

Principles of Robot Autonomy I

Course overview, intro to robotic systems and ROS



Stanford
University



From automation...



...to autonomy

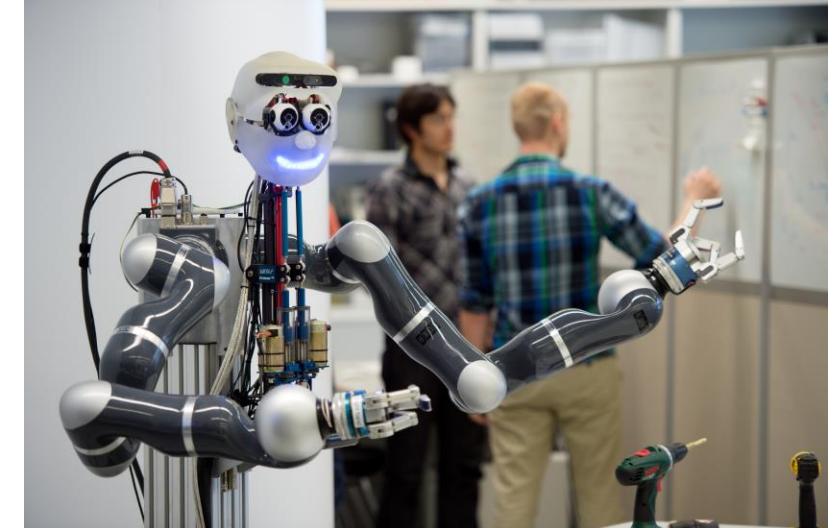
Waymo Self-Driving Car



Intuitive DaVinci Surgical Robot



Apollo Robot at MPI



Boston Dynamics – Spot Mini



Astrobee - NASA



Zipline

February 2014

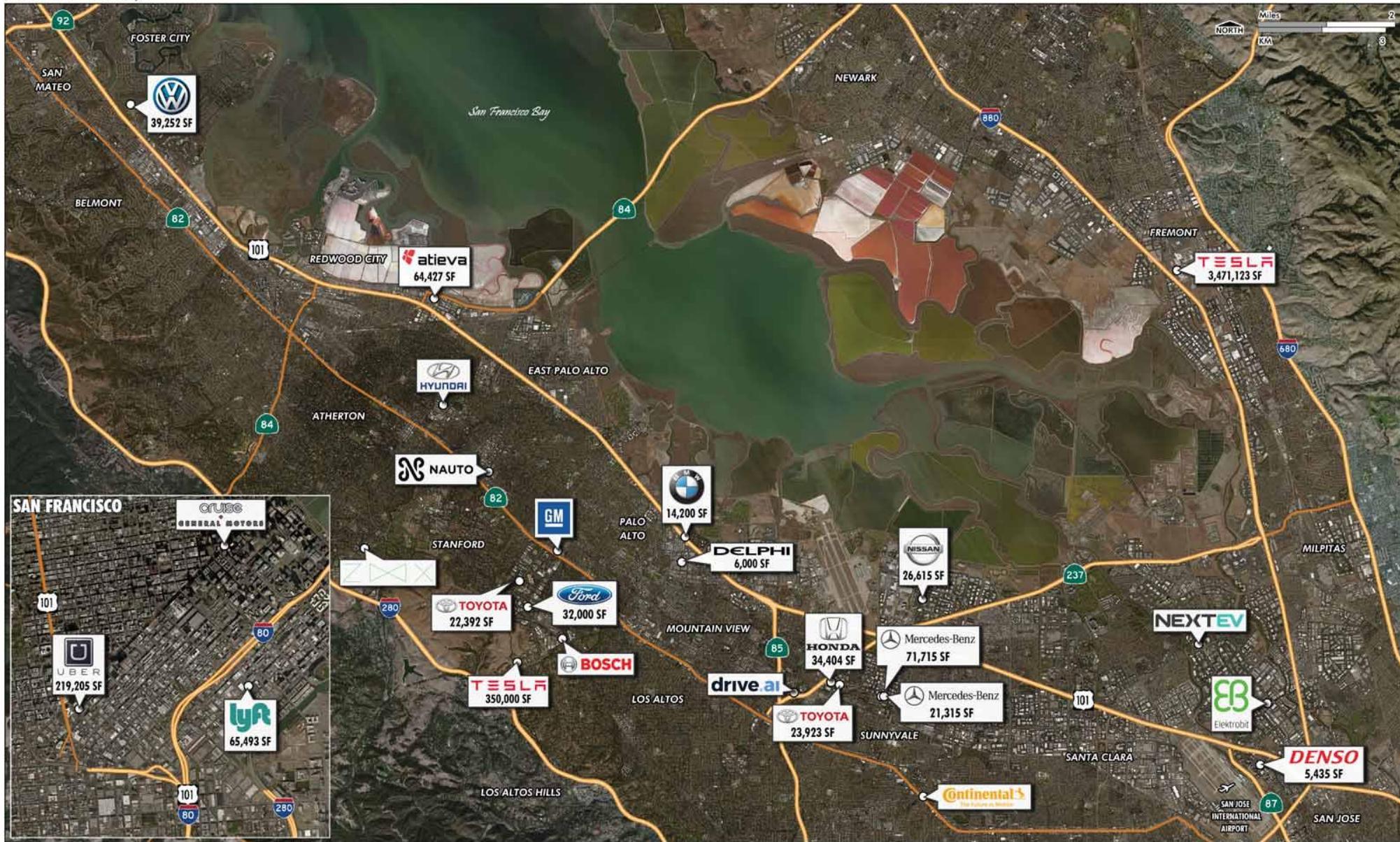
Silicon Valley



Automotive R&D

April 2016

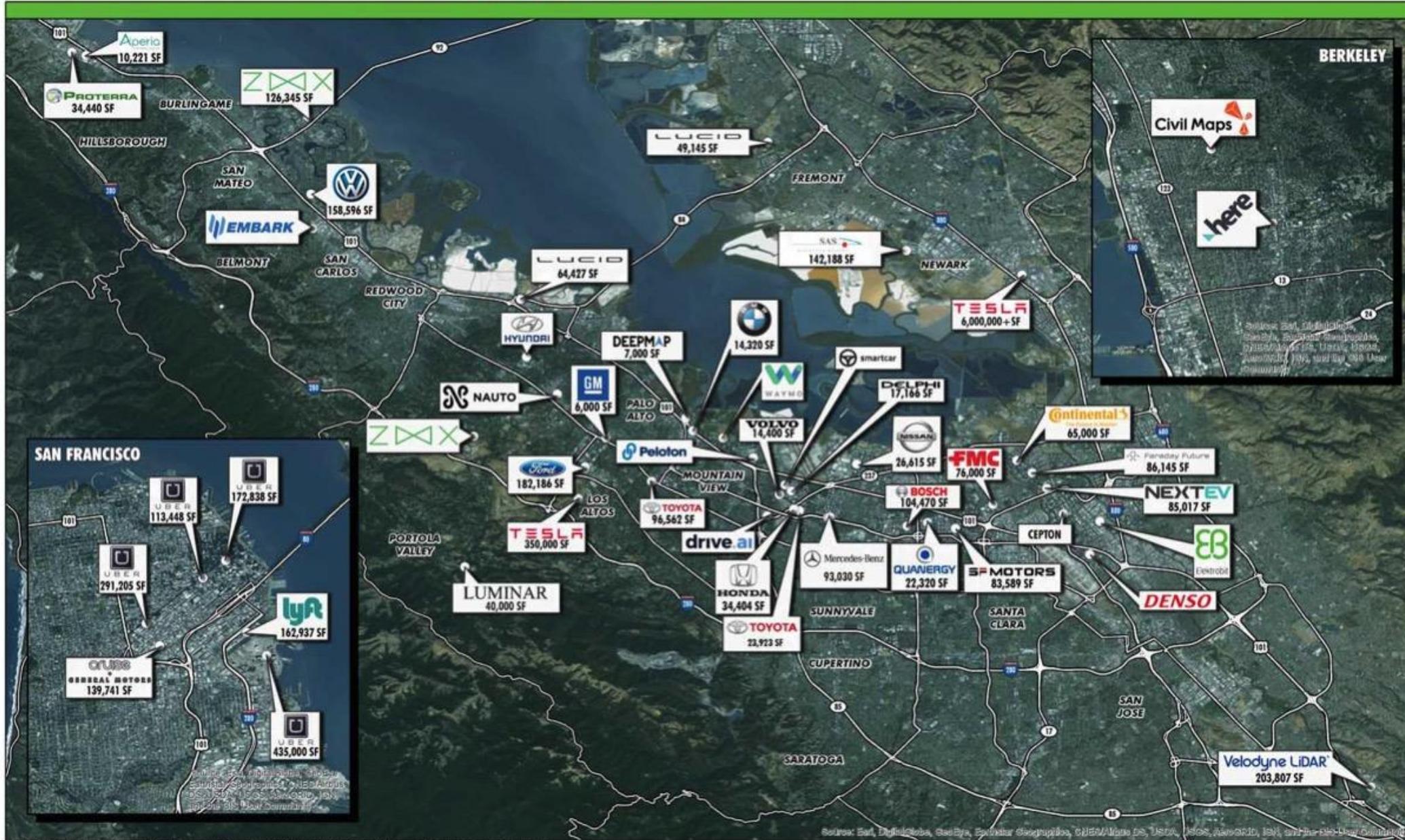
Silicon Valley



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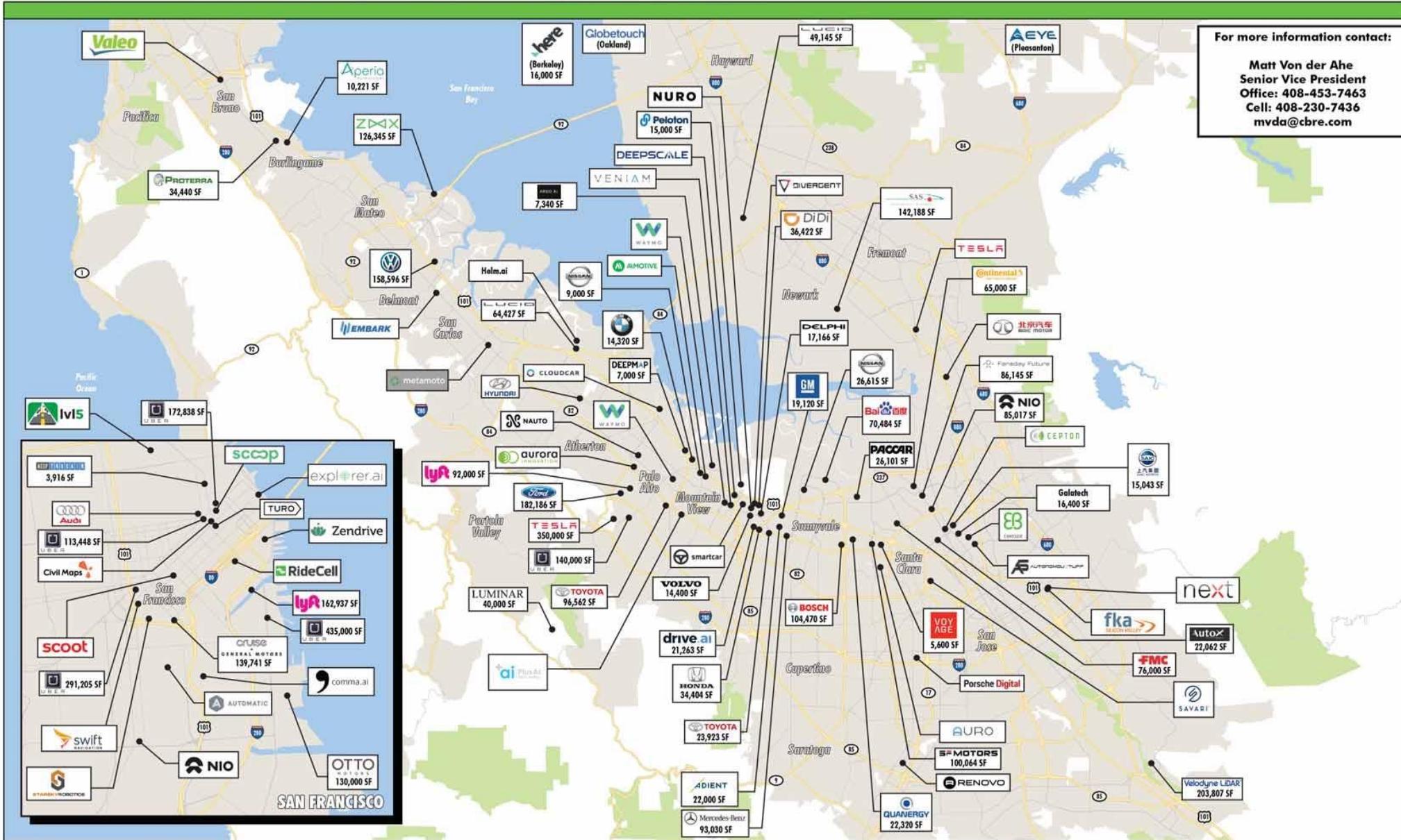
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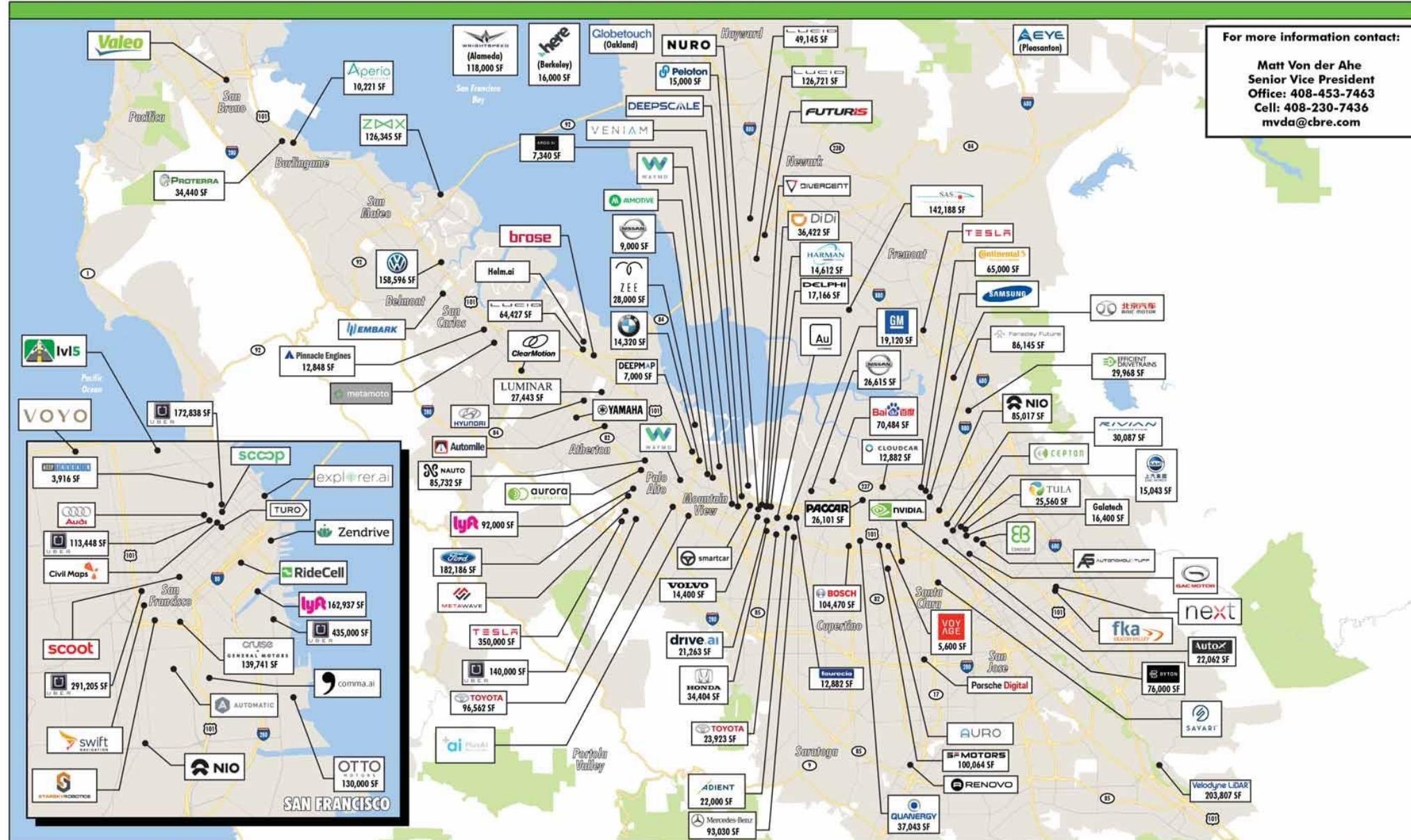
