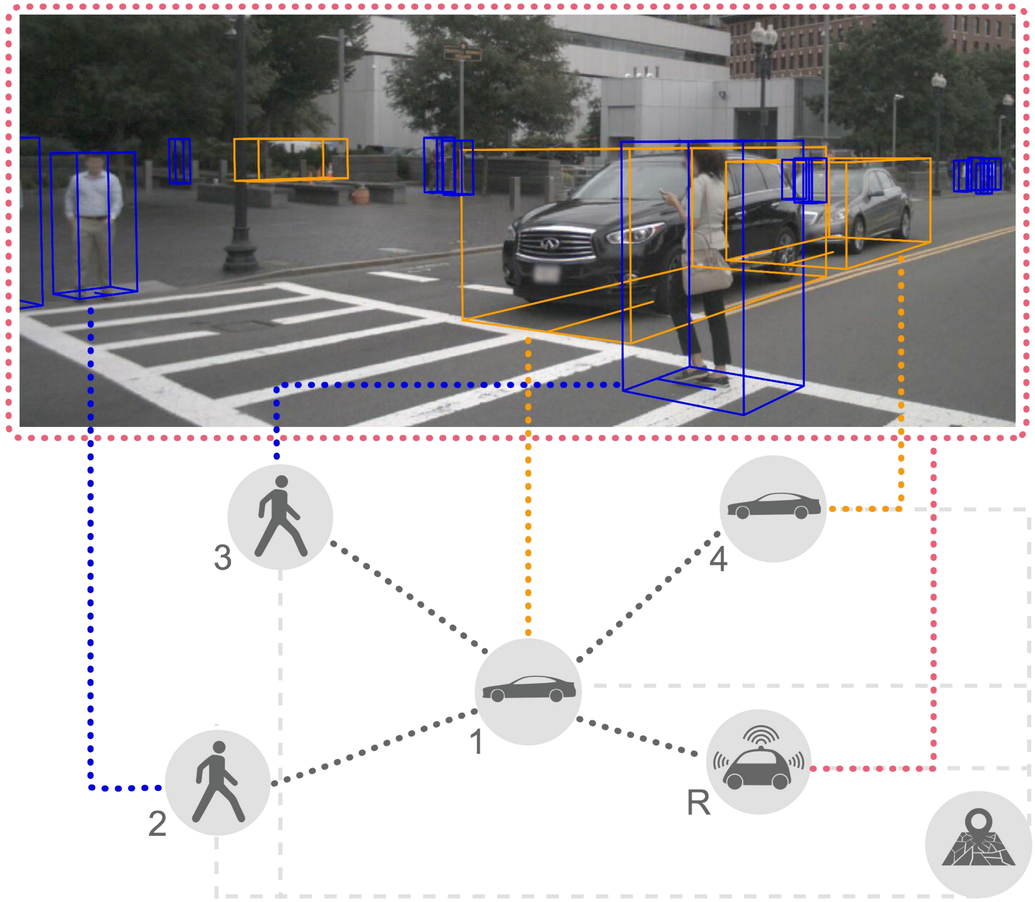
OPEN RESEARCH CHALLENGES IN VEHICLE AUTONOMY

Marco Pavone

Department of Aeronautics and Astronautics
Stanford University

Autonomous Vehicle Research Group
NVIDIA

September 27th, 2022
Driving the Next in motor risk @Swiss Re



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@drmapavone

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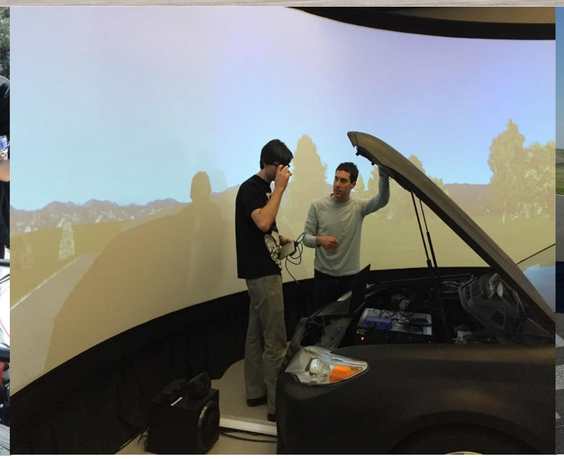
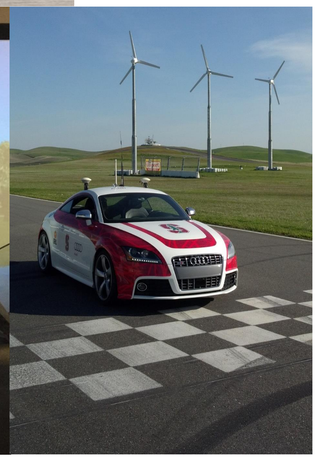
CENTER FOR AUTOMOTIVE RESEARCH AT STANFORD

Mission: link industry and academia around human-centered mobility and the future of the automobile





3M, AAA, ADIENT, Akebono, Allstate, Bridgestone, Beverly Hills Driven by Innovation, Continental, dar group, DENSO, Enterprise Holdings, esi get it right®, faurecia, FCA Fiat Chrysler Automobiles, Ford, Fujitsu Ten, GM, Hitachi Inspire the Next, Honda, Hyundai, intel, Komatsu, LG, Magna, Mercedes-Benz, Mitsubishi Corporation (Americas), Nissan, PACCAR, Panasonic, Renault, Bosch, Samsung, SOMPO Digital Lab, State Farm, Subaru, Sumitomo Electric, Tata Motors, Toyota, 啟迪國際有限公司 TUS International Limited, Valeo, Volkswagen Group of America, Yanfeng Global Automotive Interiors

Stanford University, NVIDIA

Vo port

REVS
brembo
BRIDGESTONE

Automotive R&D

April 2016

Silicon Valley

CBRE

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AUTO LAB MAP APRIL 2017 SILICON VALLEY

