

Principles of Robot Autonomy I

Course overview, intro to robotic systems and ROS



Stanford
University



From automation...



...to autonomy

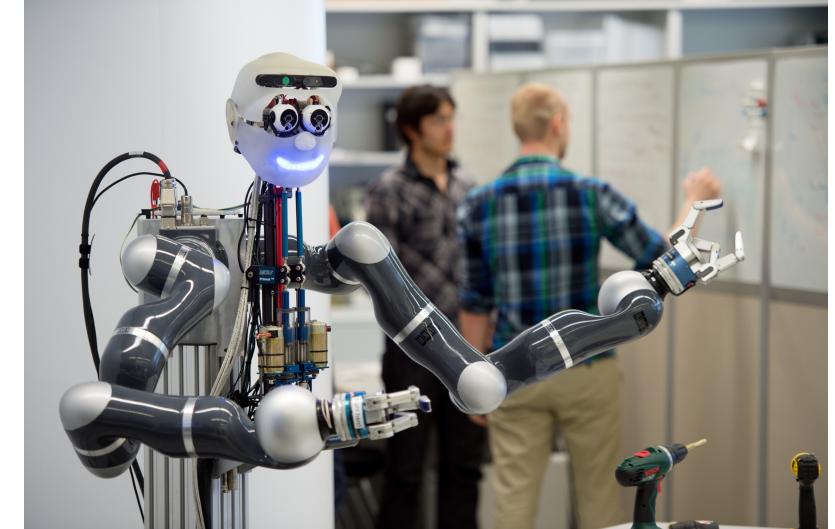
Waymo Self-Driving Car



Intuitive DaVinci Surgical Robot



Apollo Robot at MPI



Boston Dynamics – Spot Mini



Astrobee - NASA



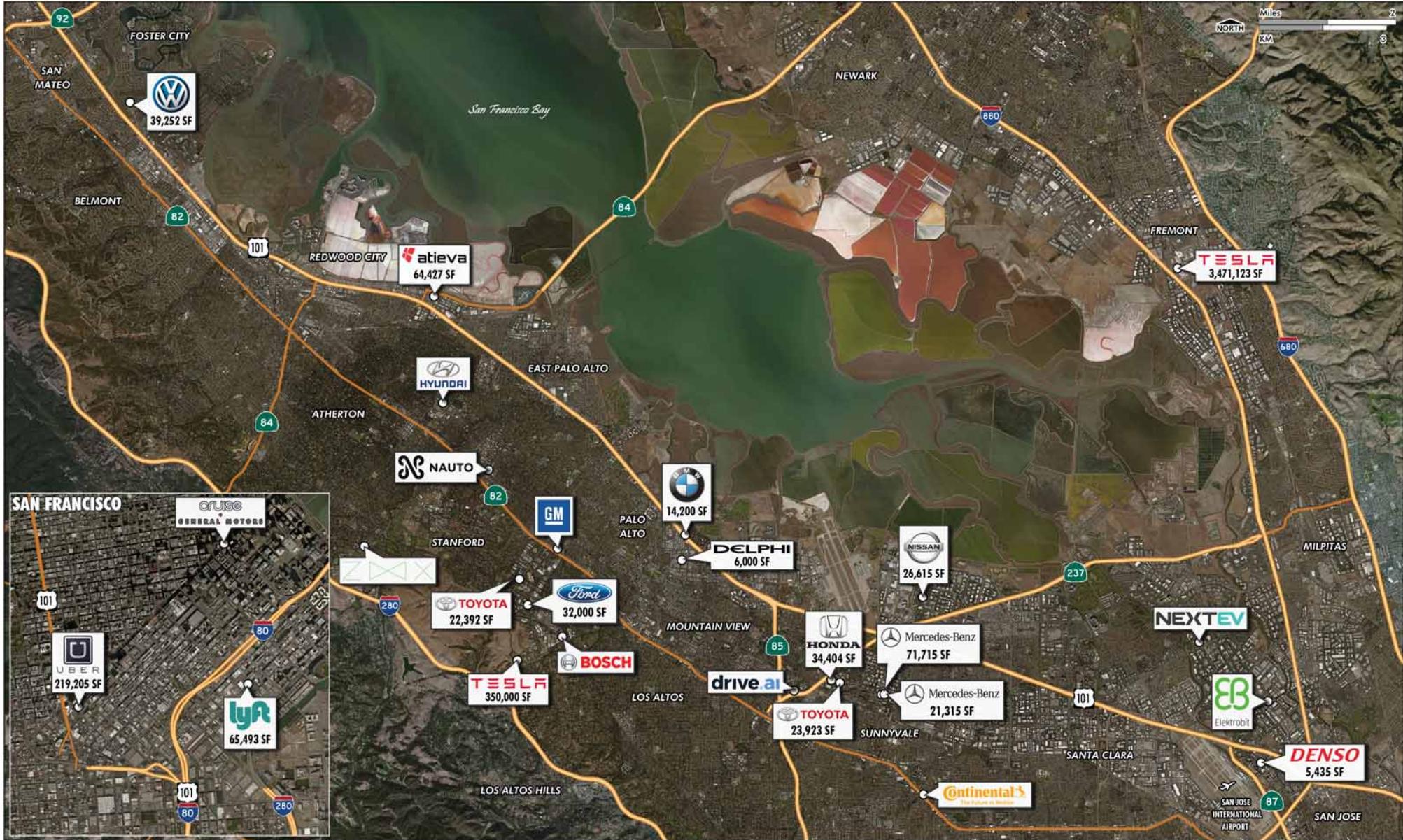
Zipline

February 2014

Silicon Valley

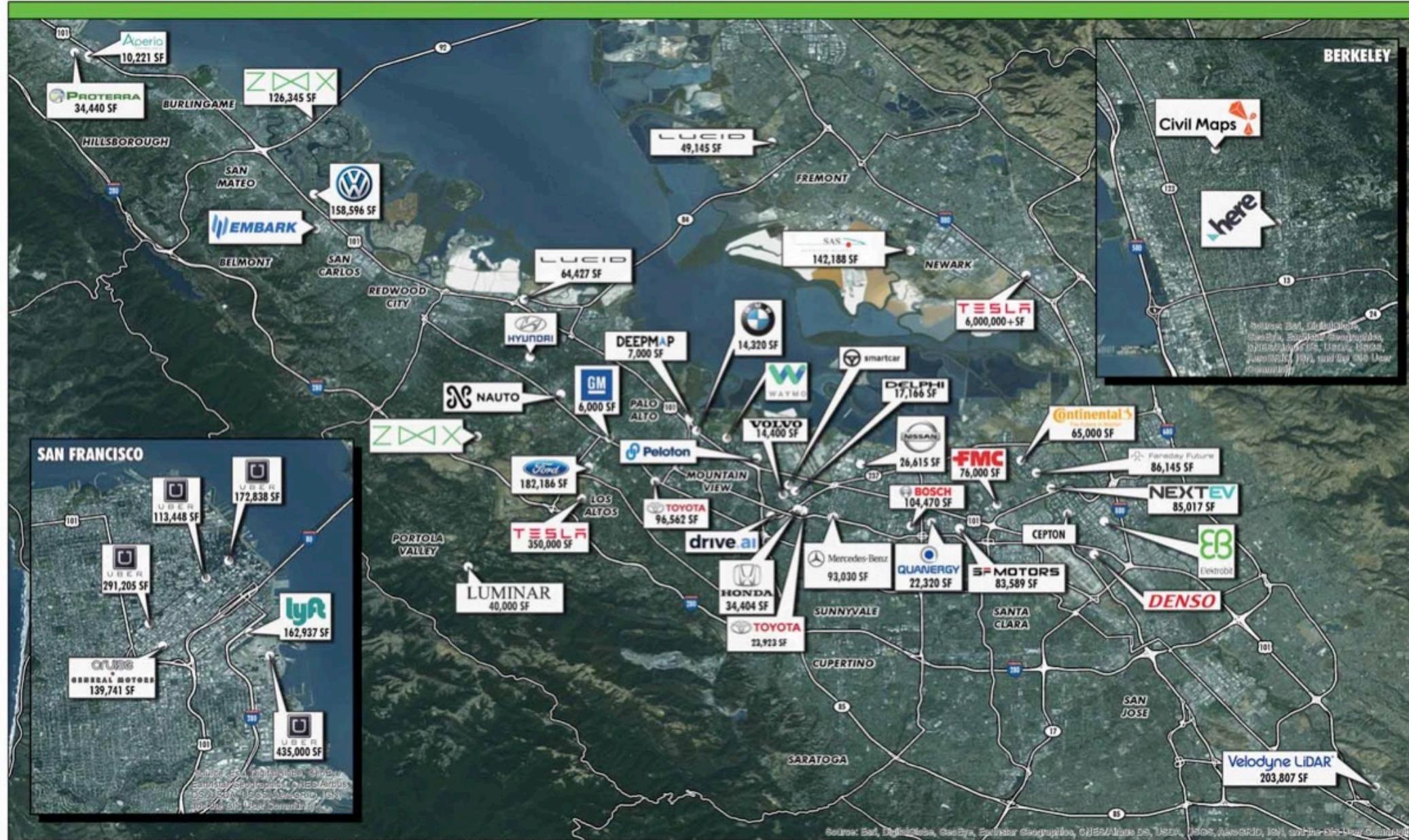


Silicon Valley



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AUTO LAB MAP APRIL 2017 SILICON VALLEY



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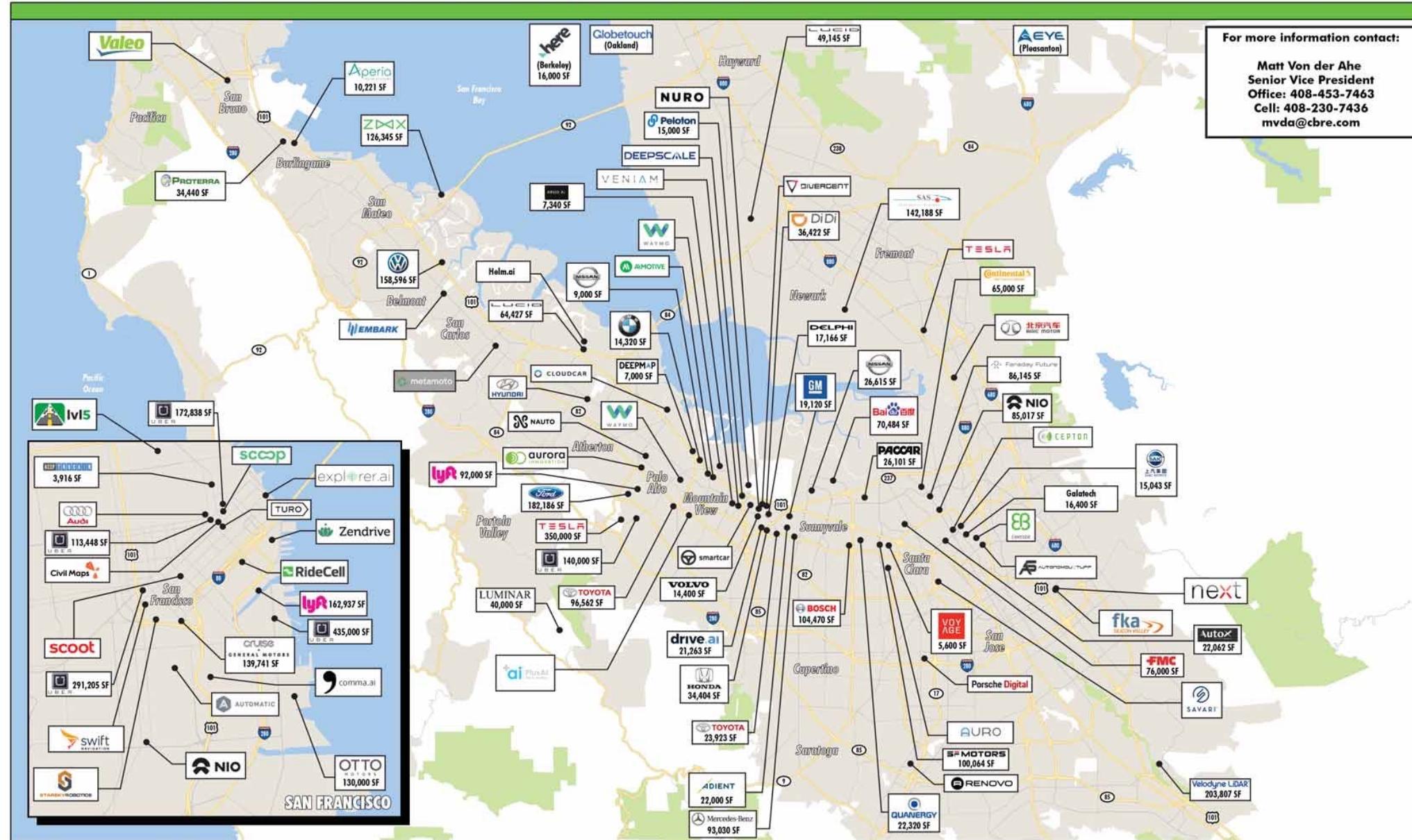
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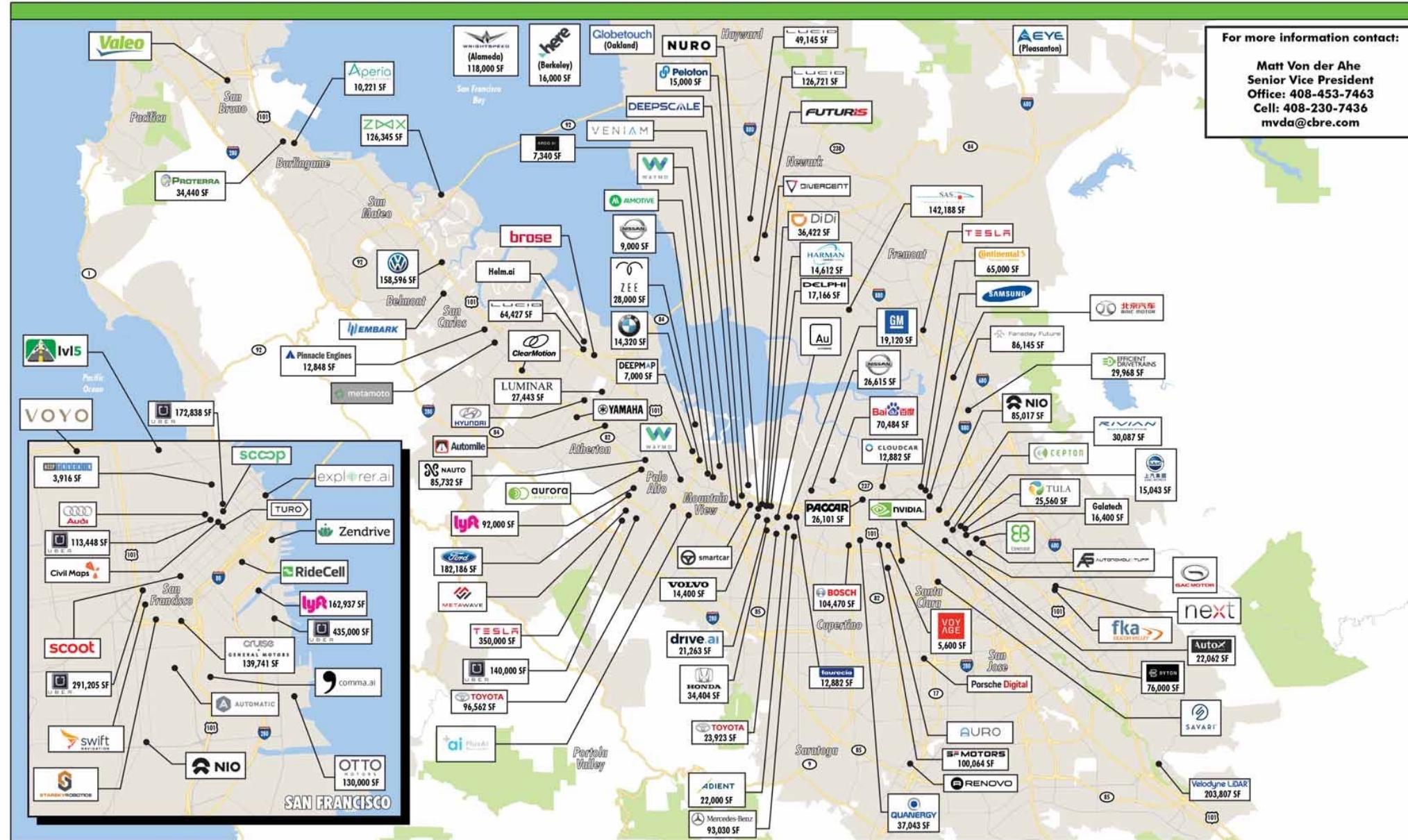
0 1.5 3 6 Miles