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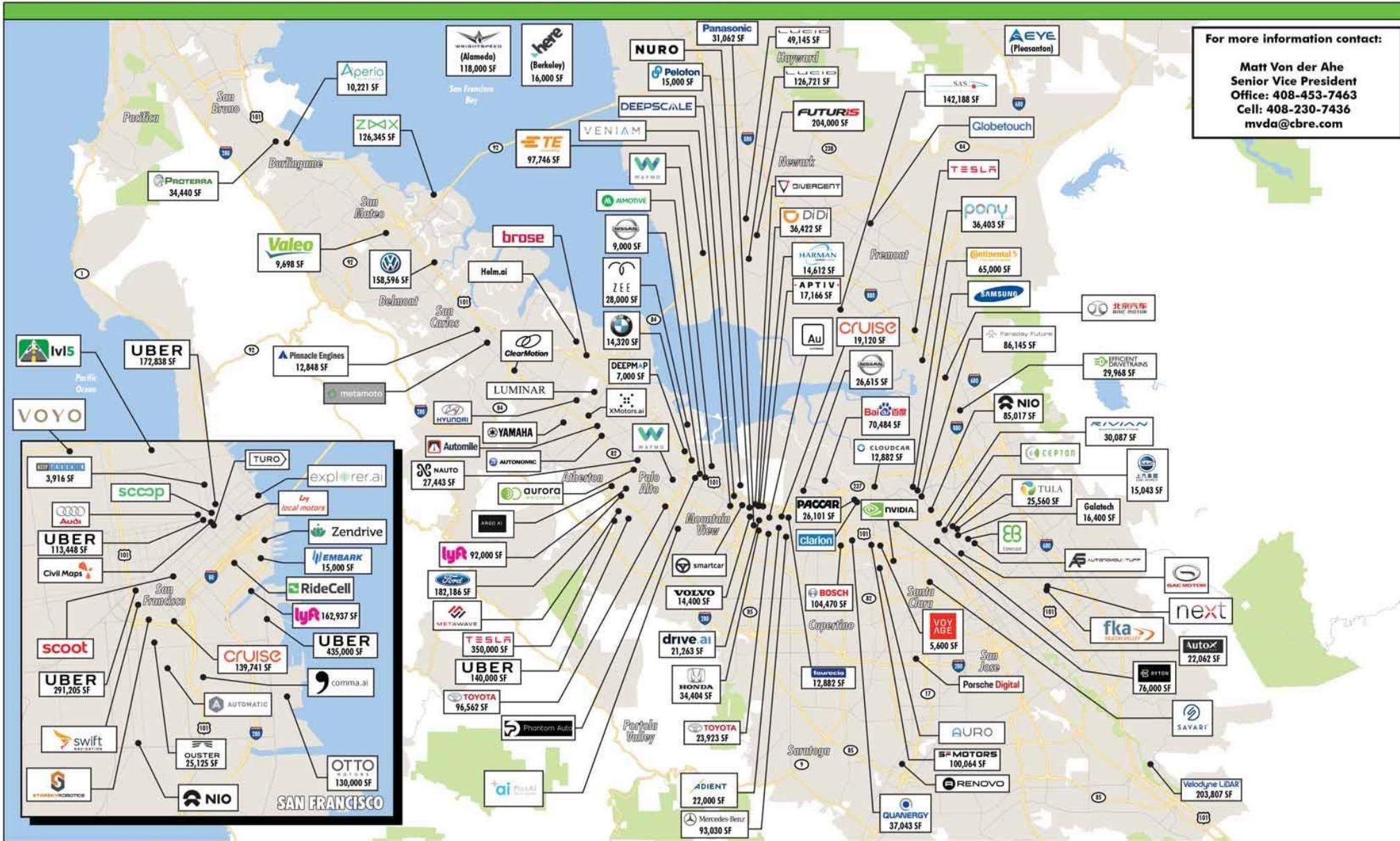
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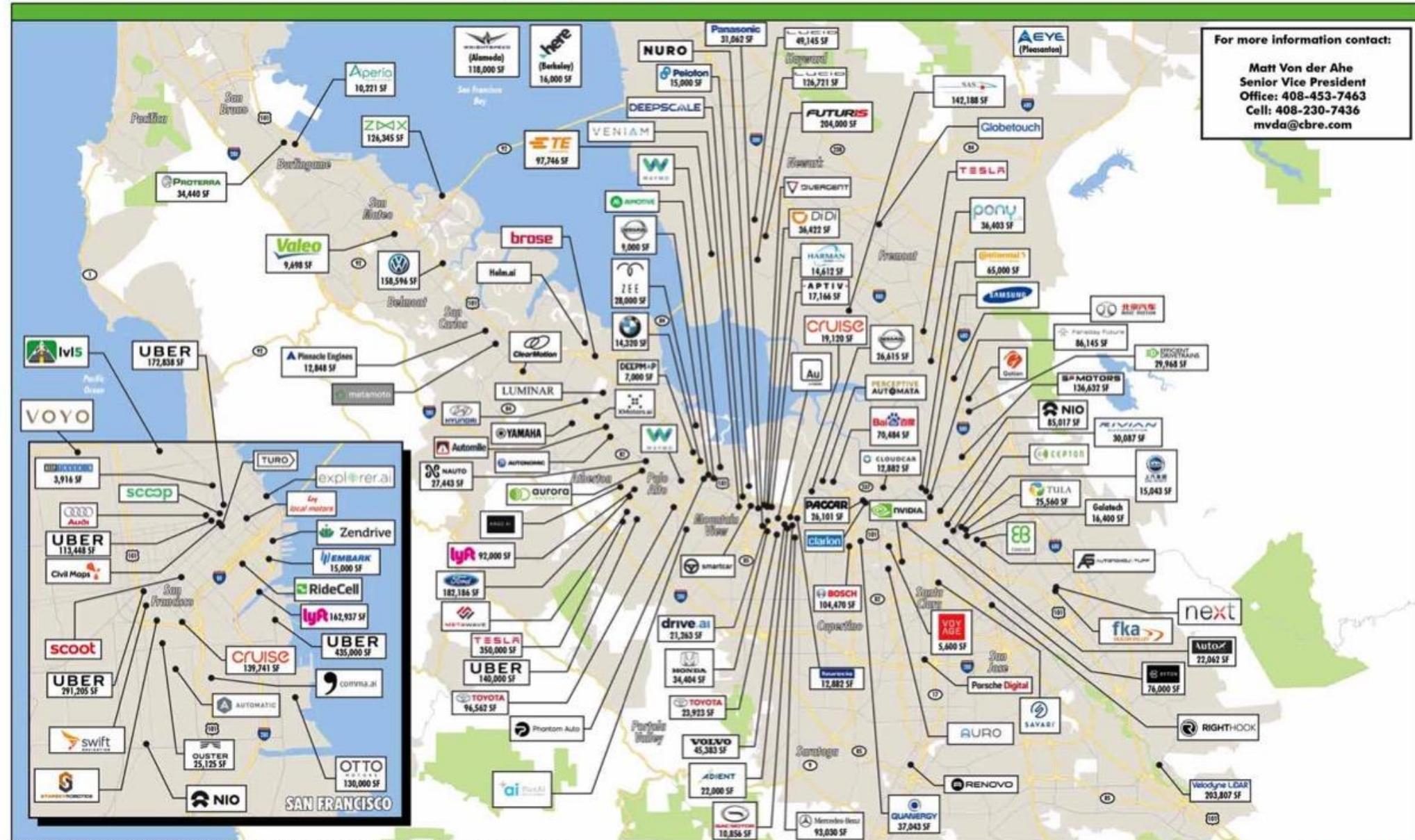
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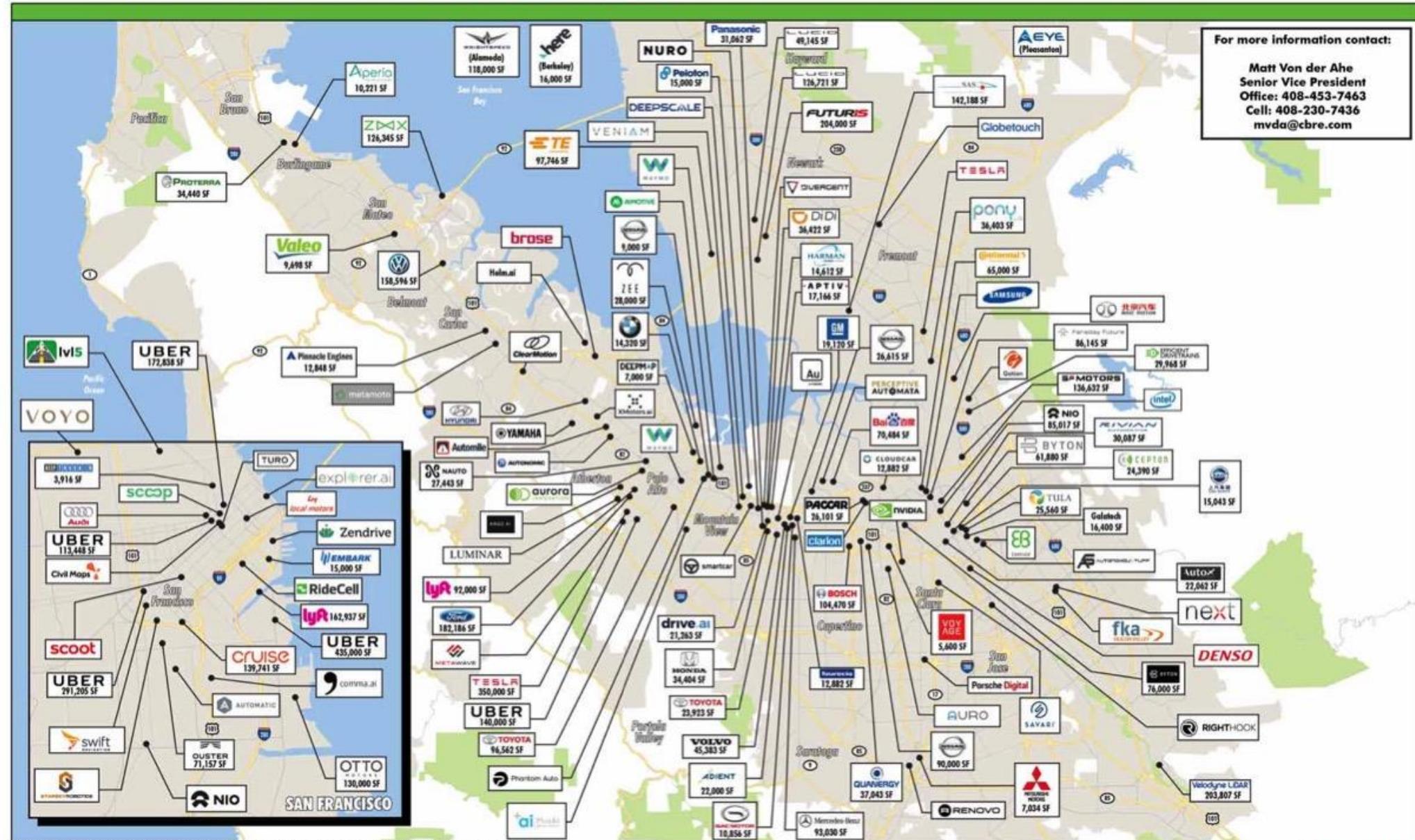
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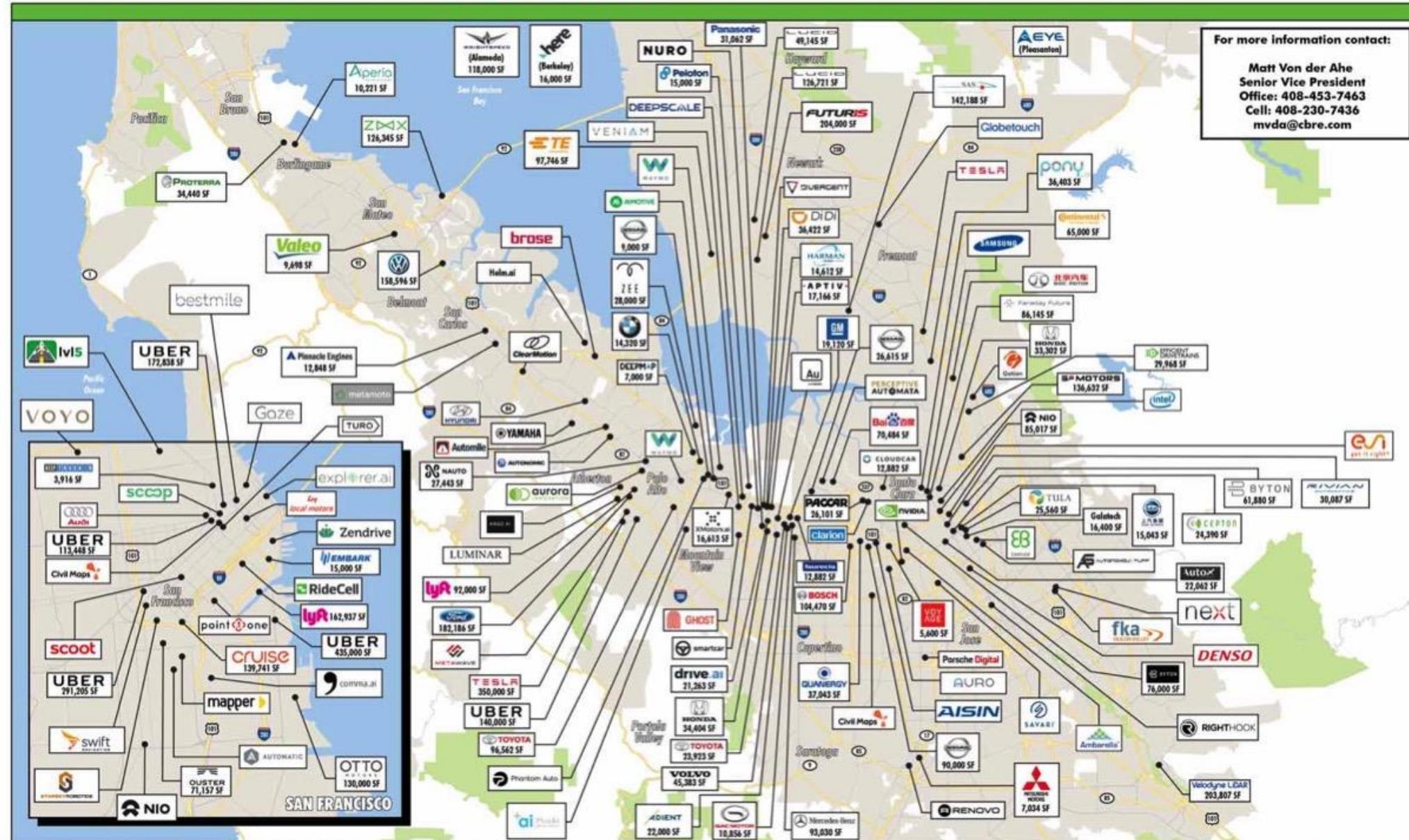
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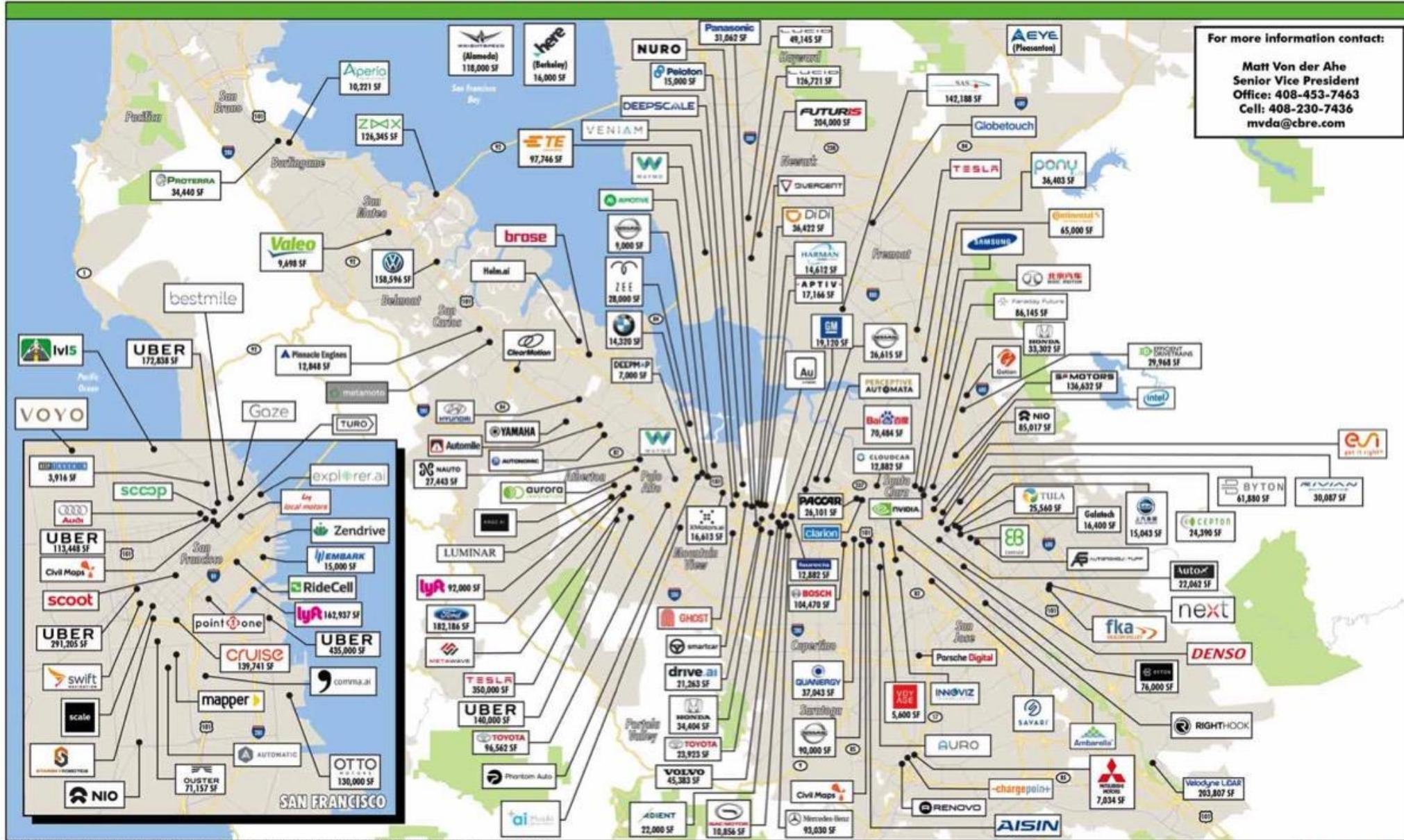
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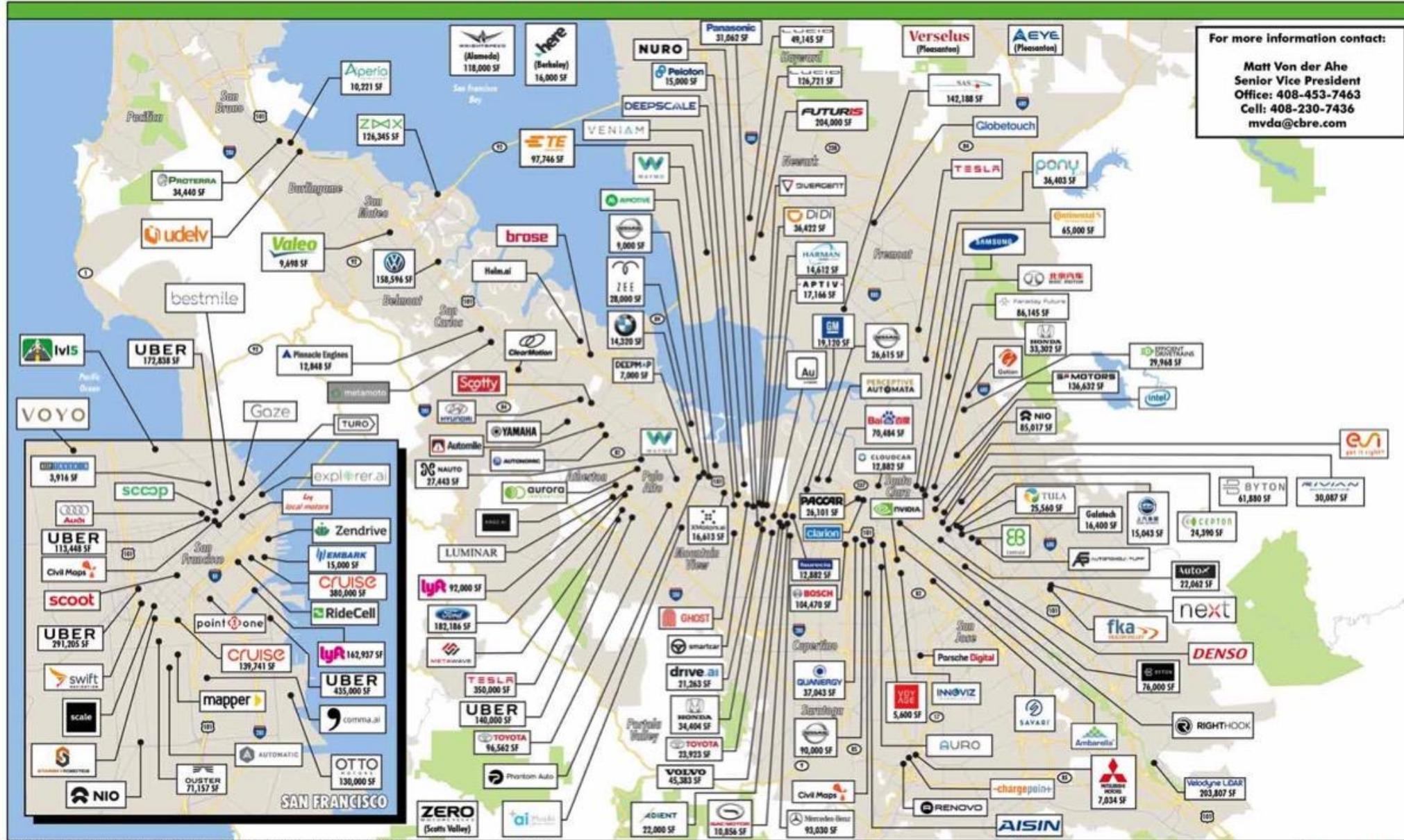
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For more information contact:

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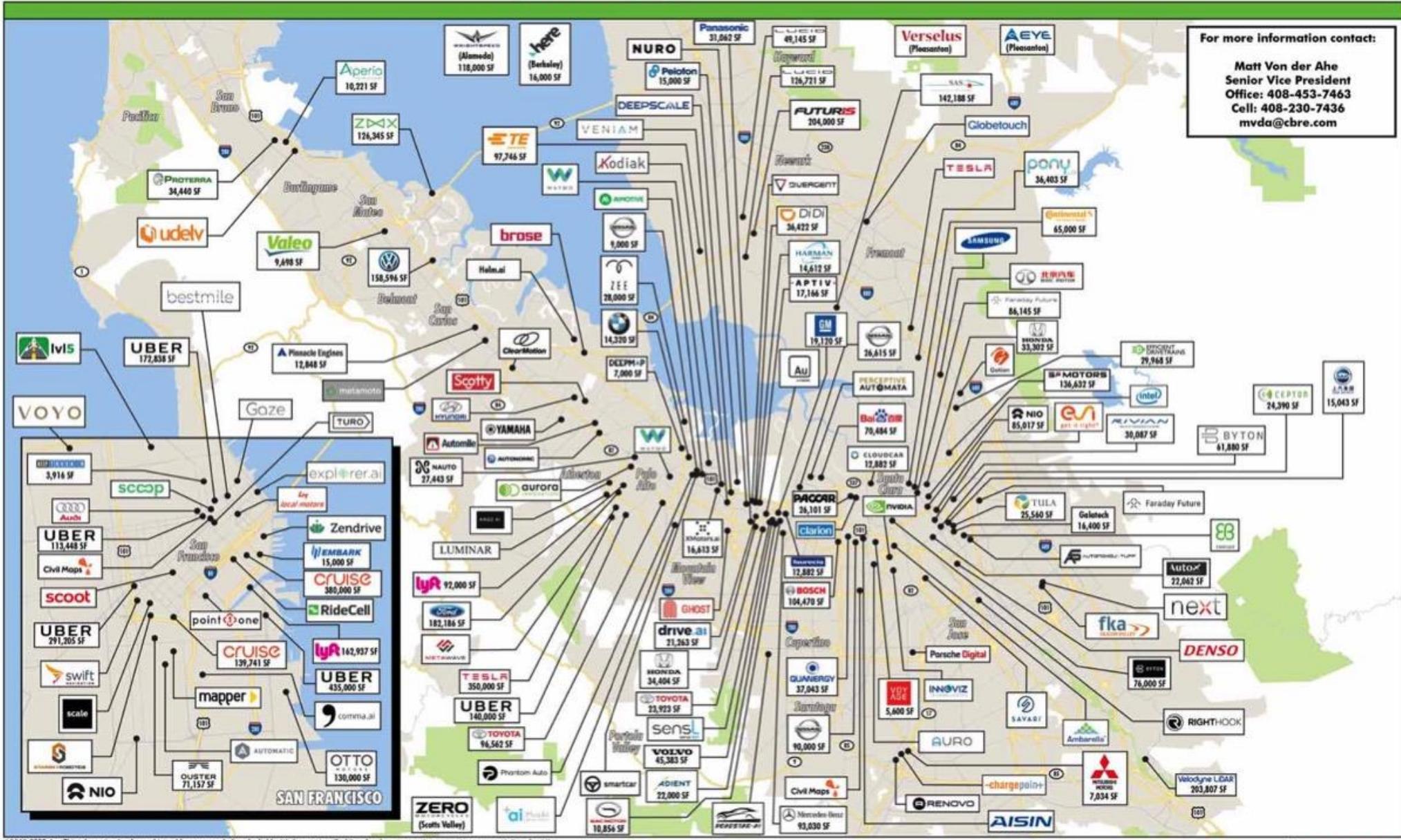
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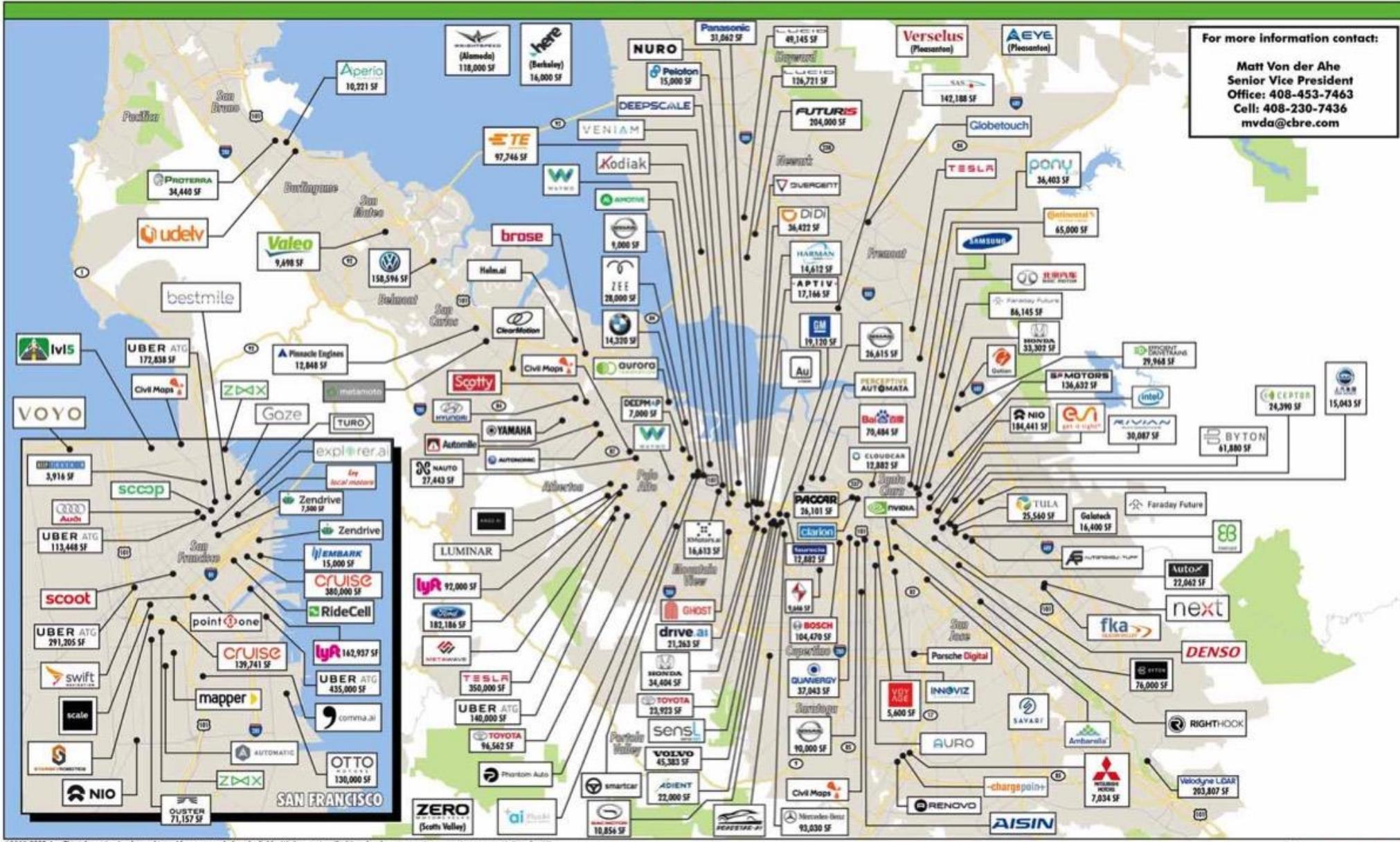
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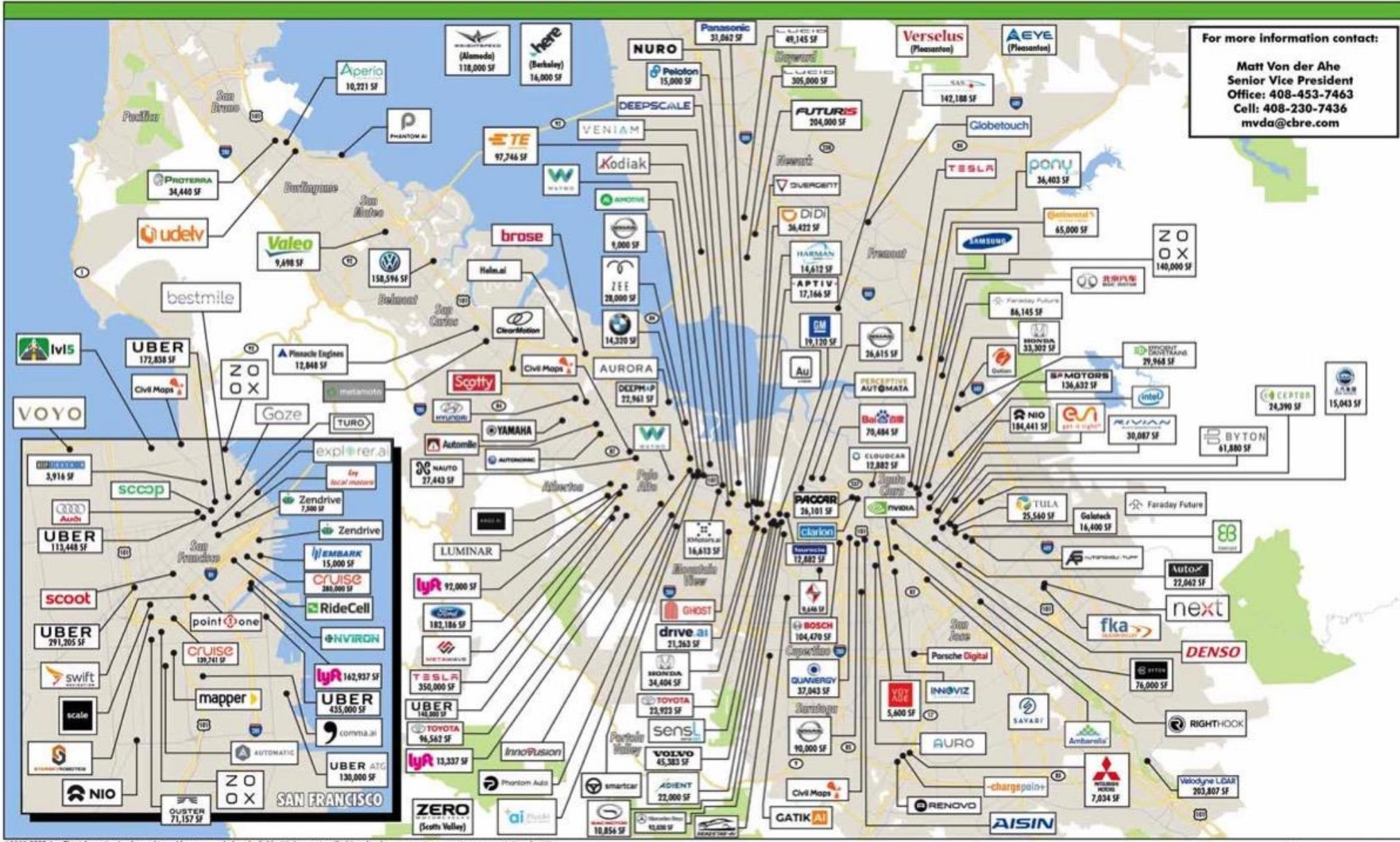
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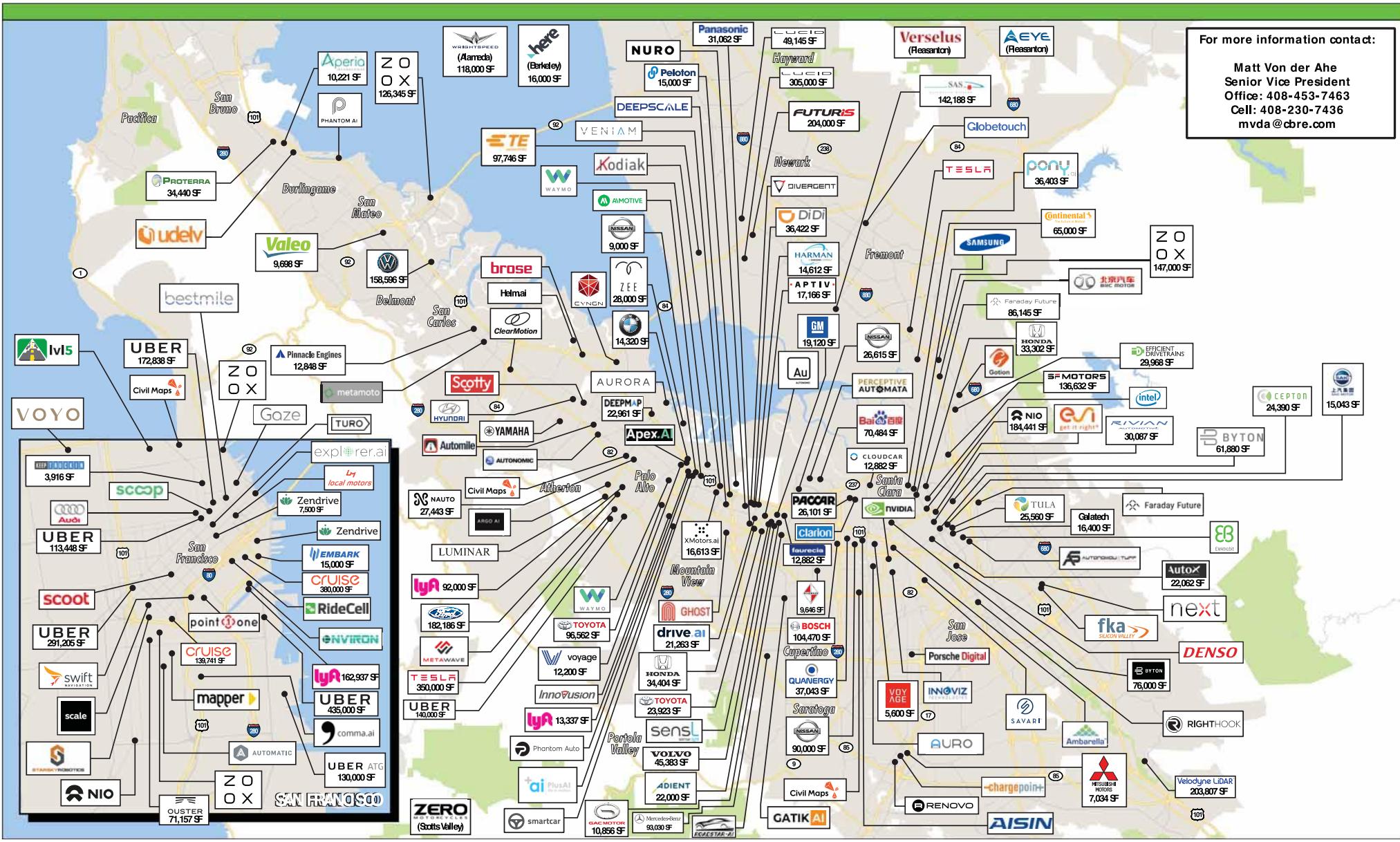