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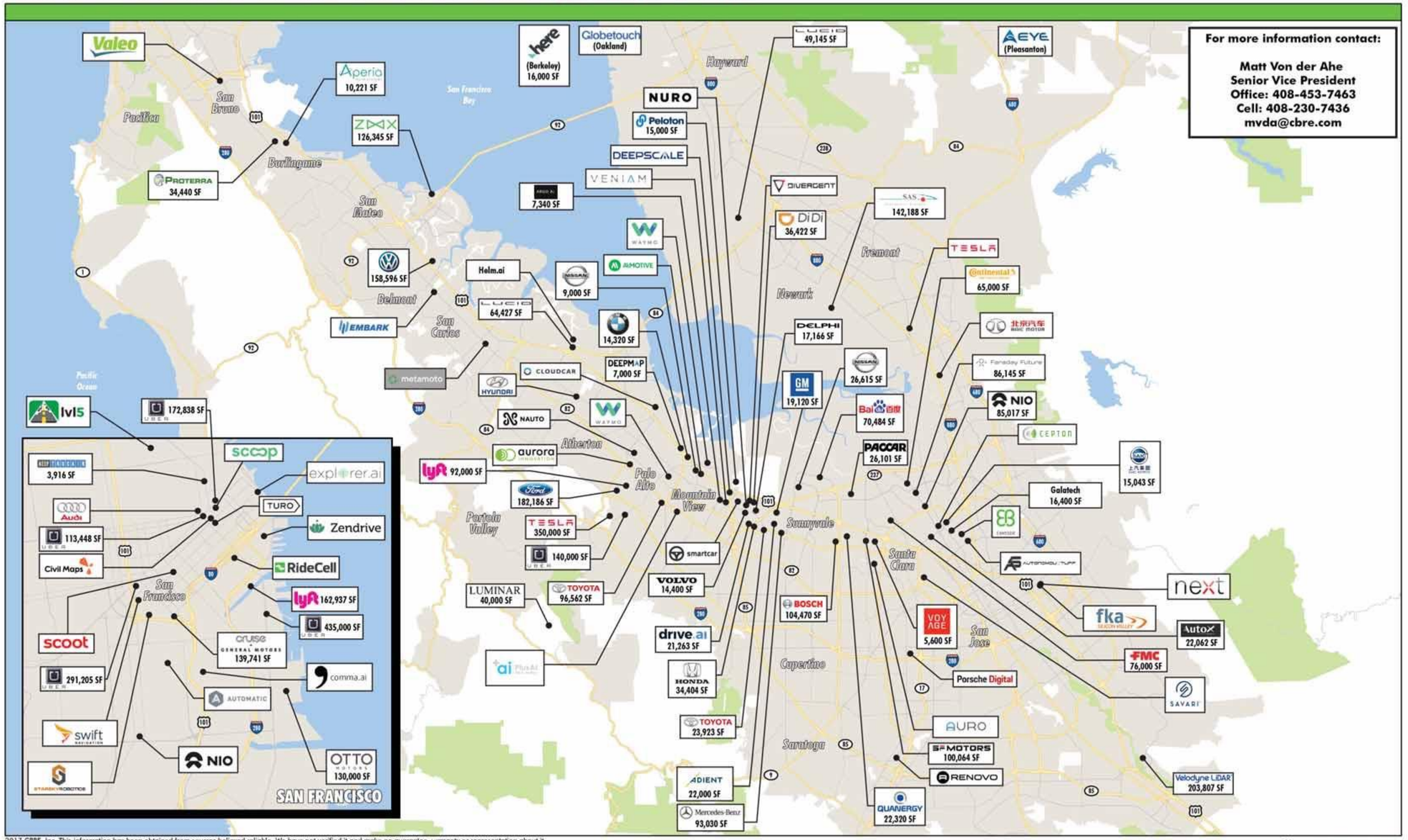
AUTO LAB MAP SEPTEMBER 2017 SILICON VALLEY



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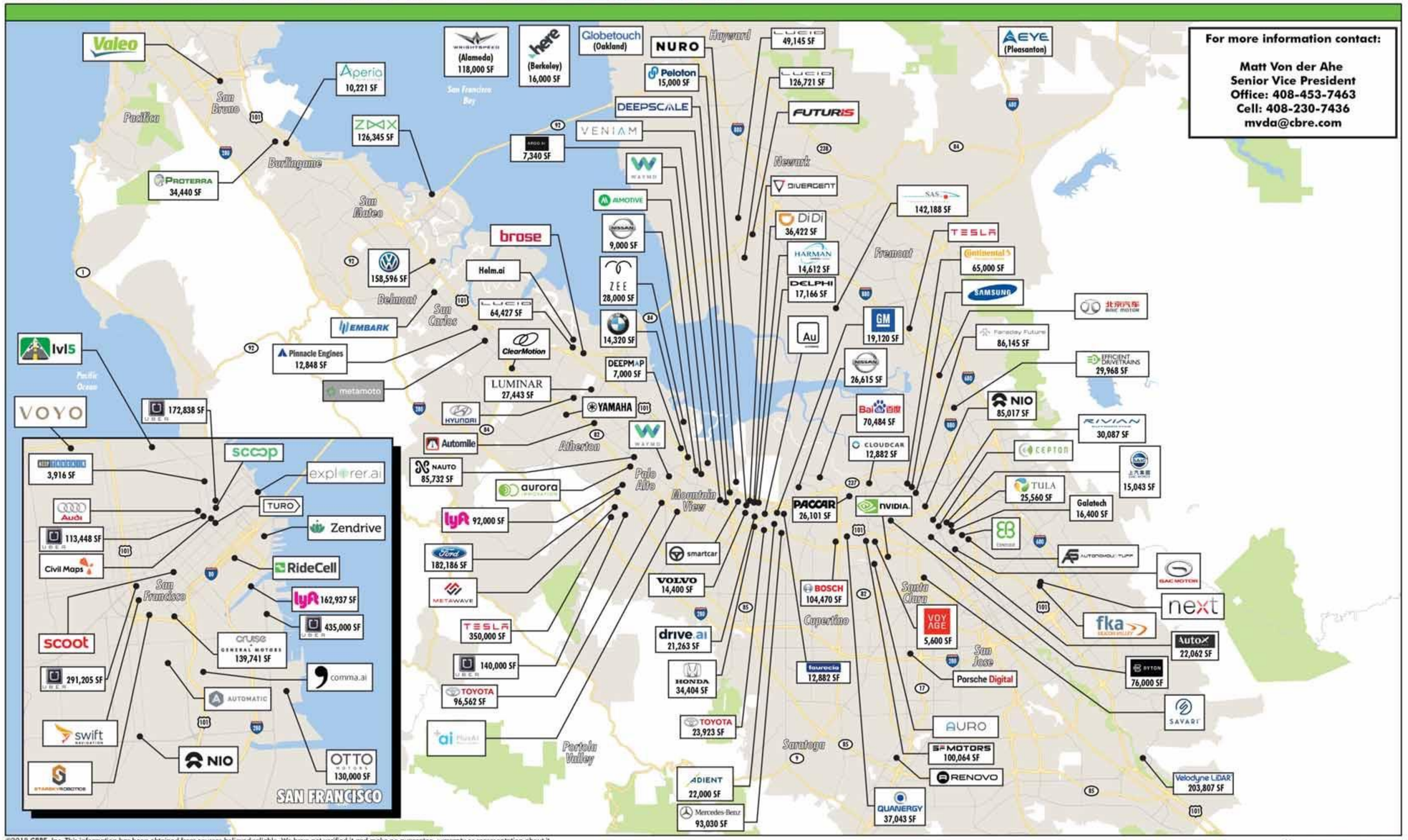
AUTO LAB MAP DECEMBER 2017 SILICON VALLEY



