Principles of Robot Autonomy I

Course overview, intro to robotic systems and ROS

Stanford University

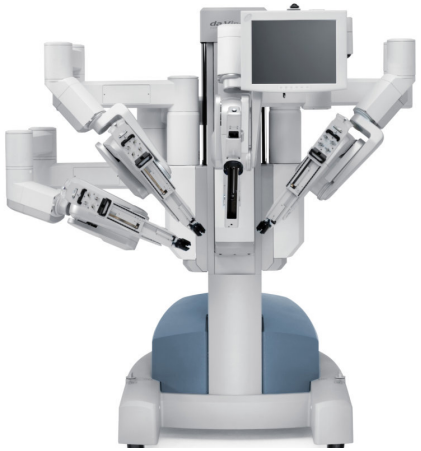
Autonomous Systems Lab

From automation…

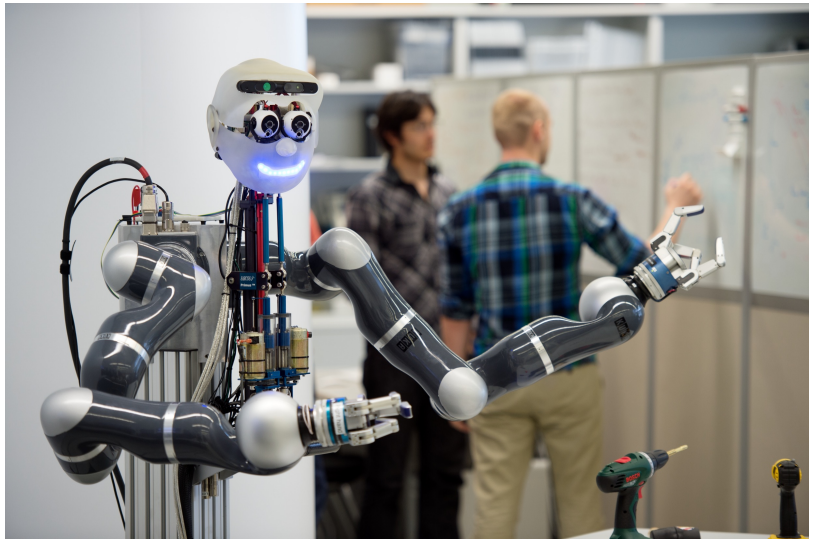
…to autonomy

Waymo Self-Driving Car

Intuitive DaVinci Surgical Robot



Apollo Robot at MPI



Astrobee - NASA

Silicon Valley

CBRE

Automotive R&D

April 2016

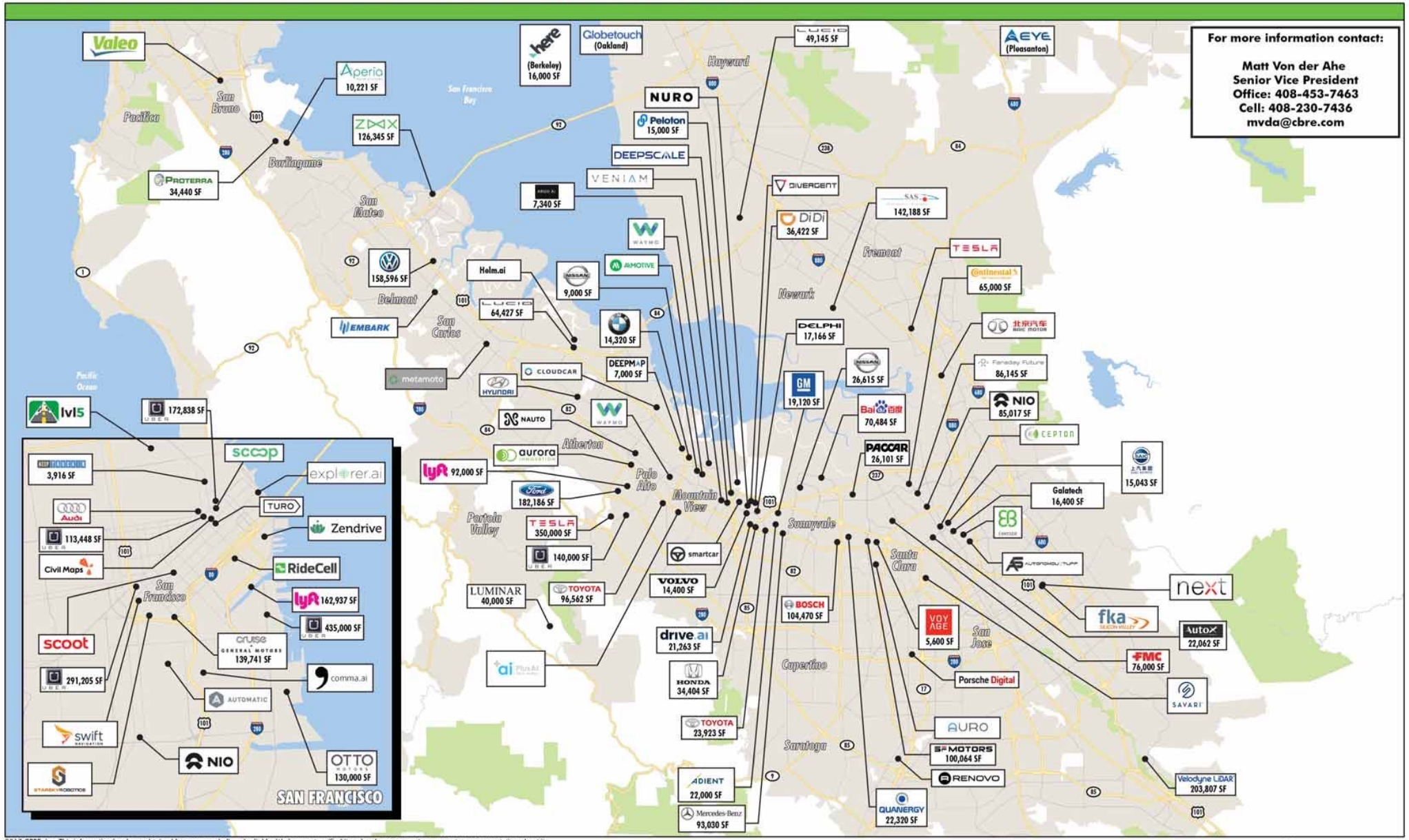
Silicon Valley

CBRE

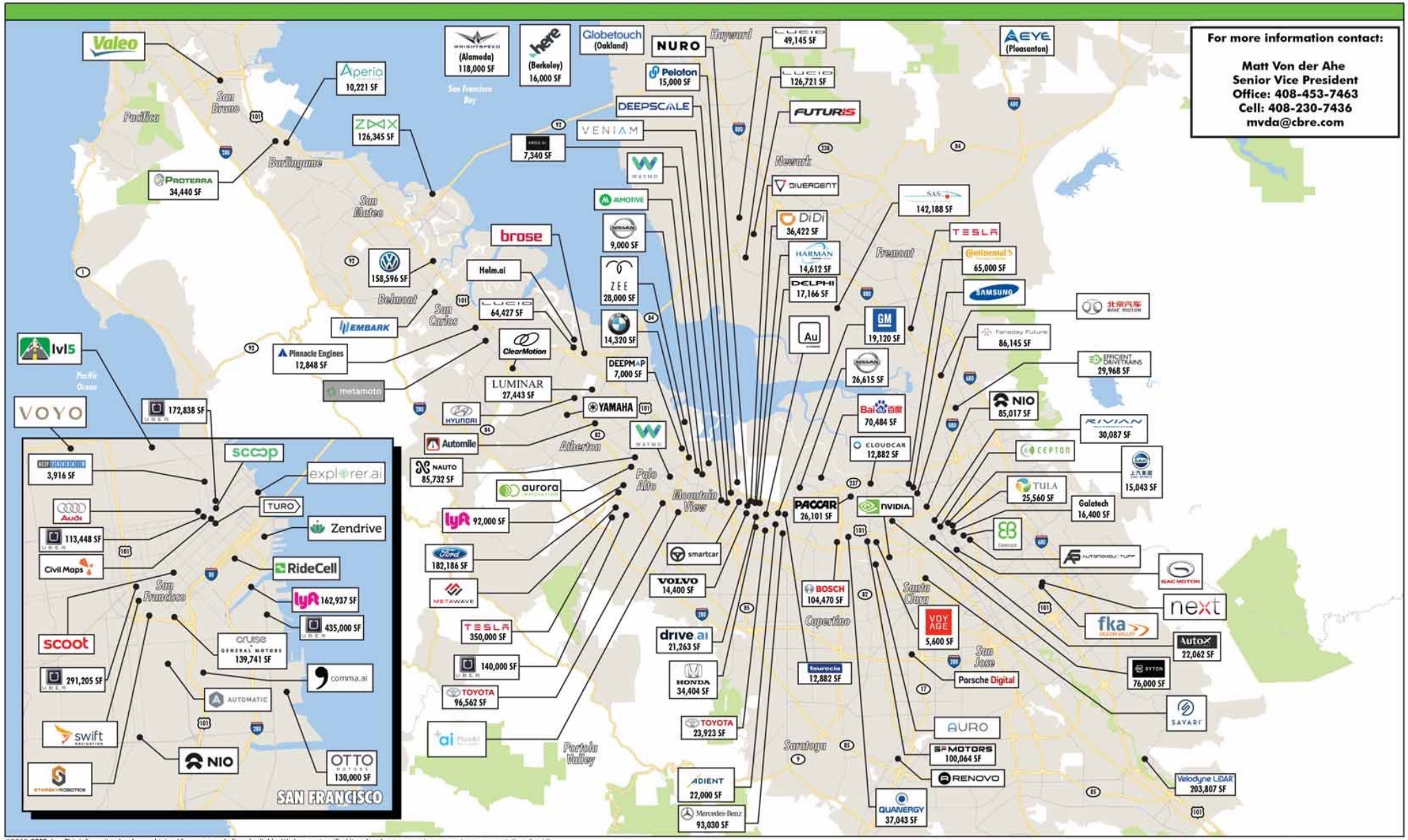
AUTO LAB MAP APRIL 2017 SILICON VALLEY

CBRE

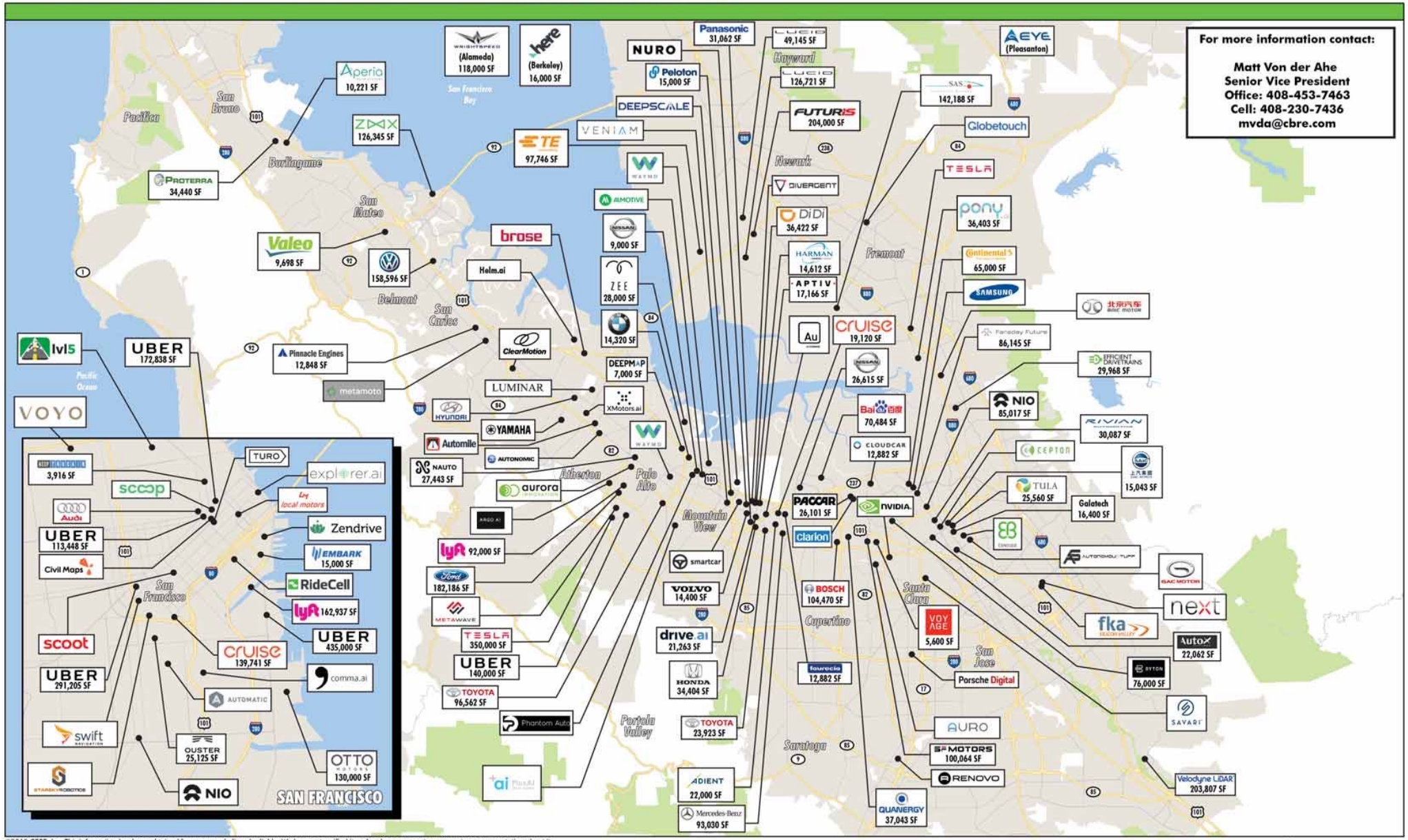
AUTO LAB MAP SEPTEMBER 2017 SILICON VALLEY



