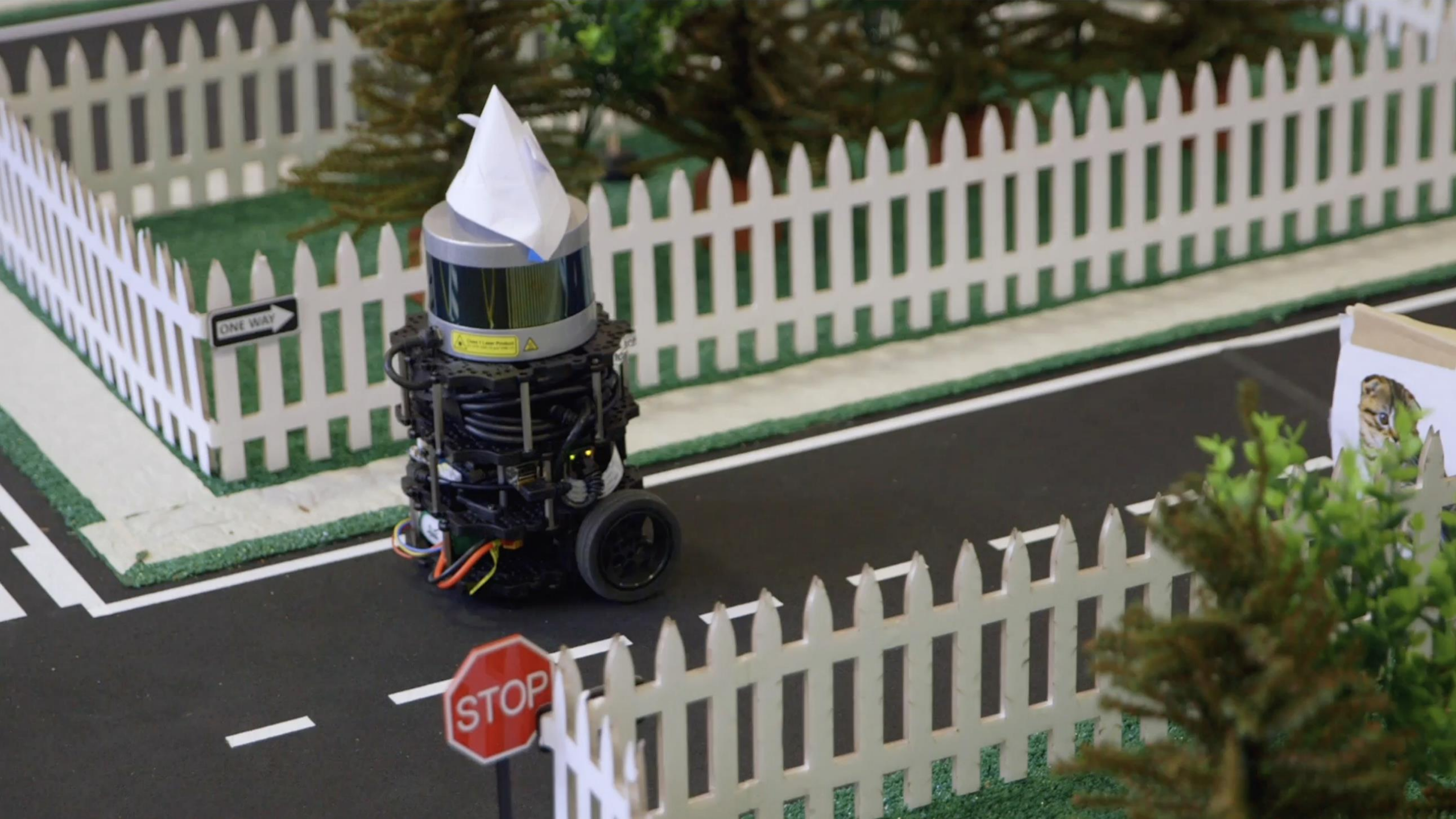
- Office hours:
 - Prof. Pavone: Tuesdays, 1:00 – 2:00pm (Durand 261), after class, and by appointment. Office hours will start during the week of Sep 28.
 - Course assistants: Wednesdays, 4:30 – 6:30pm (Durand 270), and Thursdays, 4:30 – 6:30pm (Durand 270)
- Course websites:
 - For course content: https://stanfordasl.github.io/PoRA-I/aa174a_aut2627/
 - For course announcements: <https://canvas.stanford.edu/courses/231155>
 - For course-related questions: <https://edstem.org/us/courses/106110/discussion>
 - For homework submissions: <https://www.gradescope.com/courses/1396967>
 - To contact the AA174A staff: aa174a-aut2627-staff@lists.stanford.edu