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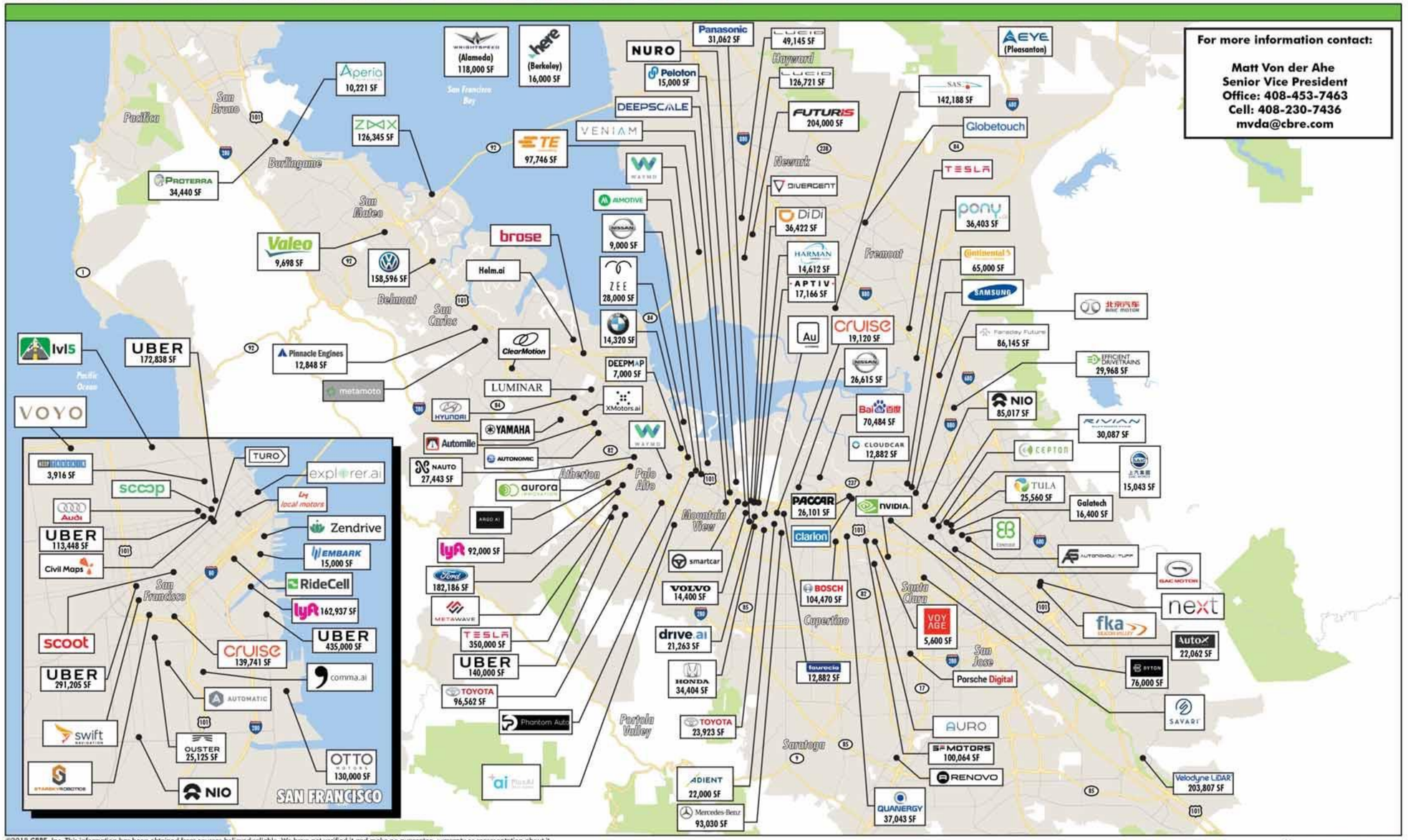
AUTO LAB MAP FEBRUARY 2018 SILICON VALLEY



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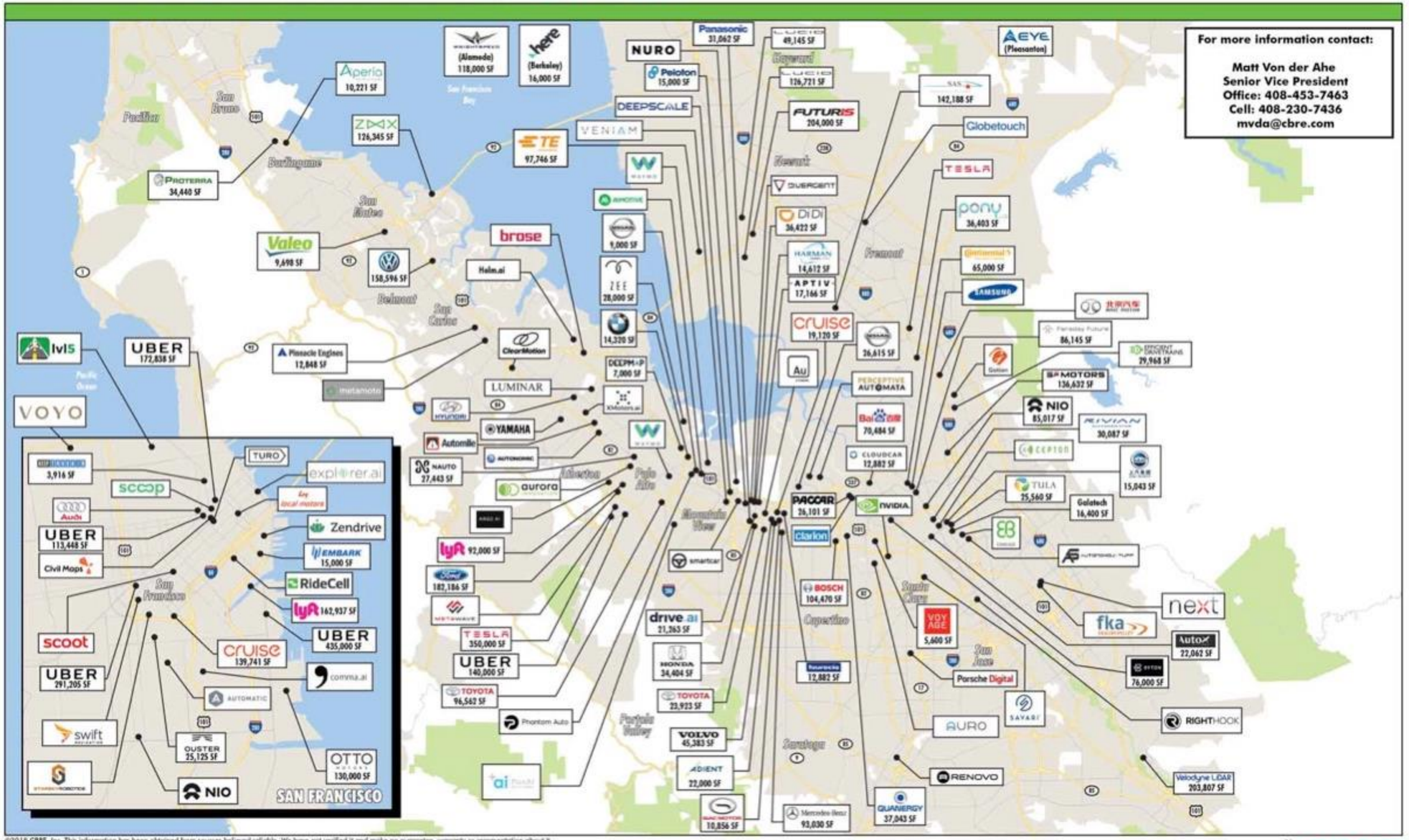
AUTO LAB MAP MARCH 2018 SILICON VALLEY