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AUTO LAB MAP DECEMBER 2017 SILICON VALLEY

For more information contact:

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mvda@cbre.com



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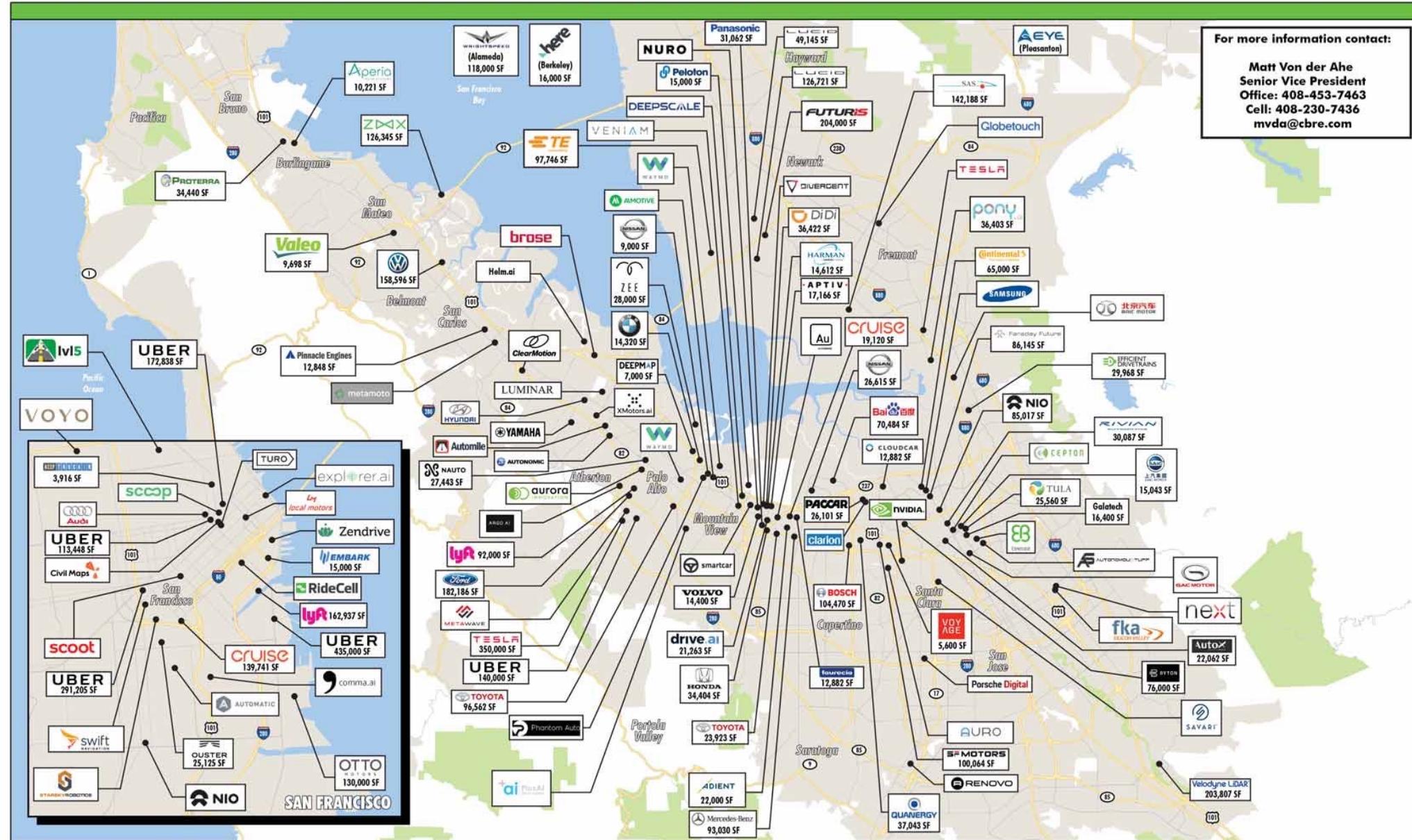
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A horizontal scale bar with tick marks at 0, 1.5, 3, and 6. The word "Miles" is written below the 6 mark.

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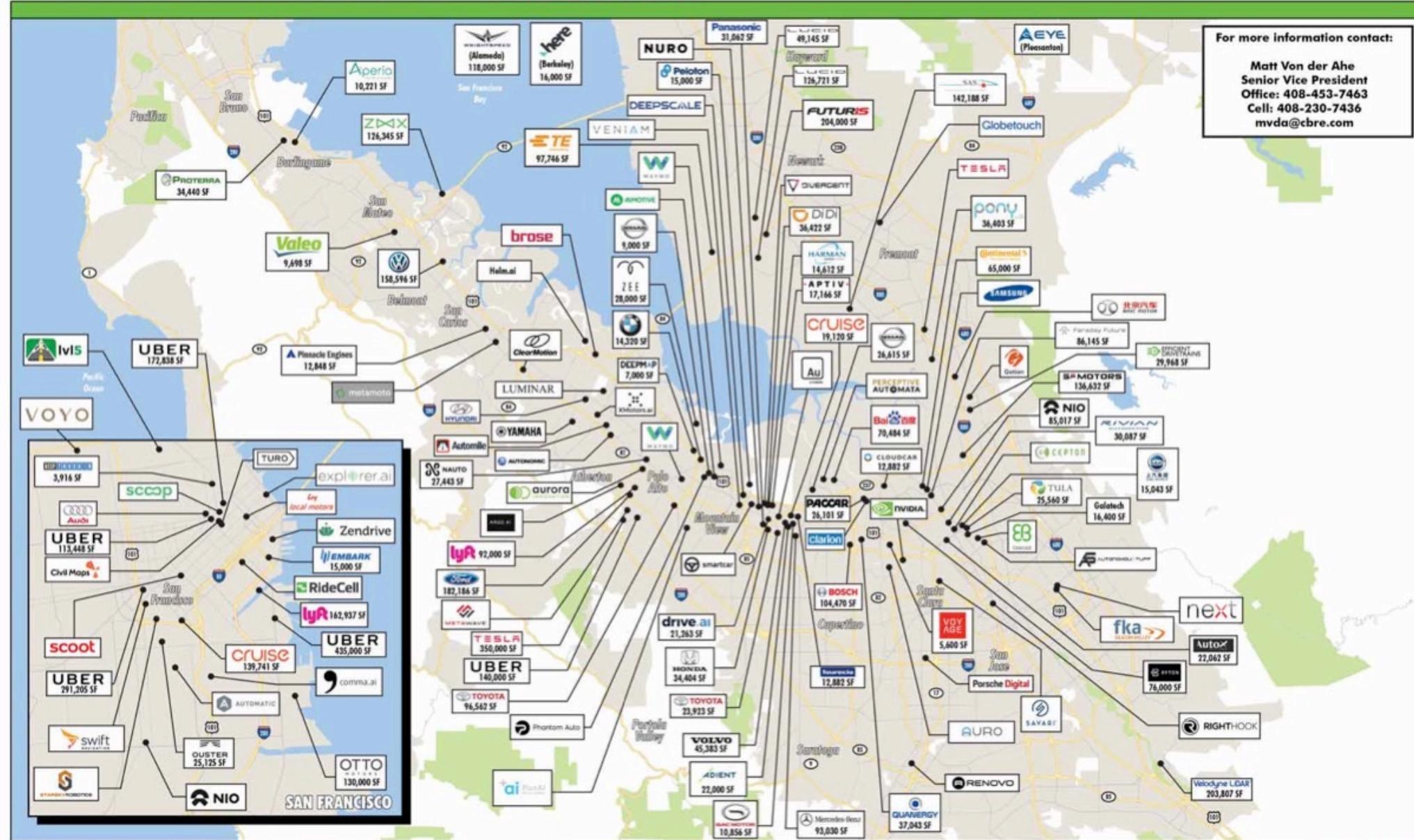
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A scale bar indicating distances in miles. The bar is divided into four segments by vertical tick marks. The first segment is labeled '0' at its left end. The second segment is labeled '1.5' at its right end. The third segment is labeled '3' at its right end. The fourth segment is labeled '6' at its right end. To the right of the fourth segment, the word 'Miles' is written vertically.



AUTO LAB MAP MARCH 2018 SILICON VALLEY



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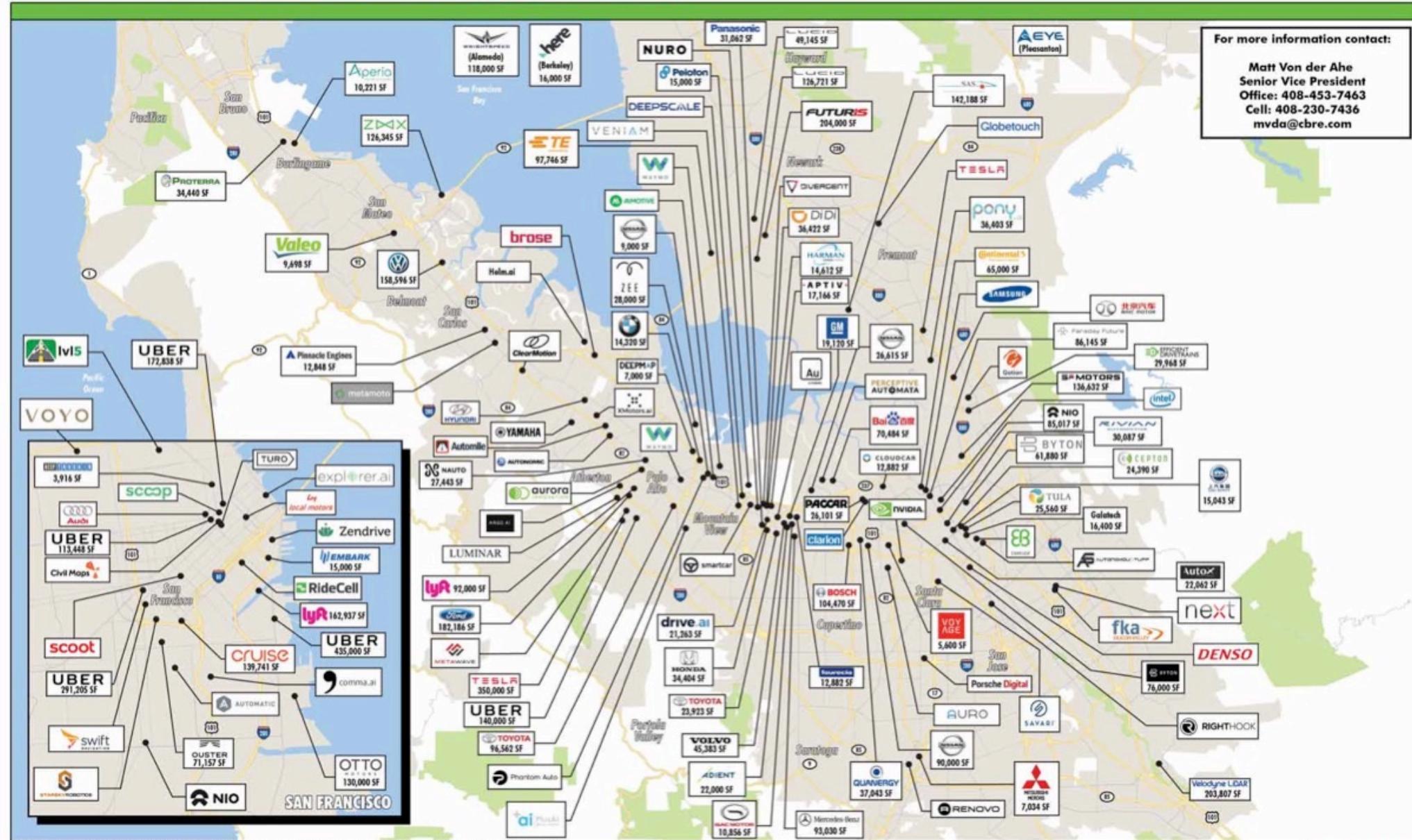
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0 1.5 3 6 Miles