Grading

- (40%) Homework (4 psets)
- (20%) Midterm exam
- (40%) Sections:
 - (16%) attendance
 - (8%) group participation
 - (16%) final section demo
- (extra 1%) Participation on Edstem
- (extra 4%) Final demo with additional autonomy features
- (extra 5%) In-person classroom attendance; link to record your attendance: https://docs.google.com/forms/d/e/1FAIpQLSeqk3kzr3e8Q2o6d-dpJtnvpVWDPtaVVOlvM_Gano4QQUnboQ/viewform

AI Policy

- AI tools are allowed: Use ChatGPT, coding assistants, and other AI tools freely for homework and projects
- **Use AI to learn, not to replace learning:** Carefully balance AI assistance with developing your own understanding and problem-solving skills
- *You are responsible:* You are responsible for the correctness of your work and for understanding anything you submit, including AI-assisted work
- Midterm: Pen-and-paper exam, with no access to AI tools
- Final demo: We will ask oral questions about your project, implementation, design choices, and underlying concepts
- Bottom line: Use AI as a powerful learning tool—but make sure you are still doing the learning.



Team and resources

Instructor



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

CAs

Erik Bauer (Head CA)



Ellie Brosius



Rohan Garg



Main reference:

- D. Gammelli, J. Lorenzetti, K. Luo, G. Zardini, M. Pavone. Principles of Robot Autonomy. 2026.
- Book website:
<https://porabook.com/>