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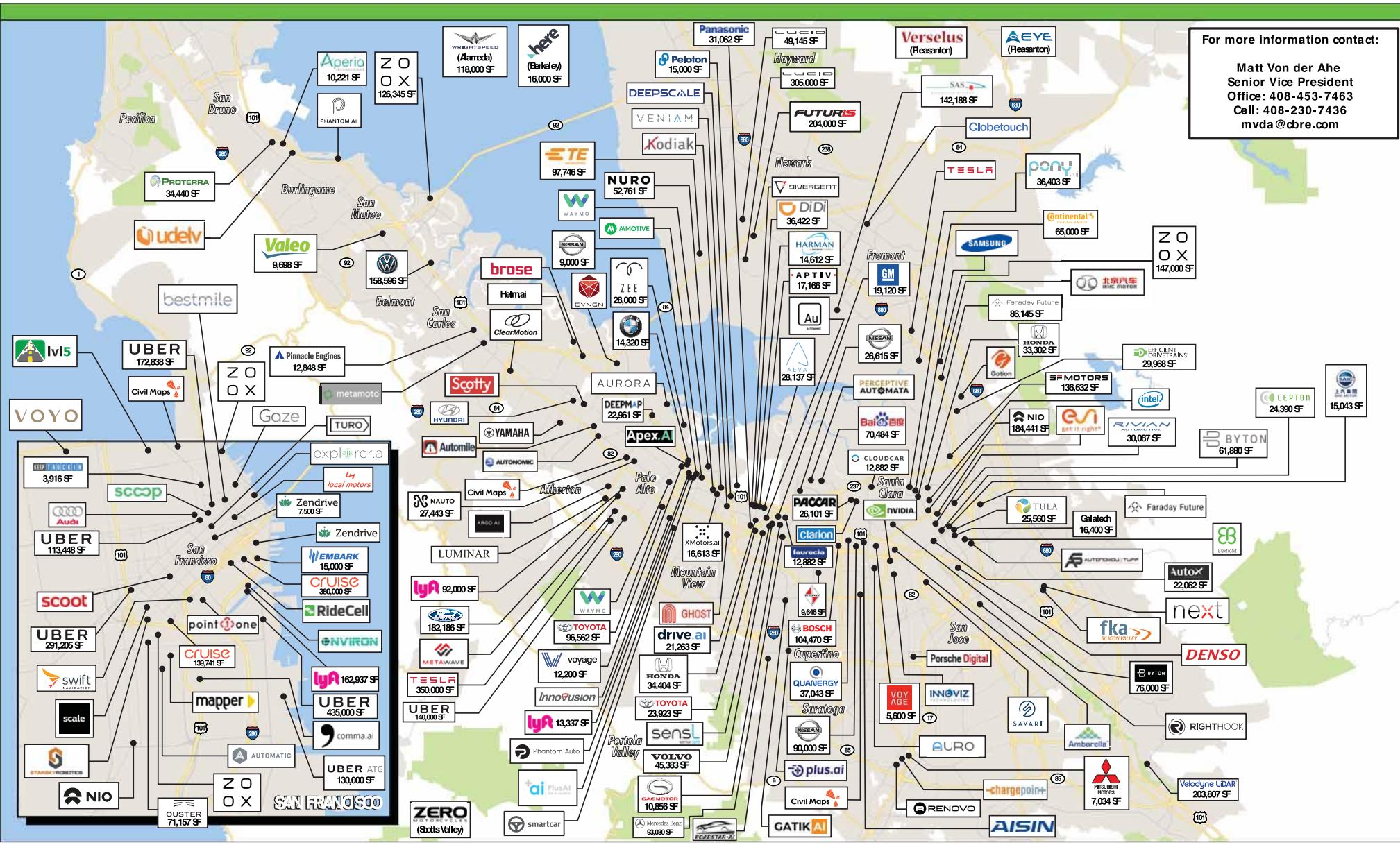
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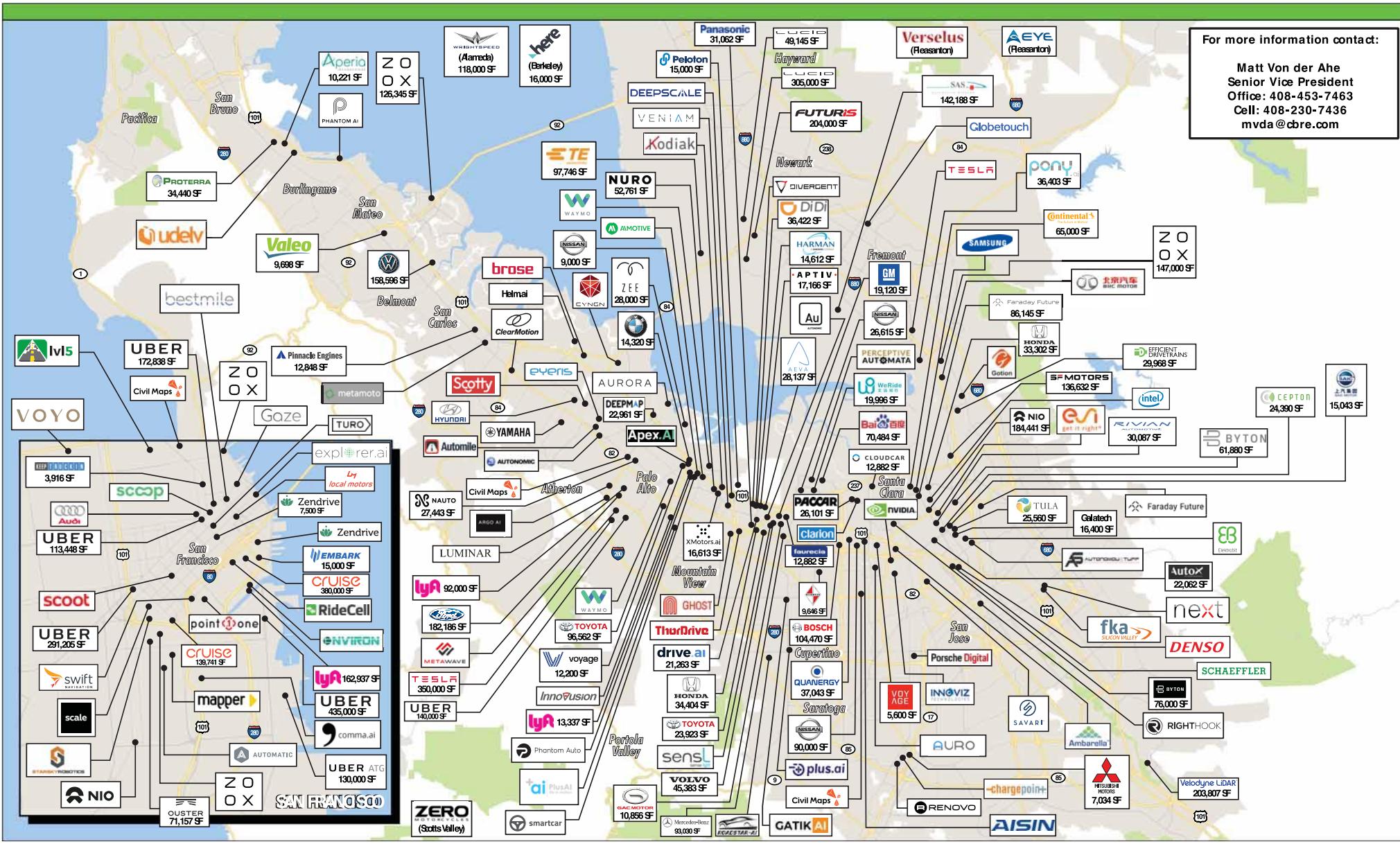
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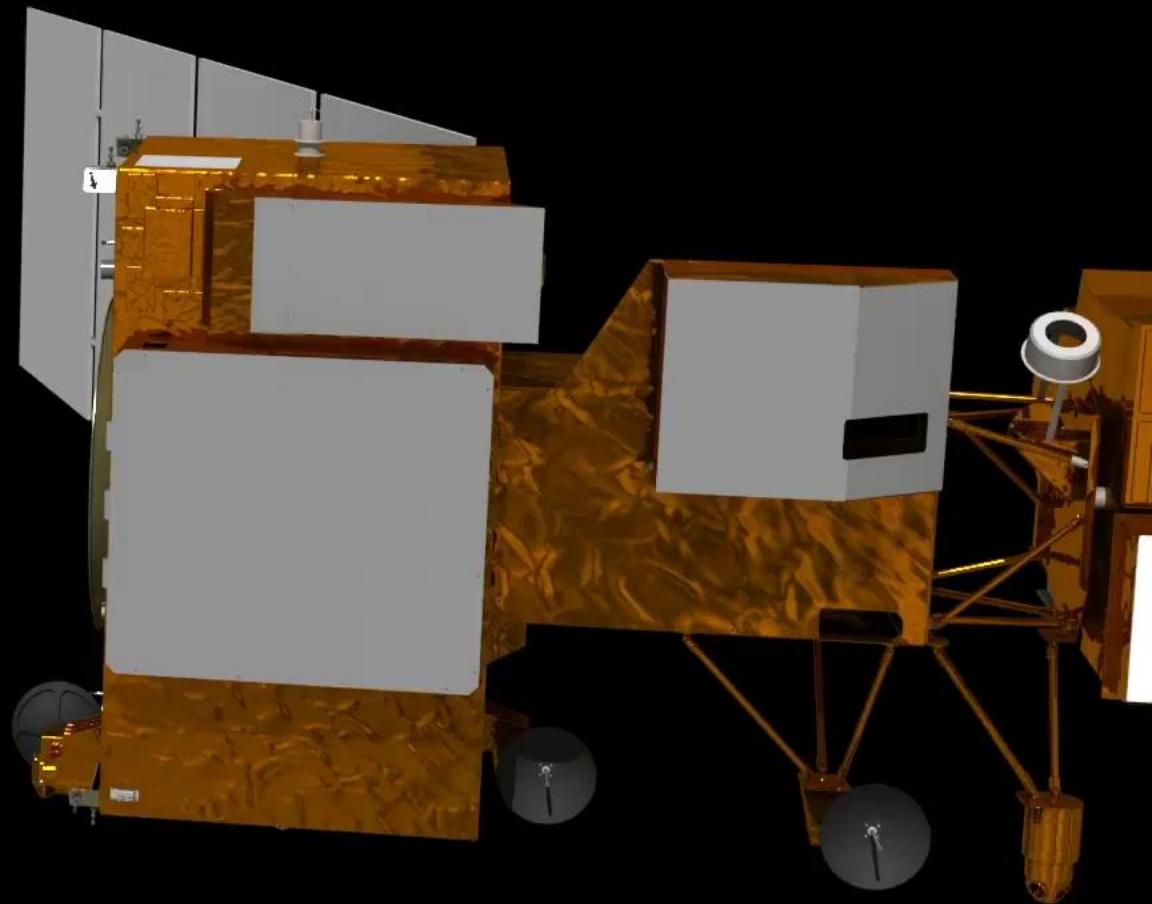
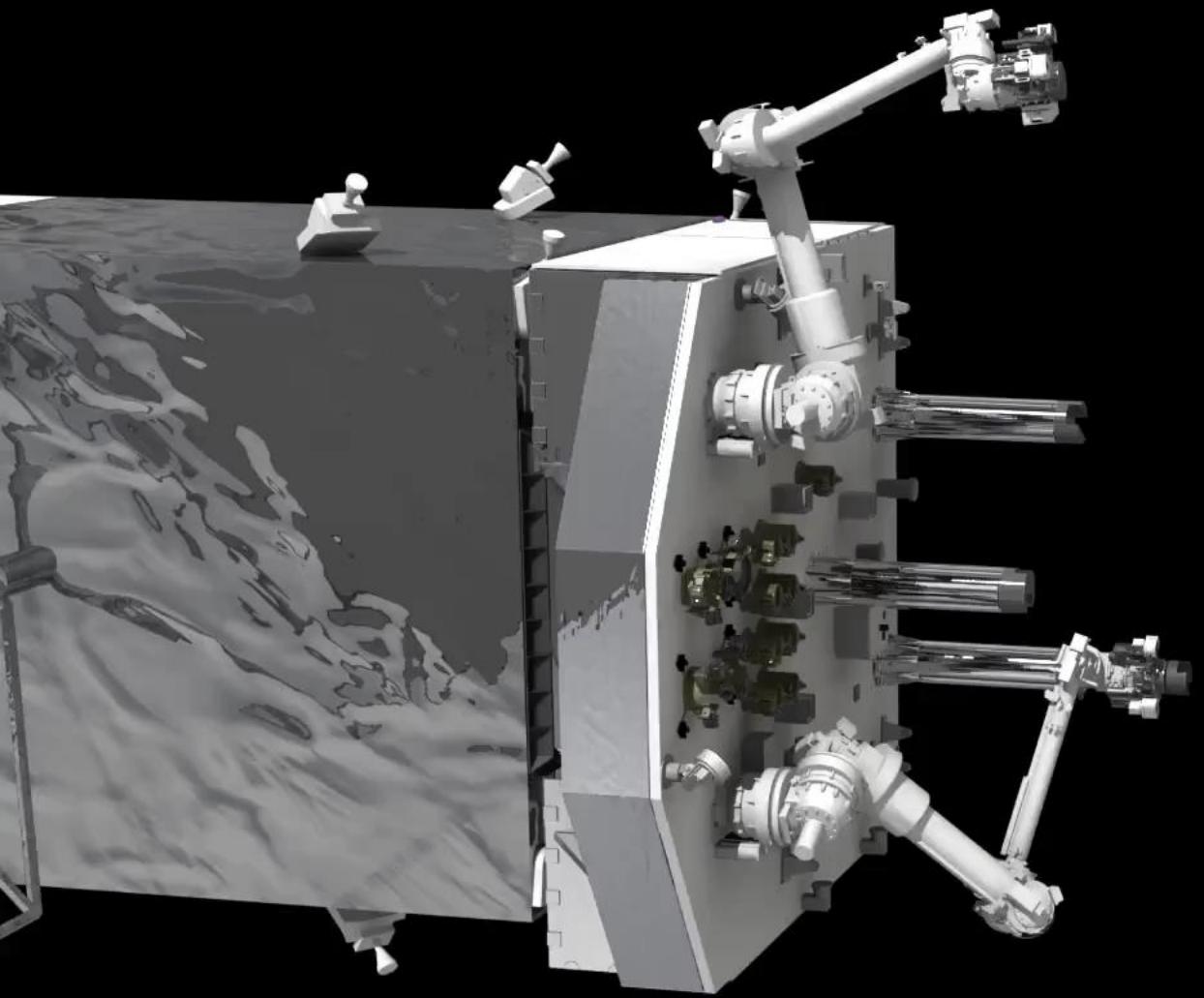