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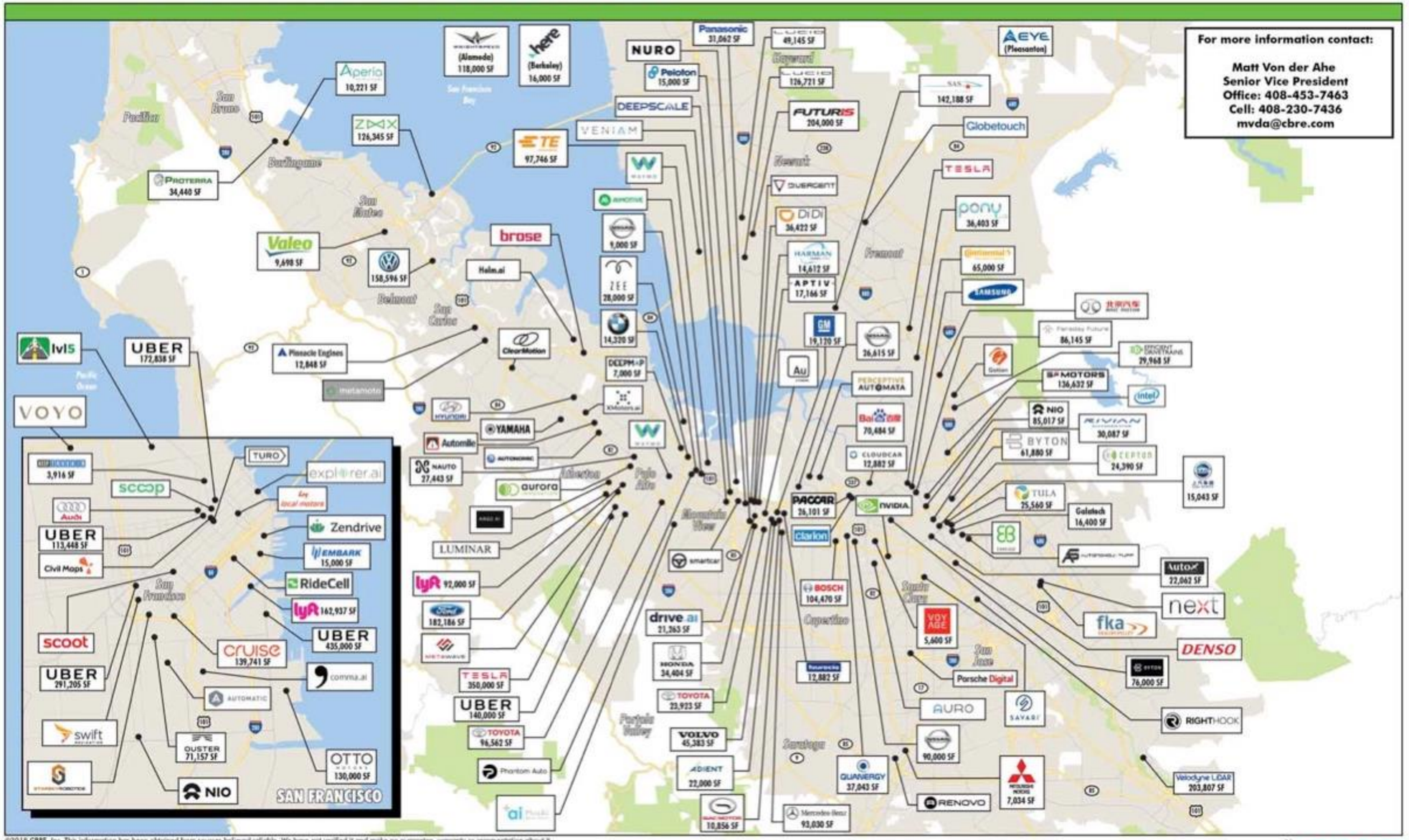
AUTO LAB MAP APRIL 2018 SILICON VALLEY



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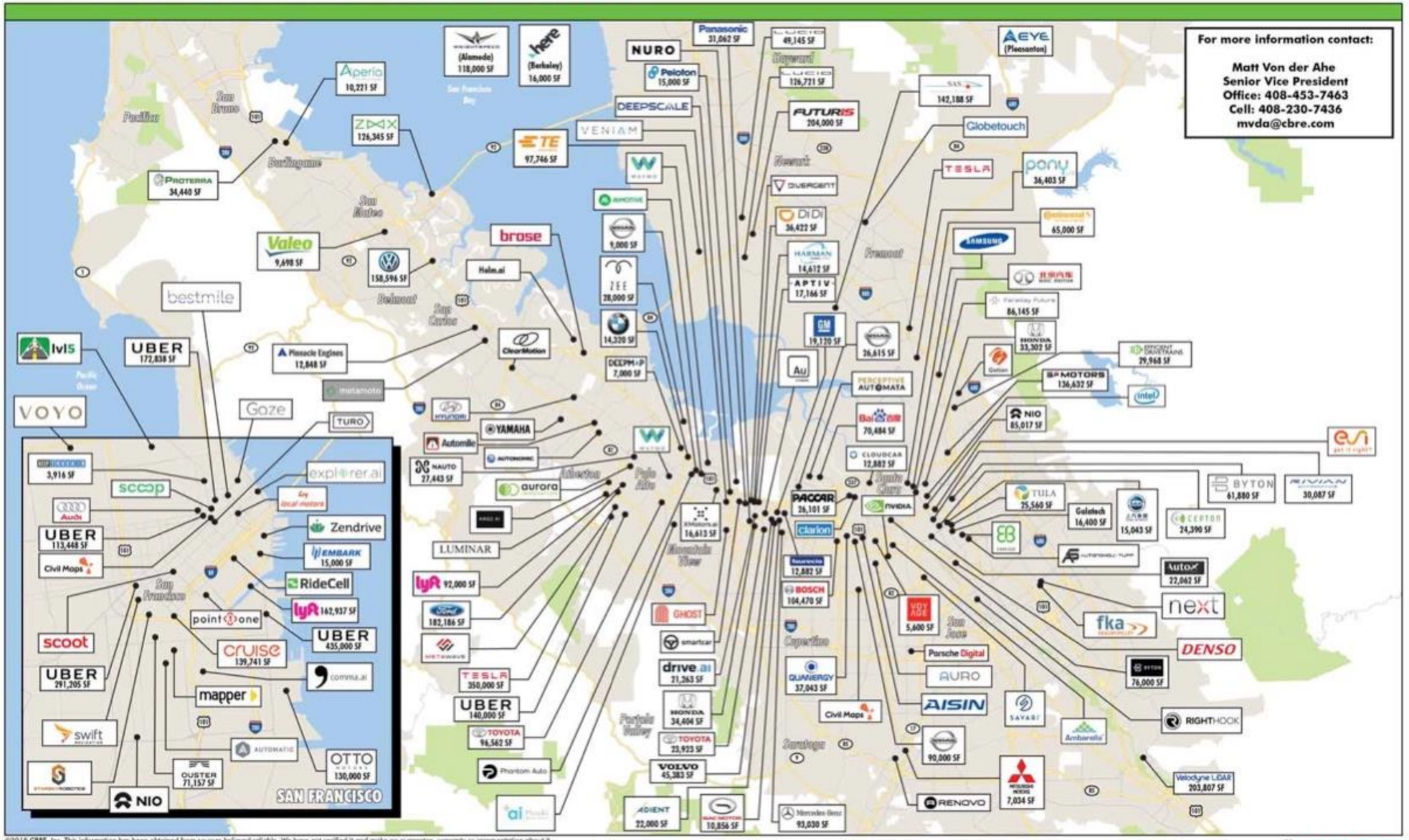
AUTO LAB MAP MAY 2018 SILICON VALLEY