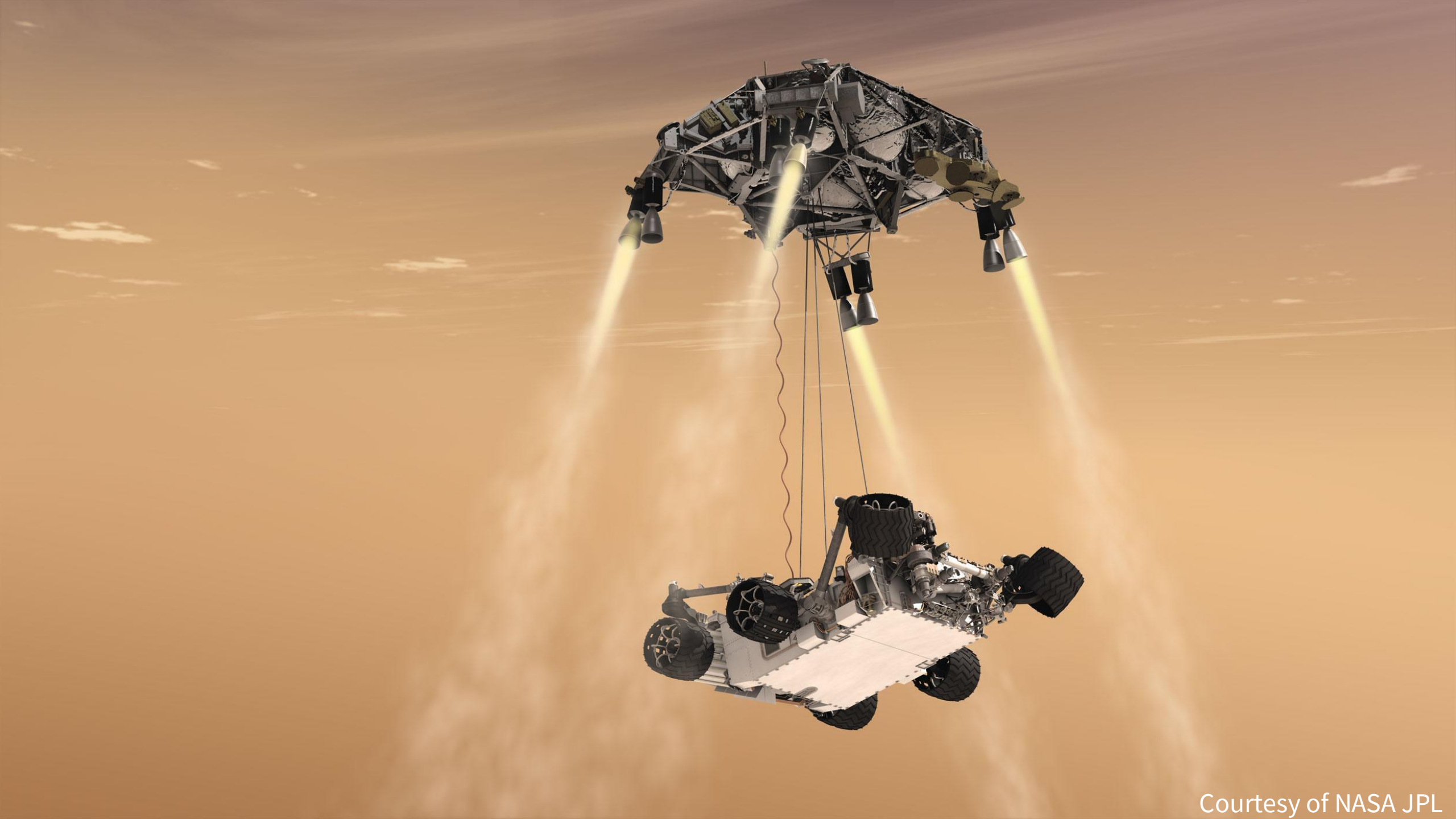


Yousef Liang

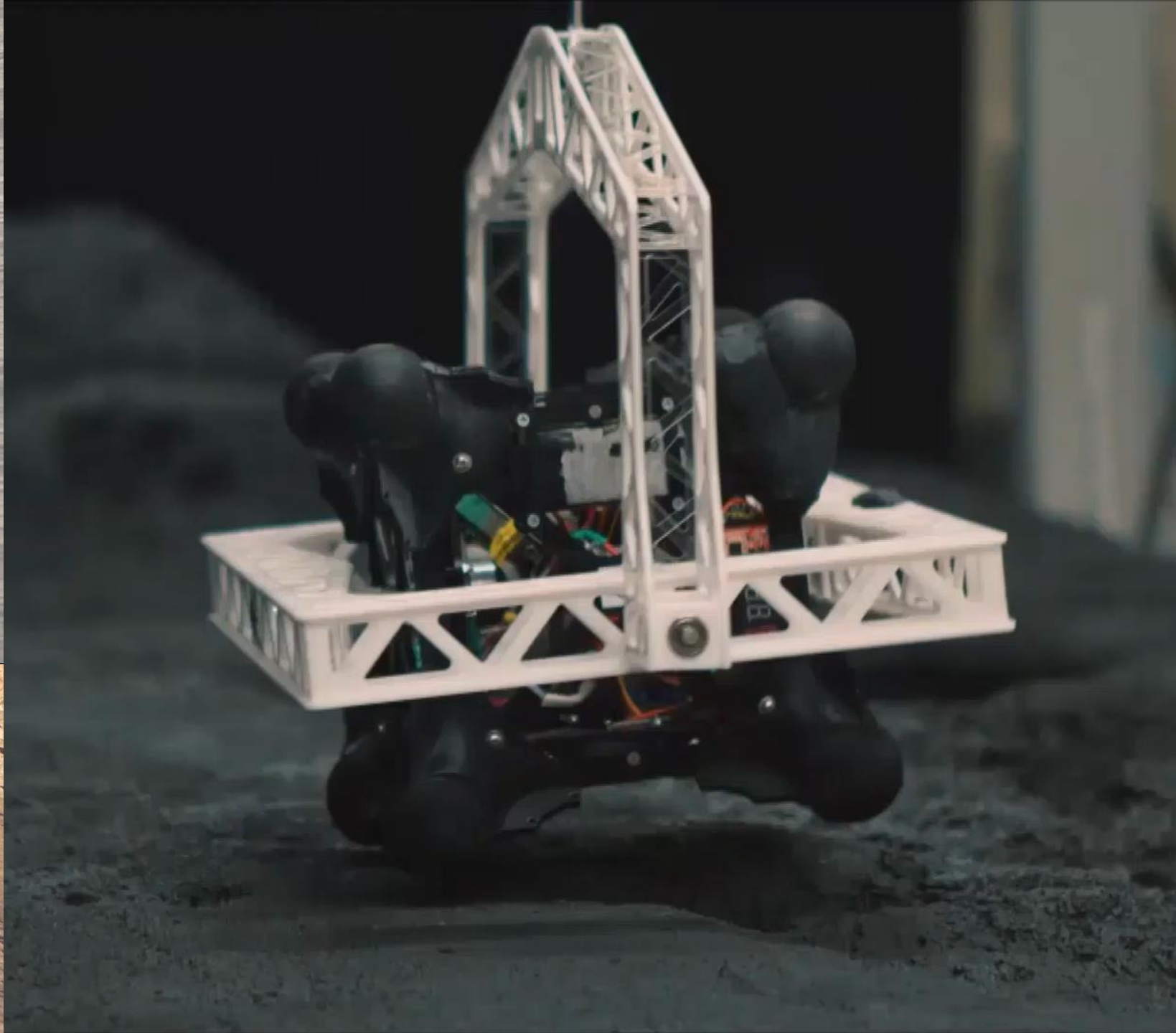


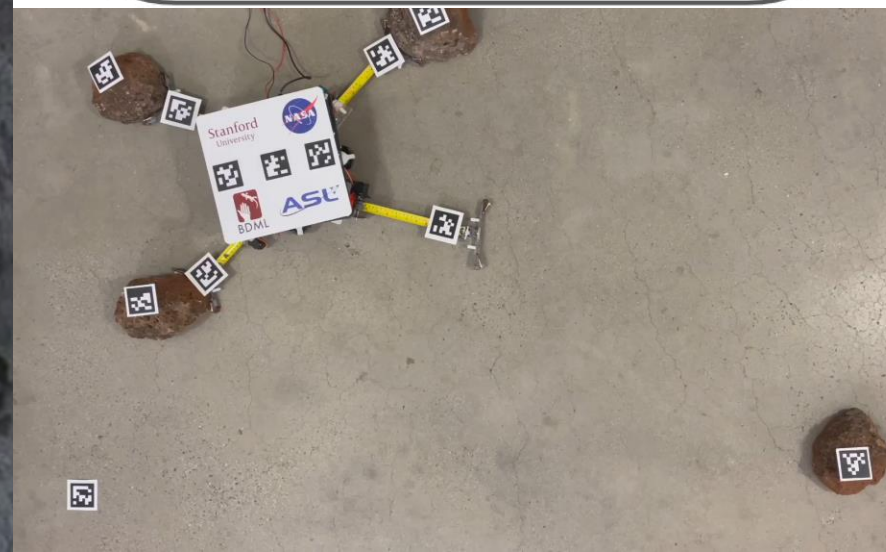
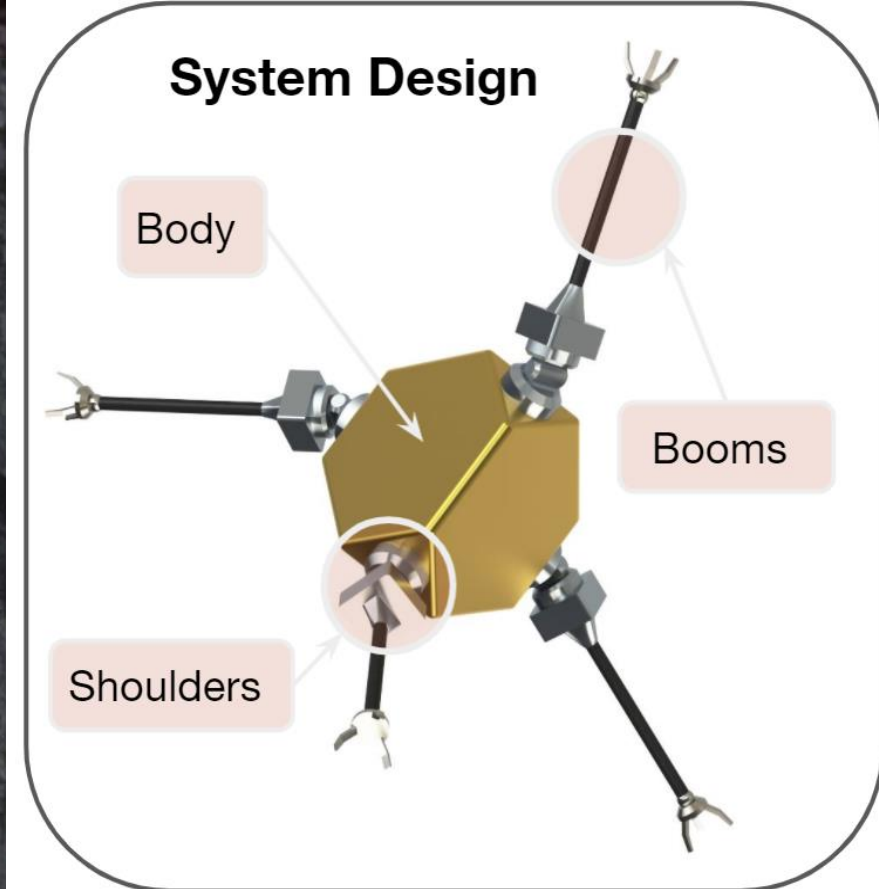
Xilun Zhang





Courtesy of NASA JPL









Autonomous Systems Lab at Stanford (ASL)

Autonomous Systems Lab

Bringing world-scale intelligence to real-world machines.