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The Drone Market Environment 2019

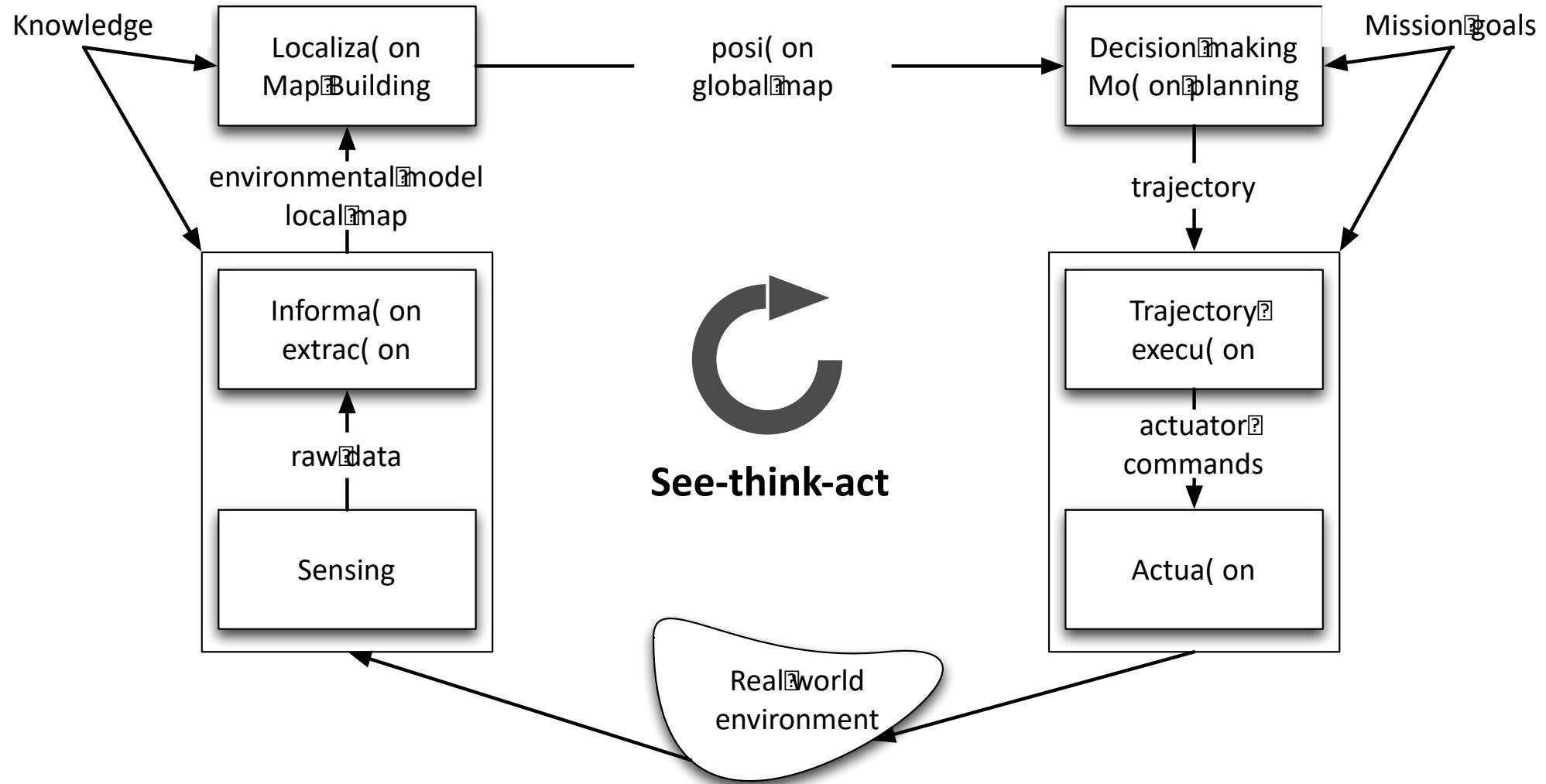
The image is a large grid of logos, each representing a company or organization within the drone industry. The grid is organized into several sections: 1. **Hardware**: Sub-sections include Agriculture, Drone Platforms, Delivery Systems, Safety & Security, Fixed-Wing, VTOL Fixed-Wing, Recreational, and Passenger Drones / eVTOLs / Air Taxis. 2. **Software**: Sub-sections include 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, and Test Sites. 4. **Events**: Sub-sections include Market Research & Consulting, User Groups, Networks, Media, News, Blogs & Magazines, Marketplaces, Shows, Conferences, Events, and Coalitions, Organizations & Initiatives. 5. **Logos Only**: A final section containing many logos without a descriptive label.