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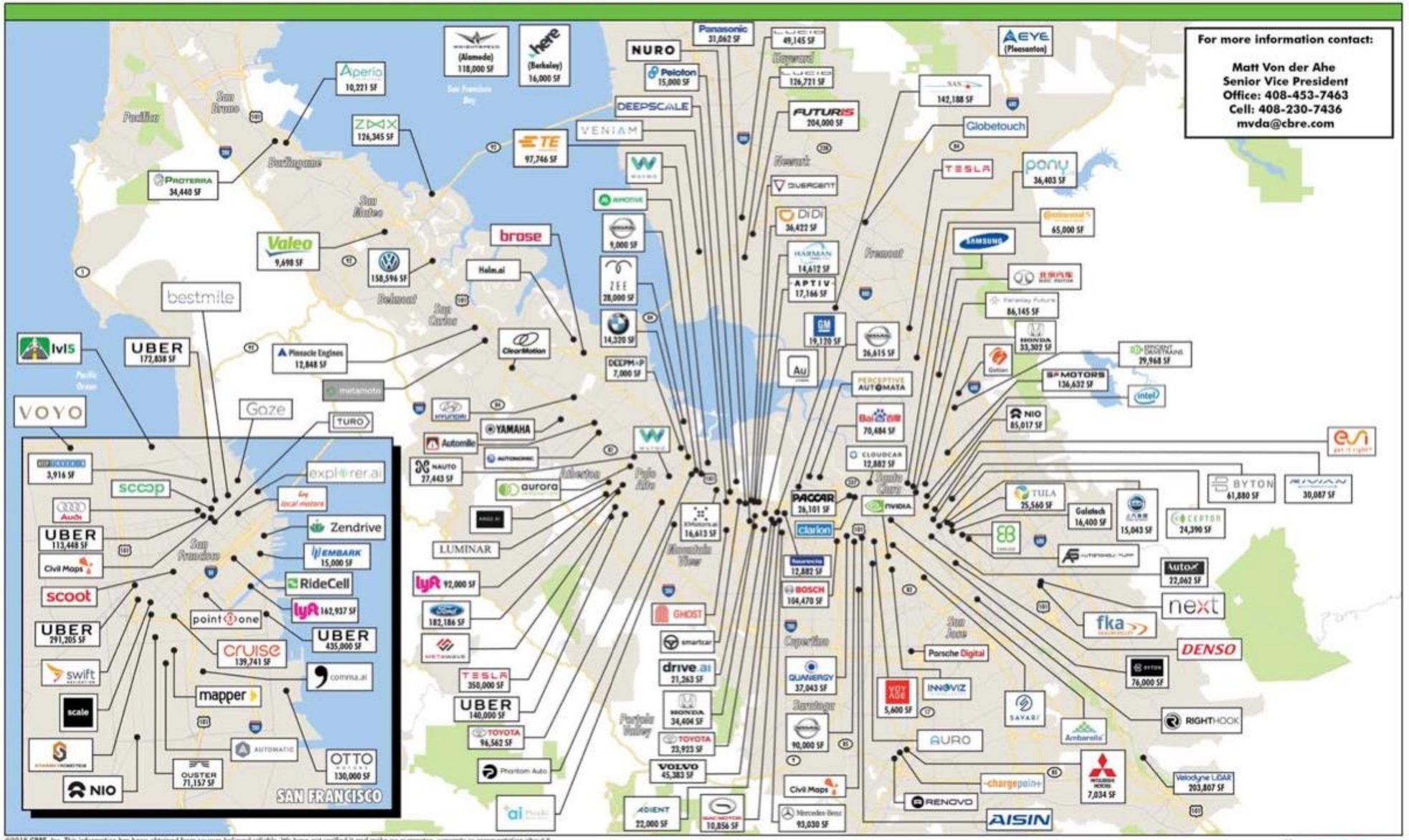
AUTO LAB MAP JUNE 2018 SILICON VALLEY



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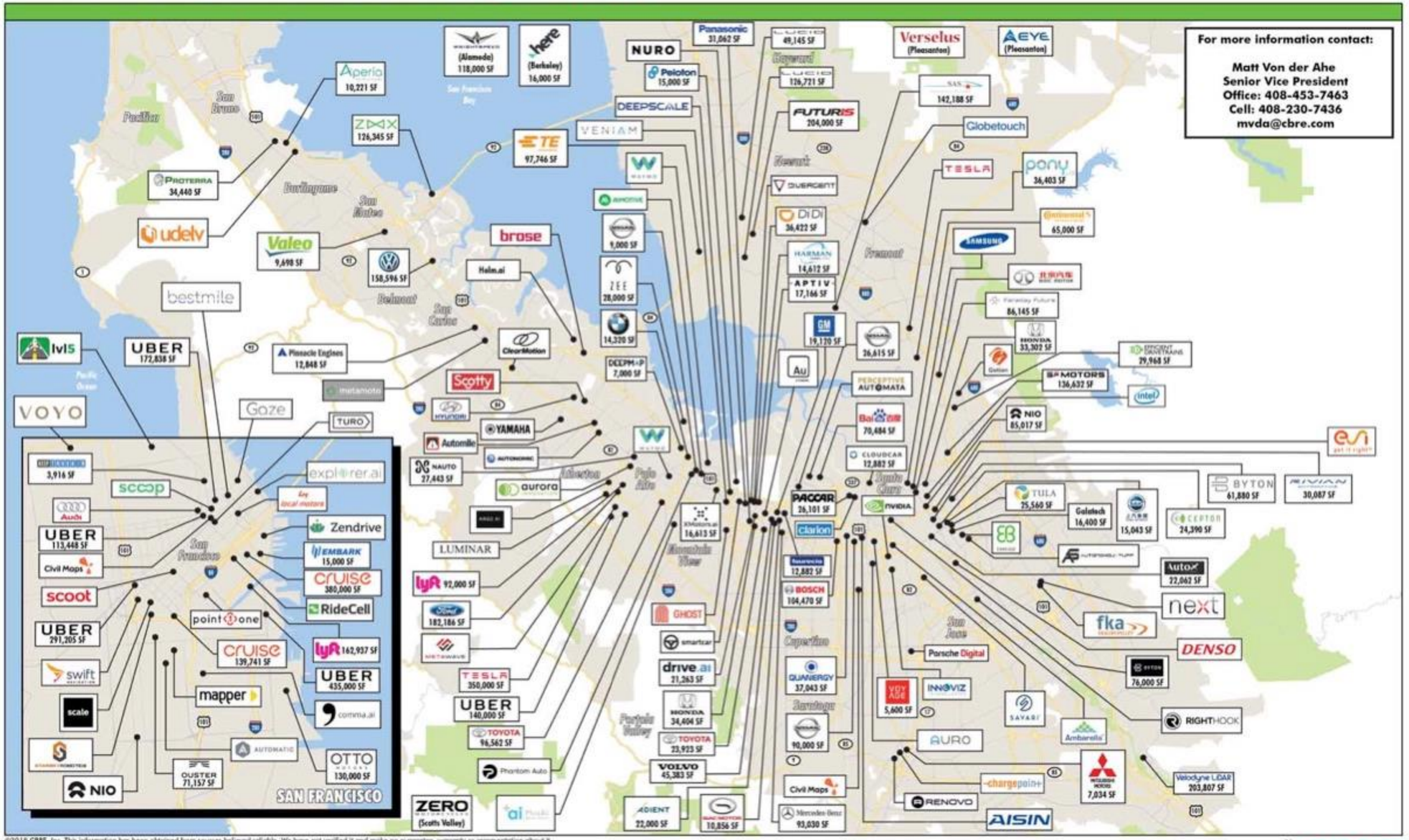

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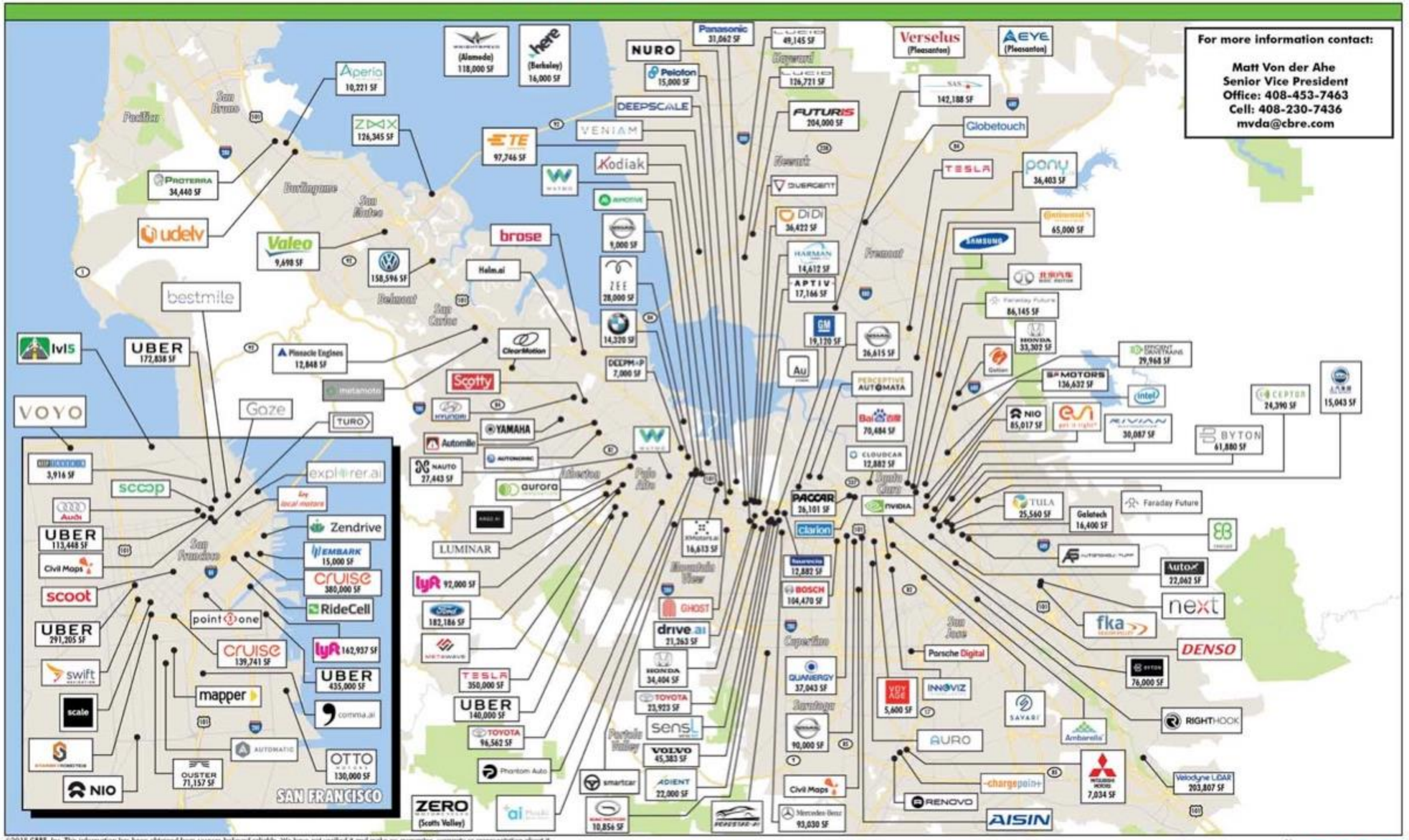
AUTO LAB MAP AUGUST 2018 SILICON VALLEY