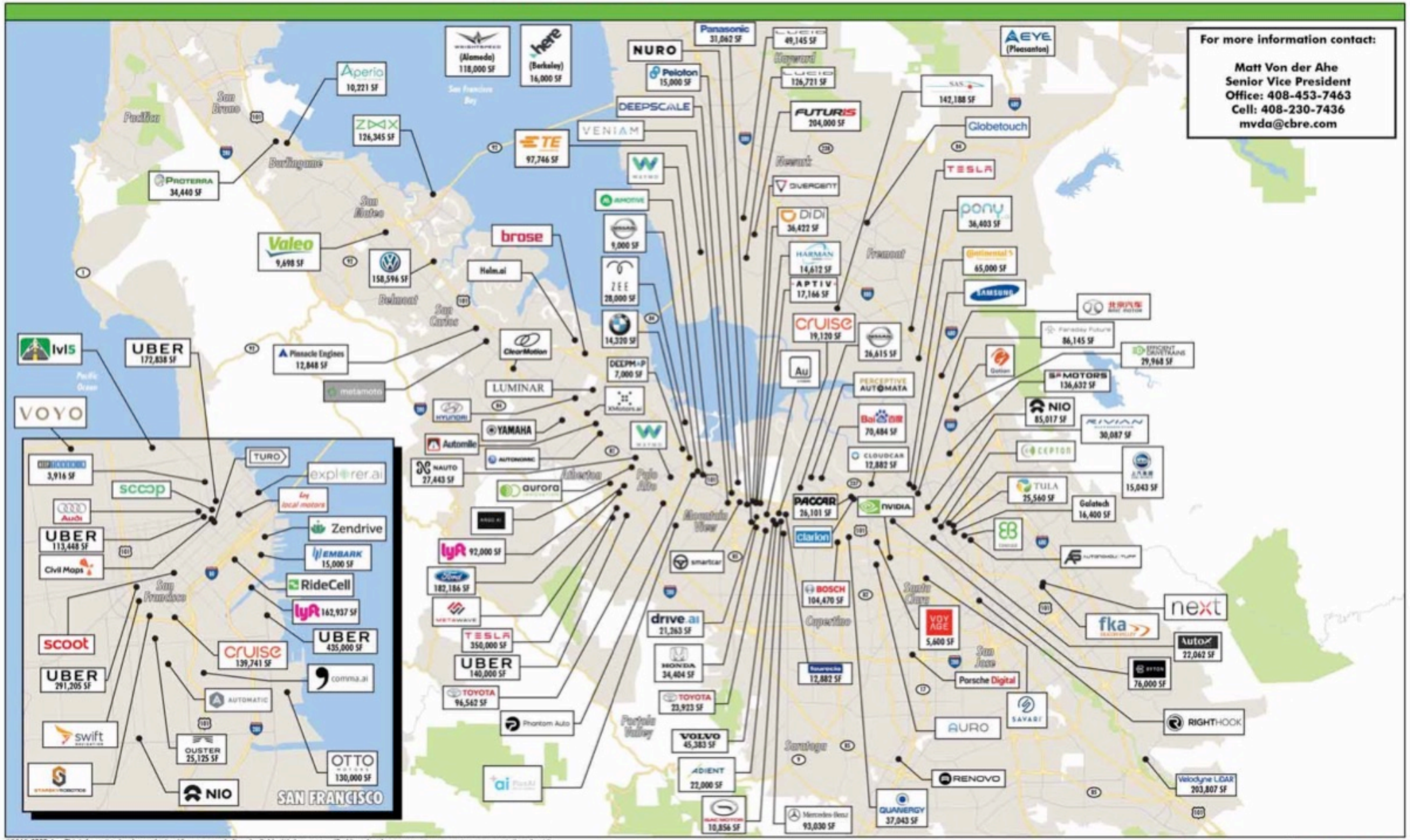
AUTO LAB MAP DECEMBER 2017 SILICON VALLEY