Research Thrusts

EMBEDDED INTELLIGENCE We develop the learning and reasoning foundations for generalist robot policies — making vision-language-action and world models deployable through test-time scaling, reasoning, and physically grounded simulation and modeling.	EMBODIED AI AGENTS From digital to physical We extend the orchestration, planning, and world knowledge of modern agents systems to physical robots, grounding them in multi-modal perception and online interaction.	PHYSICAL AI SAFETY Safe and reliable autonomy Our research integrates monitoring, guarding, and alignment techniques that keep embodied systems safe, predictable, and reliable in the real world.
DATA FLOWBUILT FOR ROBOTS Self-improving autonomy We design automated evaluation and data pipelines that close feedback loops and enable continuously advancing robotic systems.	OPTIMAL & LEARNING-BASED CONTROL Operate at the limits We look at the complementary nature of optimization-based and learning-based control and planning methods. At their interface, we can bring the speed, interpretability, and consistent substitution of optimization to the limited capabilities and generalization of machine learning.	OFFLINE AUTONOMY Deploy in high-impact domains We deploy autonomy in the field — spanning space robotics, logged and humanoid systems, autonomous vehicles, and manipulation — where operating in the world's most challenging environments grounds and drives our core research.

<https://stanfordasl.github.io/>

Autonomous Systems and Physical AI Research (ASPIRE)



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

Schedule

Date	Topic	Assignments
09/22	Course overview, intro to robotic systems and ROS	HW1 out
09/24	Fundamentals of ROS & vectorized computation in Python	
09/25	★ Section 1 – UNIX, Git, and Python	
09/29	State space dynamics – definitions and modeling	
10/01	State space dynamics – computation and simulation	
10/02	★ Section 2 – ROS, workspaces, packages, nodes	
10/06	Trajectory optimization	HW2 out
10/08	Trajectory tracking	HW1 due
10/09	★ Section 3 – Launch files & RVIZ	
10/13	Motion planning I: graph search algorithms	HW2 due
10/15	Motion planning II: sampling-based methods	
10/16	★ Section 4 – Controller gain tuning in hardware	
10/20	Robotic sensors & introduction to computer vision	HW3 out
10/22	Camera models and camera calibration	
10/23	★ Section 5 – Running a point-to-point navigator	
10/27	Image processing, feature detection, & feature description	HW3 due, HW4 (part 1) out
10/29	Information extraction	
10/30	★ Section 5 cont. & Section 6 head start	

11/03	No Lecture – Democracy Day	
11/05	<i>In-class midterm</i>	
11/06	★ No Section	
11/10	Deep learning for computer vision	
11/12	Intro to state estimation & filtering theory	
11/13	★ Section 6 – Object detection	HW4 (part 2) out
11/17	Parametric filtering (KF and EKF)	HW4 (part 1) due
11/19	Markov localization and EKF-localization	
11/20	★ Section 7 – Frontier exploration	
11/24		
11/26	<i>Thanksgiving</i>	
11/27		
12/01	Multi-sensor perception & sensor fusion	HW4 (part 2) due
12/03	Simultaneous localization and mapping (SLAM)	
12/04	★ Section 7 cont.	

[Turtlebot3](#)