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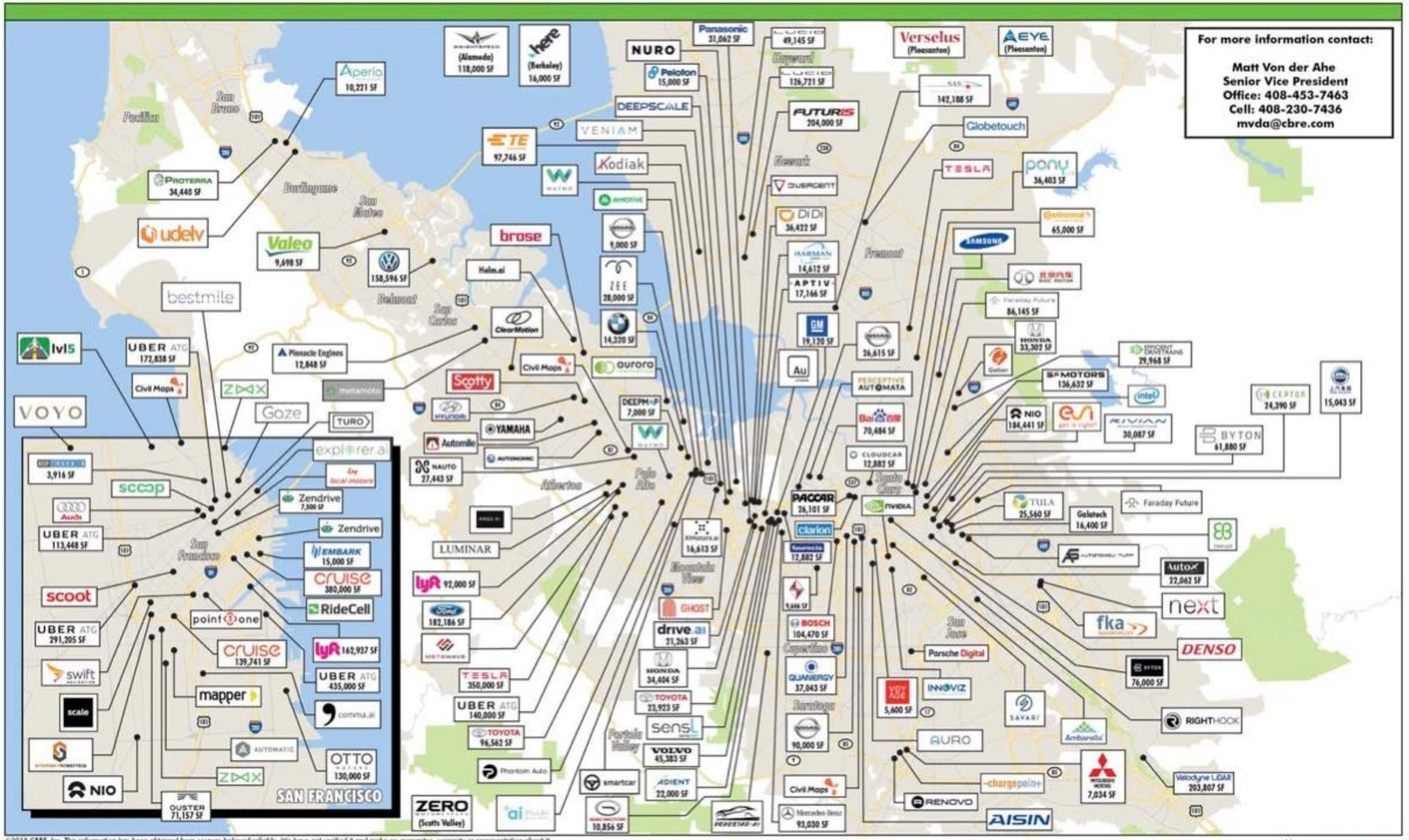

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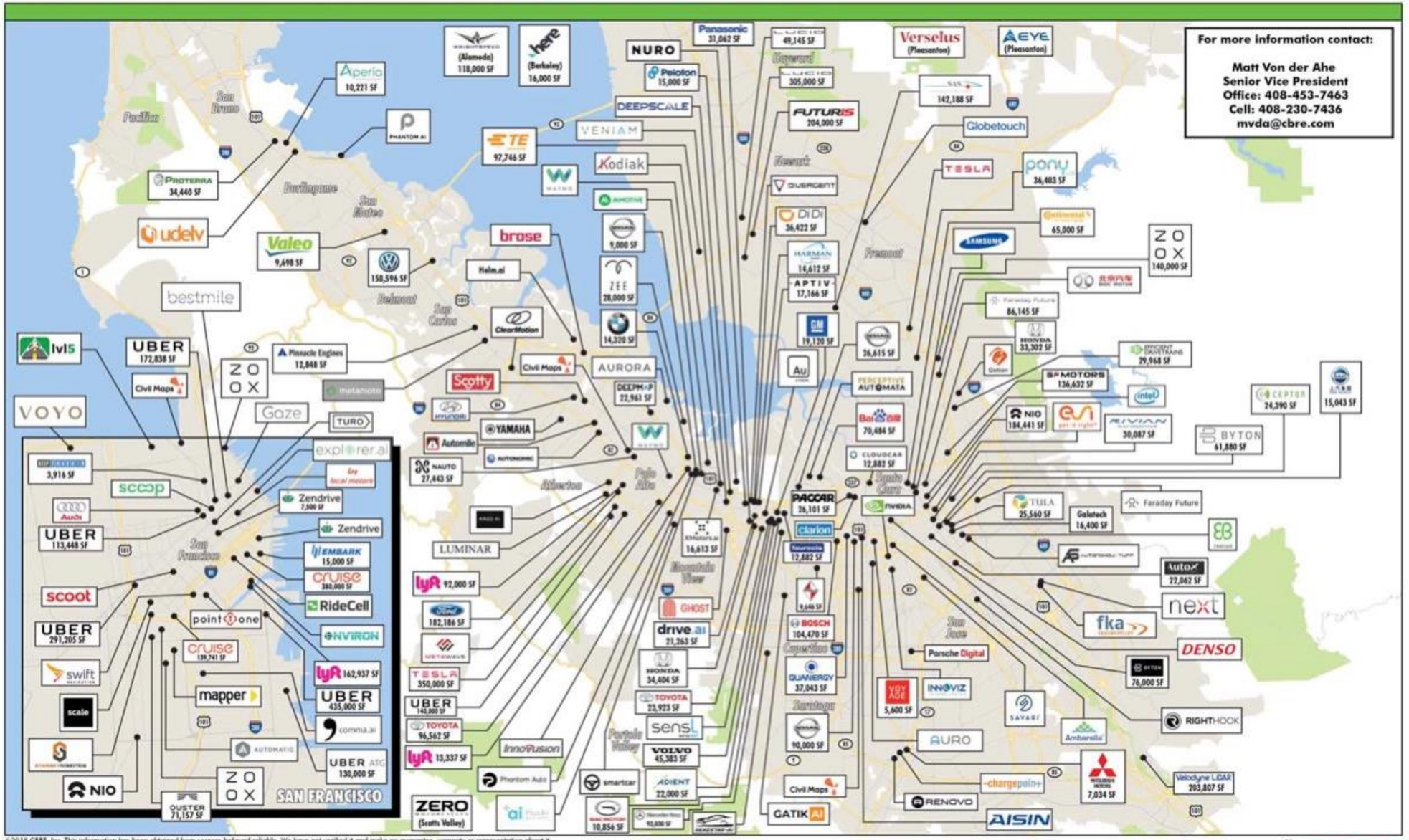
AUTO LAB MAP OCTOBER 2018 SILICON VALLEY