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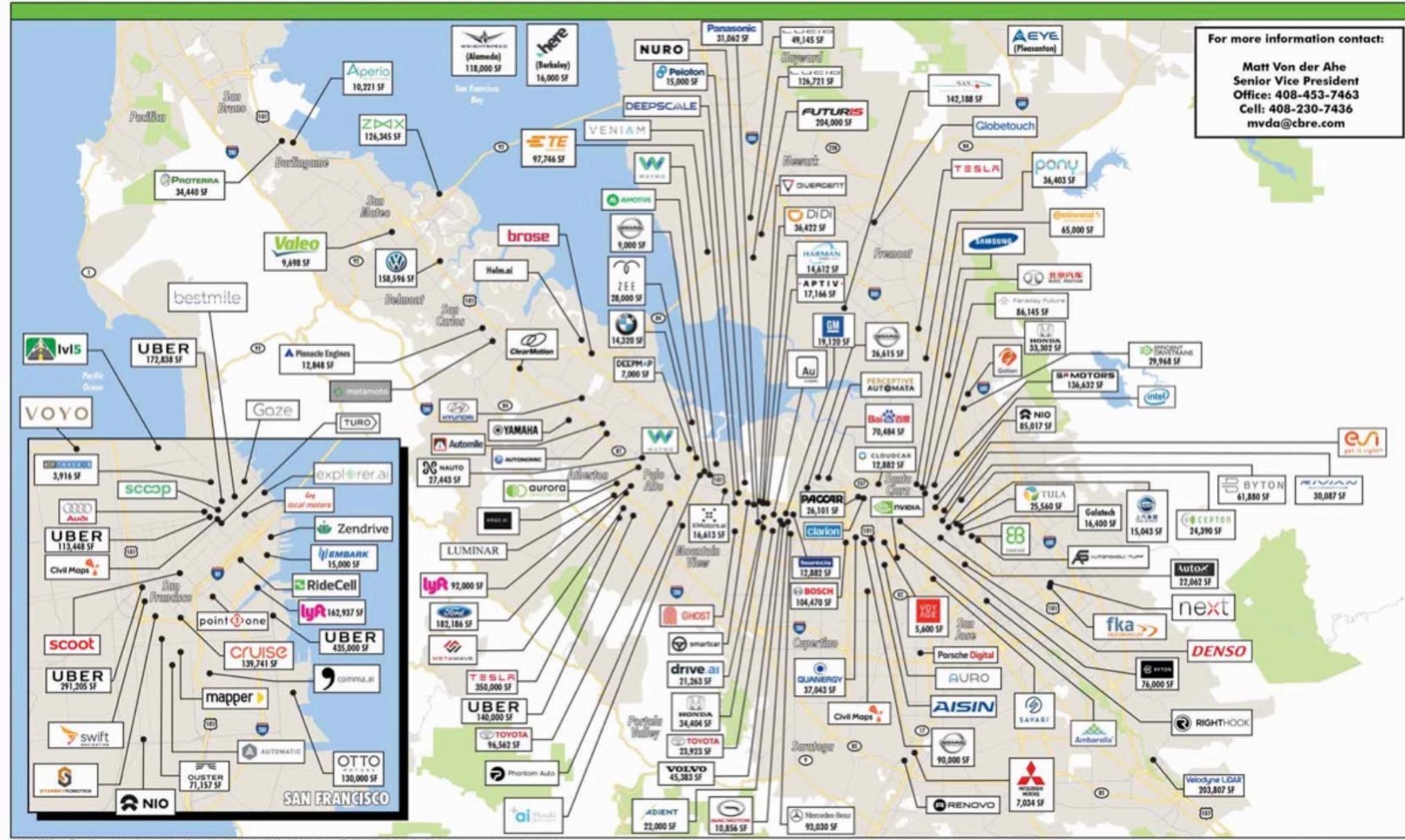
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0 1.5 3 6 Miles



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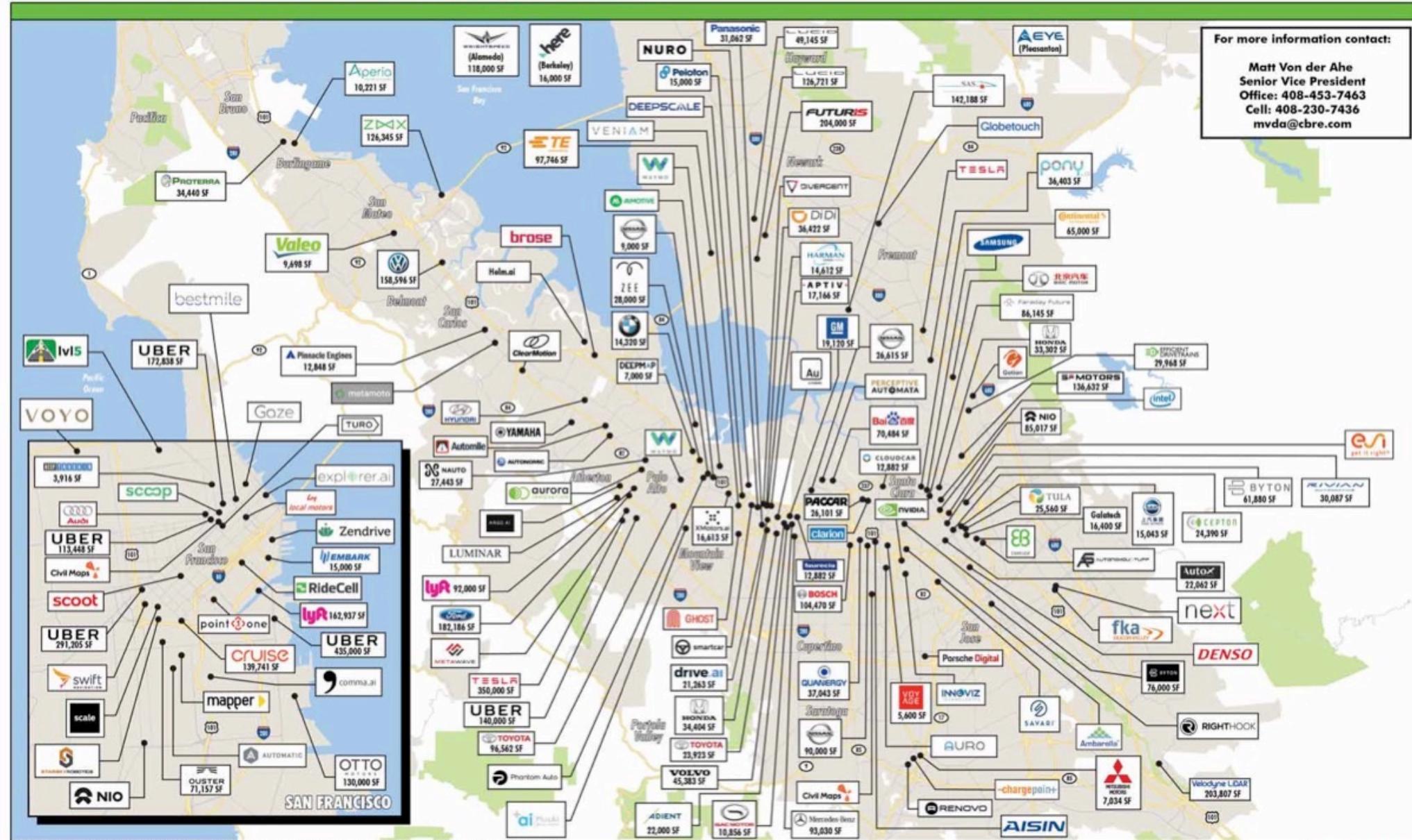
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0 1.5 3 6 Miles

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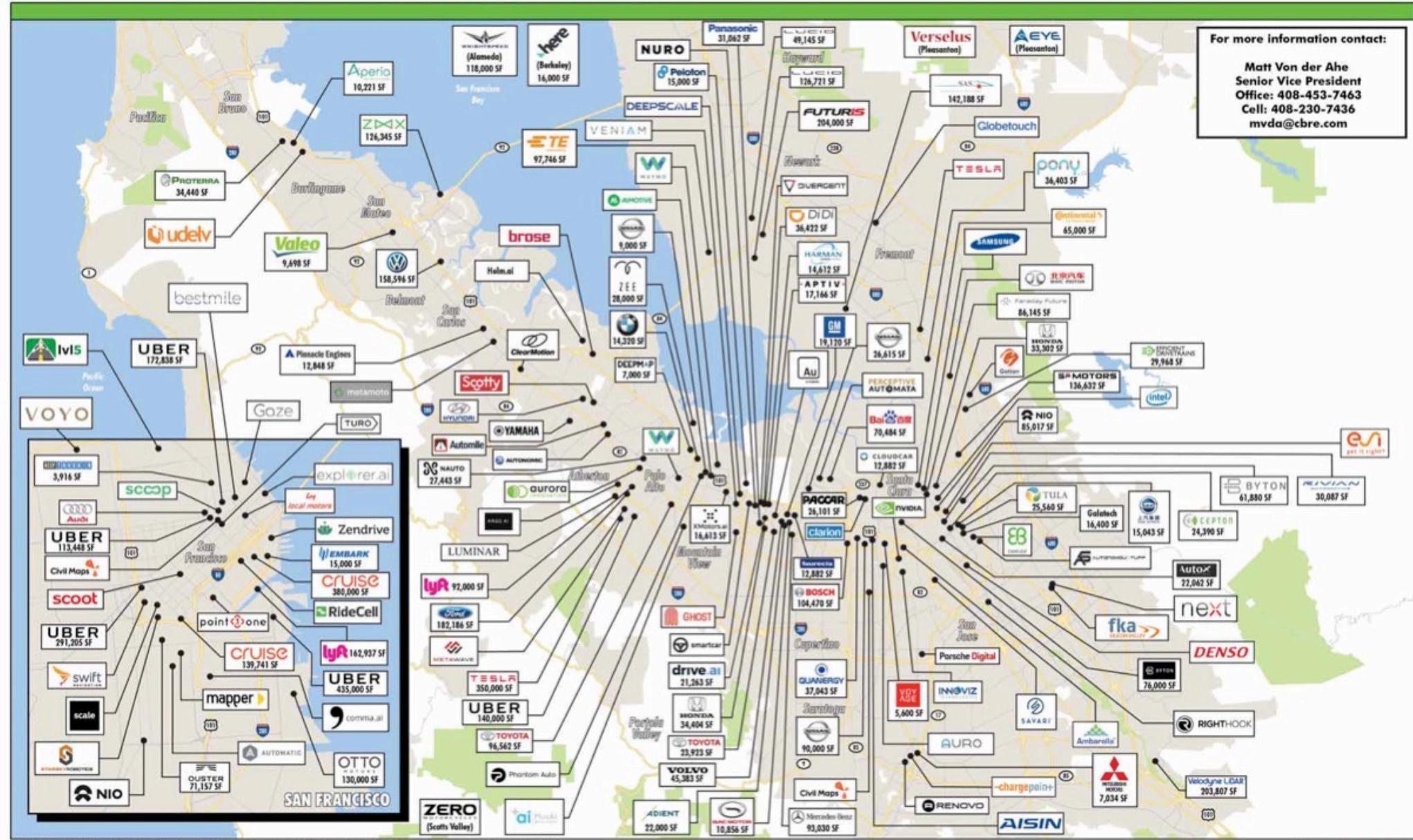
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0 1.5 3 6 Miles



AUTO LAB MAP JULY 2018 SILICON VALLEY



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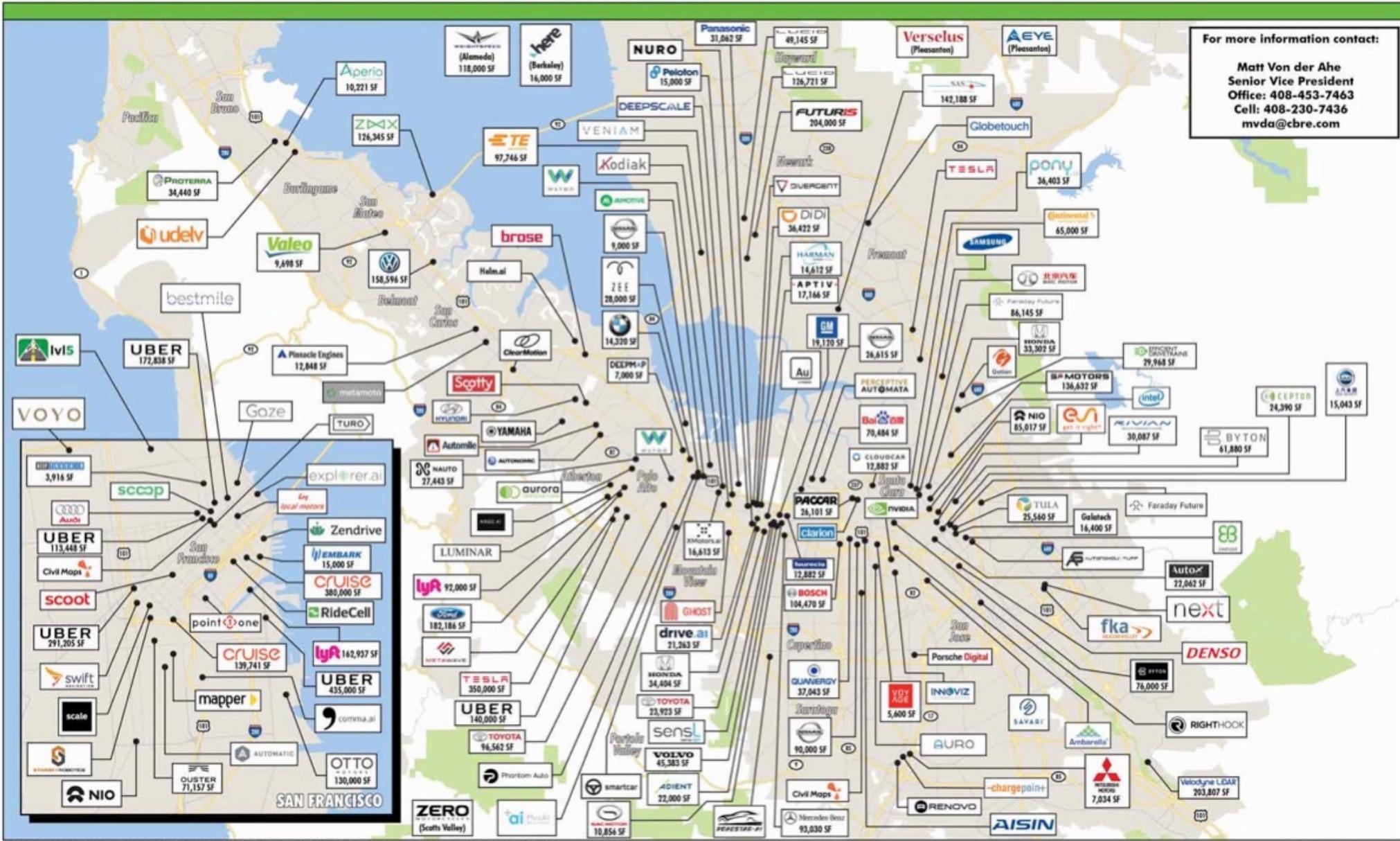
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A horizontal scale bar representing distance in miles. It features numerical markings at 0, 1.5, 3, and 6 miles. A thick black line segment starts at the 0 mark and extends to the 6 mark, with the word "Miles" written vertically next to the 6 mark.