AUTO LAB MAP FEBRUARY 2018 SILICON VALLEY



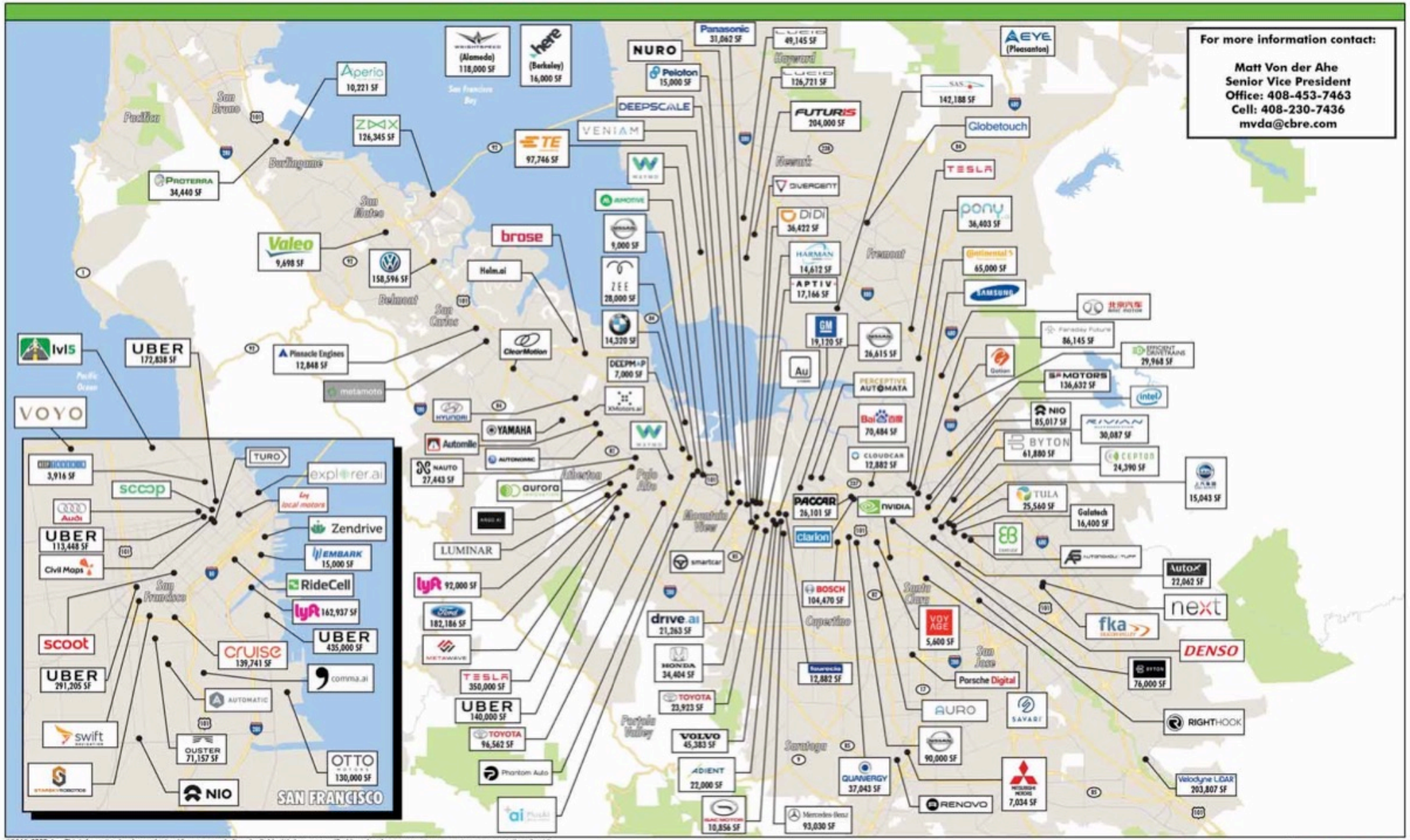
AUTO LAB MAP MARCH 2018 SILICON VALLEY



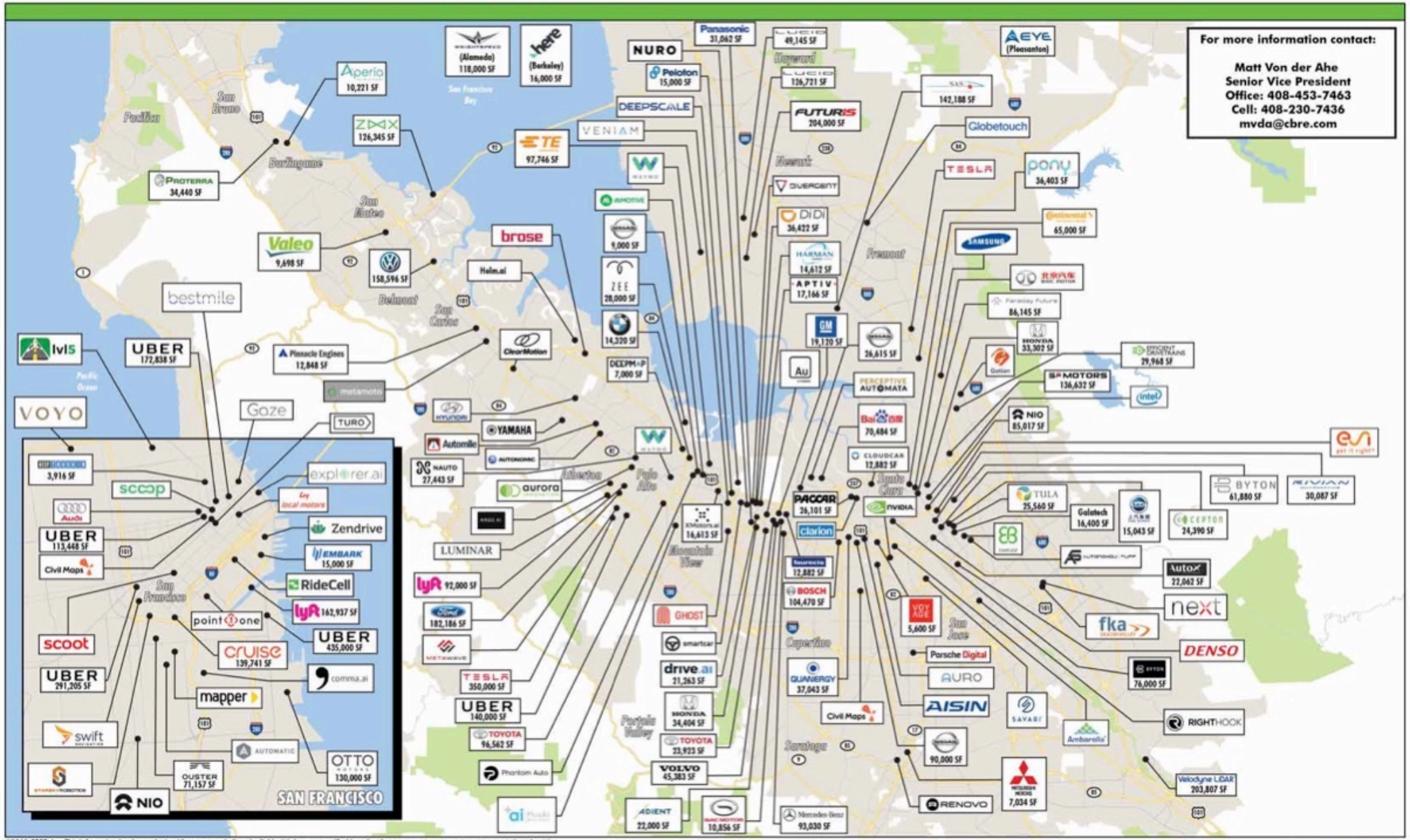
0 1.5 3 6 Miles

N CBRE

AUTO LAB MAP APRIL 2018 SILICON VALLEY



AUTO LAB MAP MAY 2018 SILICON VALLEY



0 1.5 3 6 Miles

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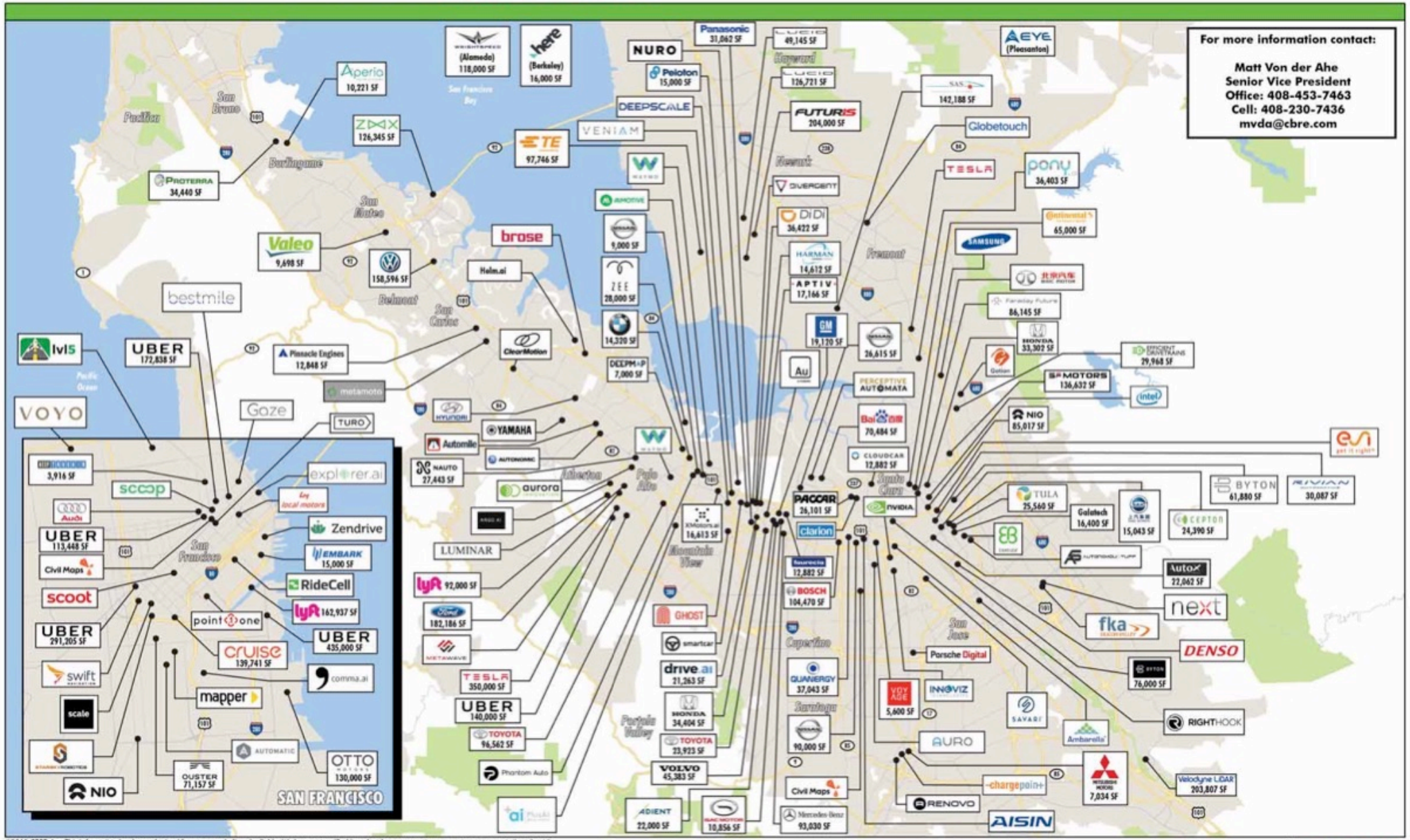
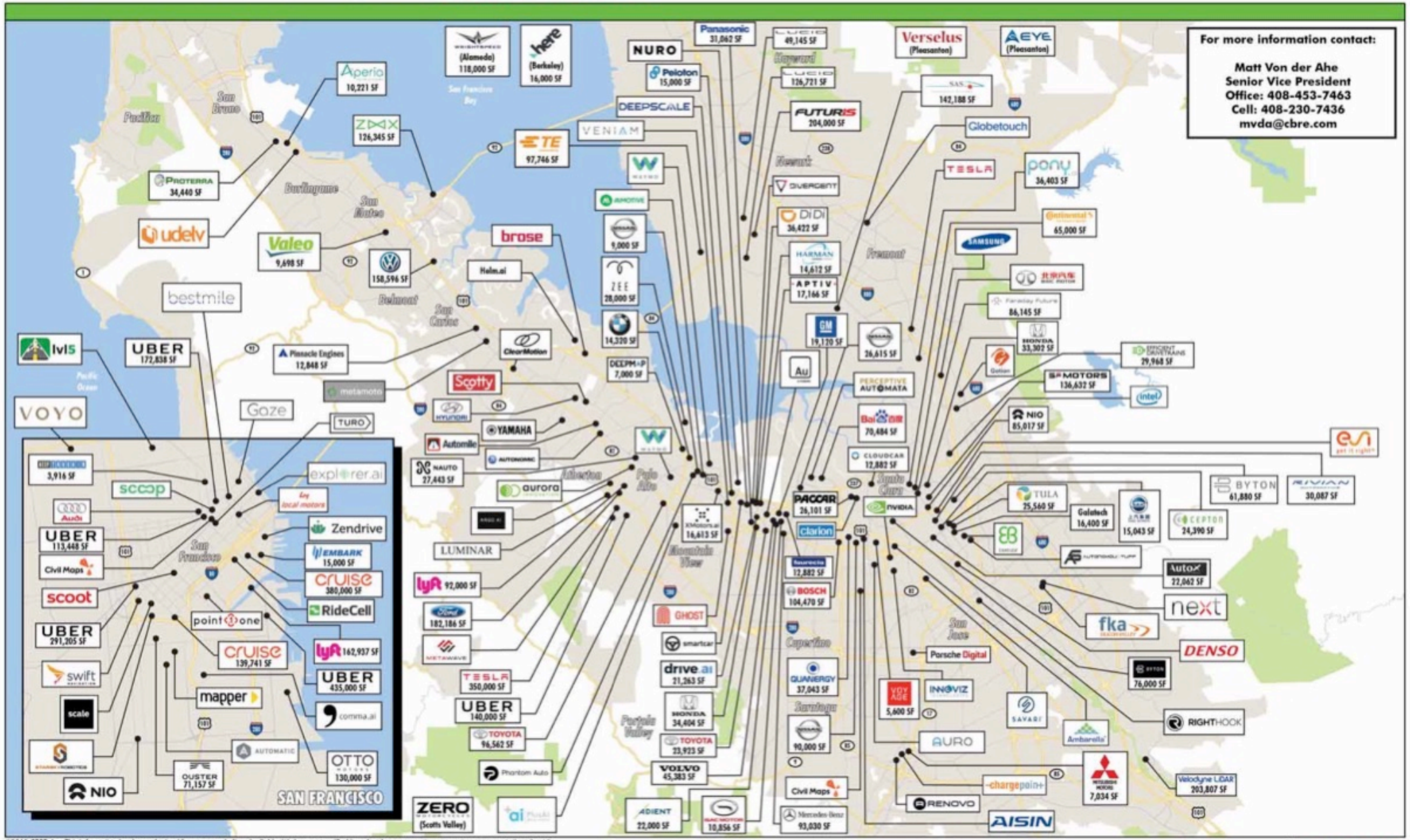
CBRE