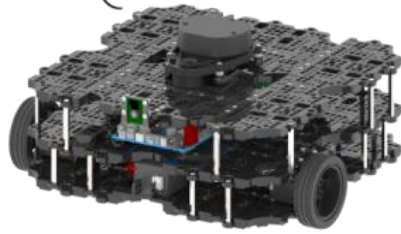
TurtleBot3
Burger



TurtleBot3
Waffle



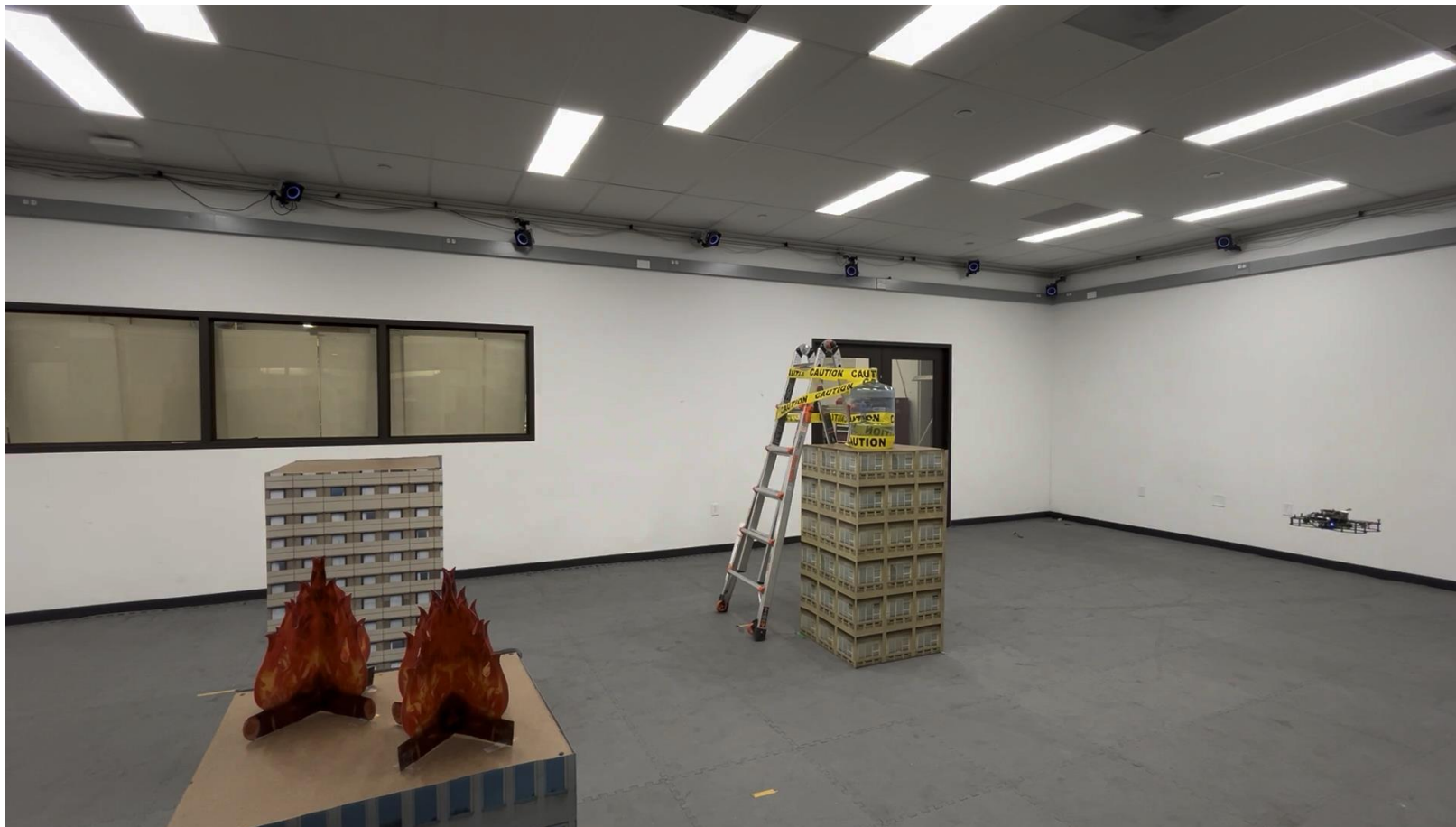
TurtleBot3
Waffle Pi



[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?