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AUTO LAB MAP AUGUST 2018 SILICON VALLEY



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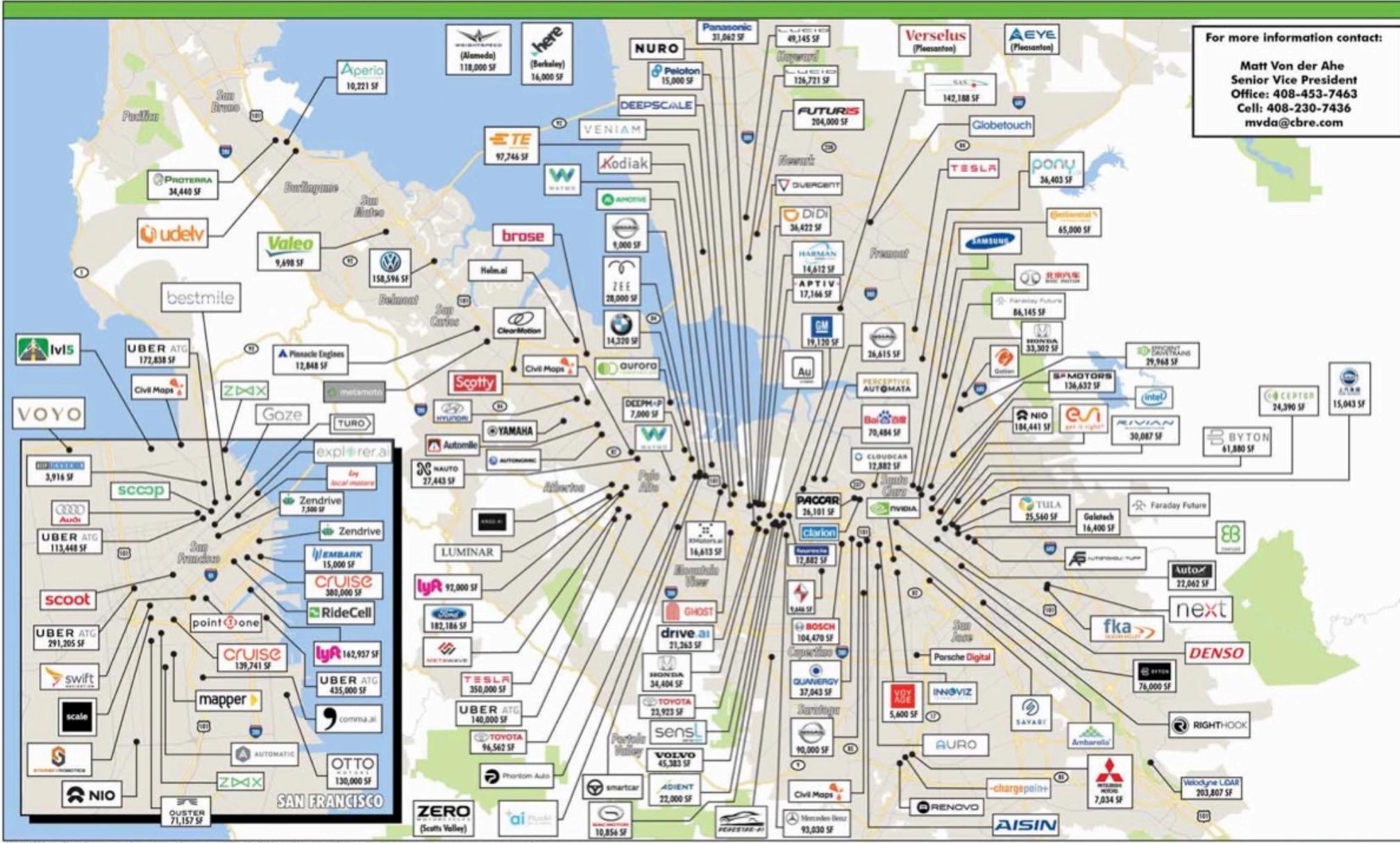
0 1.5 3 6 Miles

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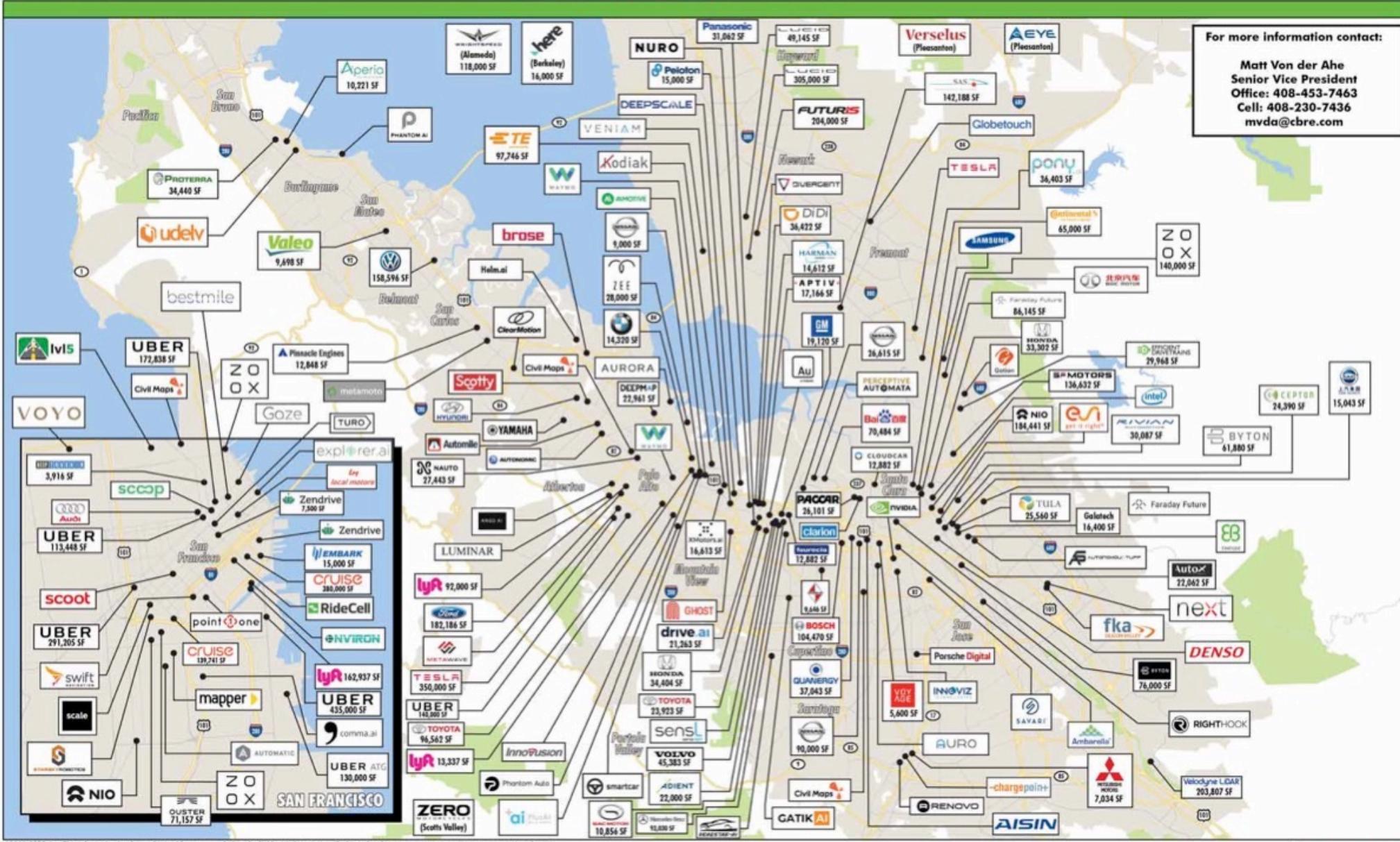
A horizontal number line representing distance in miles. The line starts at 0 and ends at 6. There are tick marks at 0, 1.5, 3, and 6. A thick black bar is drawn from the 0 mark to the 1.5 mark.



AUTO LAB MAP OCTOBER 2018 SILICON VALLEY

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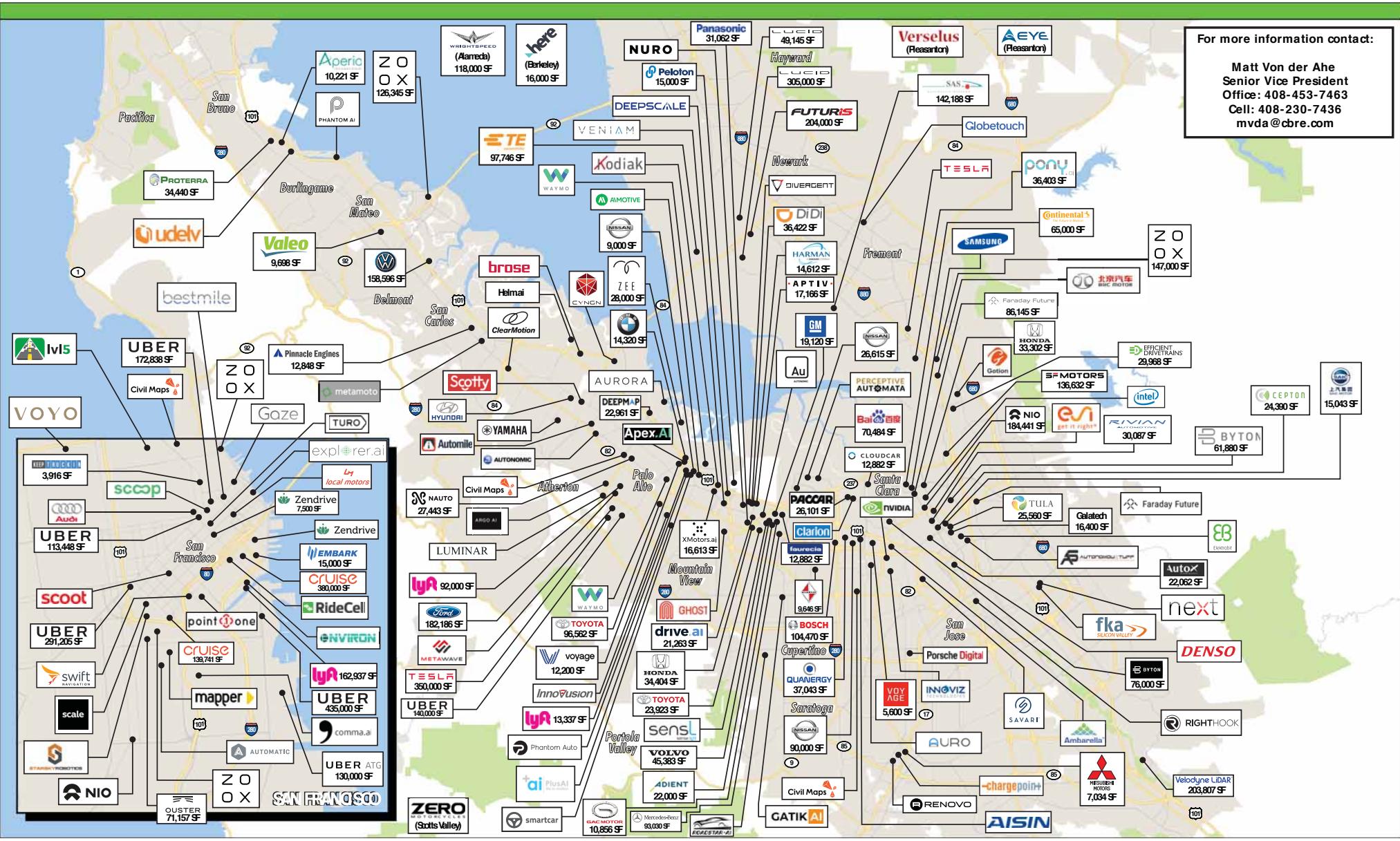
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AUTO LAB MAP NOVEMBER 2018 SILICON VALLEY