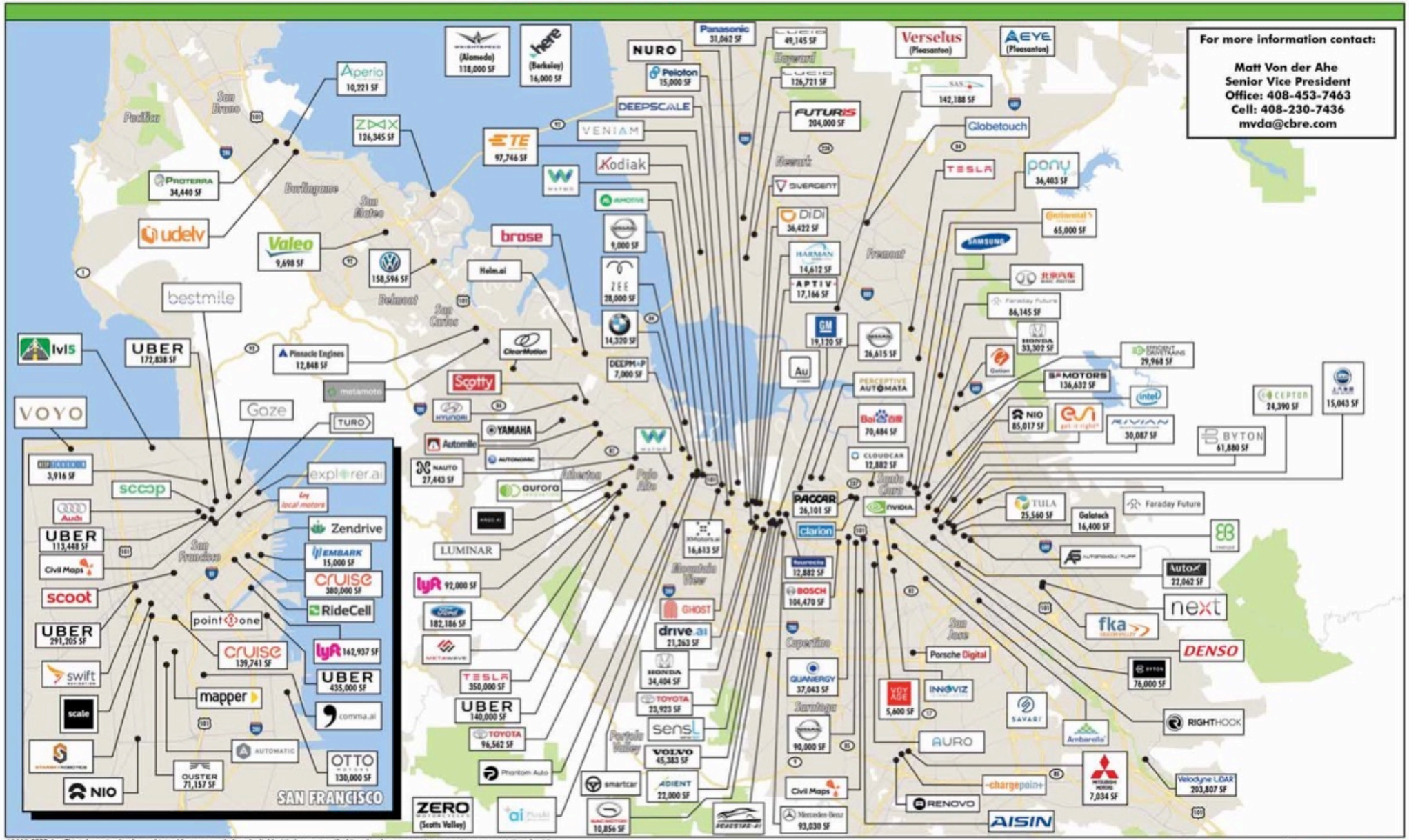
AUTO LAB MAP JUNE 2018 SILICON VALLEY



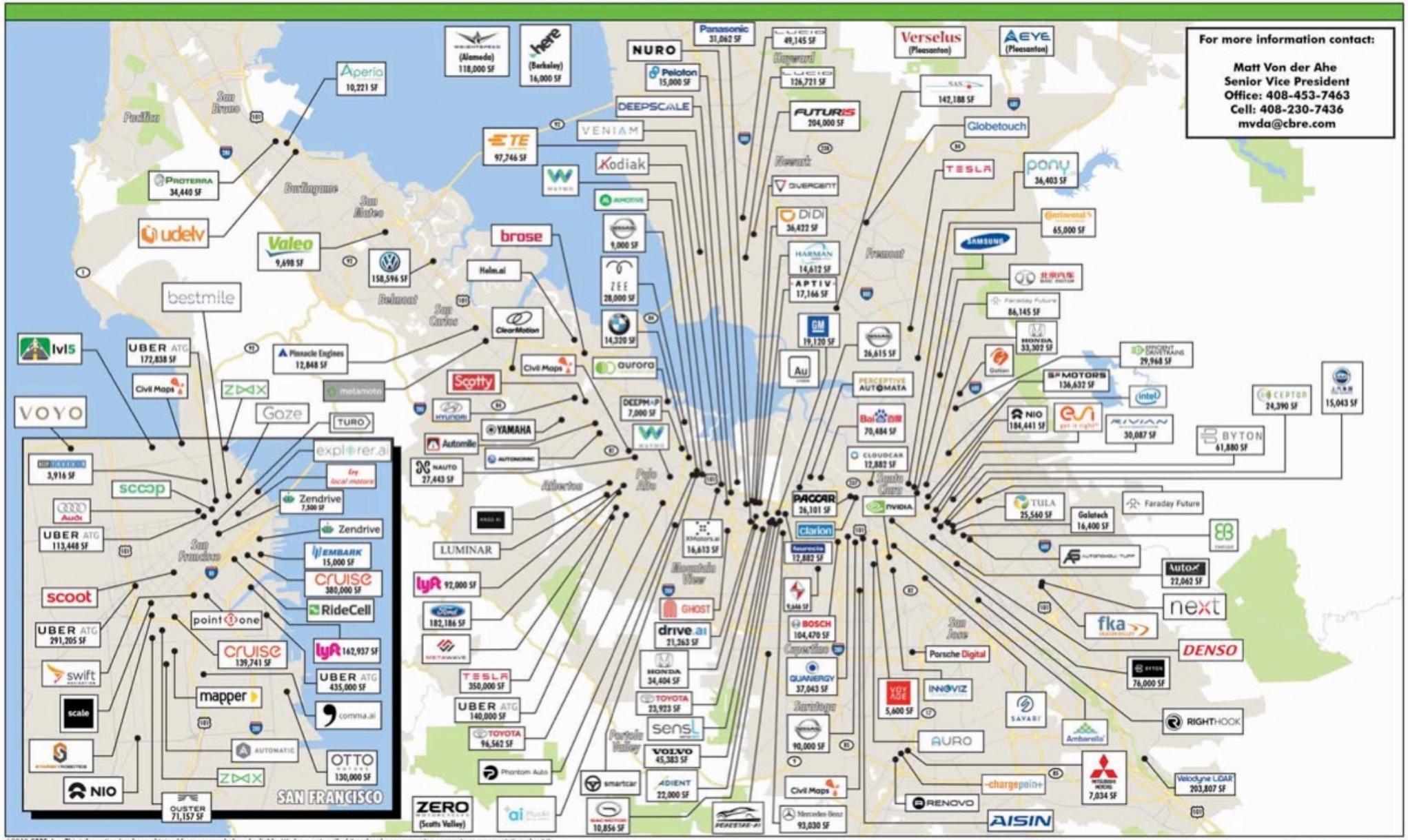
AUTO LAB MAP JULY 2018 SILICON VALLEY



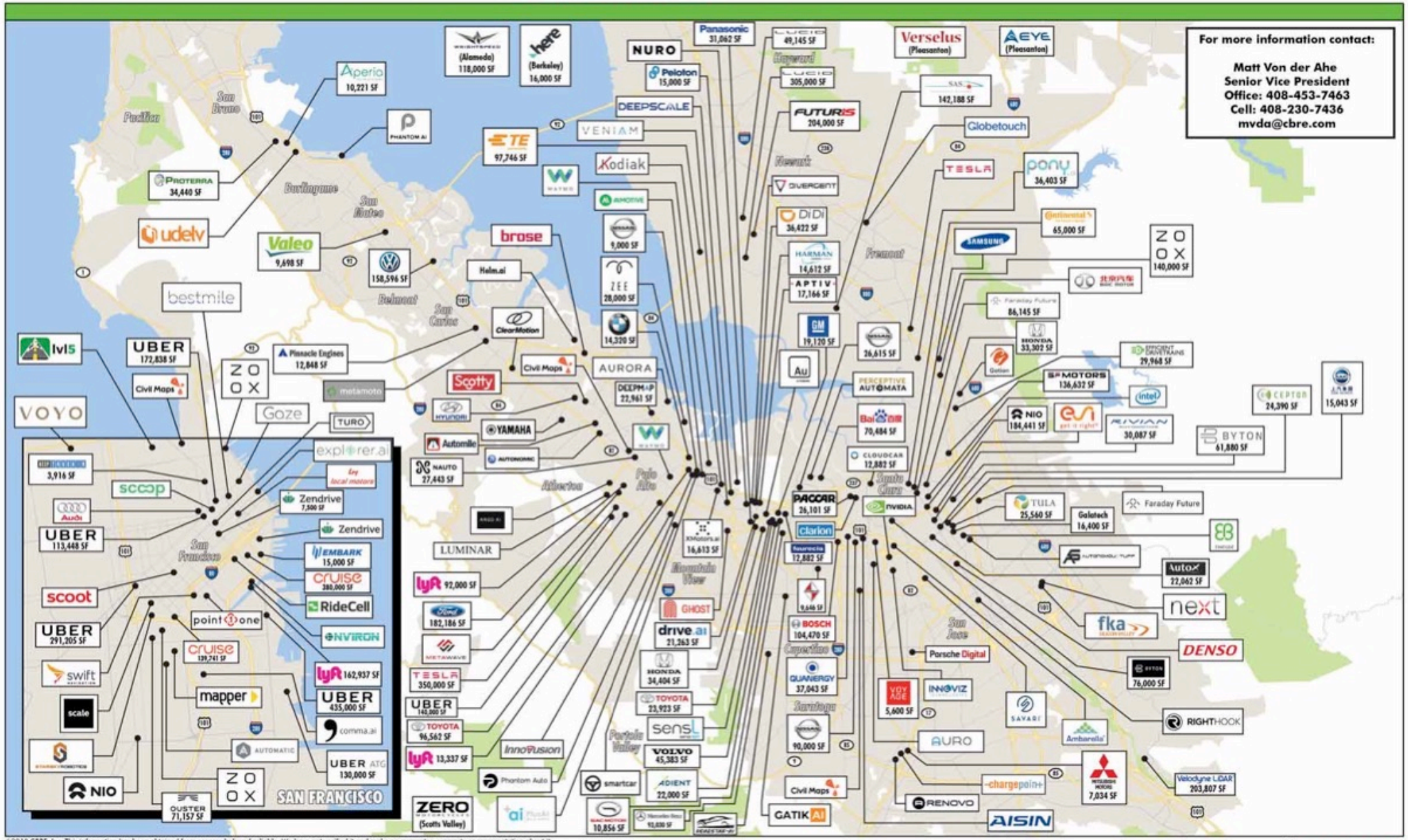
AUTO LAB MAP AUGUST 2018 SILICON VALLEY