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

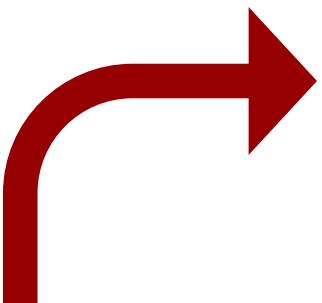
The see-think-act cycle



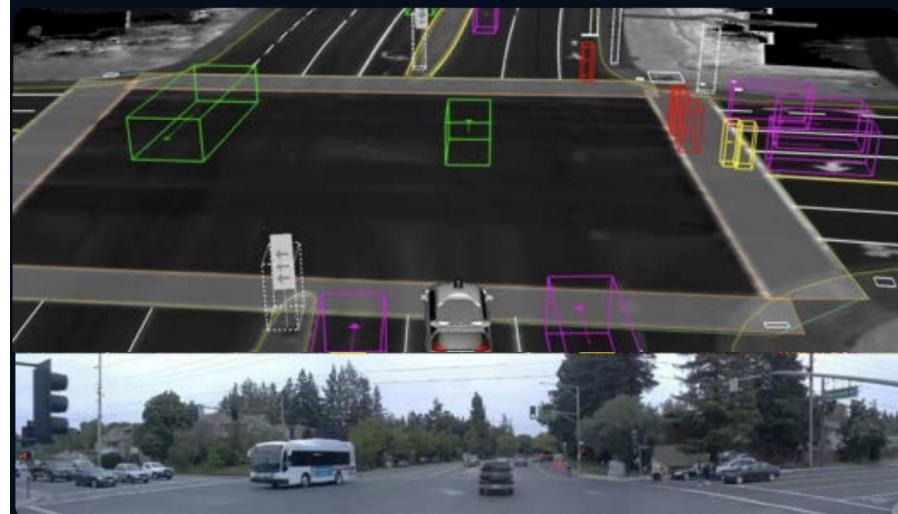
See-think-act cycle for AVs

Think

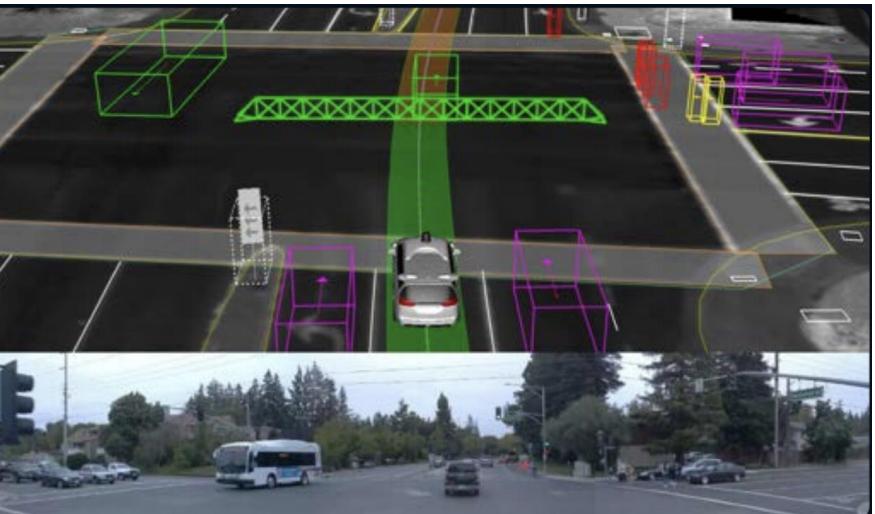
Note: other architectures are possible and subject of active R&D!



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

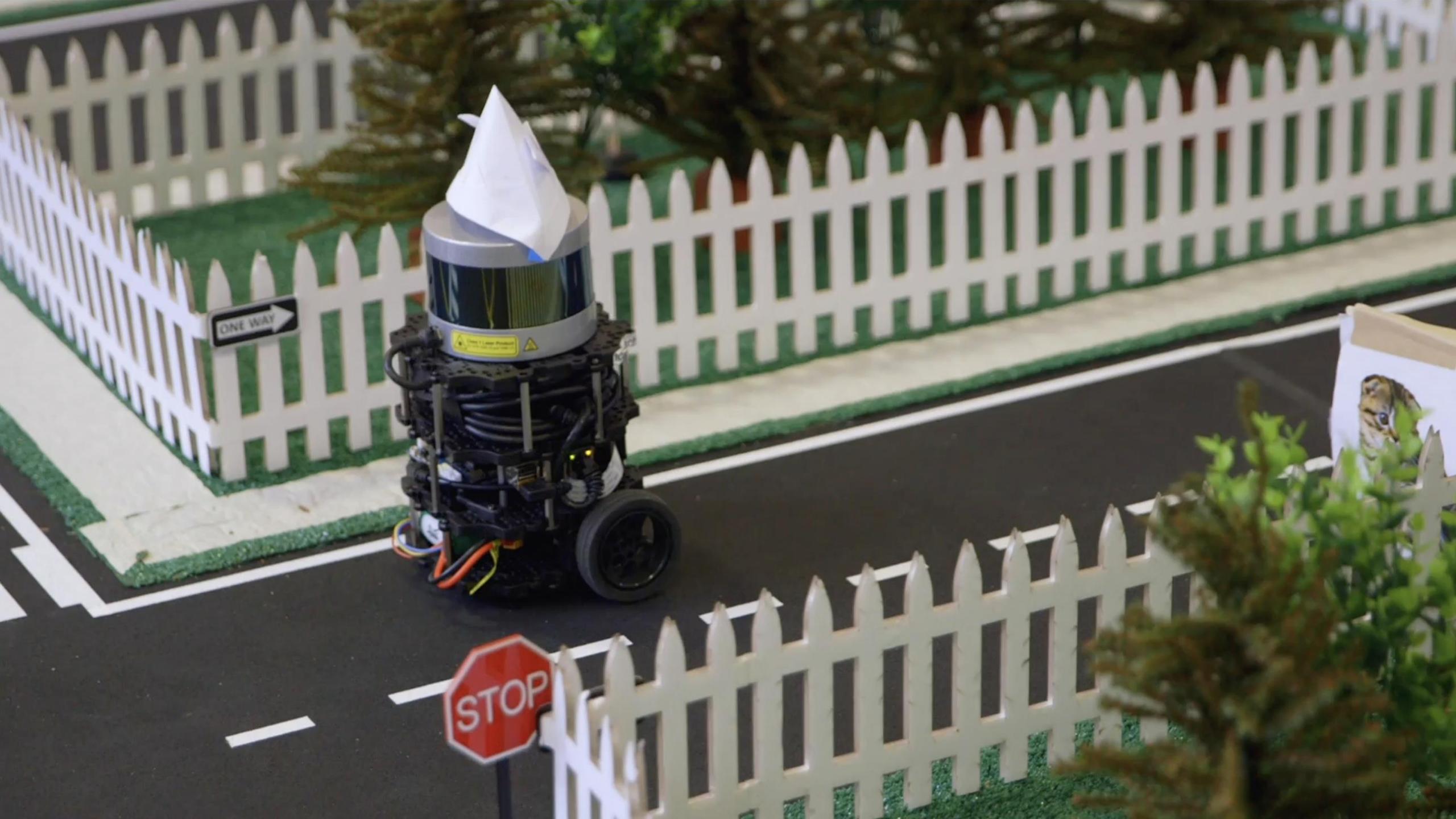
- Lectures:
 - Tuesdays and Thursdays, 10:30am – 11:50am (320-109)
- Sections
 - 2-hour, once-a-week on Fridays, Skilling Lab space
 - Hands-on exercises that complement the lecture material, build familiarity with ROS, and develop skills necessary for working with hardware
 - [Link](#) to the section sign-up sheet (section times confirmed!)
 - Fridays, 9:30am – 11:30am or 4:30pm – 6:30pm

Logistics

- Office hours:
 - Prof. Pavone: Tuesdays, 1:00 – 2:00pm (Durand 261), after class, and by appointment.
 - Course assistants: Tuesdays, 2:00 - 4:00pm @ Durand 023, Thursdays, 4:00 - 6:00pm @ Durand 270 (except October 24th & November 7th, which are @ Durand 114, 4:00 - 6:00pm)
- Course websites:
 - For course content: https://stanfordasl.github.io/PoRA-I/aa174a_aut2425/
 - For course announcements: <https://canvas.stanford.edu/courses/197347>
 - For course-related questions:
<https://edstem.org/us/courses/66279/discussion/>
 - For homework submissions: <https://www.gradescope.com/courses/865637>
 - To contact the AA174A staff: aa174a-aut2425-staff@lists.stanford.edu

Grading

- (40%) Homework
- (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



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



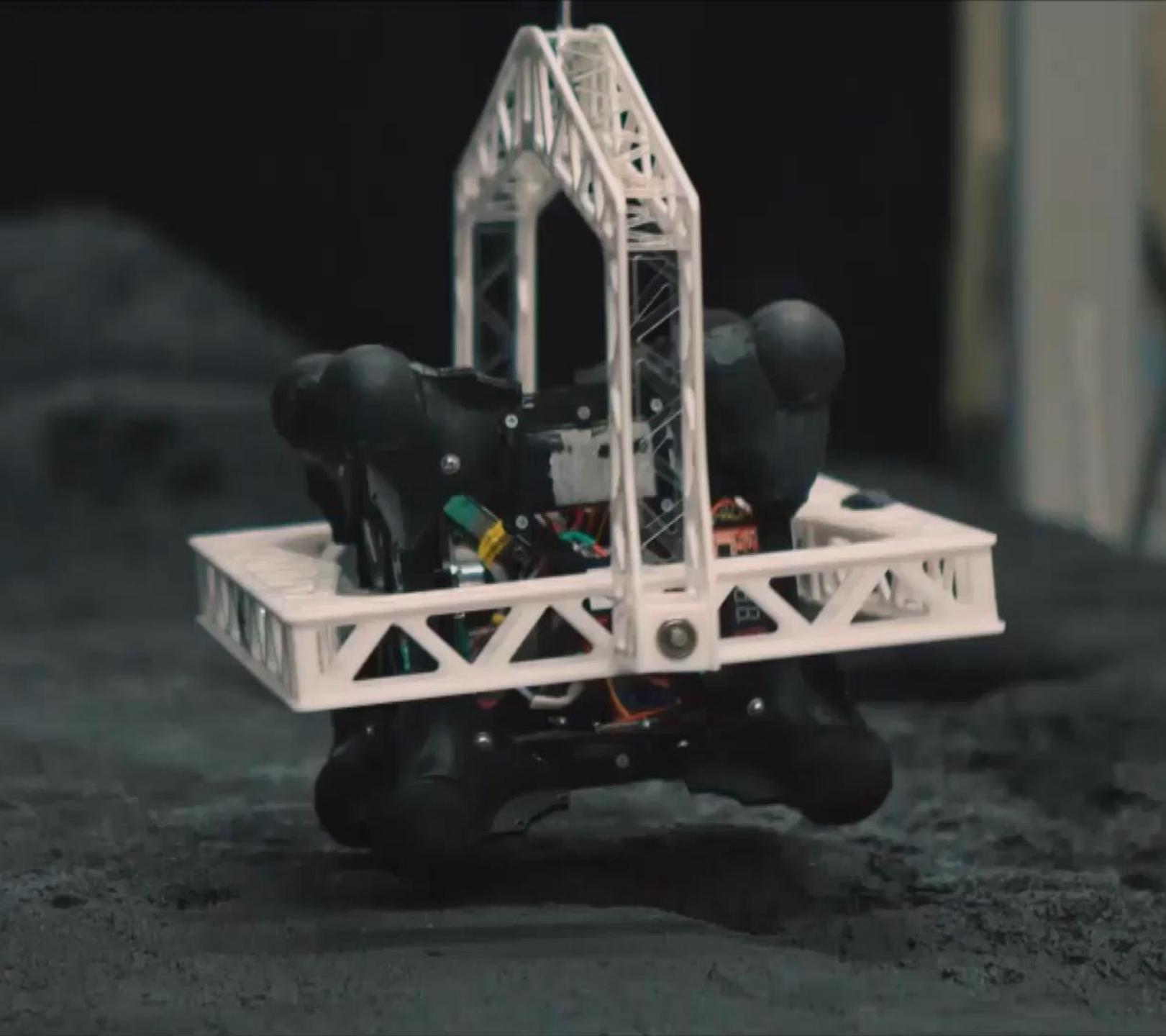
Luis Pabon



Rohan Sinha

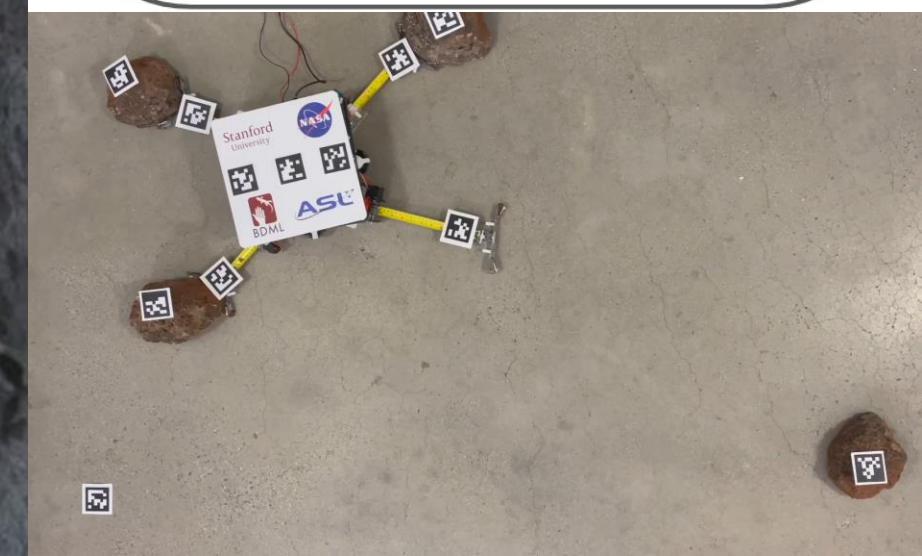
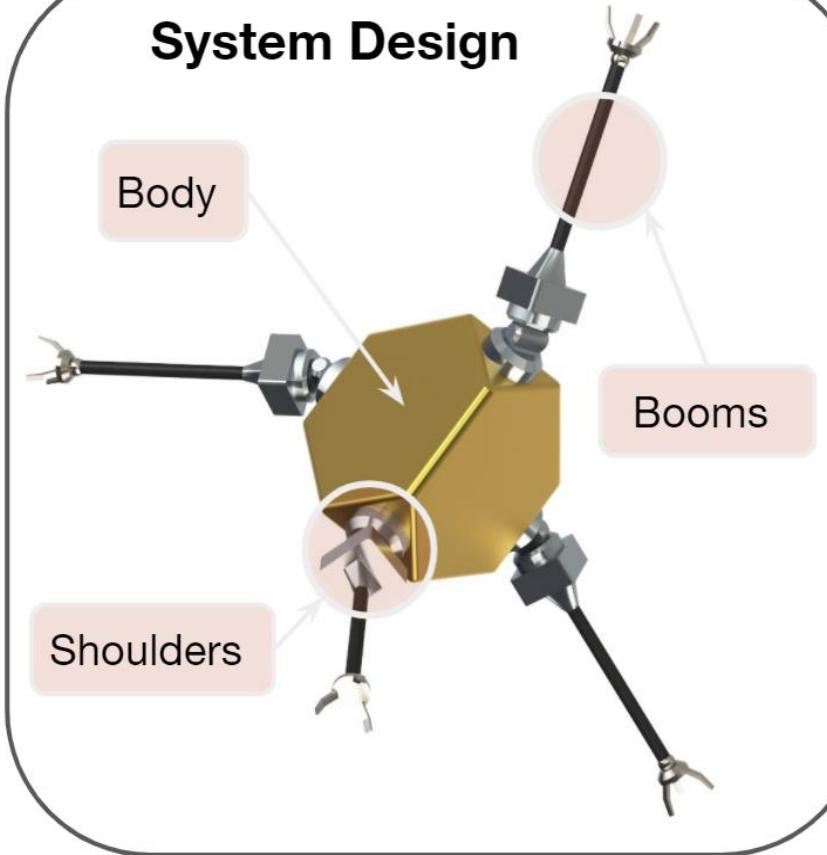