For more information contact:
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Cell: 408-230-7436
mvda@cbre.com
NURO
Panasonic 31,062 SF
Verselus (Pleasanton)
AEYE (Pleasanton)
Aperia 10,221 SF
(Alameda) 118,000 SF
here (Berkeley) 16,000 SF
Pelaton 15,000 SF
DEEPSCALE
VENIAM
TE 97,746 SF
Kodiak
PHANTOM AI
PROTERRA 34,440 SF
udelv
Valeo 9,698 SF
158,596 SF
brose
Halo.ai
bestmile
ClearMotion
Civil Maps
Scotty
AURORA
DEEPMAP 22,961 SF
Pinnacle Engines 12,848 SF
metamoto
Gaze
TURO
YAMAHA
Automile
NAUTO 27,443 SF
LUMINAR
lyft 92,000 SF
182,186 SF
TESLA 350,000 SF
UBER 140,000 SF
TOYOTA 96,562 SF
lyft 13,337 SF
InnoVusion
Phantom Auto
smartcar
ZERO (Scotts Valley)
ai
10,856 SF
ivl5
UBER 172,838 SF
ZOOX
VOYO
UBER 113,448 SF
scoot
UBER 291,205 SF
swift
scale
NIO
OUSTER 71,157 SF
3,916 SF
scoop
Audi
Zendrive 7,500 SF
Zendrive
EMBARK 15,000 SF
cruise 380,000 SF
RideCell
point one
NVIDIA
cruise 139,741 SF
lyft 162,937 SF
UBER 435,000 SF
mapper
comma.ai
AUTOMATIC
UBER ATG 130,000 SF
ZOOX
SAN FRANCISCO
explorer.ai
Ike local motors
San Francisco
Palo Alto
Mountain View
Sunnyvale
San Jose
Cupertino
Saratoga
Fremont
Newark
Redwood City
Pleasanton
Livermore
Menlo Park
Portola Valley
Los Altos
Los Gatos
Milpitas
Alameda
San Bruno
Pacifica
Burlingame
San Mateo
San Carlos
Belmont
Redwood Shores
Foster City
Hayward
Union City
Fremont
Newark
Milpitas
Los Gatos
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Mountain View
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Burlingame
Foster City
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Hayward
Newark
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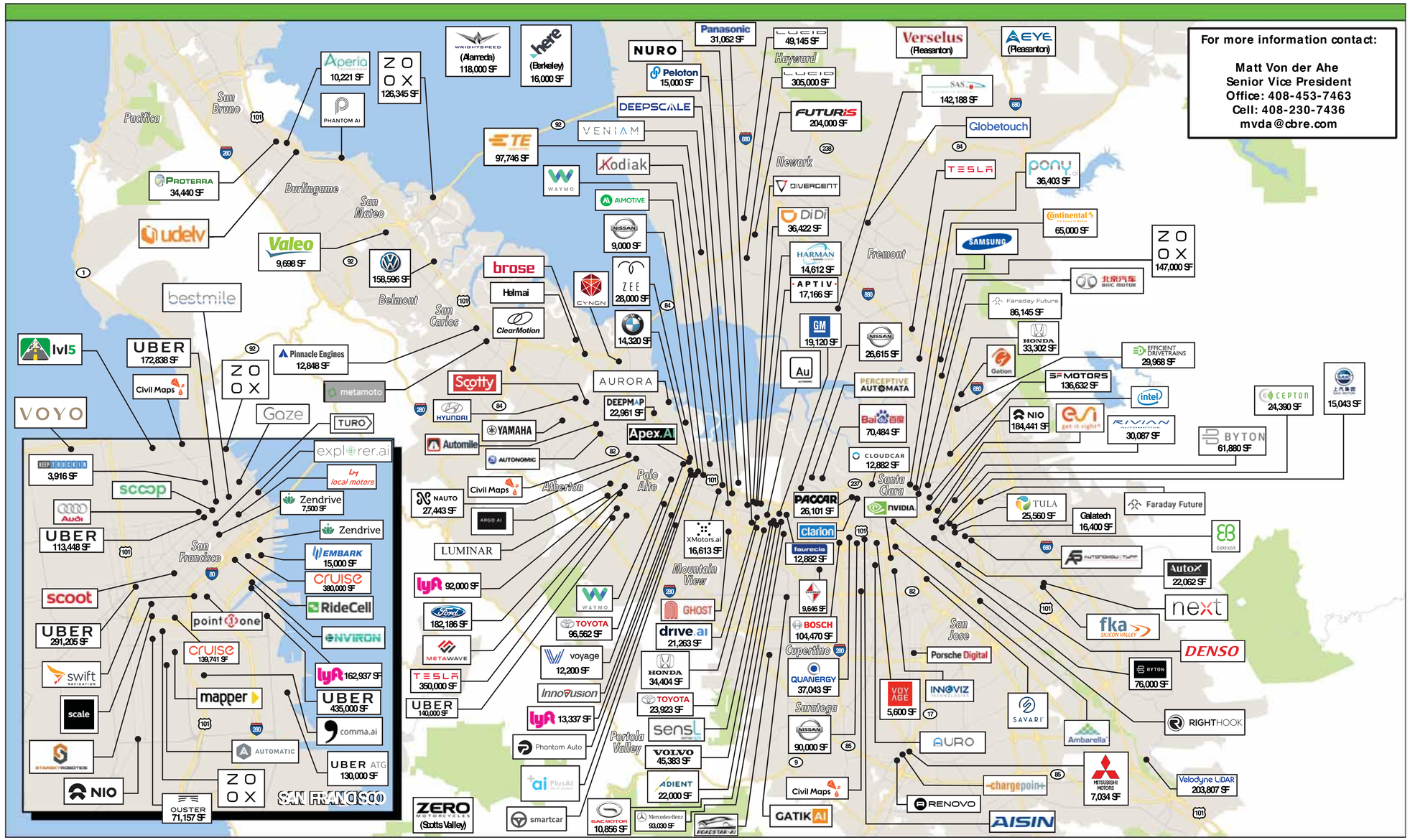
San Jose