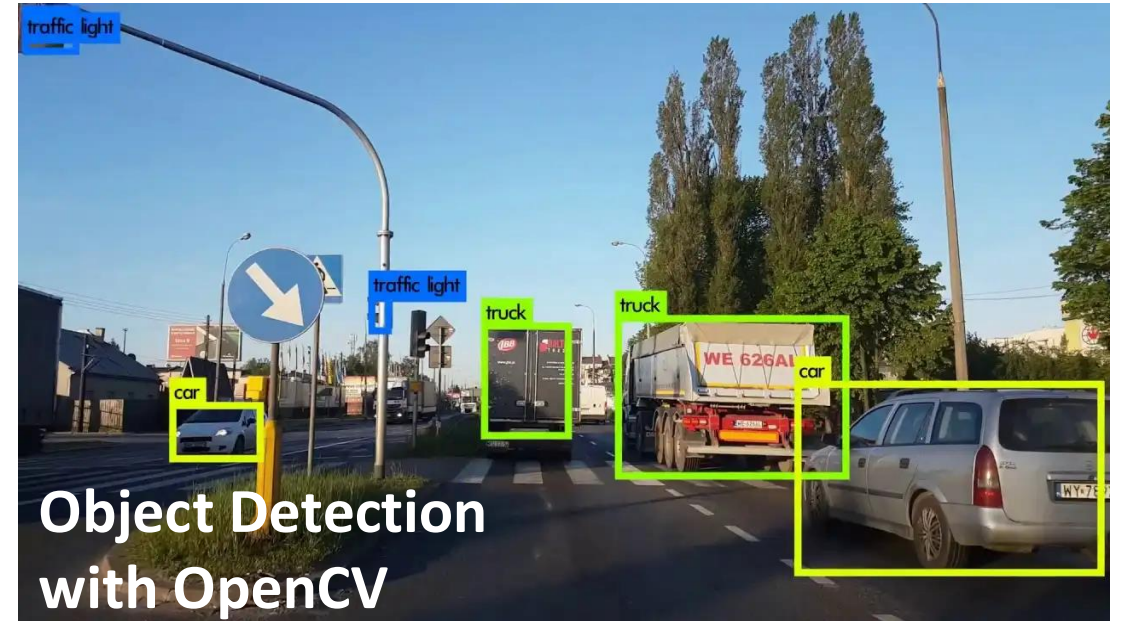
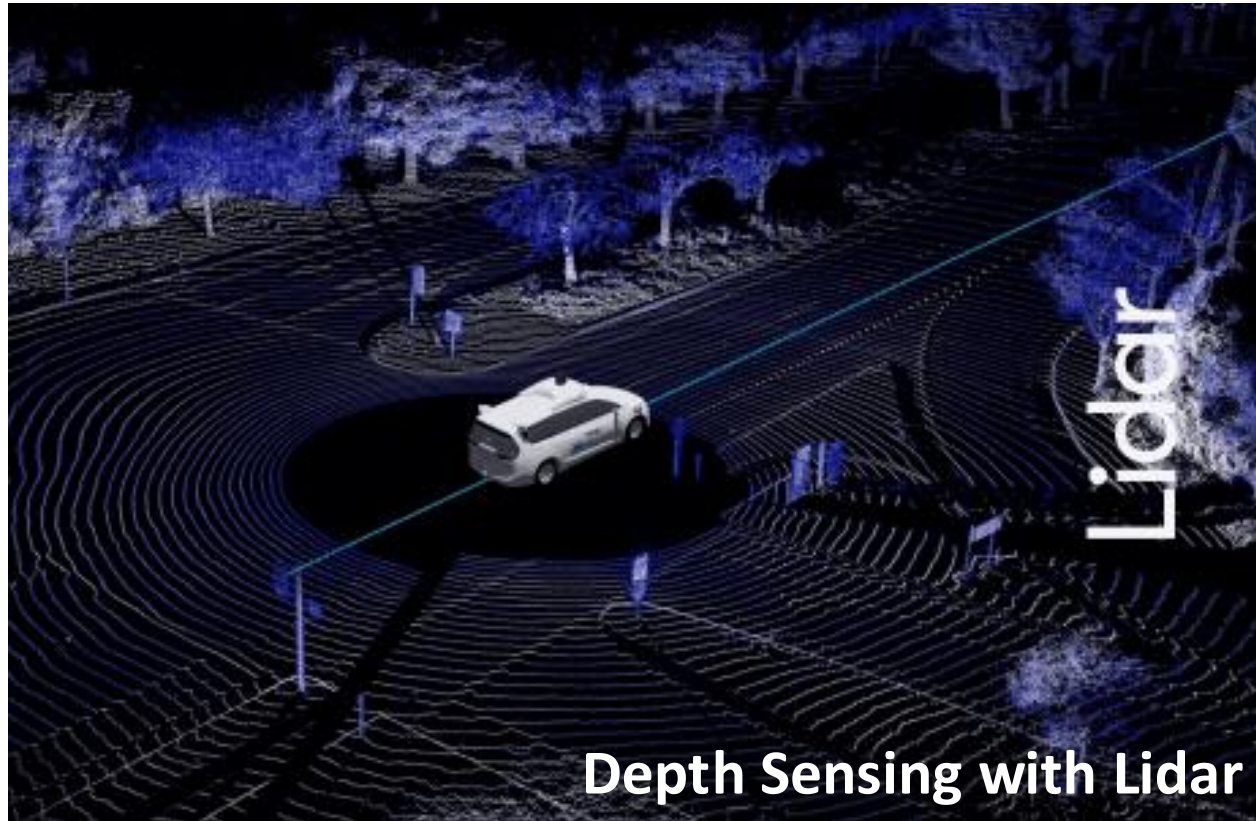
- Write custom code to connect sensors and actuators.
- Reinvent tools for visualization, debugging, and simulation.
- Struggle with versioning, testing, and sharing code.

What is ROS?