Courtesy of NASA JPL





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
09/24	Course overview, intro to robotic systems and ROS	
09/26	Fundamentals of ROS & vectorized computation in Python	
09/27	* Section 1 – UNIX, Git, and Python	HW1 out
10/01	State space dynamics – definitions and modeling	
10/03	State space dynamics – computation and simulation	
10/04	* Section 2 – ROS, workspaces, packages, nodes	
10/08	Trajectory optimization	HW2 out
10/10	Trajectory tracking	
10/11	* Section 3 – Launch files & RVIZ	HW1 due
10/15	Motion planning I: graph search algorithms	
10/17	Motion planning II: sampling-based methods	
10/18	* Section 4 – Controller gain tuning in hardware	HW2 due
10/22	Robotic sensors & introduction to computer vision	HW3 out
10/24	Camera models and camera calibration	
10/25	* Section 5 – Running a point-to-point navigator	
10/29	Image processing, feature detection, & feature description	
10/31	Information extraction	
11/01	* No Section	HW3 due, HW4 (part 1) out
11/05	No Lecture – Democracy Day	
11/07	<i>In-class midterm</i>	
11/08	* No Section	
11/12	Deep learning for computer vision	
11/14	Intro to state estimation & filtering theory	
11/15	* Section 6 – Object detection	HW4 (part 2) out
11/19		
11/21	<i>Thanksgiving</i>	HW4 (part 1) due
11/22		
11/26	Parametric filtering (KF and EKF)	
11/28	Markov localization and EKF-localization	
11/29	* Section 7 – Frontier exploration	
12/03	Multi-sensor perception & sensor fusion	HW4 (part 2) due
12/05	Simultaneous localization and mapping (SLAM)	
12/06	* No Section	

Robot Operating System – History

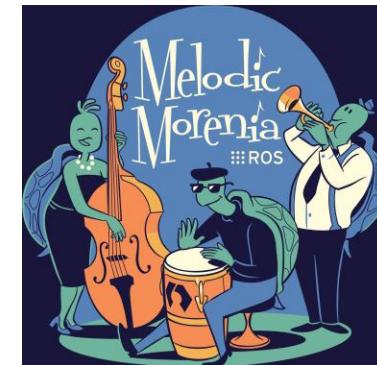
ROS 1



2014 - 2019



2016 - 2021

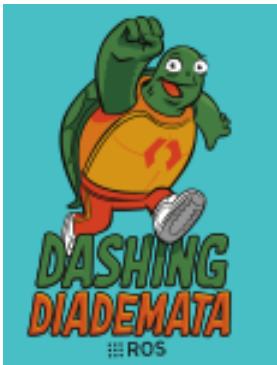


2018 - 2023



2020 - 2025

ROS 2



2019 - 2021



2020 - 2023



2022 - 2027



2024 - 2029



2017 - Present

Robot Operating System – History

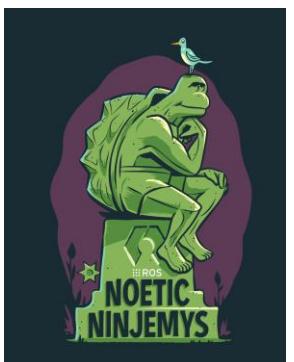
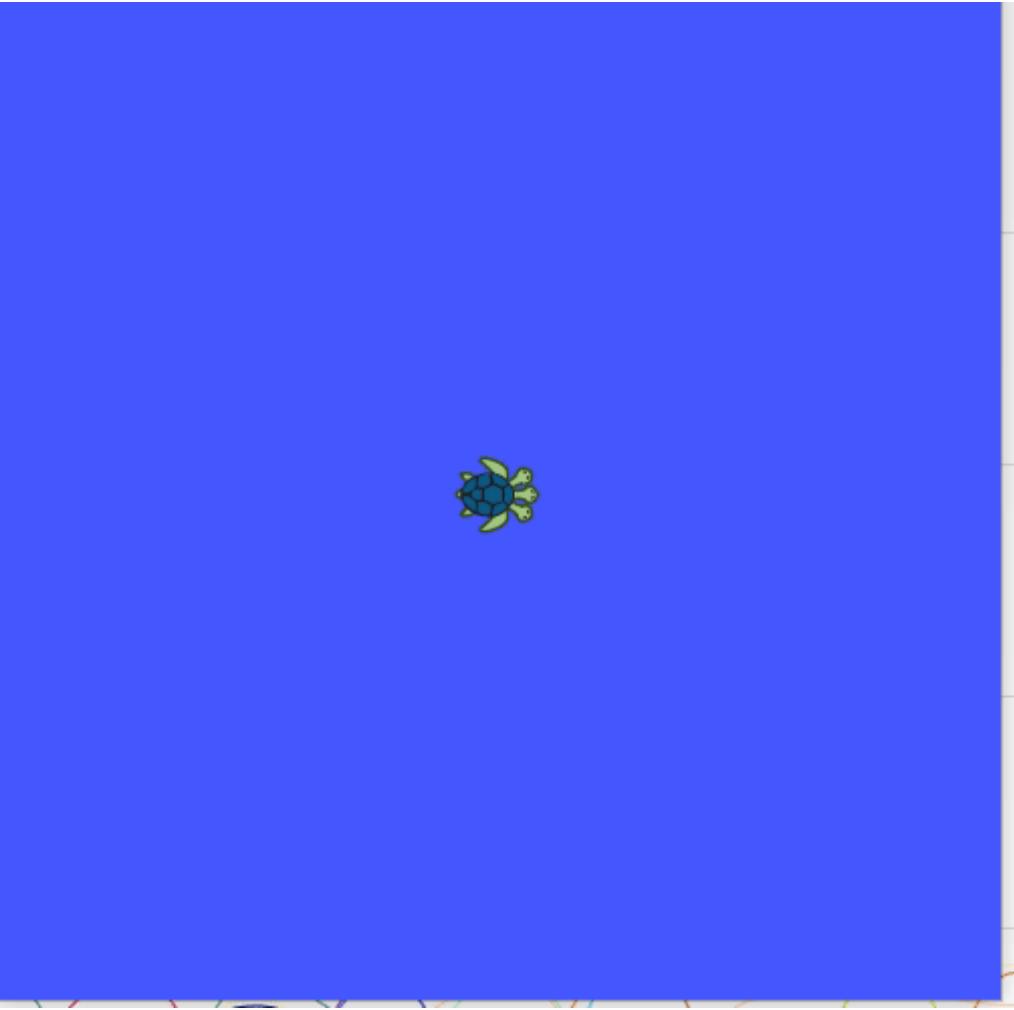
ROS 1



2014 - 2019



2019 - 2021



2020 - 2025



2017 - Present

Robot Operating System – History

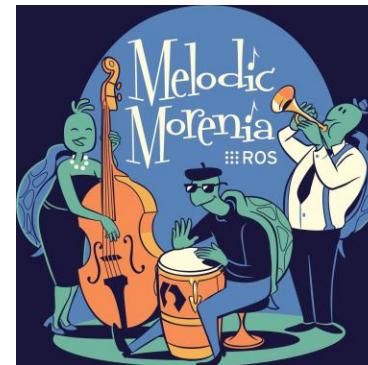
ROS 1



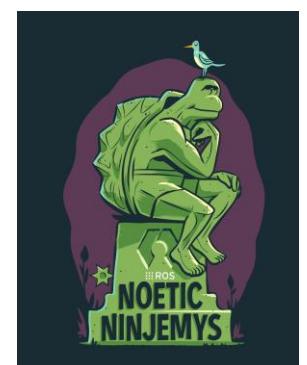
2014 - 2019



2016 - 2021

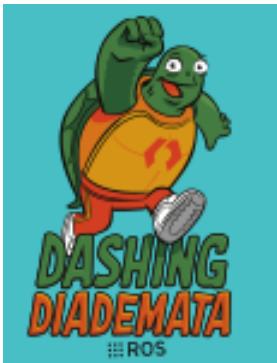


2018 - 2023



2020 - 2025

ROS 2



2019 - 2021



2020 - 2023



2022 - 2027



2024 - 2029



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 more than a decade old and still going strong



Robot Operating System – Overview

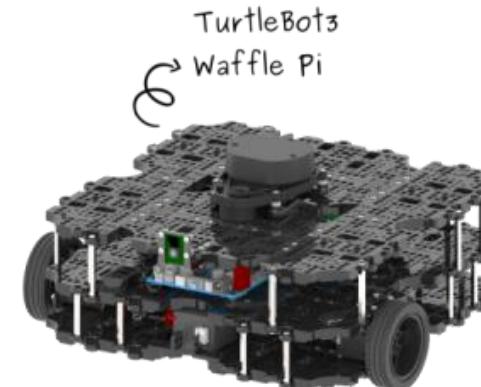
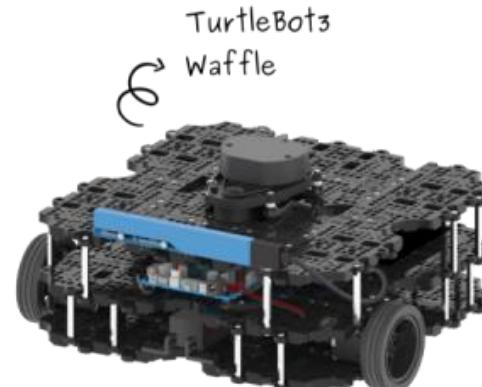
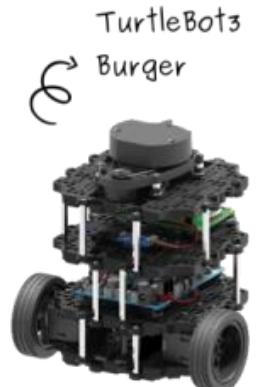
- Community & Ecosystem
 - Hardware Drivers
 - Software
- Tooling
 - Visualization
 - Debugging
- Asynchronous Programming Model

Robot Operating System – ROS2

- Community & Ecosystem
 - Hardware Drivers
 - Software

Robot Operating System – ROS2

- Community & Ecosystem
 - Hardware Drivers
 - Software



[Turtlebot3](#)



[Crazyflie](#)



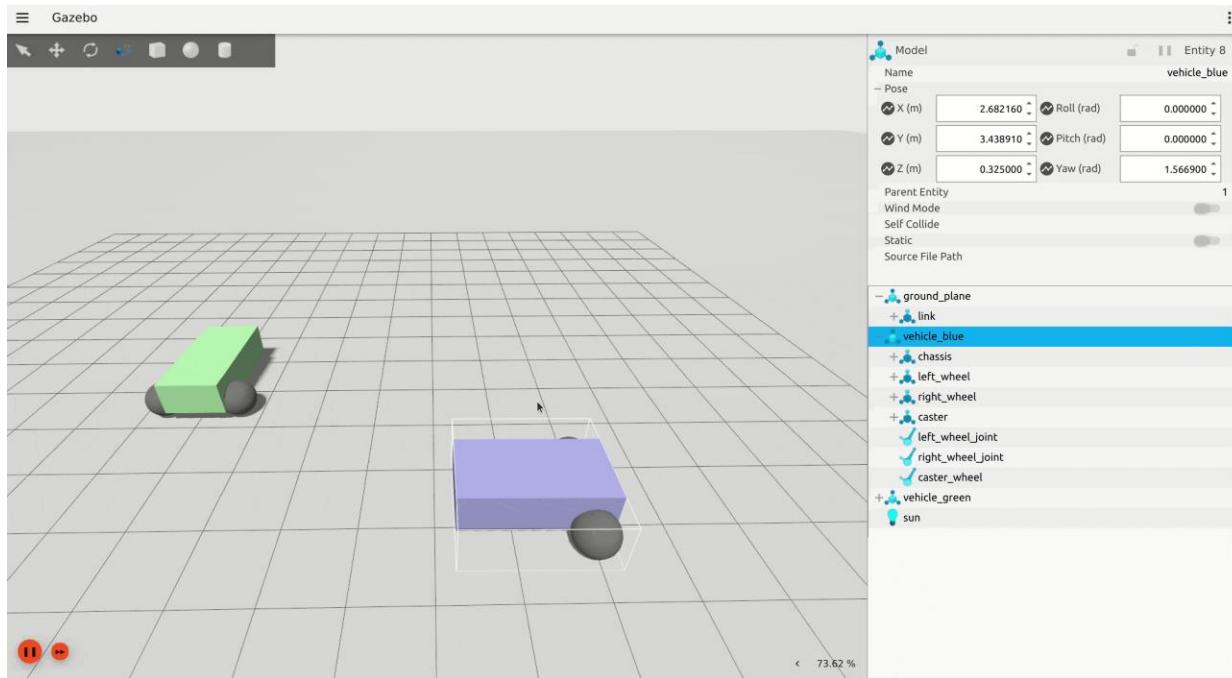
[Joysticks](#)