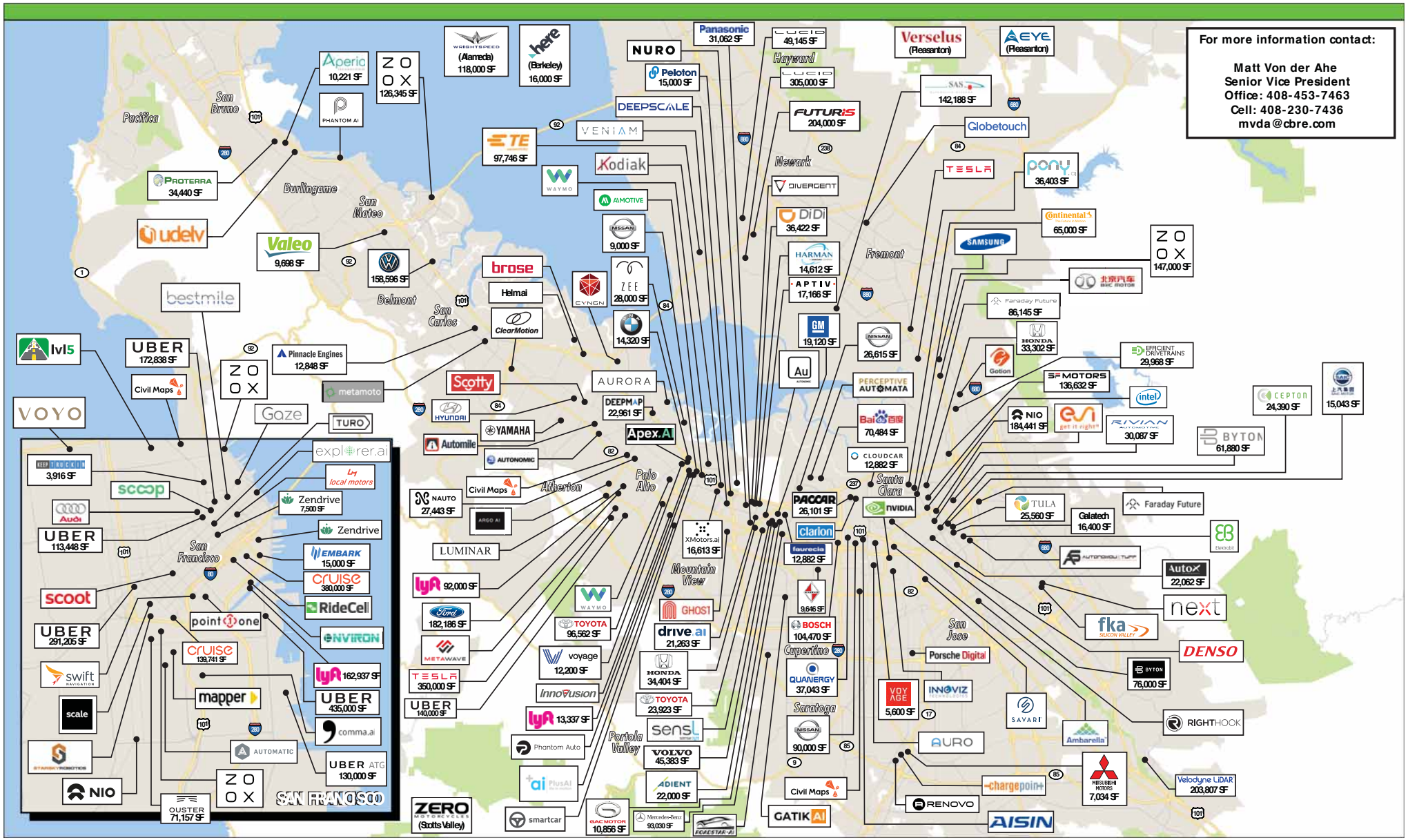
AUTO LAB MAP SEPTEMBER 2018 SILICON VALLEY



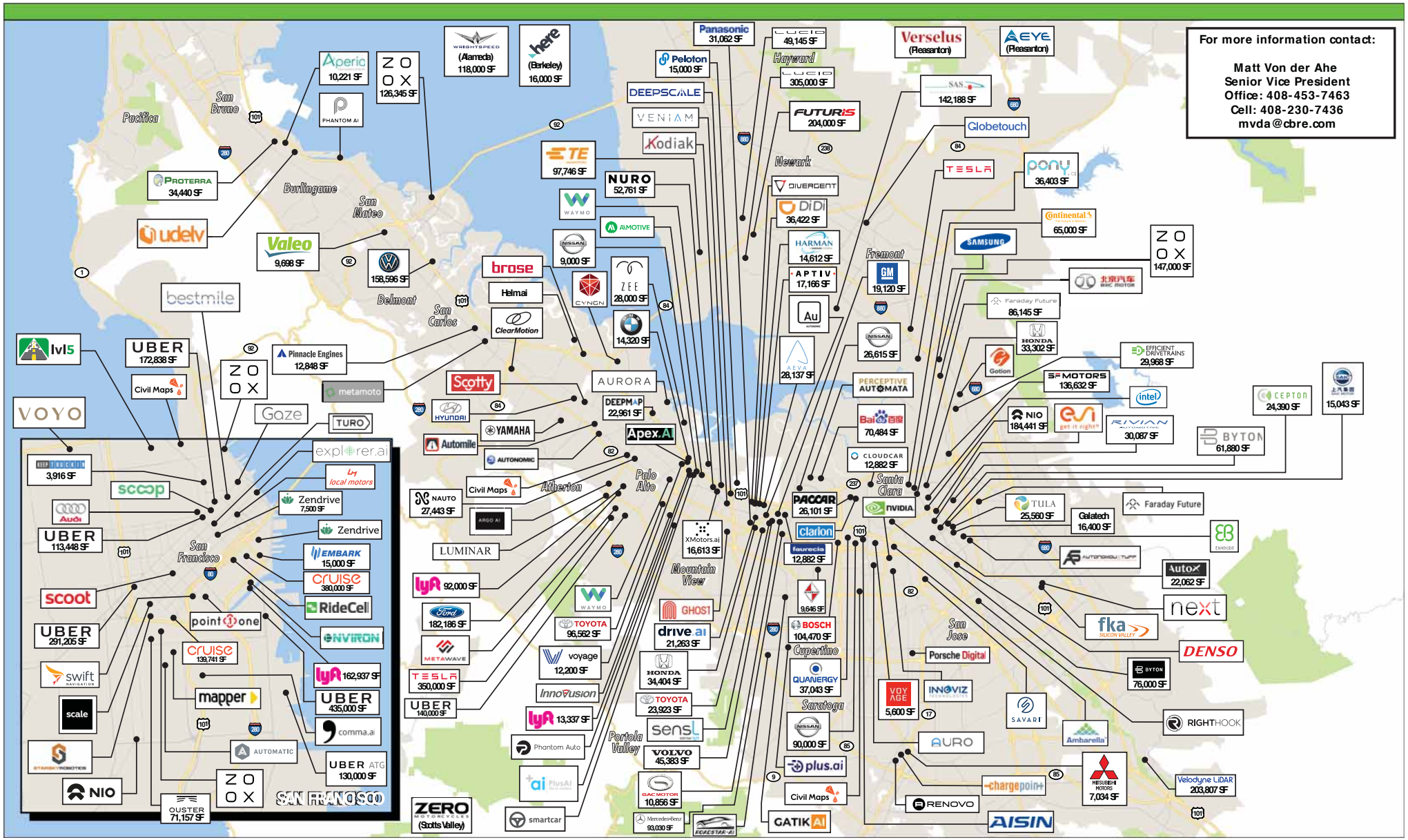
AUTO LAB MAP OCTOBER 2018 SILICON VALLEY



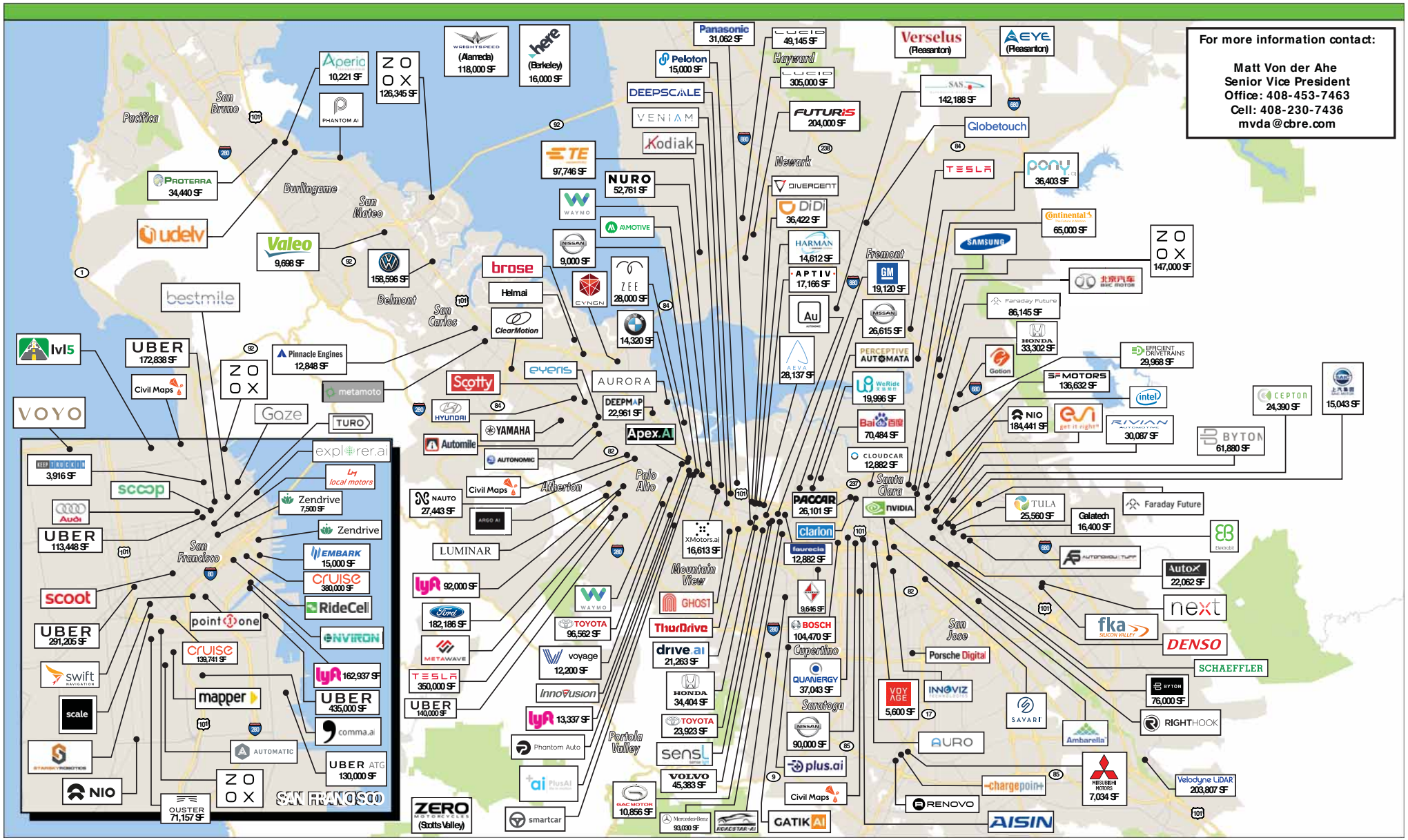
AUTO LAB MAP NOVEMBER 2018 SILICON VALLEY