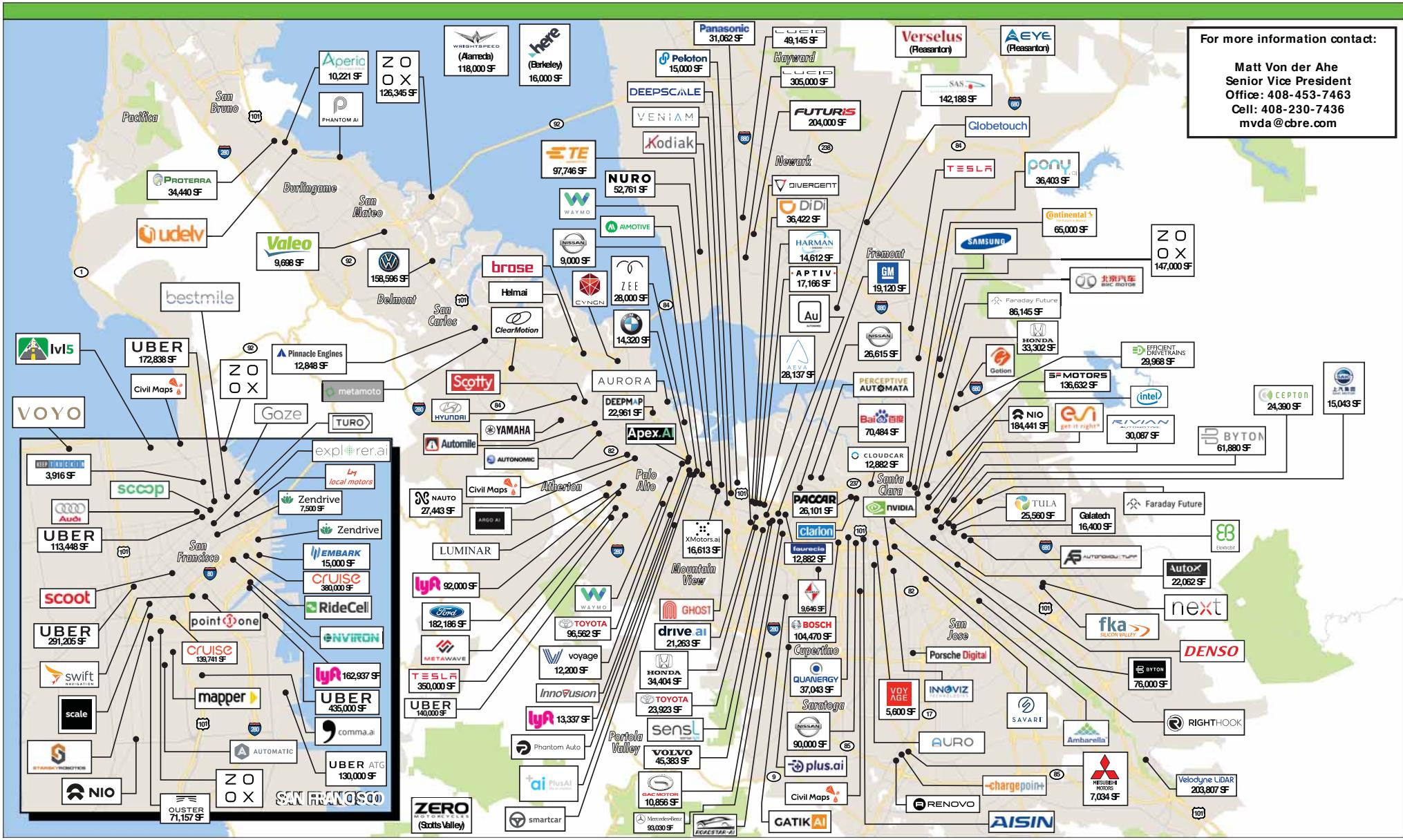
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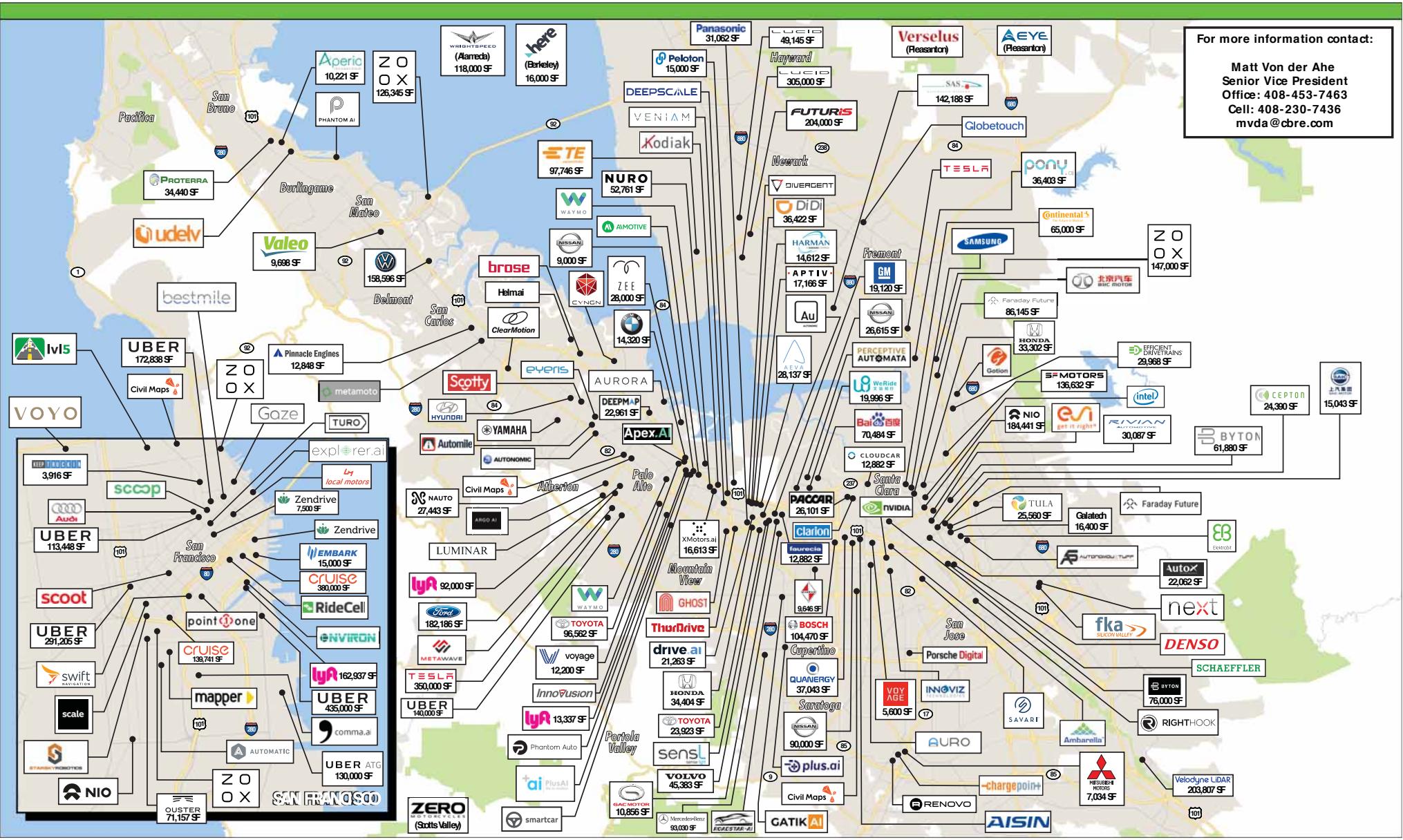
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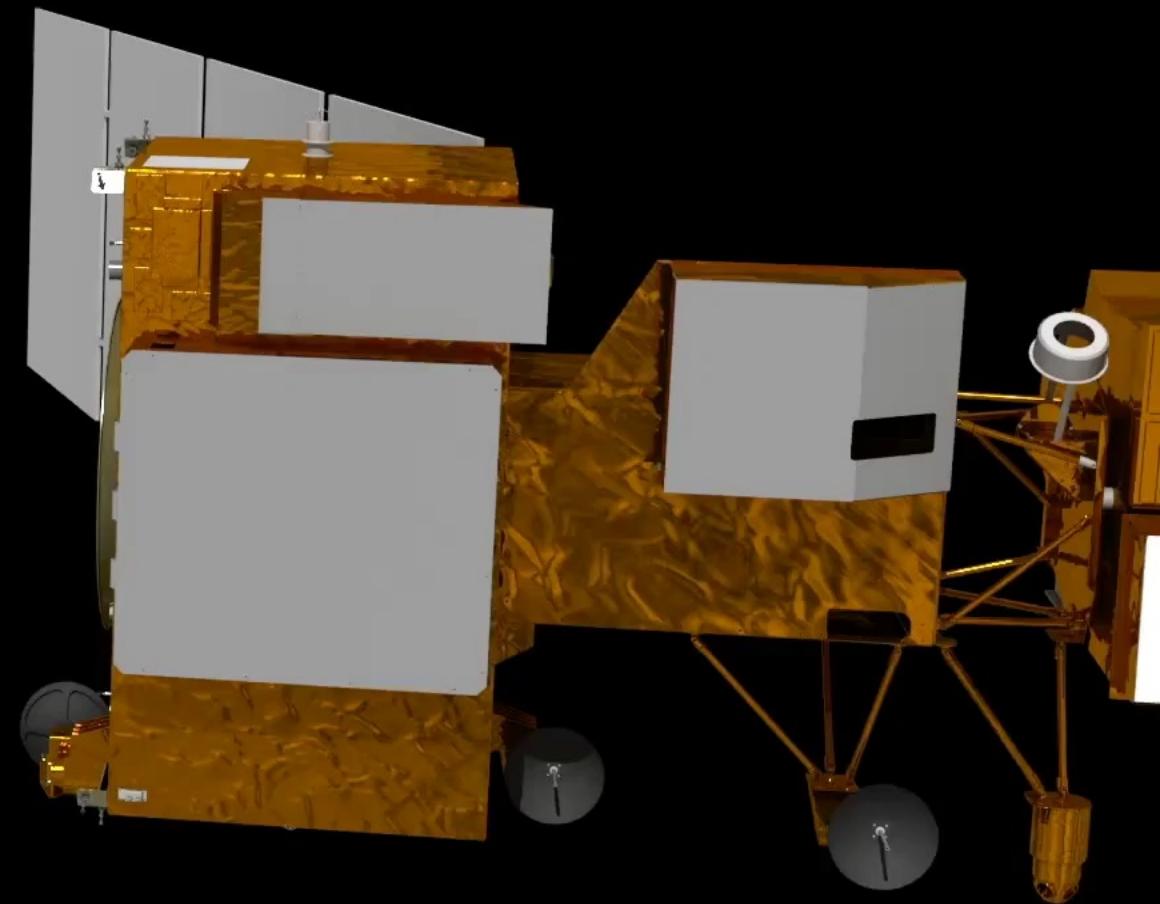
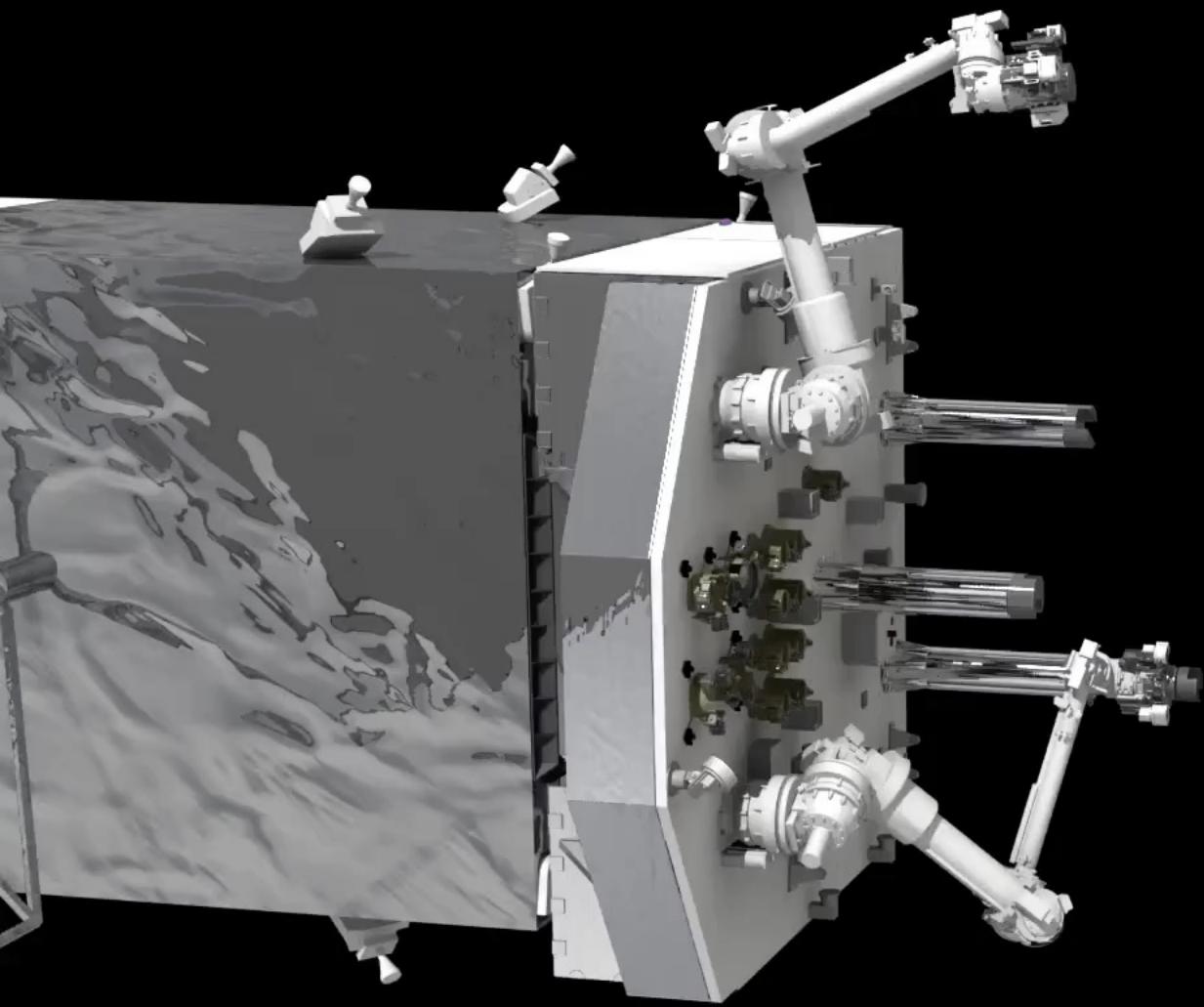
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The Drone Market Environment 2019