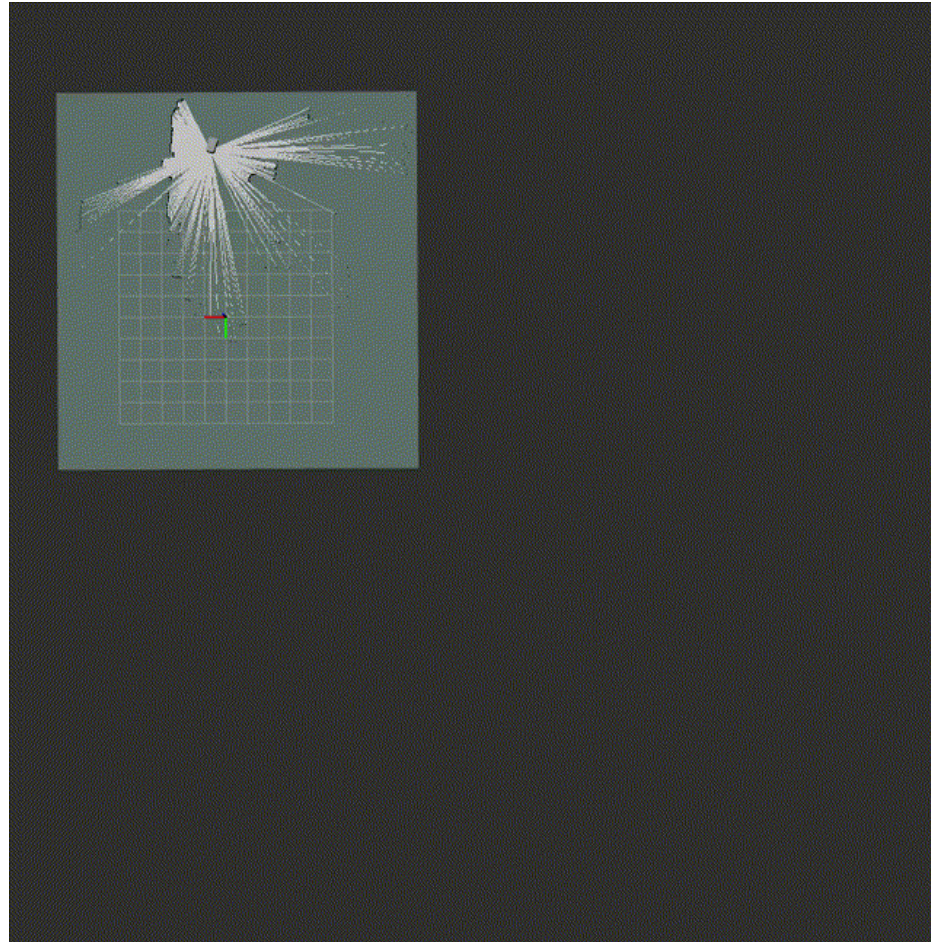


- Middleware (Not an operating system)
- ROS provides:
 - Launching different components
 - Communication between components → Publish/subscribe messaging system.
 - Reusable components → Packages for navigation, vision, motion planning
 - Tools for visualization & debugging → RViz, Gazebo, rqt.
 - Community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

Perception



Localization and Mapping



Navigation



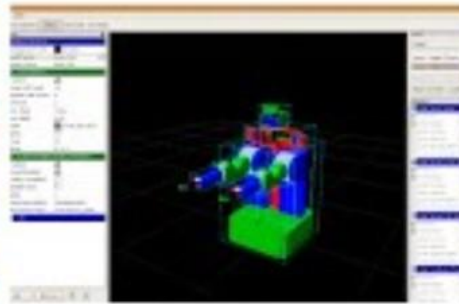
Manipulation



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

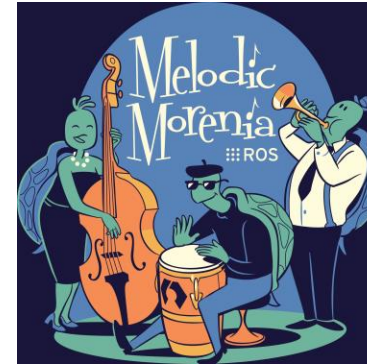
ROS 1



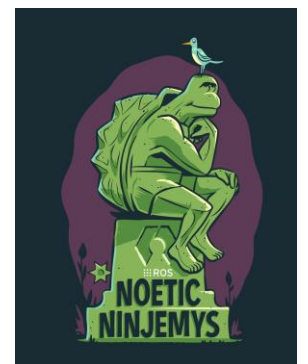
2014 - 2019



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, ...



Next time: fundamentals of ROS



Robot Operating System