AUTO LAB MAP DECEMBER 2018 SILICON VALLEY



AUTO LAB MAP JANUARY 2019 SILICON VALLEY



The Drone Market Environment 2019

Hardware

Drone Platforms

Agriculture

Delivery Systems

Safety & Security

Lighter-Than-Air

Drone-in-a-Box

Helicopter

Fixed-Wing

VTOL Fixed-Wing

Recreational

Passenger Drones / eVTOLs / Air Taxis

Counter-Drone Solutions

Components & Systems

Cameras, Imagining and Vision Systems

Launch and Recovery Systems

Navigation & Guidance Systems

Propulsion & Power

Data and Communication

Software

Flight, Fleet & Operation Management

Open Source Infrastructure, SDK

Navigation, CV and AI

UTM, LAANC Suppliers

Data Analytics, Workflow, CV and AI

Services

Drone-as-a-Service Providers

Delivery

Drone Show Providers

Education, Simulation, Training

System Integration, Engineering, Advisory

Maintenance

Supplier, Retailers

Test Sites

Market Research & Consulting

User Groups, Networks

Media, News, Blogs & Magazines

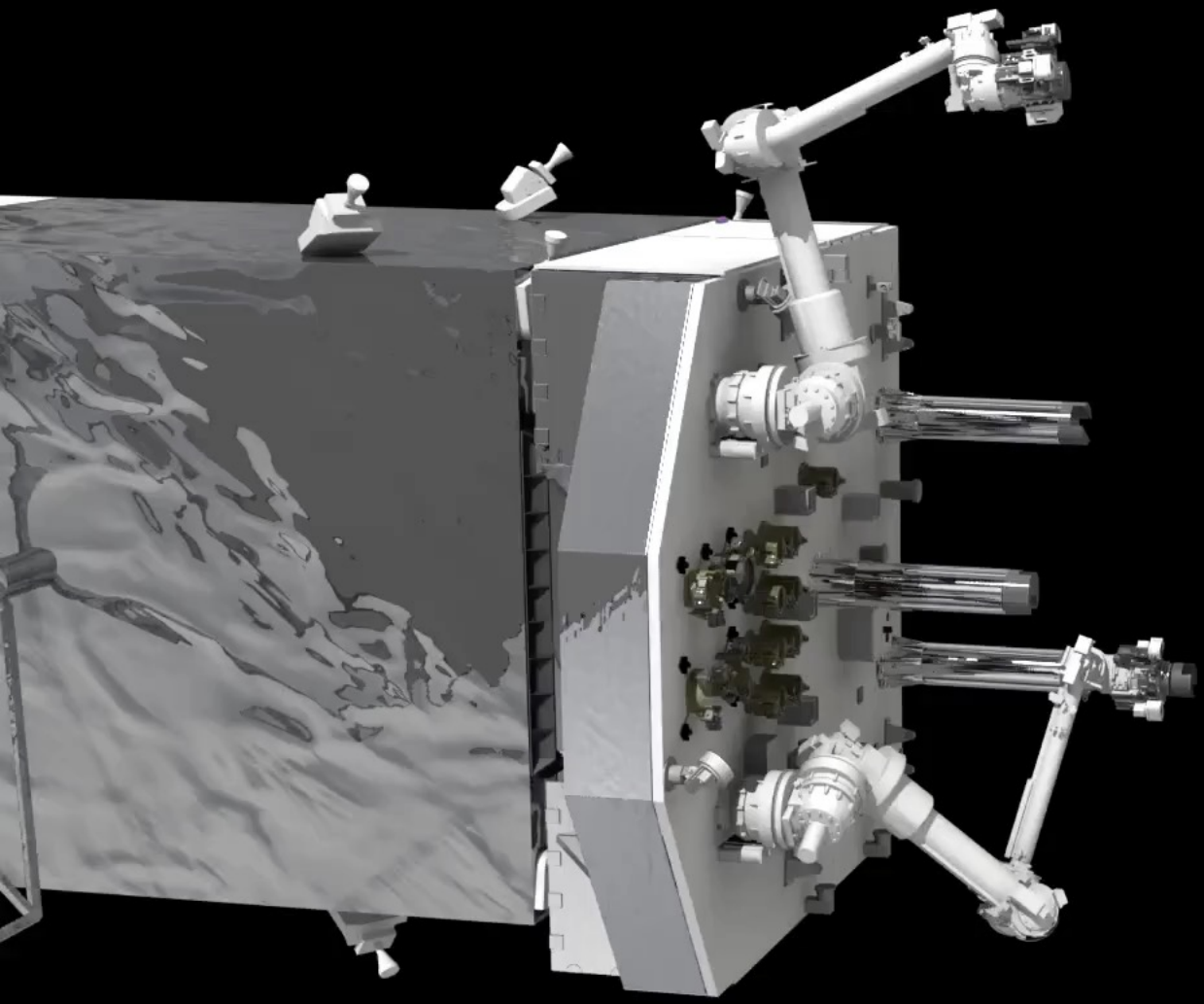
Podcast

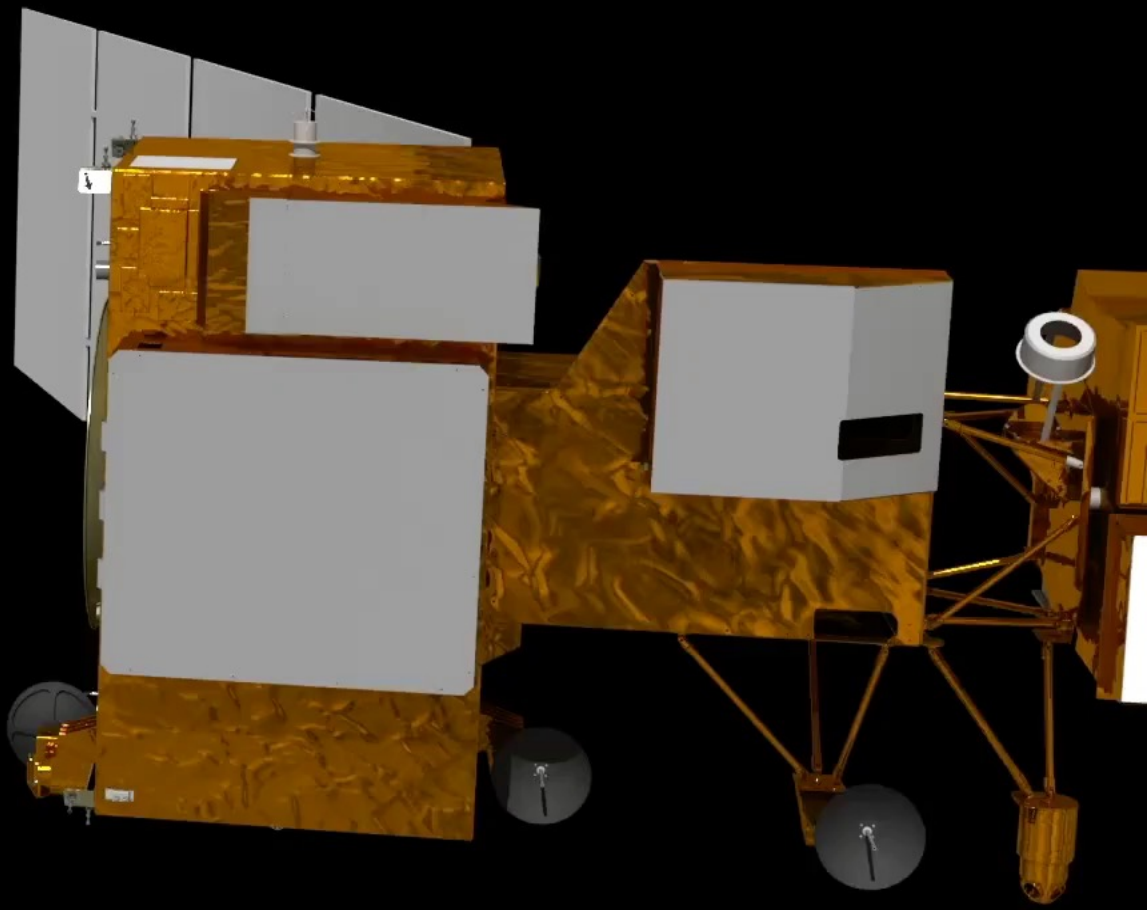
Marketplaces

Shows, Conferences, Events

Insurances

Coalitions, Organizations & Initiatives

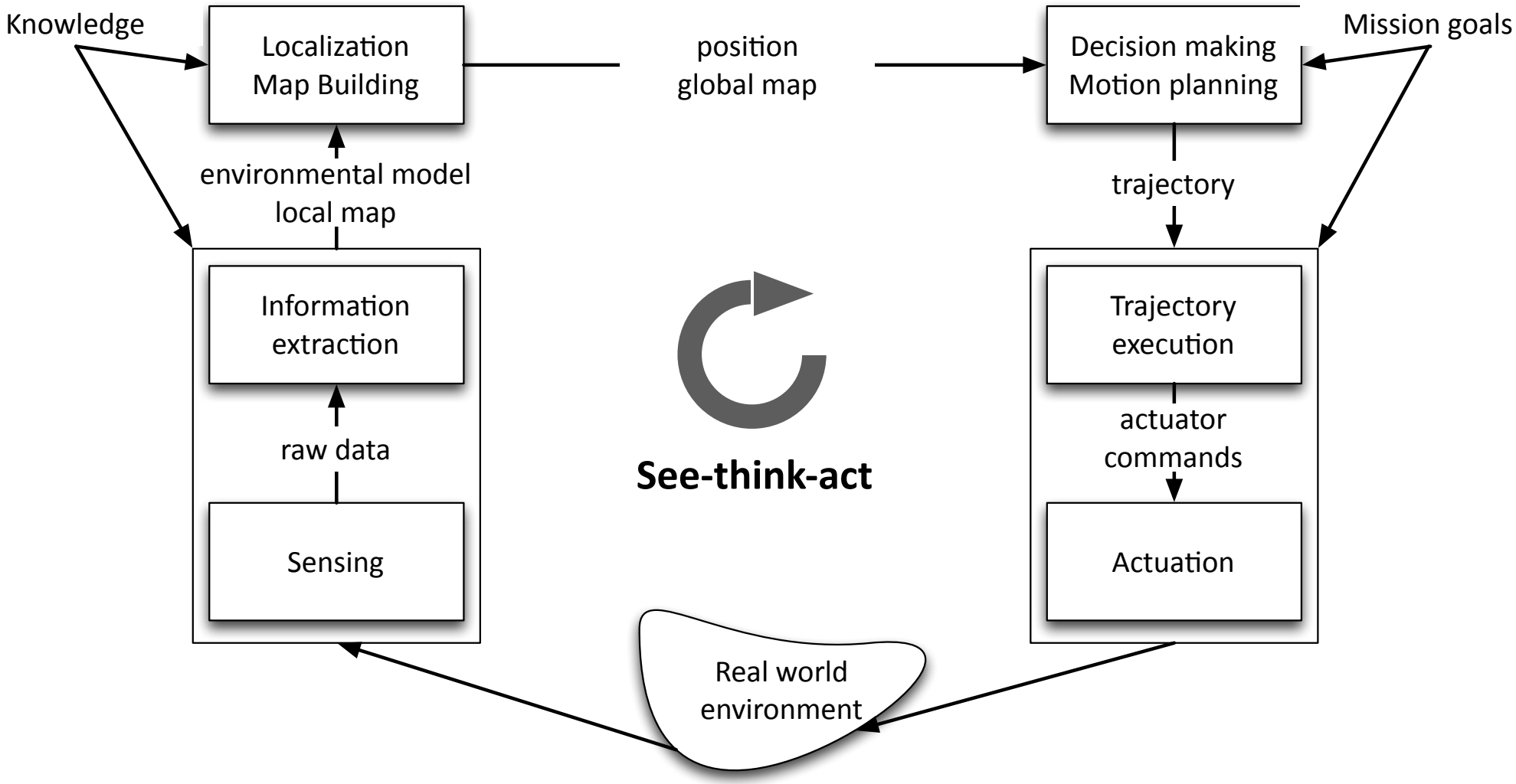




Course goals

- 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

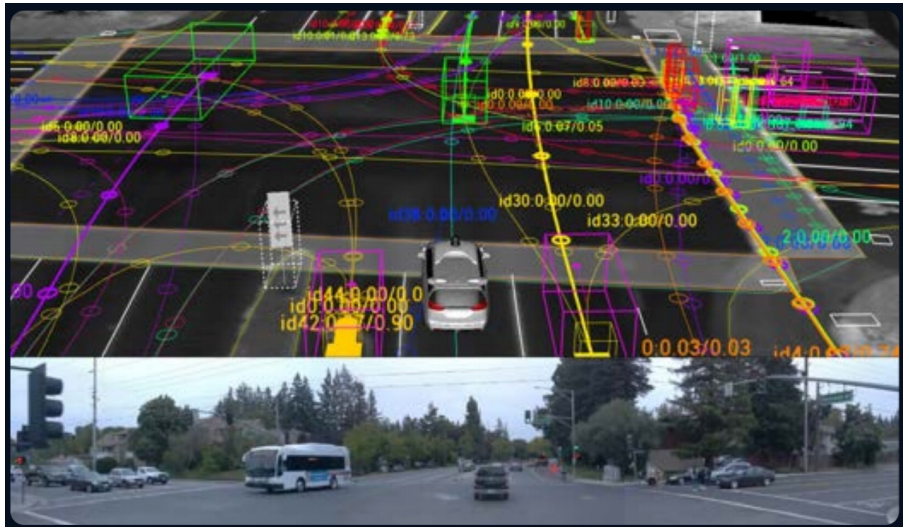
The see-think-act cycle



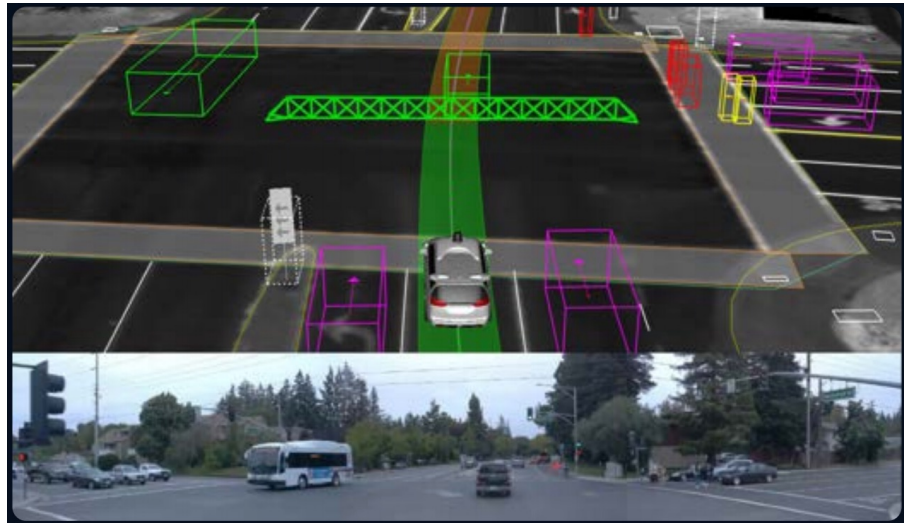
See-think-act cycle for AVs

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

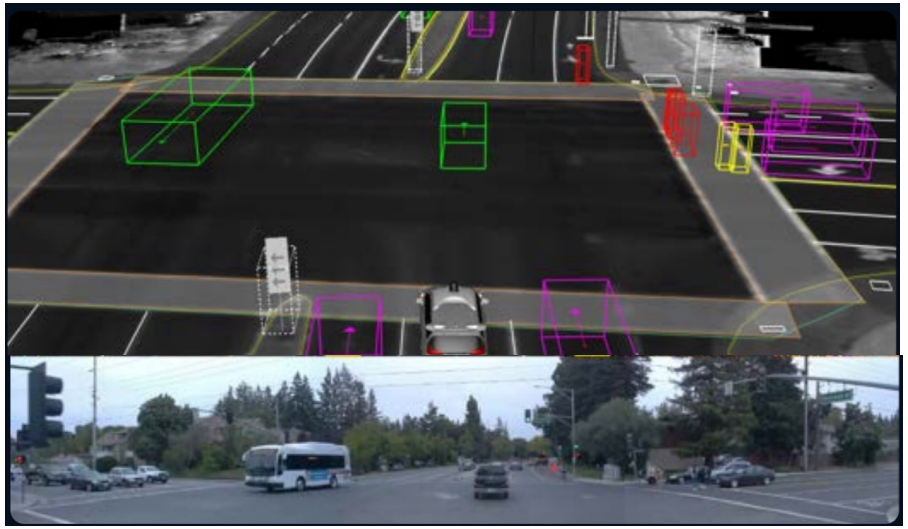
Think



Act



See



Waymo report, 2020

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

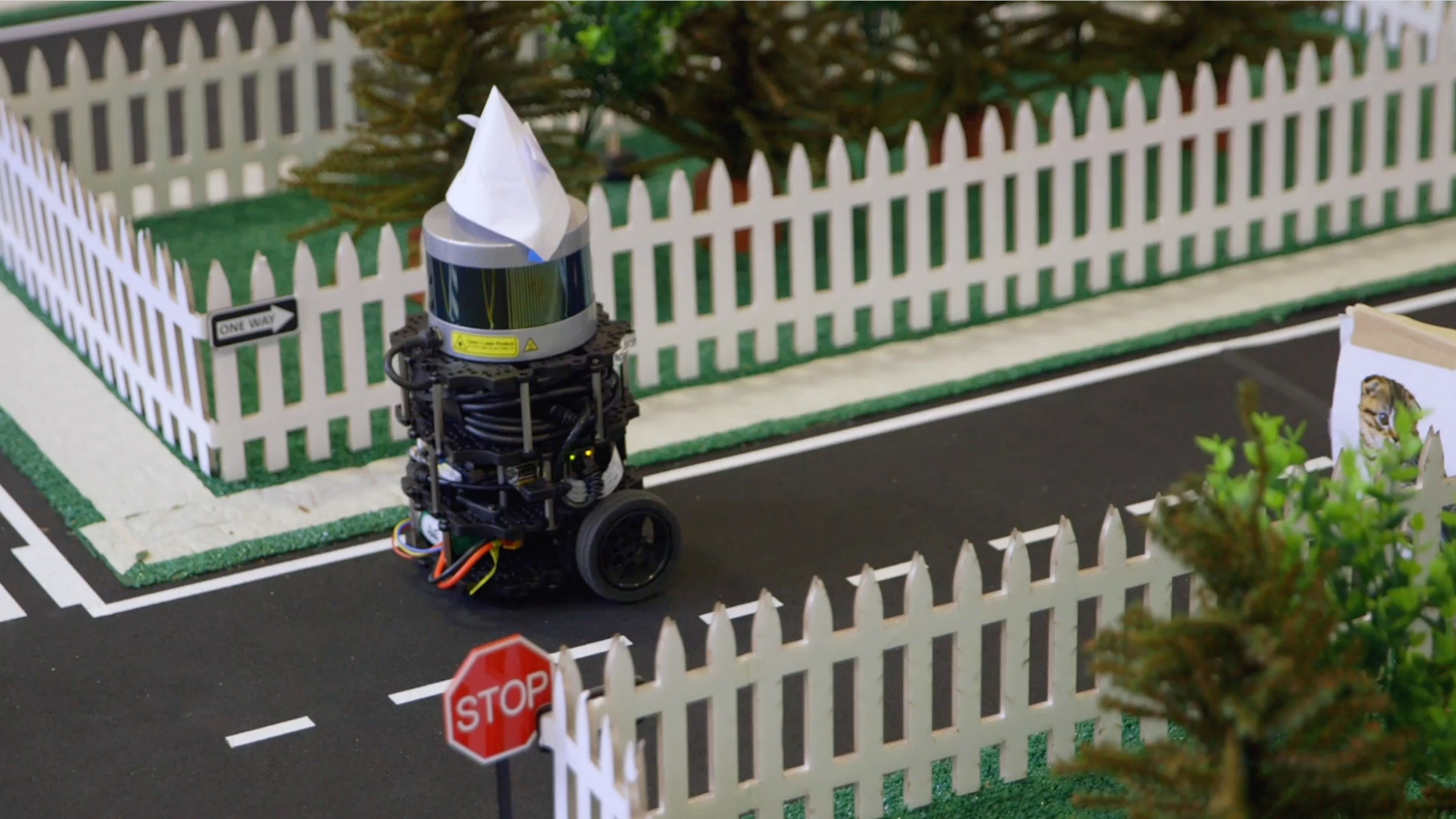
- Lectures:
  - Tuesdays and Thursdays, 10:30am – 11:50am (Shriram 104)

- 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.
  - Course assistants: Tuesdays, 2:00 – 4:00pm, and Thursdays, 4:00 – 6:00pm, room TBD.

- Course websites:
  - For course content: https://asl.stanford.edu/aa174a
  - For course announcements: https://canvas.stanford.edu/courses/180672
  - For course-related questions: https://edstem.org/us/courses/47593/discussion/
  - For homework submissions: https://www.gradescope.com/courses/623415
  - To contact the AA174A staff: aa174a-aut2324-staff@lists.stanford.edu