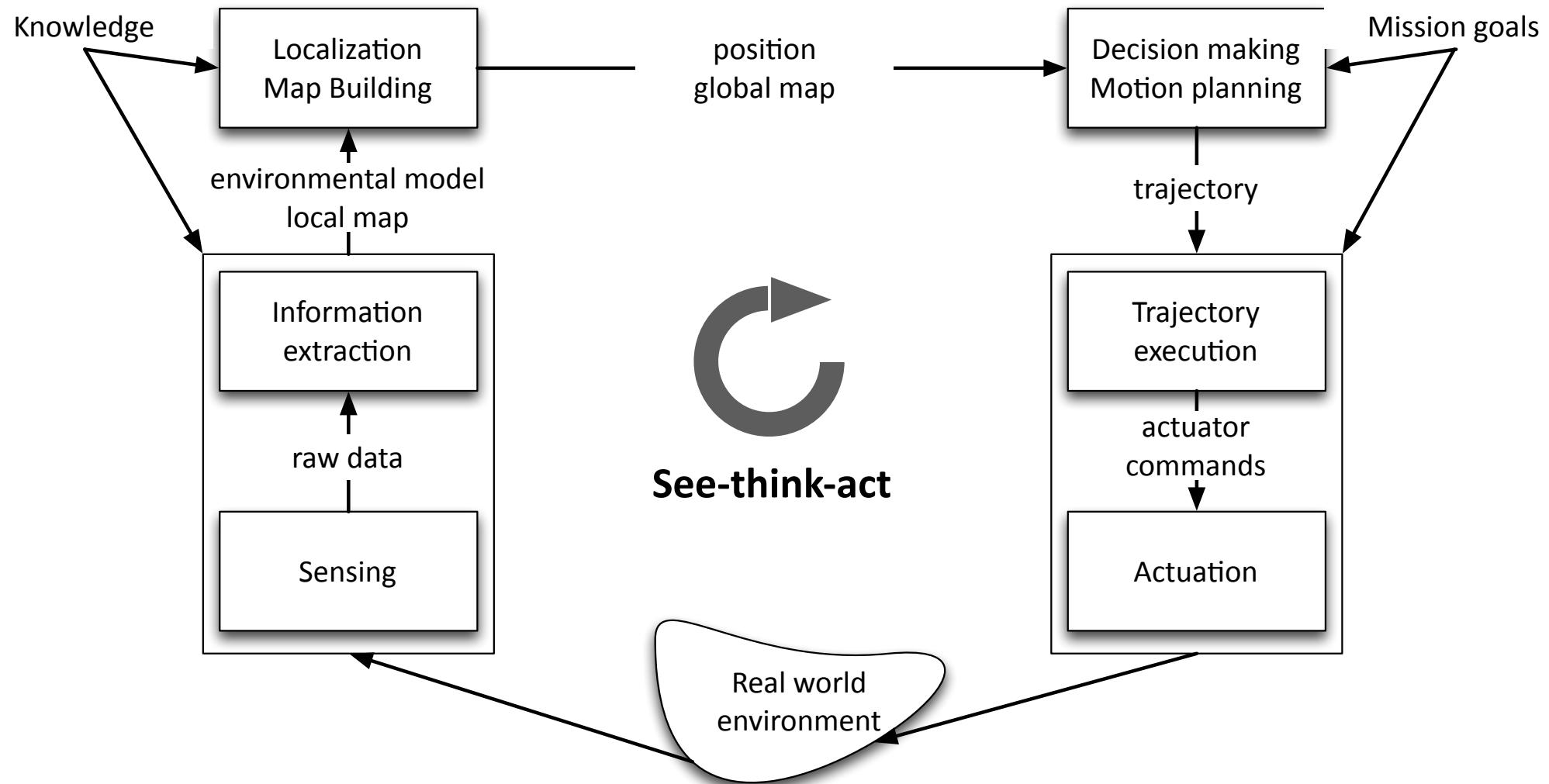
The image is a large grid of logos, each representing a company or organization within the drone industry. The grid is organized into several sections: 1. **Hardware**: Sub-sections include Agriculture, Drone Platforms, Delivery Systems, Safety & Security, Fixed-Wing, VTOL Fixed-Wing, Recreational, and Counter-Drone Solutions. 2. **Software**: Sub-sections include Drone-in-a-Box, Flight, Fleet & Operation Management, Open Source Infrastructure, SDK, Navigation, CV and AI, UTM, LAANC Suppliers, Data Analytics, Workflow, CV and AI, and Maintenance. 3. **Services**: Sub-sections include Drone-as-a-Service Providers, Delivery, Drone Show Providers, Education, Simulation, Training, System Integration, Engineering, Advisory, Supplier, Retailers, Test Sites, Market Research & Consulting, User Groups, Networks, Media, News, Blogs & Magazines, Marketplaces, Shows, Conferences, Events, and Coalitions, Organizations & Initiatives. 4. **Other**: Includes a section for Insurances. The logos are arranged in a grid format, with each logo being a small square containing the company's name and sometimes a small icon.



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

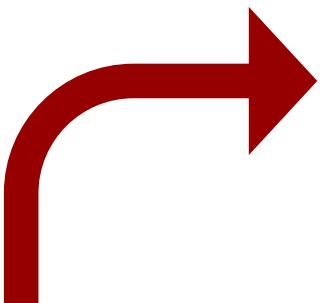
The see-think-act cycle



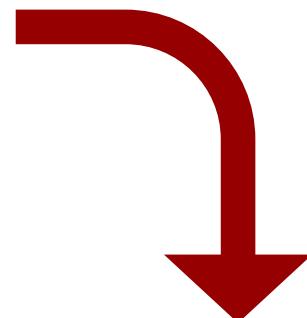
See-think-act cycle for AVs

Think

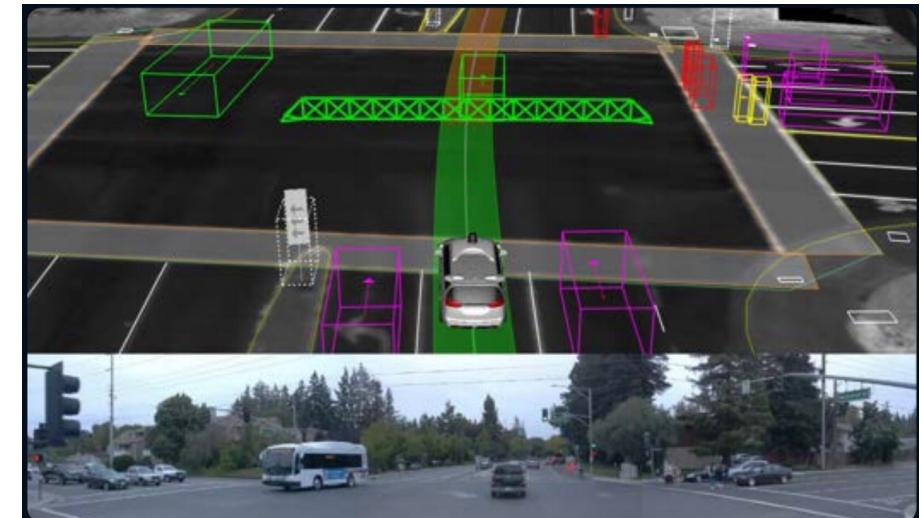
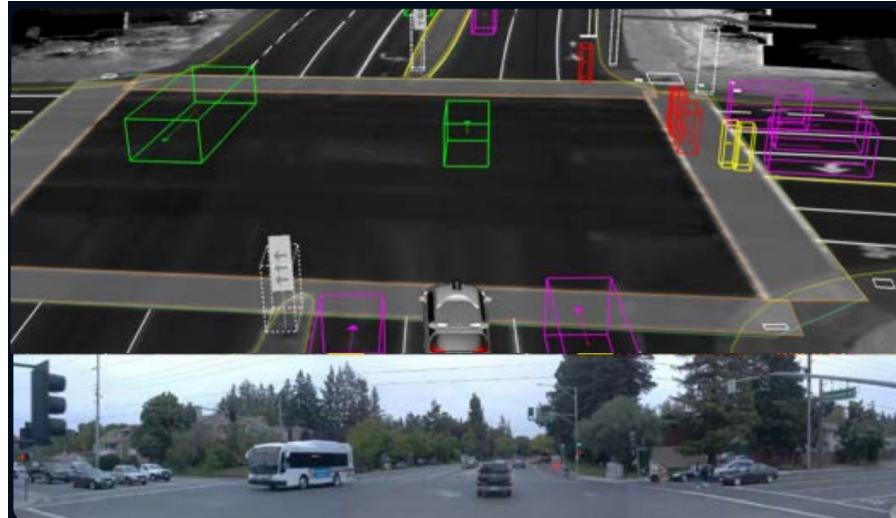
Note: other architectures are possible and subject of active R&D!



See



Act



Course structure

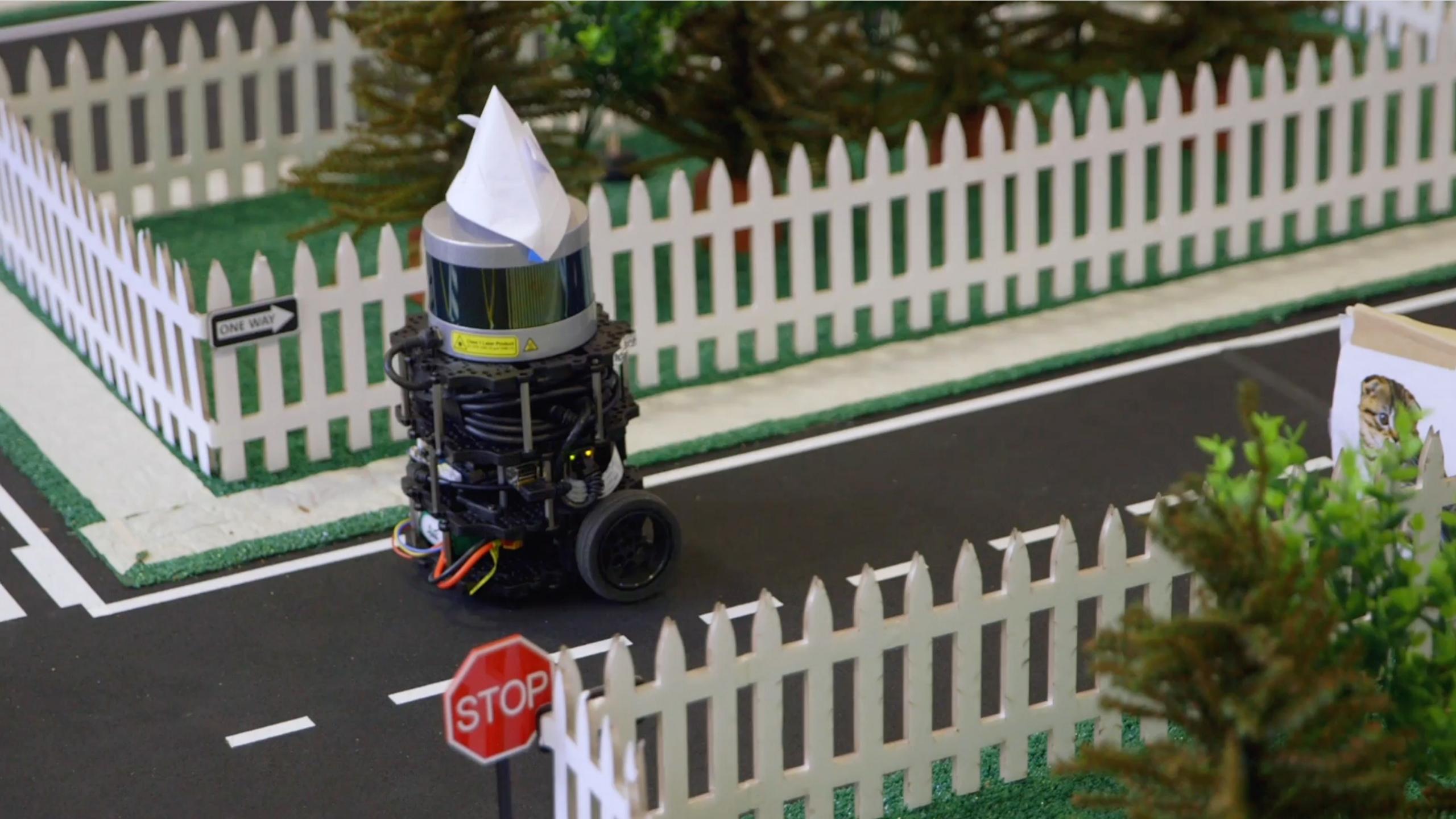
- Four main topics:
 1. Robot Operating System (week 1)
 2. Controls & Motion Planning (weeks 2-4) -- *act*
 3. Perception (weeks 5-8) -- *see*
 4. State Estimation, Localization & SLAM (weeks 8-11) -- *think*
- Extensive use of the Robot Operating System (ROS)
- Requirements
 - CS 106A or equivalent
 - 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 (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



Team

Instructor



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

Collaborators

- Daniel Watzenig

Labs



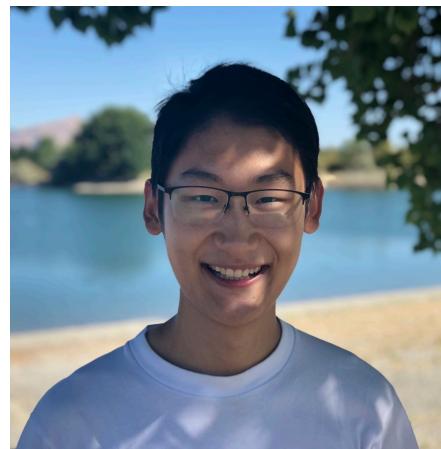
*Center for Automotive
Research at Stanford*