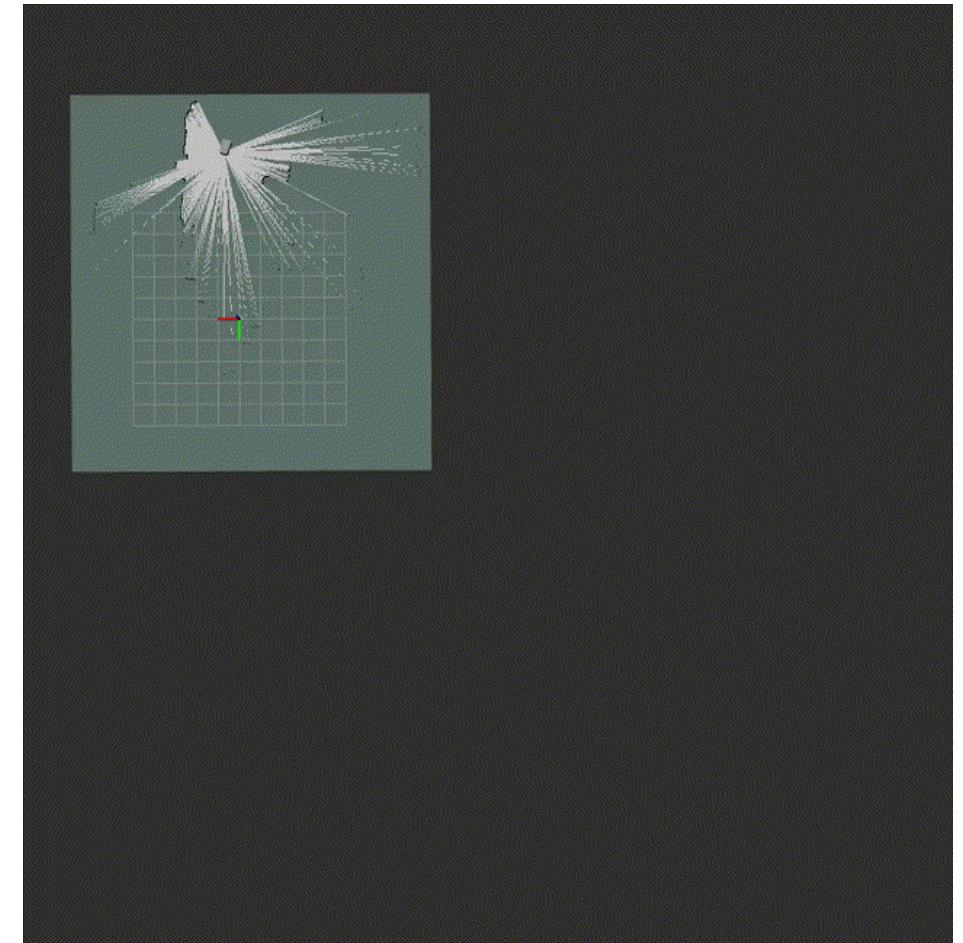
[Velodyne LiDAR](#)

Robot Operating System – ROS2

- Community & Ecosystem
 - Hardware Drivers
 - Software



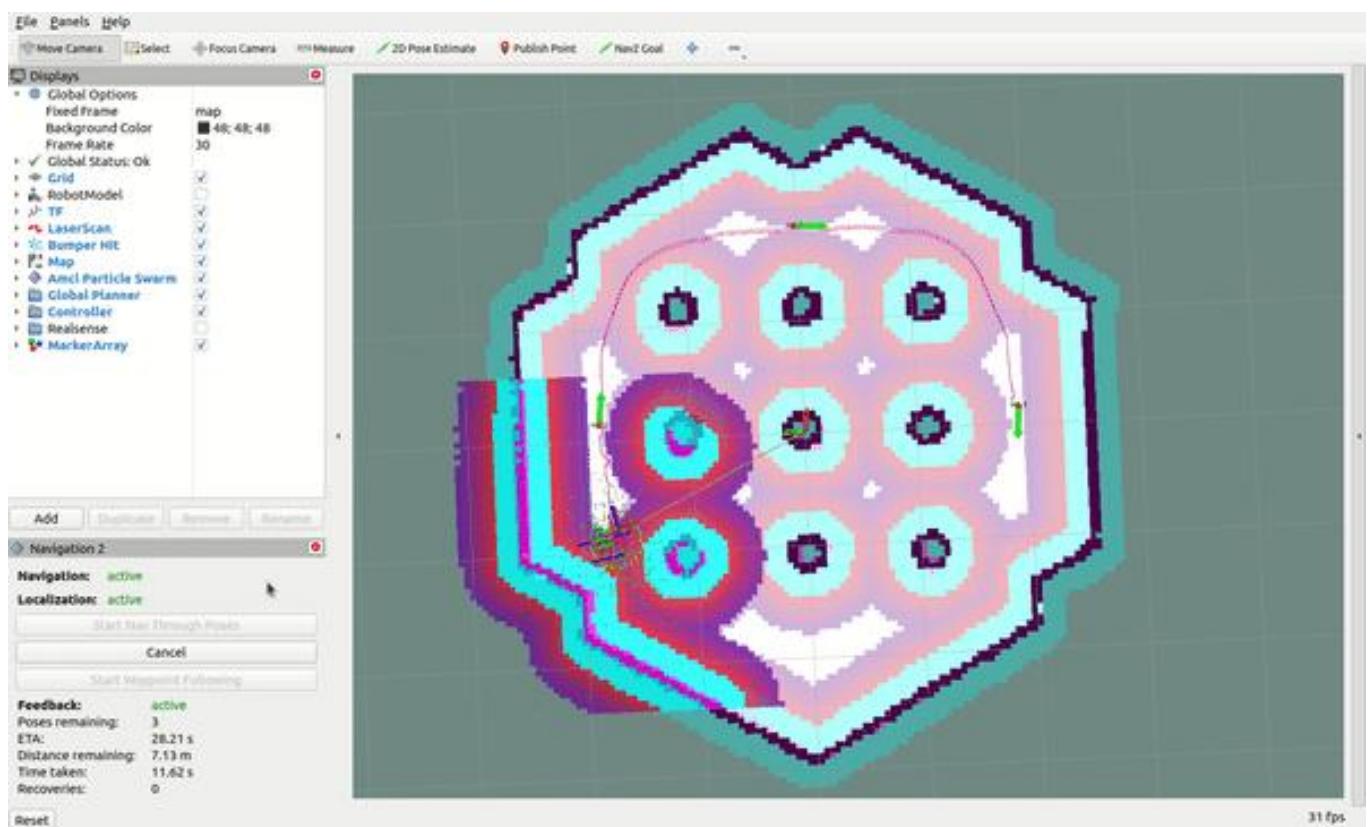
[Gazebo Sim](#)



[SLAM Toolbox](#)

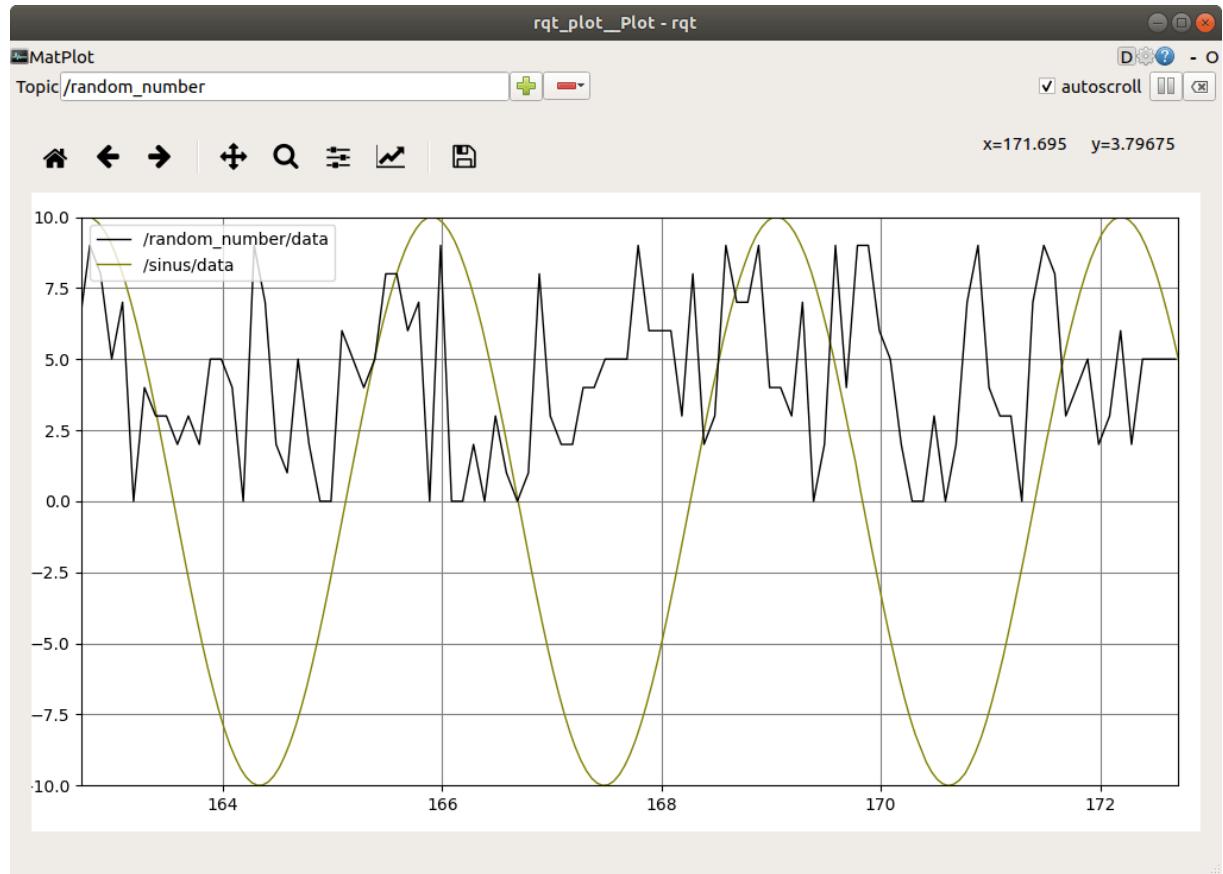
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 - Visualization
 - Debugging



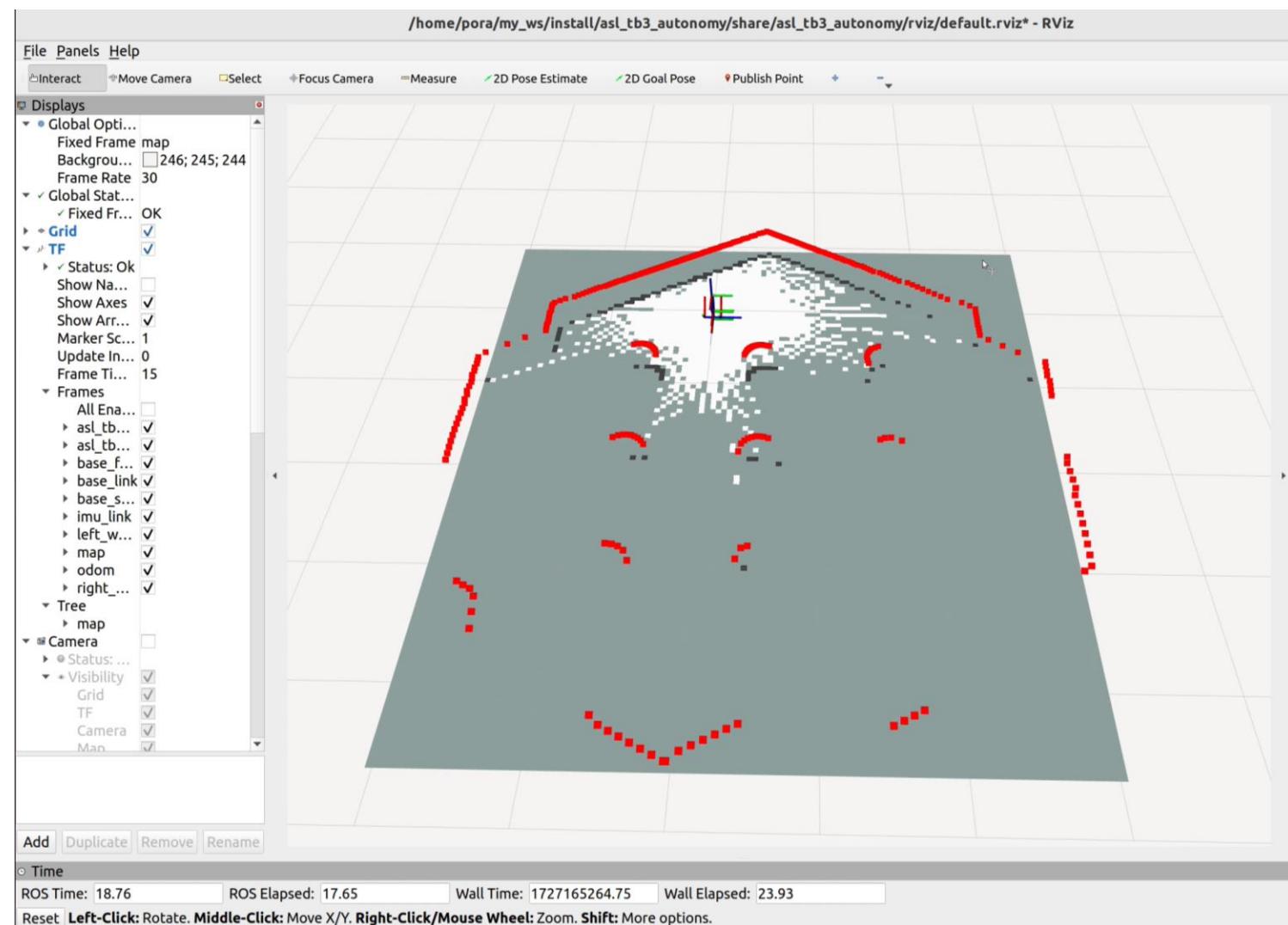
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- Asynchronous Programming Model



See-think-act

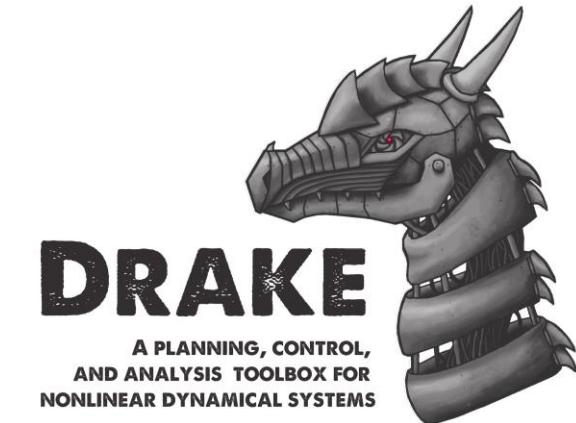
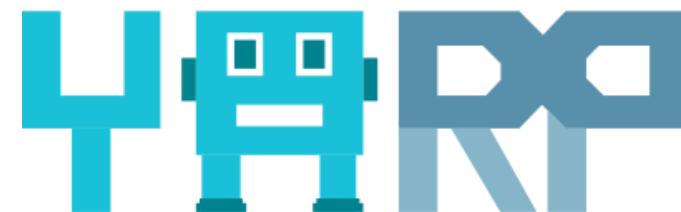
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Let's write some code!

Are there “Alternatives” to ROS?

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



Next time: fundamentals of ROS



Robot Operating System