ONE WAY
STOP

Team

Instructor

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

CAs

Chris Agia

Luis Pabon

Alvin Sun

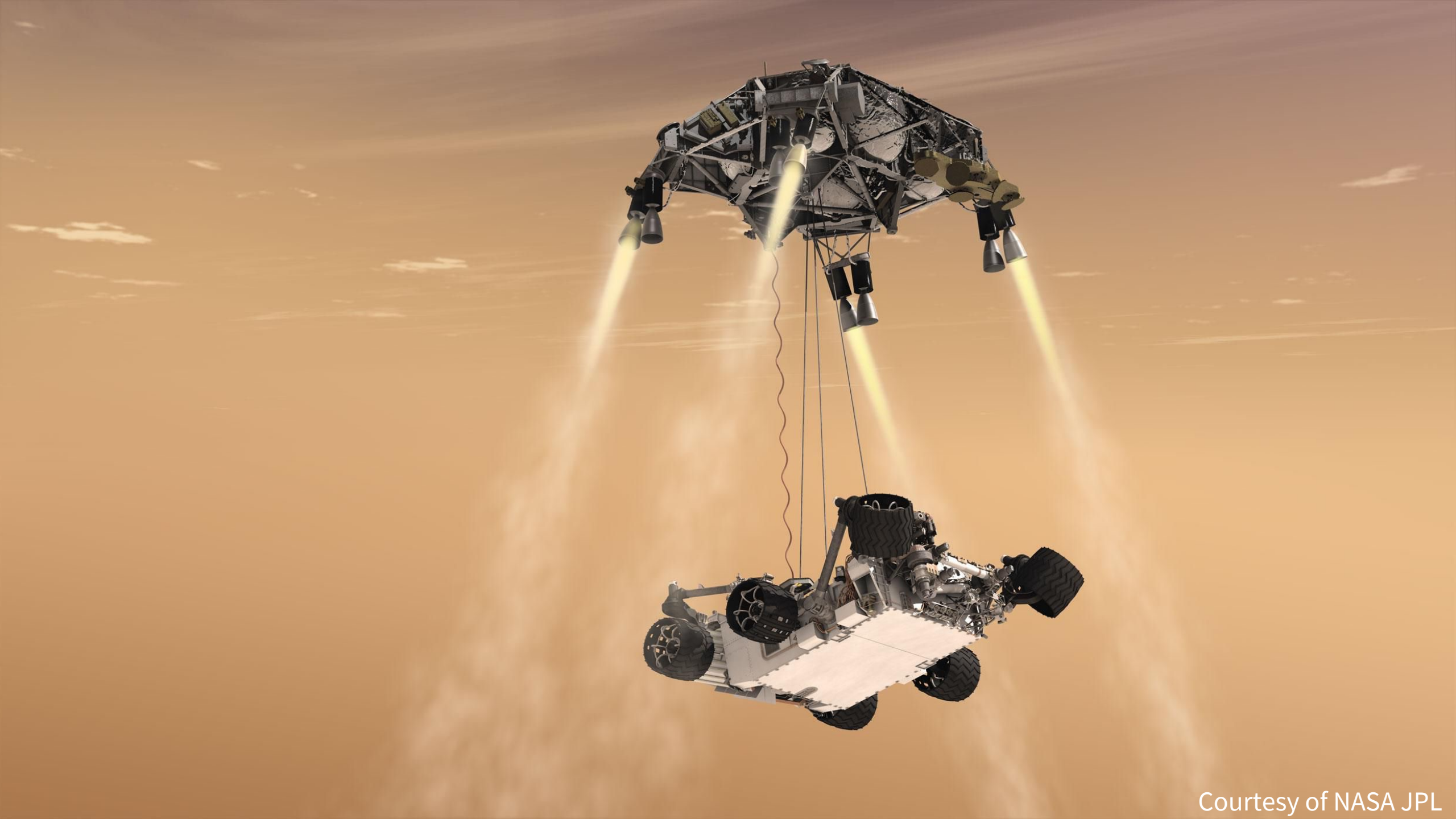
Collaborators

- Daniel Watzenig

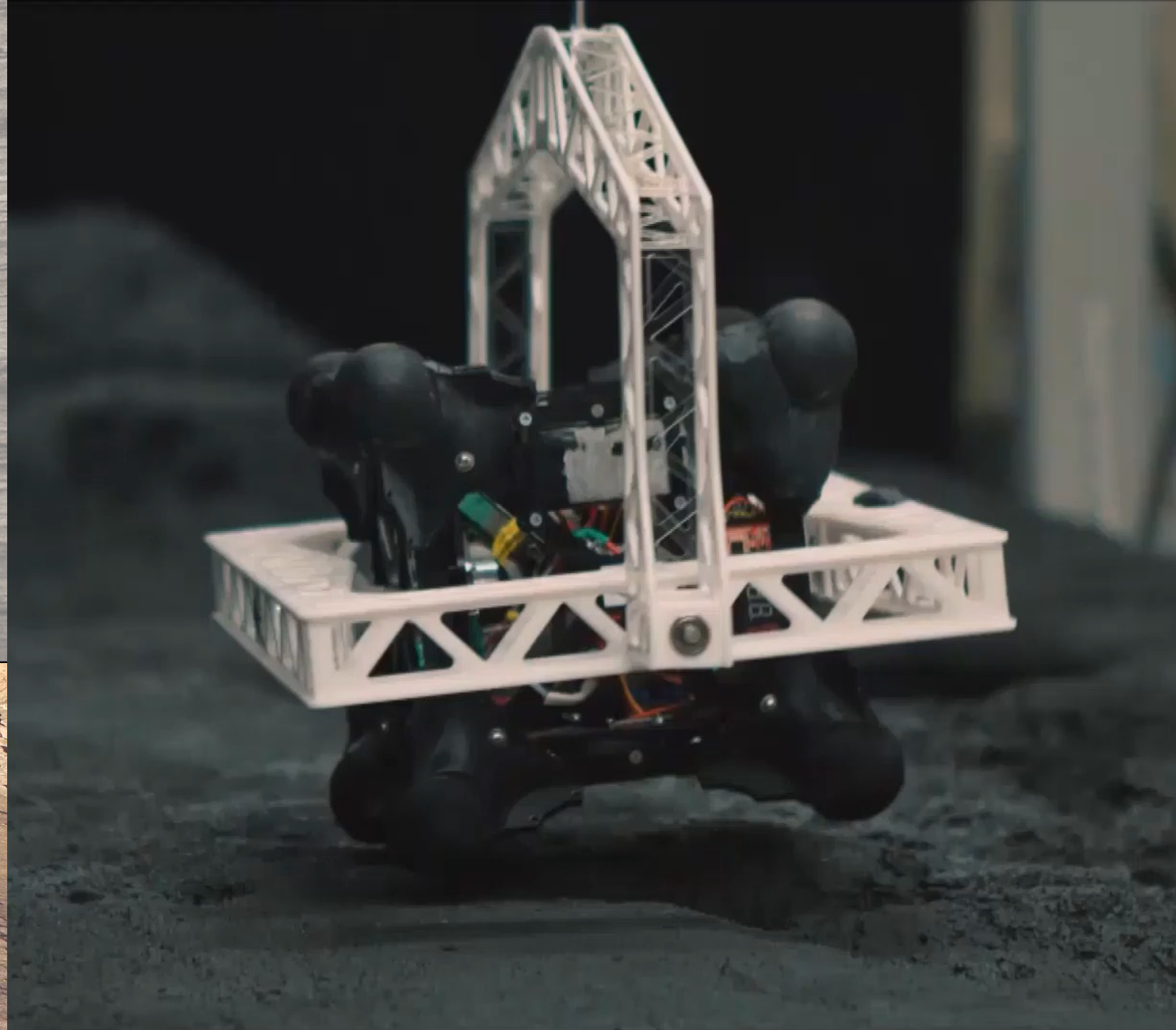
Labs

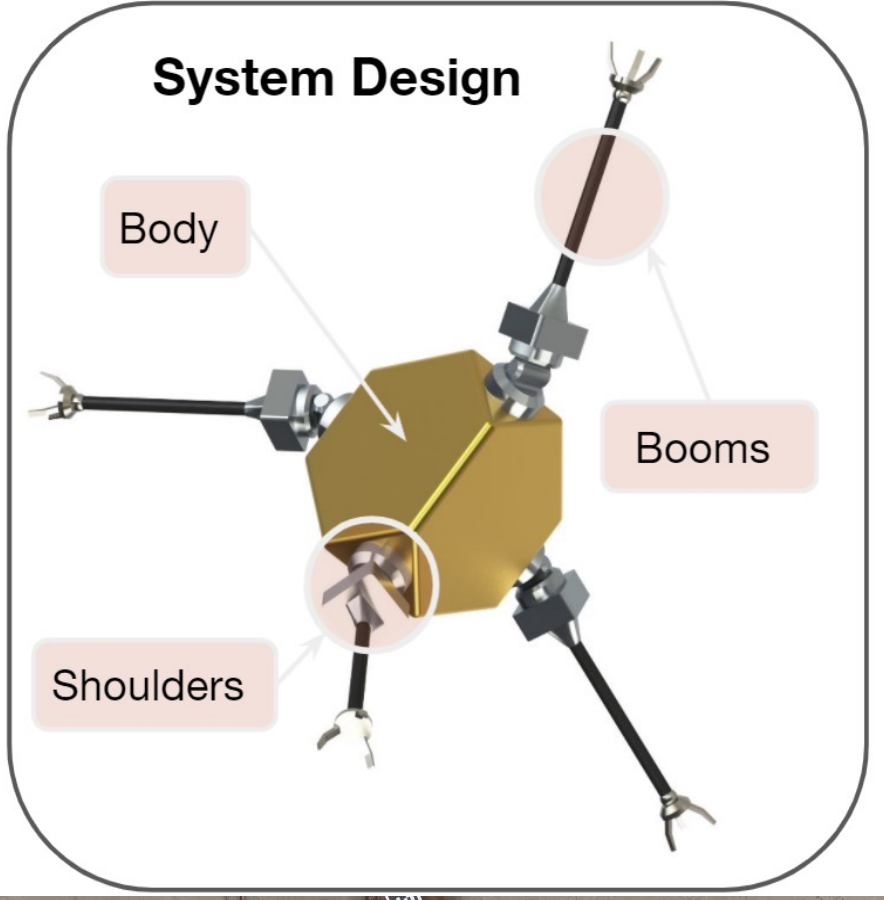
ASL
Autonomous Systems Lab

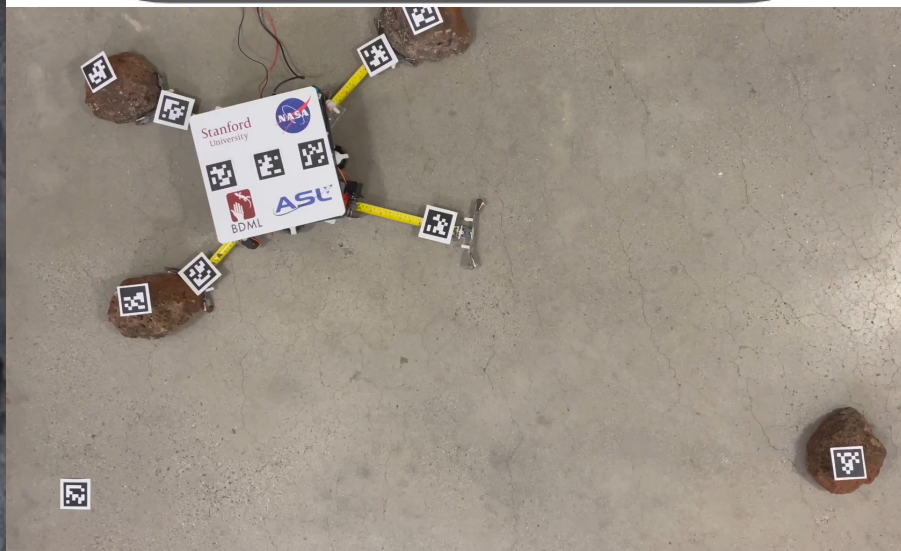
CARS
Center for Automotive
Research at Stanford



Courtesy of NASA JPL




System Design
Body
Booms
Shoulders


Stanford University
NASA
BDML
ASL

FIRE PORT

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
09/26	Course overview, intro to robotic systems and ROS	
09/28	Fundamentals of ROS	
09/29	⋆ Section 1 – intro to UNIX environment	
10/03	State space dynamics – definitions and modeling	HW1 out
10/05	State space dynamics – computation and simulation	
10/06	⋆ Section 2 – ROS2 packages, publication, and subscription	
10/10	Trajectory optimization	
10/12	Trajectory tracking & closed-loop control	
10/13	⋆ Section 3 – ROS2 launch files & RVIZ	
10/17	Graph search algorithms	HW1 due, HW2 out
10/19	Sampling-based motion planning	
10/20	⋆ Section 4 – heading control	
10/24	Robotic sensors & introduction to computer vision	
10/26	Camera models & coordinate frames	
10/27	⋆ Section 5 – point-to-point navigation 1	
10/31	Image processing & information extraction	HW2 due, HW3 out
11/02	Visual camera tracking & control	
11/03	⋆ Section 6 – point-to-point navigation 2	
11/07	No Lecture – Democracy Day	
11/09	*In-class midterm*	
11/10	⋆ No Section	
11/14	Deep learning for computer vision	
11/16	Intro to state estimation & filtering theory	
11/17	⋆ Section 7 – object detection	HW3 due, HW4 out
11/21		
11/23	*Thanksgiving*	
11/24		
11/28	Parametric filtering (KF and EKF)	
11/30	Object tracking and EKF localization	
12/01	⋆ Section 8 – frontier exploration	
12/05	Multi-sensor perception & sensor fusion	
12/07	Simultaneous localization and mapping (SLAM)	
12/08	⋆ Section 9 (optional) – extra credit work	HW4 due

Robot Operating System – History

ROS 1

2014 - 2019

2016 - 2021

2018 - 2023

2020 - 2025

ROS 2

2019 - 2021

2020 - 2023

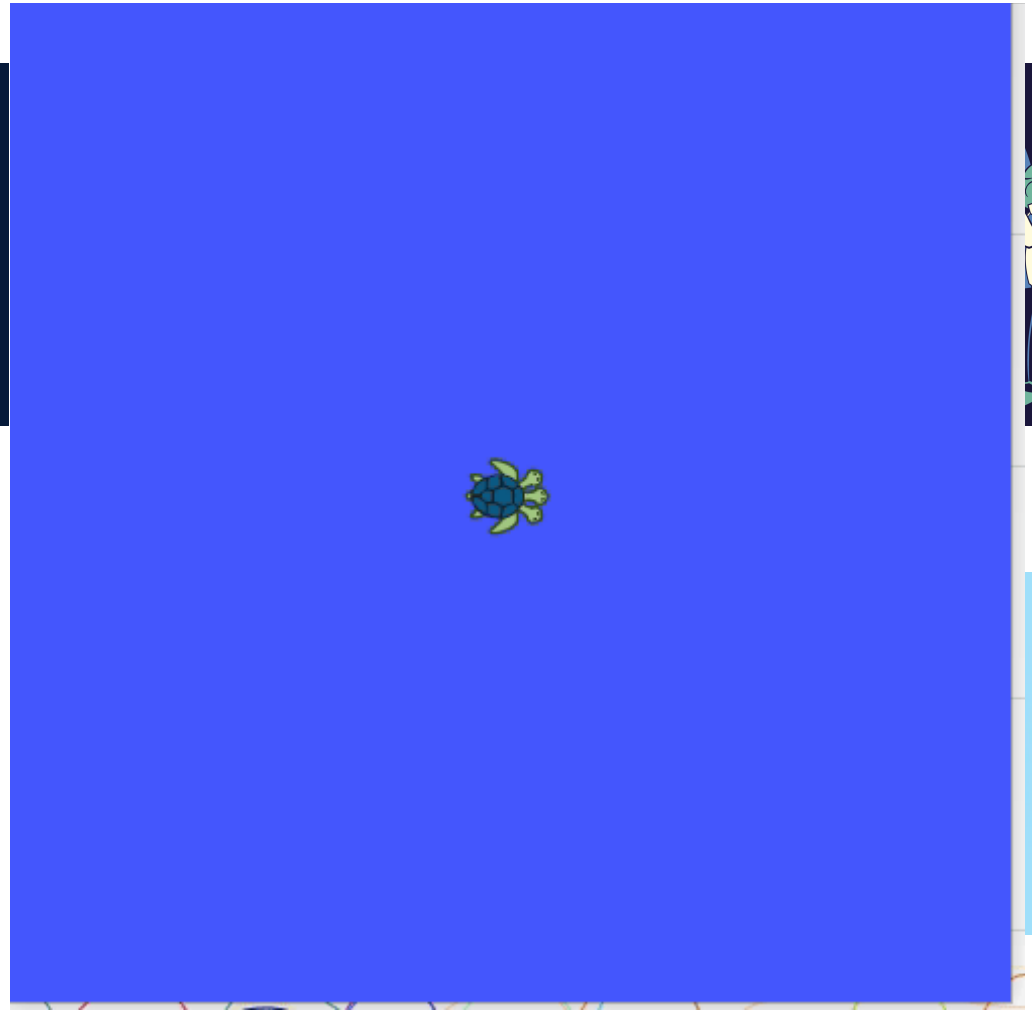
2022 - 2027

2017 - Present

Robot Operating System – History

ROS 1

2014 - 2019



2020 - 2025

ROS 2

2019 - 2021

2017 - Present

Robot Operating System – History

ROS 1

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2018 - 2023

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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

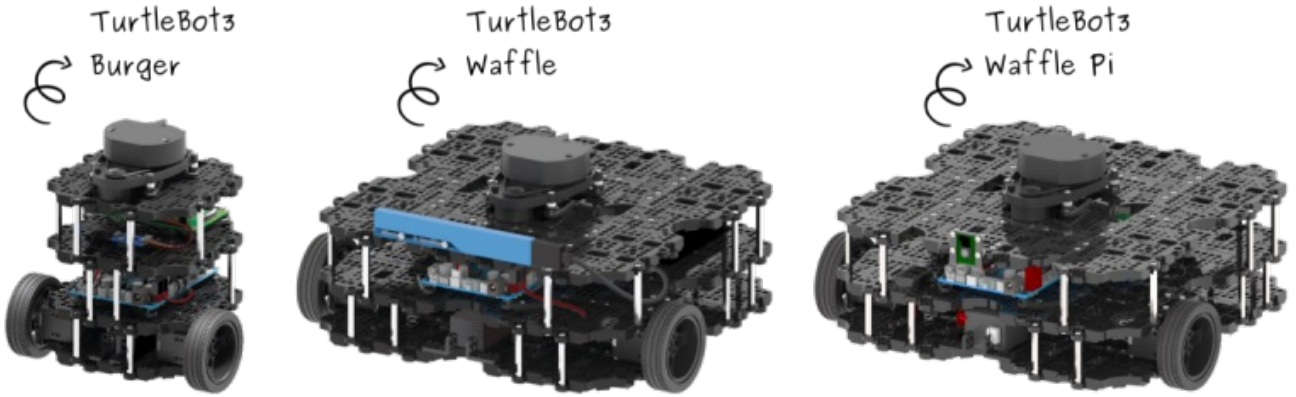
- Community & Ecosystem
  - Hardware Drivers
  - Software