CAs

Chris Agia



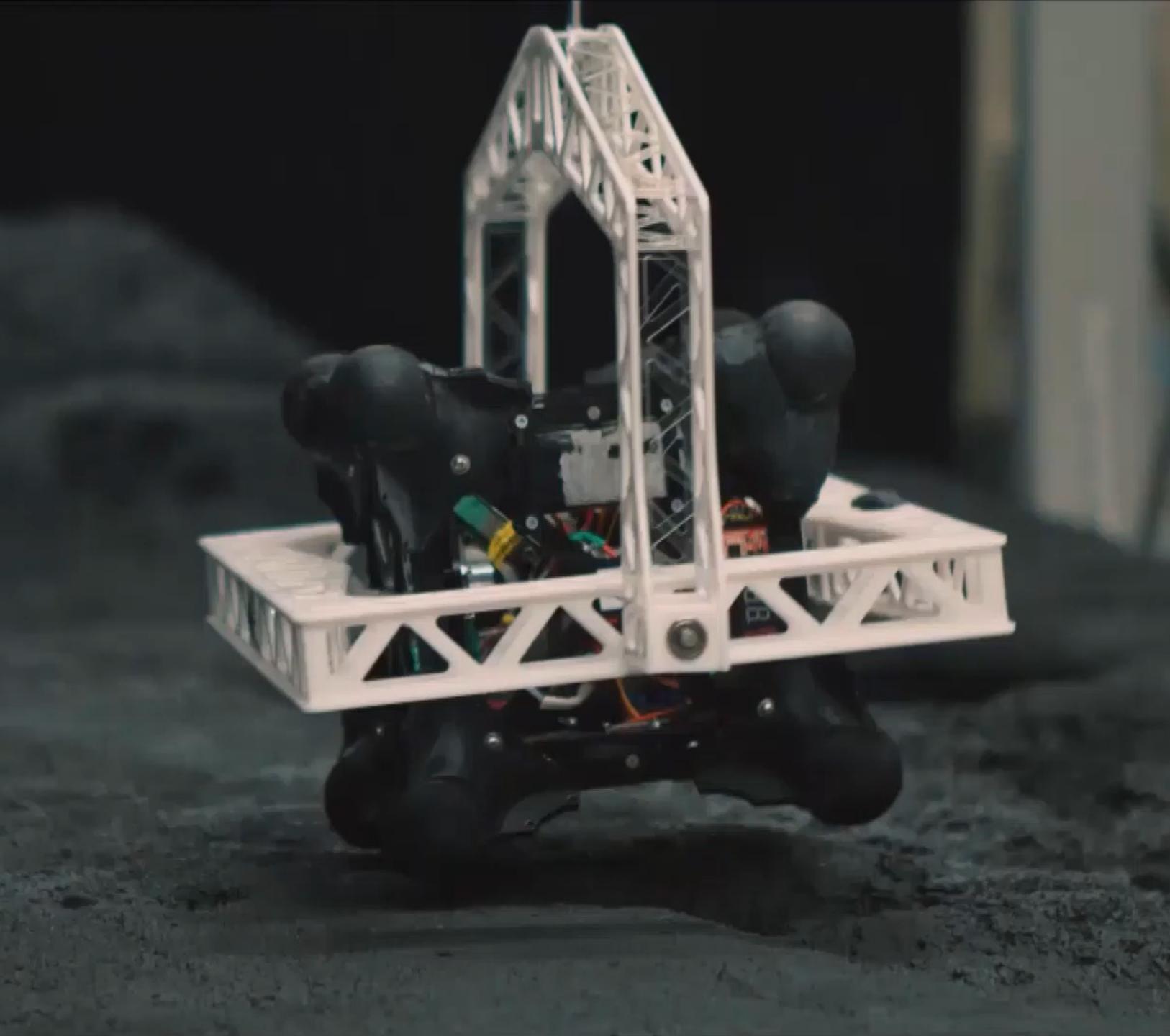
Luis Pabon



Alvin Sun

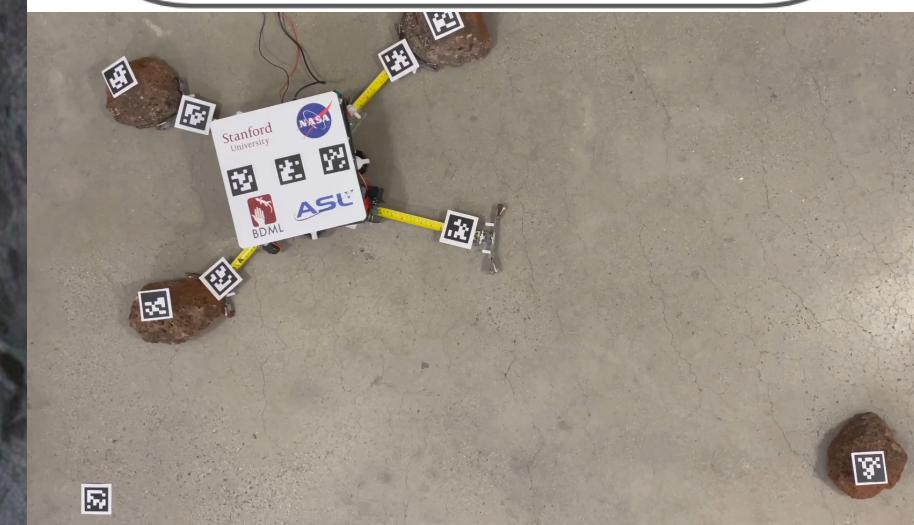
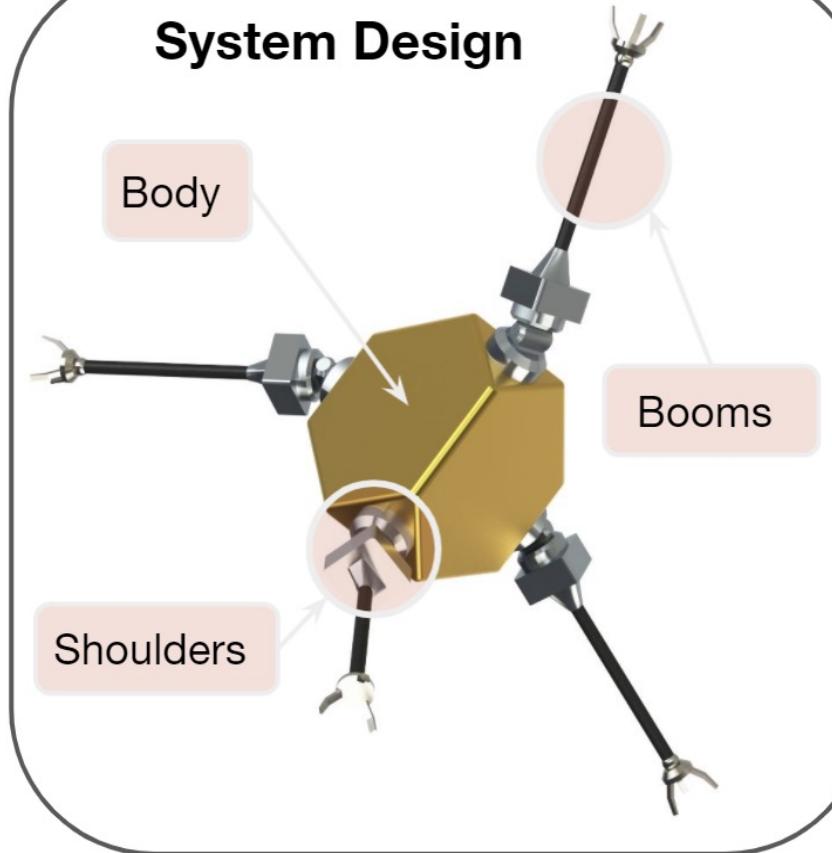


Courtesy of NASA JPL





System Design





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	<i>In-class midterm</i>	
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	<i>Thanksgiving</i>	
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



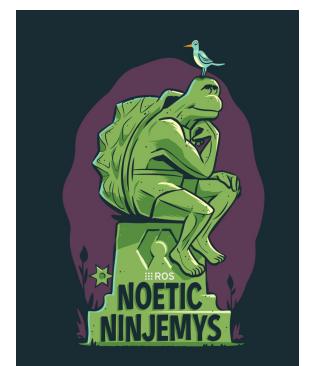
2014 - 2019



2016 - 2021

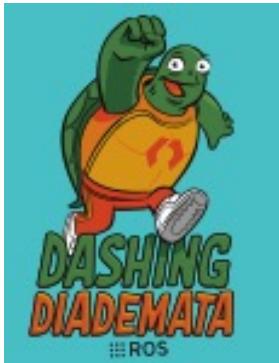


2018 - 2023



2020 - 2025

ROS 2



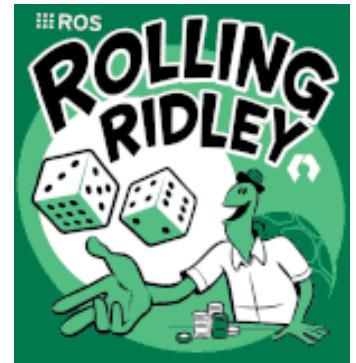
2019 - 2021



2020 - 2023



2022 - 2027



2017 - Present

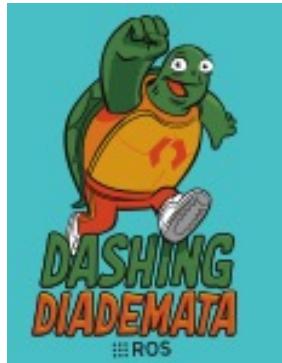
Robot Operating System – History

ROS 1

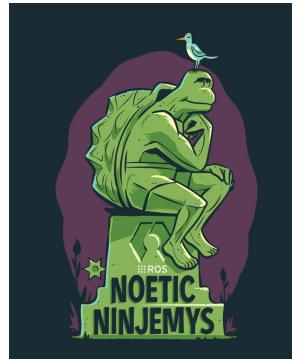
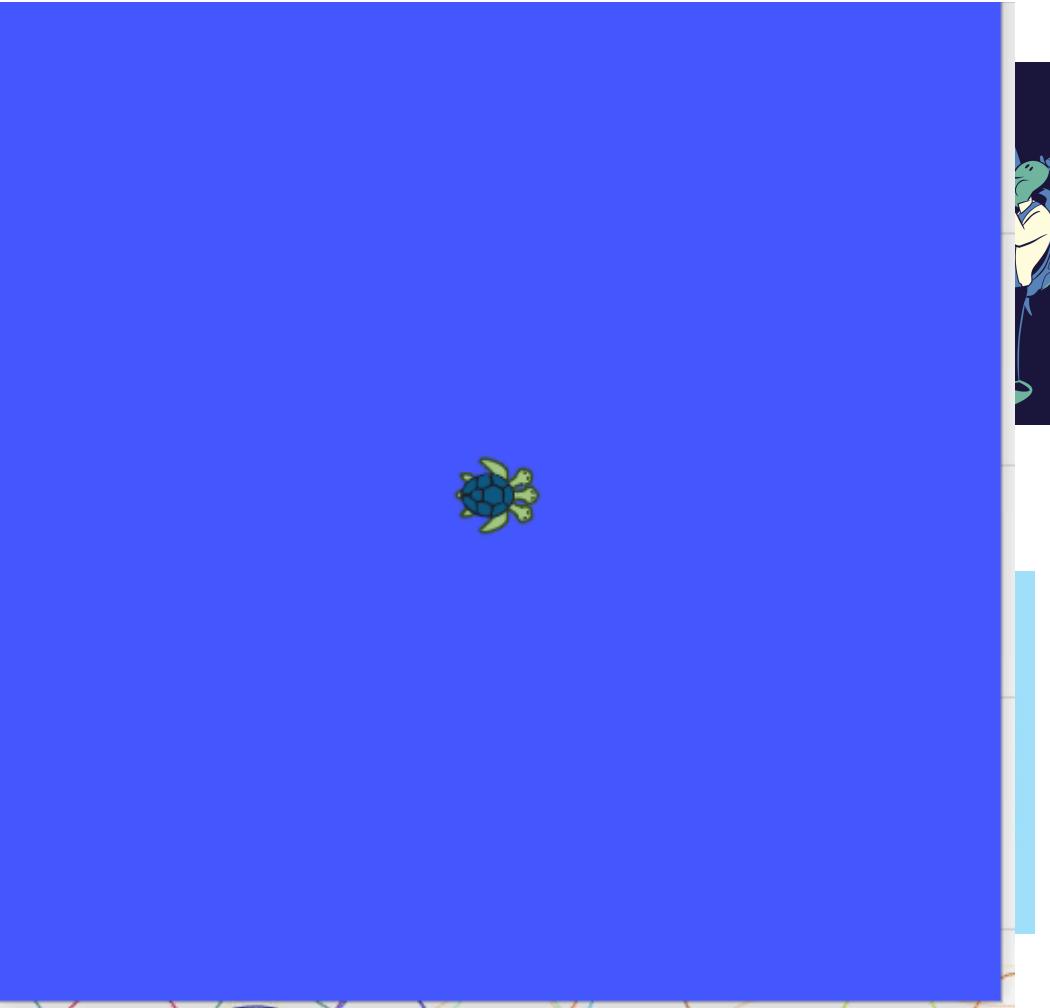


2014 - 2019

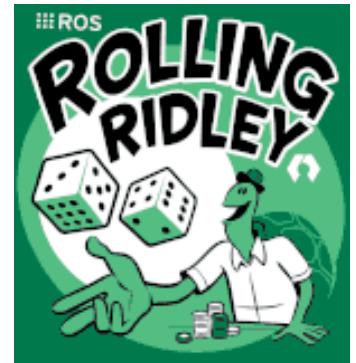
ROS 2



2019 - 2021



2020 - 2025



2017 - Present

Robot Operating System – History

ROS 1



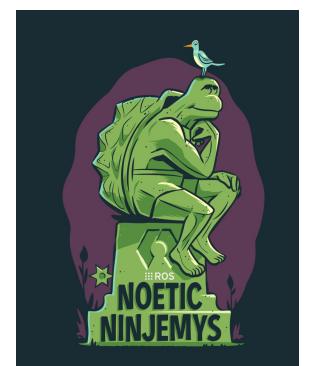
2014 - 2019



2016 - 2021

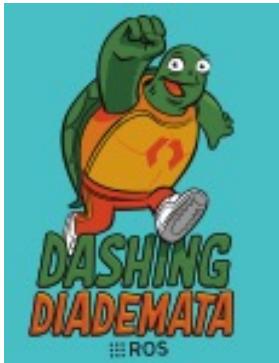


2018 - 2023



2020 - 2025

ROS 2



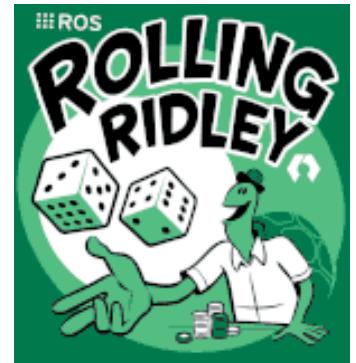
2019 - 2021



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

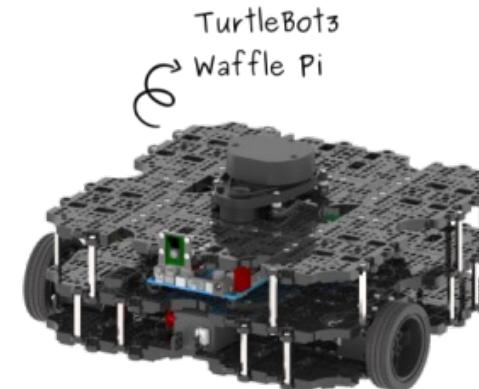
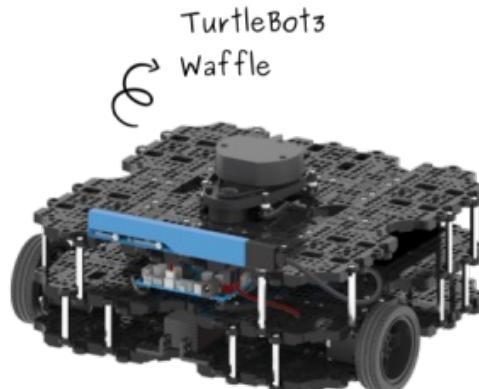
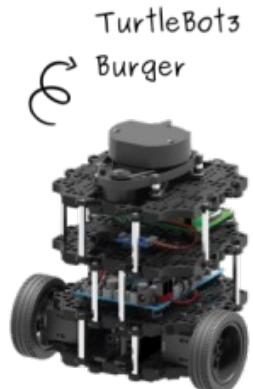
- Community & Ecosystem
 - Hardware Drivers
 - Software
- Tooling
 - Visualization
 - Debugging
- Asynchronous Programming Model

Robot Operating System – ROS2

- Community & Ecosystem
 - Hardware Drivers
 - Software

Robot Operating System – ROS2

- Community & Ecosystem
 - Hardware Drivers
 - Software



[Turtlebot3](#)



[Crazyflie](#)



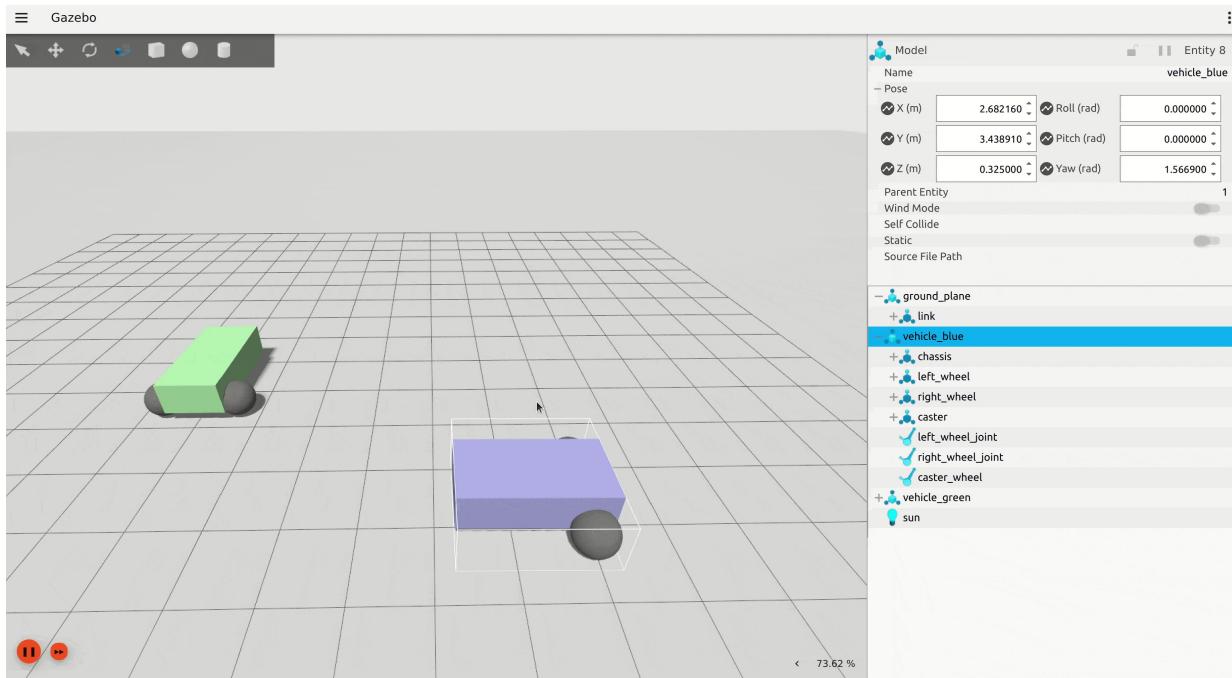
[Joysticks](#)



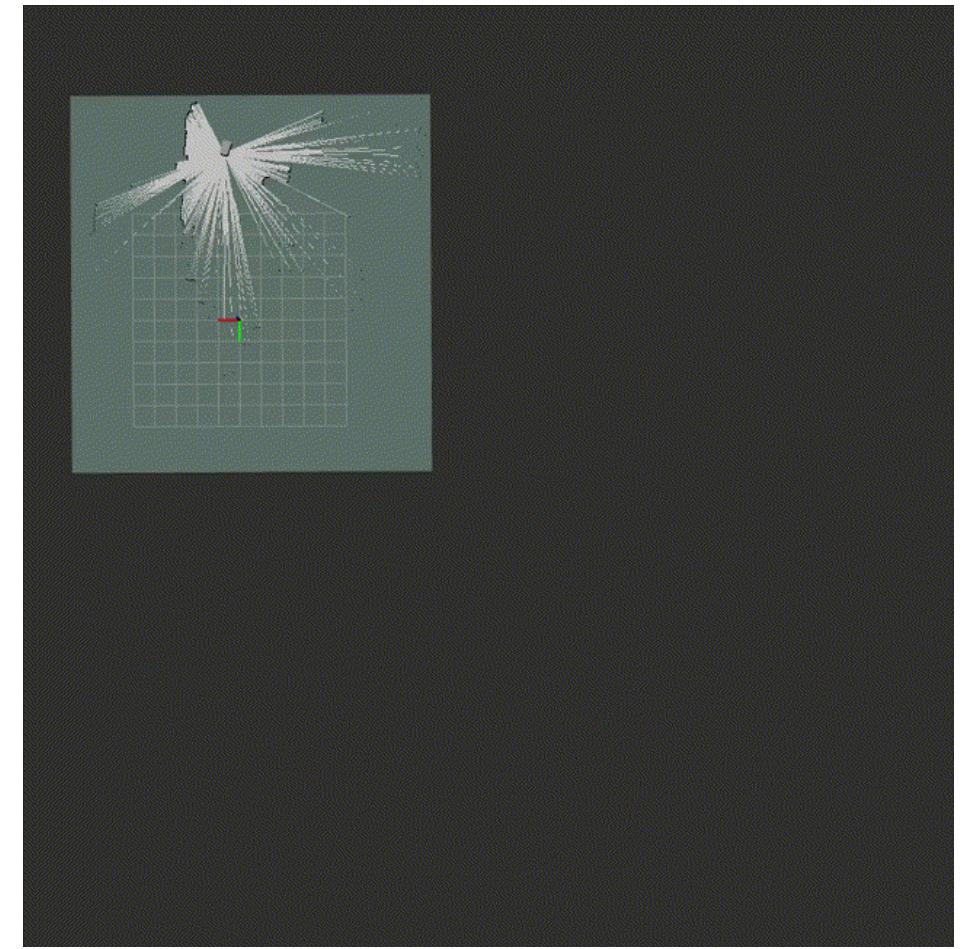
[Velodyne LiDAR](#)

Robot Operating System – ROS2

- Community & Ecosystem
 - Hardware Drivers
 - Software



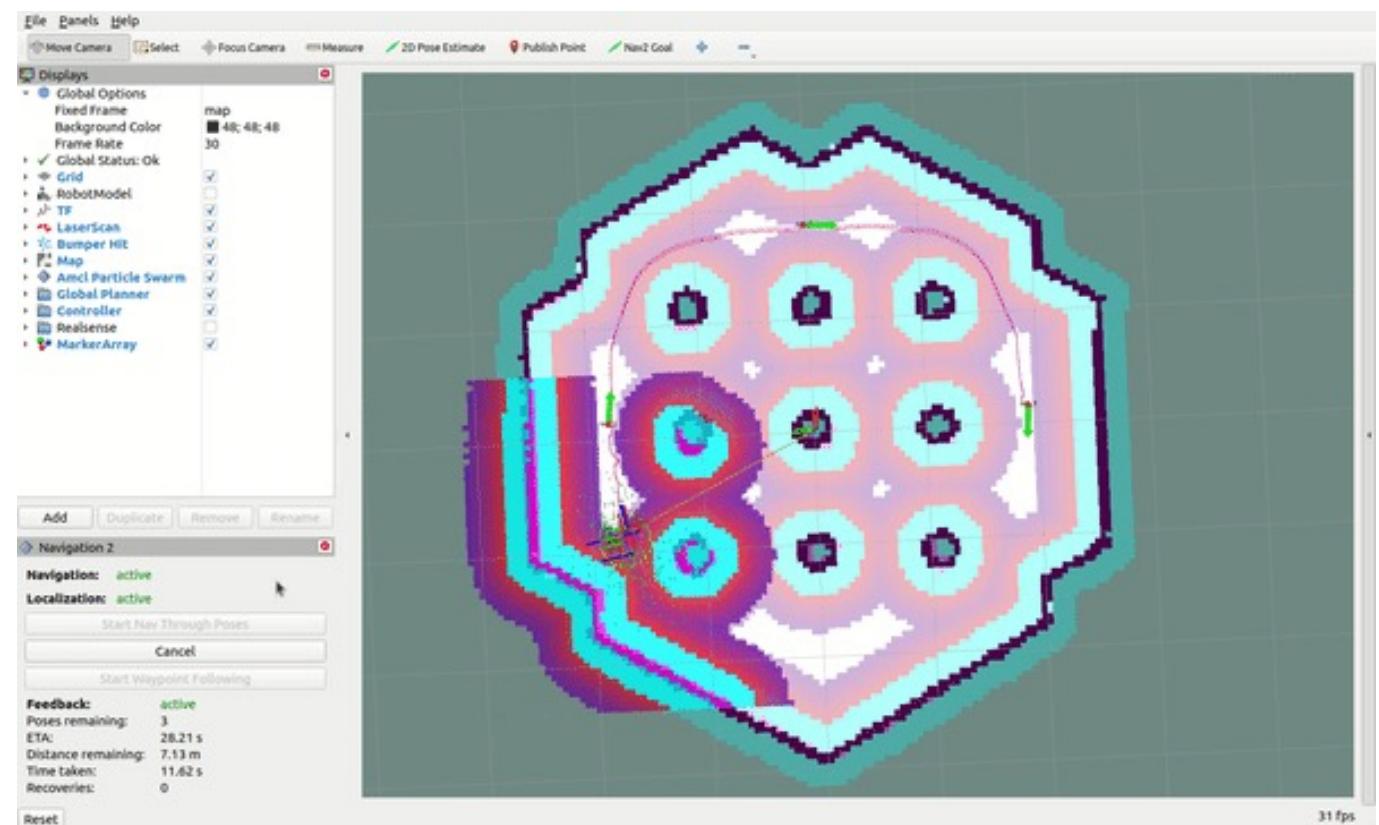
[Gazebo Sim](#)



[SLAM Toolbox](#)

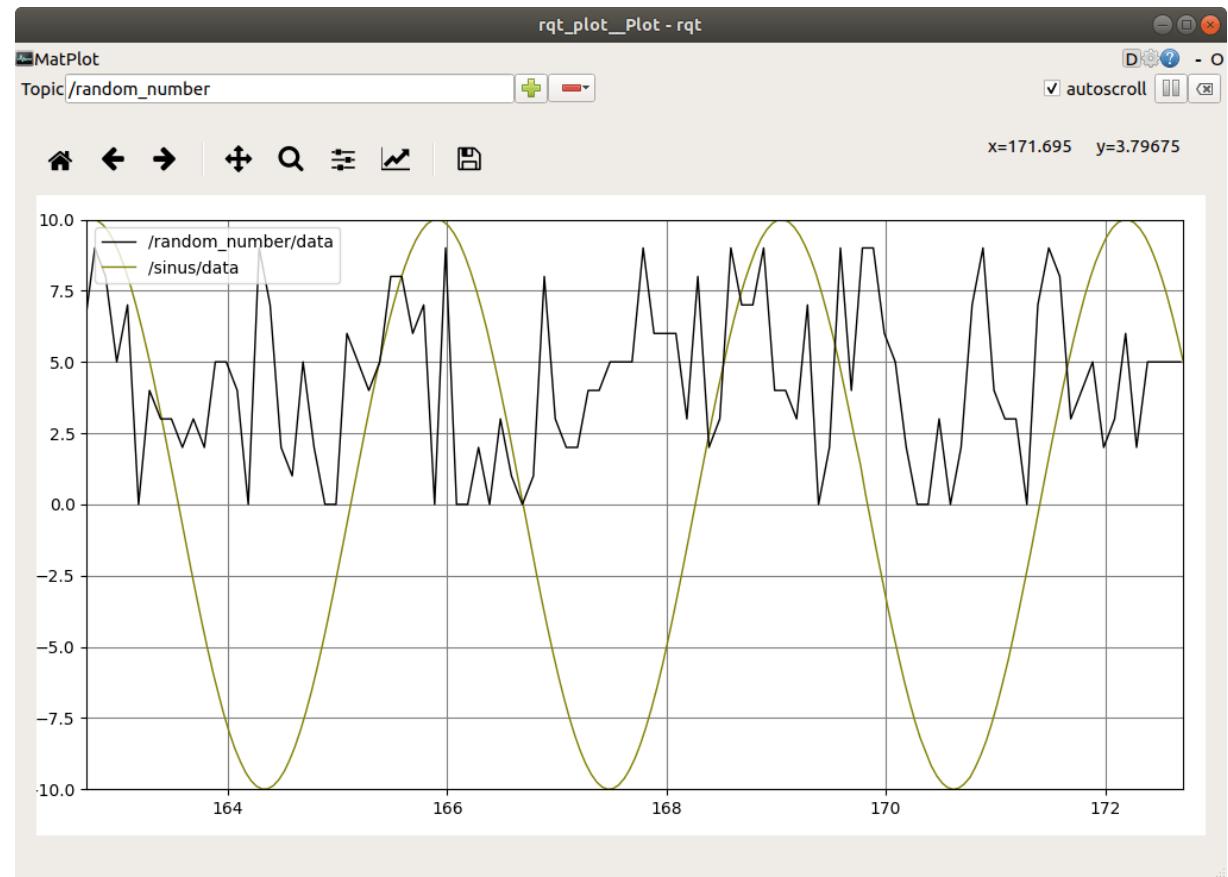
Robot Operating System – ROS2

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Robot Operating System – ROS2

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Robot Operating System – ROS2

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Turtlebot
Autonomy
Demo

Robot Operating System – ROS2

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See-think-act

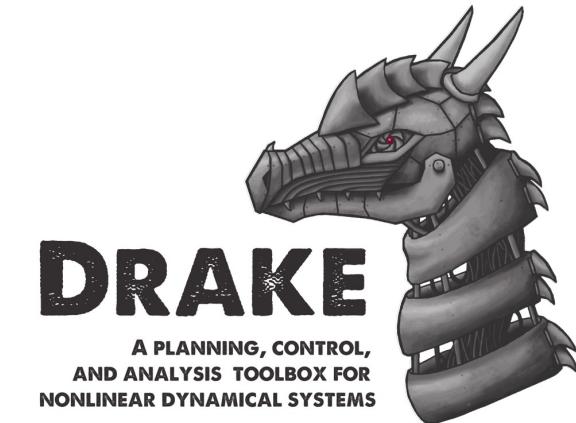
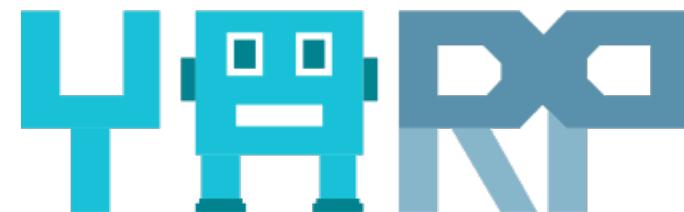
Robot Operating System – ROS2

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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