Robot Operating System – ROS2

- Community & Ecosystem
  - Hardware Drivers
  - Software

Crazyflie

Joysticks

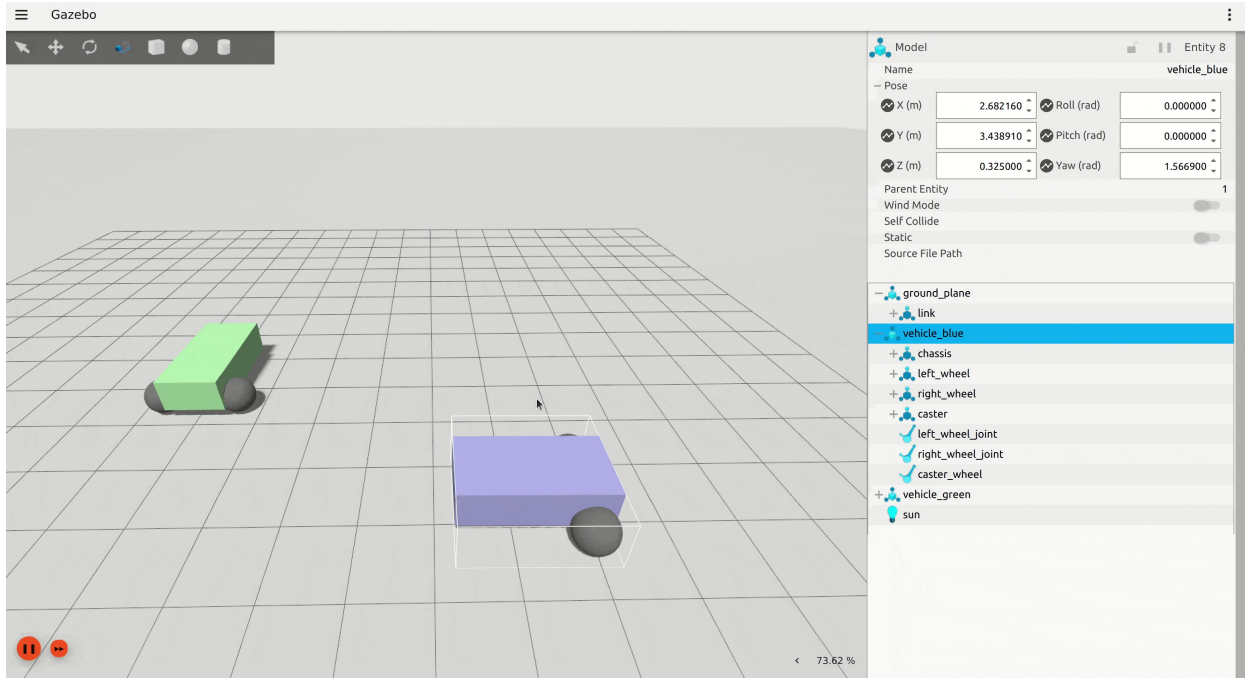


Turtlebot3

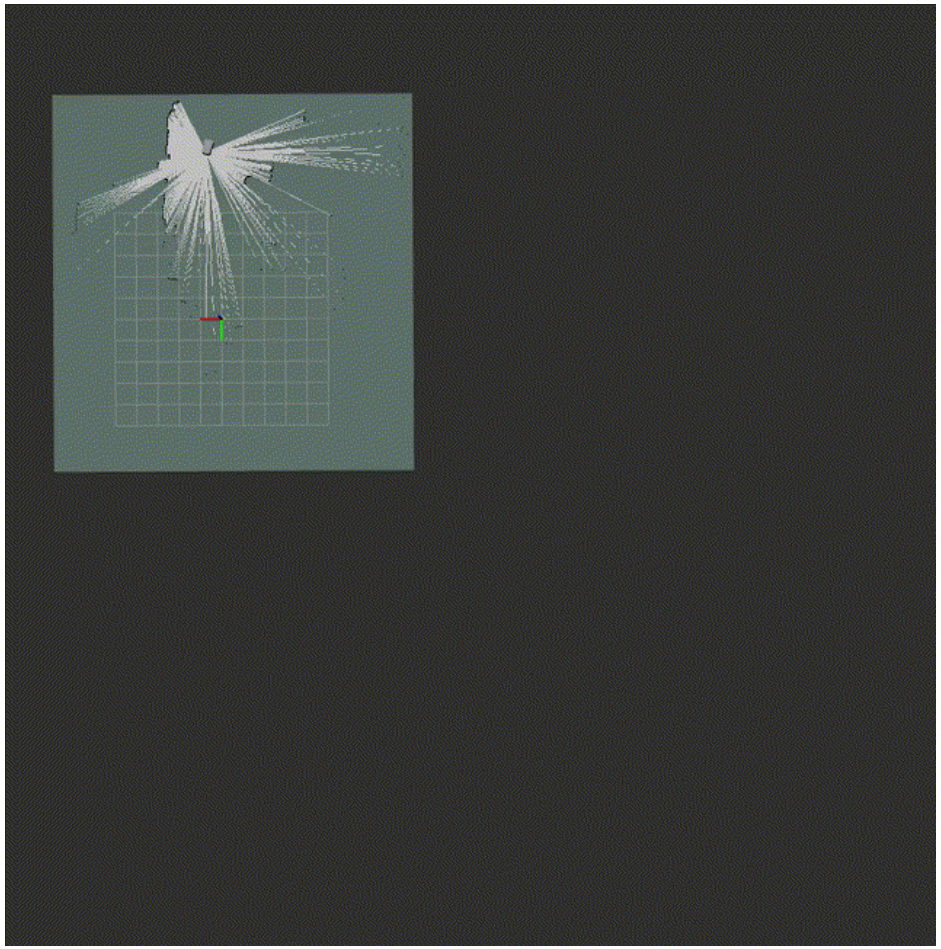
Velodyne LiDAR

Robot Operating System – ROS2

- Community & Ecosystem
  - Hardware Drivers
  - Software



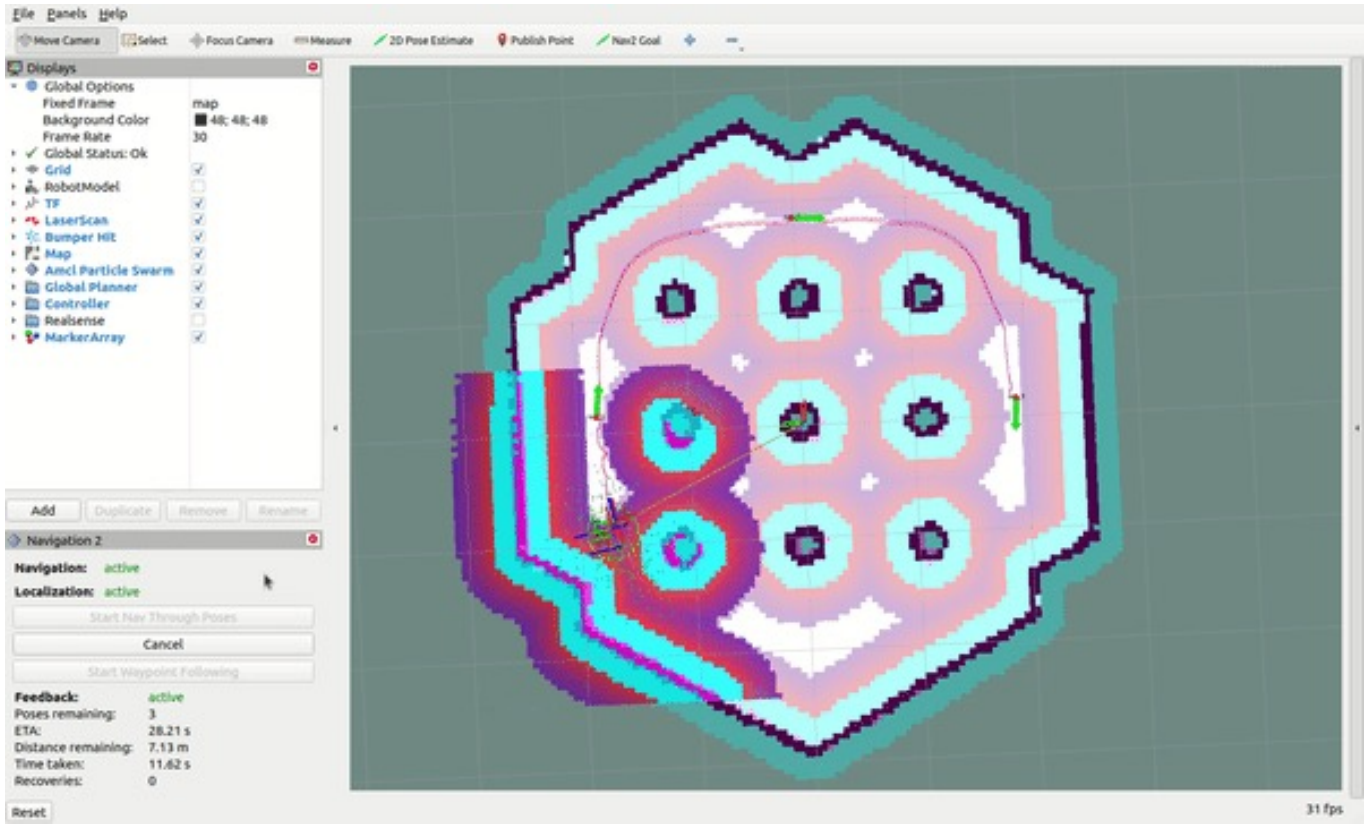
Gazebo Sim



SLAM Toolbox

Robot Operating System – ROS2

- Community & Ecosystem
  - Hardware Drivers
  - Software
- Tooling
  - Visualization
  - Debugging



Robot Operating System – ROS2

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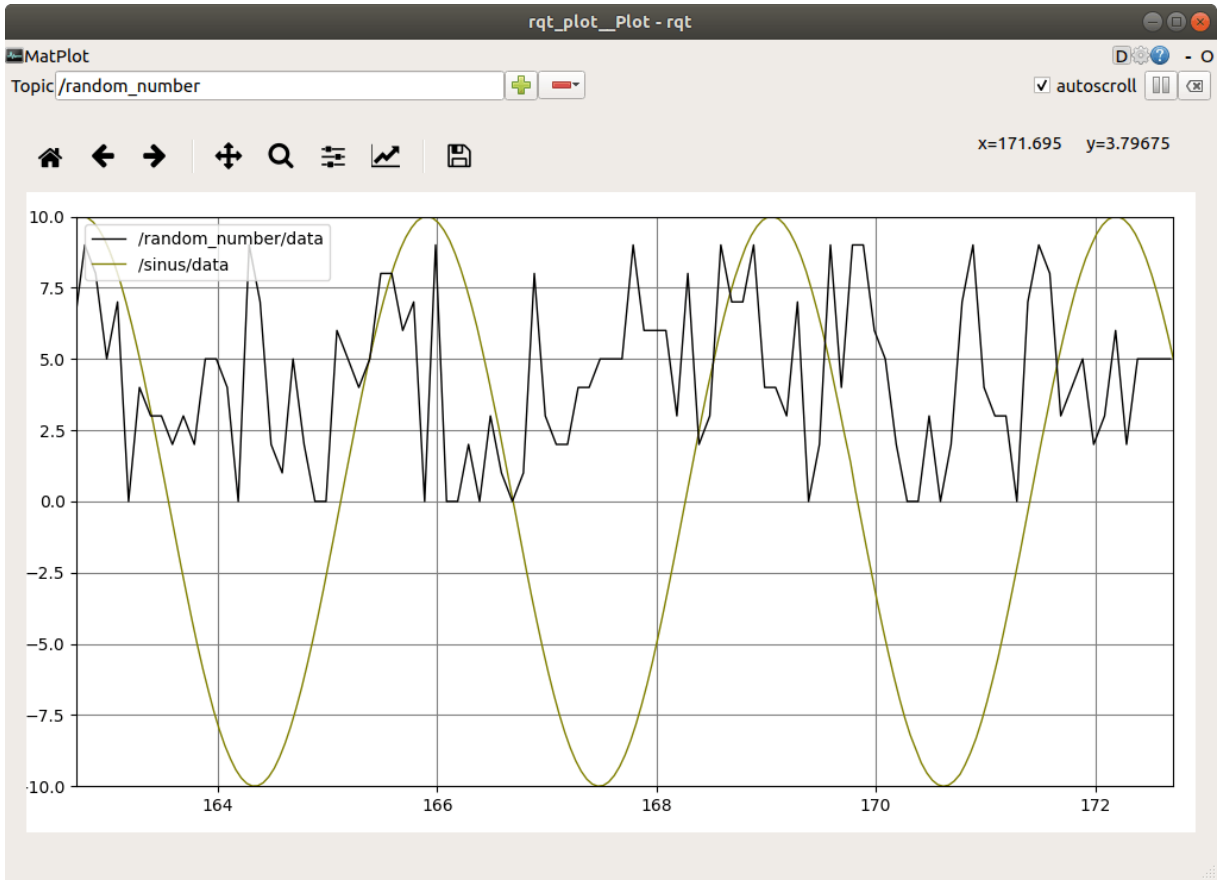

Robot Operating System – ROS2

- Community & Ecosystem
  - Hardware Drivers
  - Software
- Tooling
  - Visualization
  - Debugging

Turtlebot Autonomy Demo

Robot Operating System – ROS2

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

See-think-act

Robot Operating System – ROS2

- Community & Ecosystem
  - Hardware Drivers
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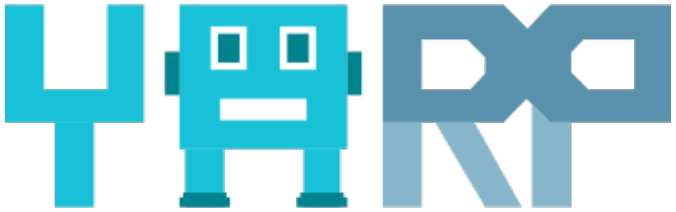
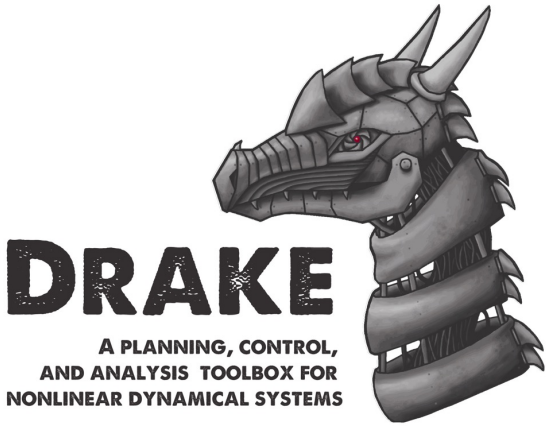
  - Debugging
- Asynchronous Programming Model

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