AUTO LAB MAP NOVEMBER 2018 SILICON VALLEY



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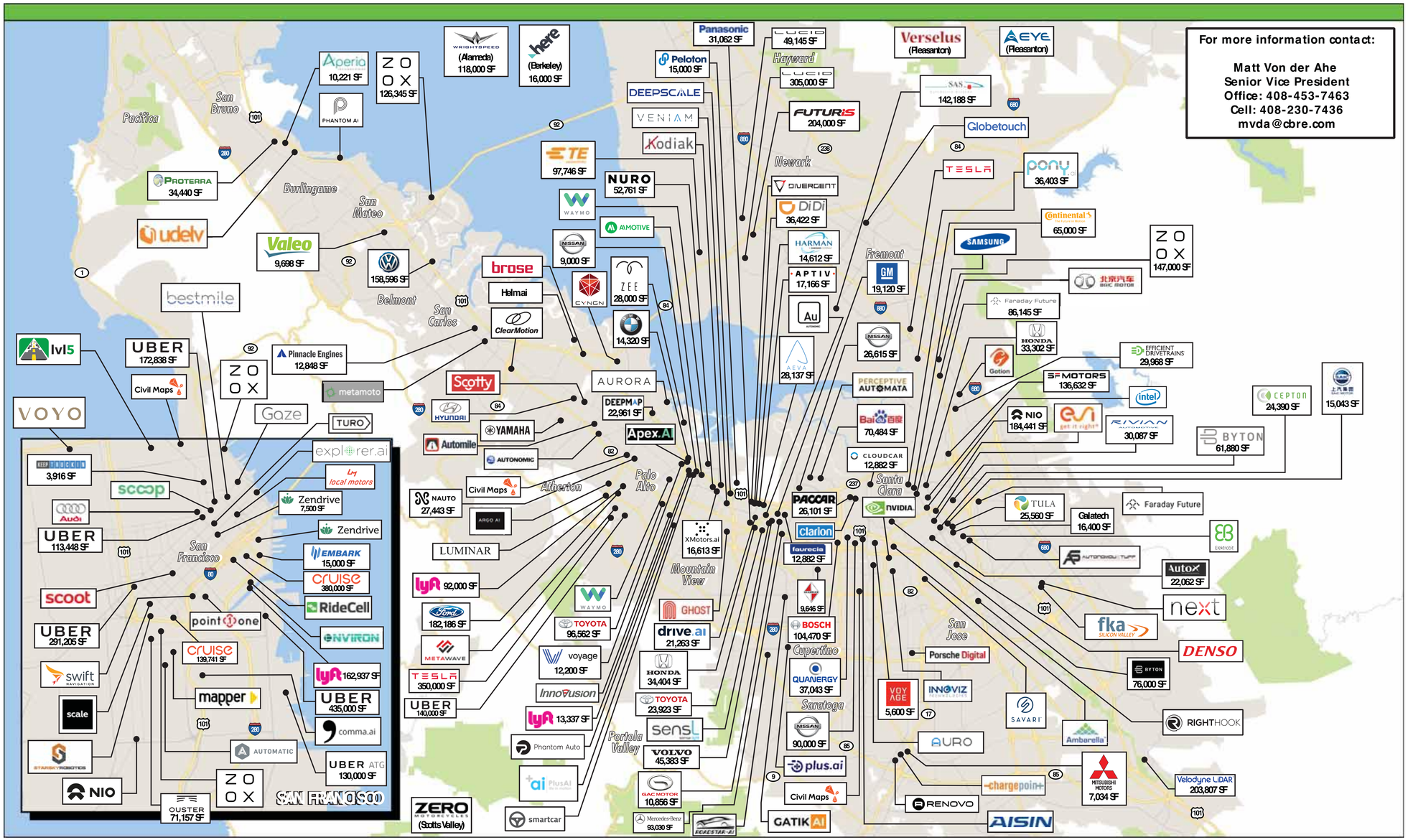

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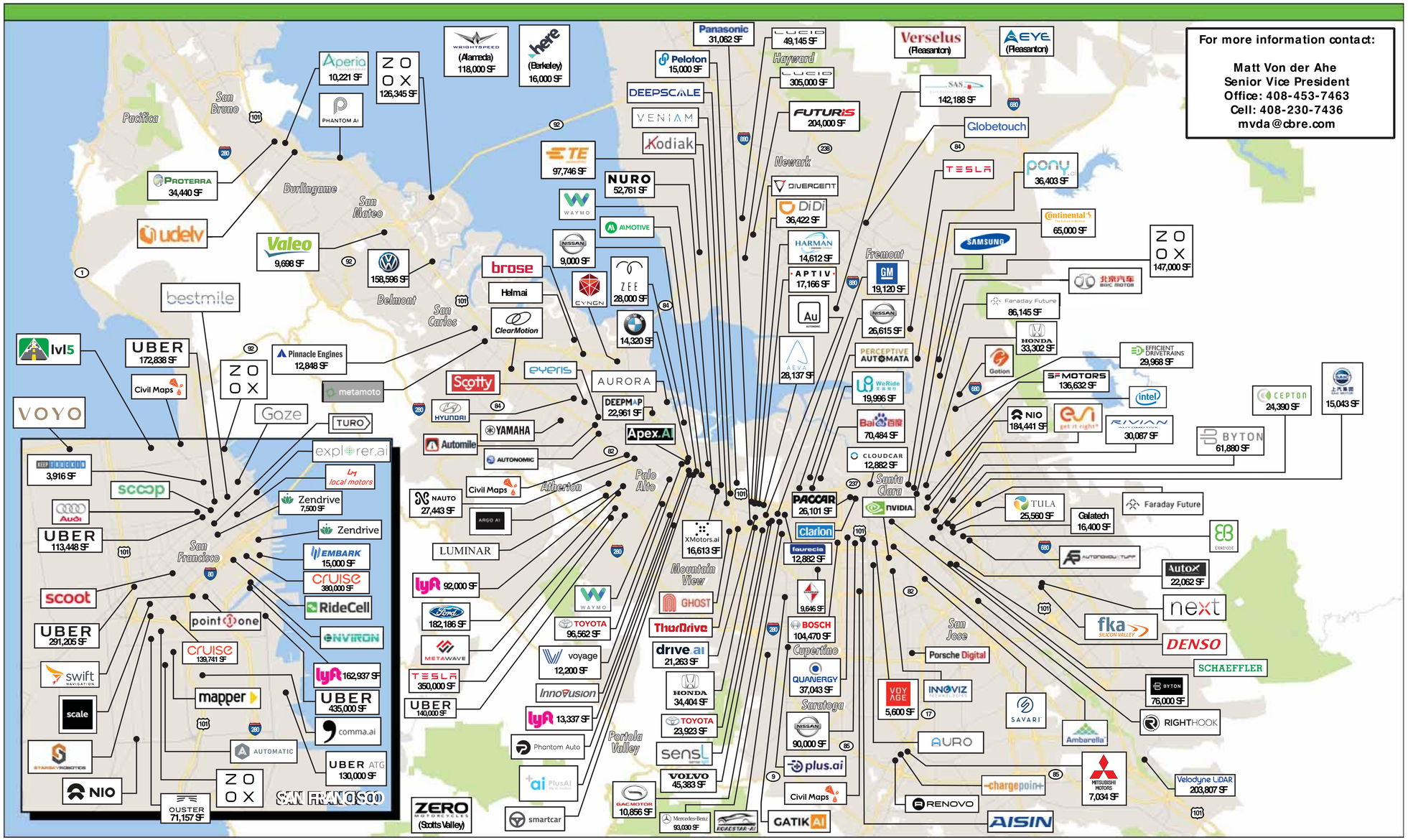

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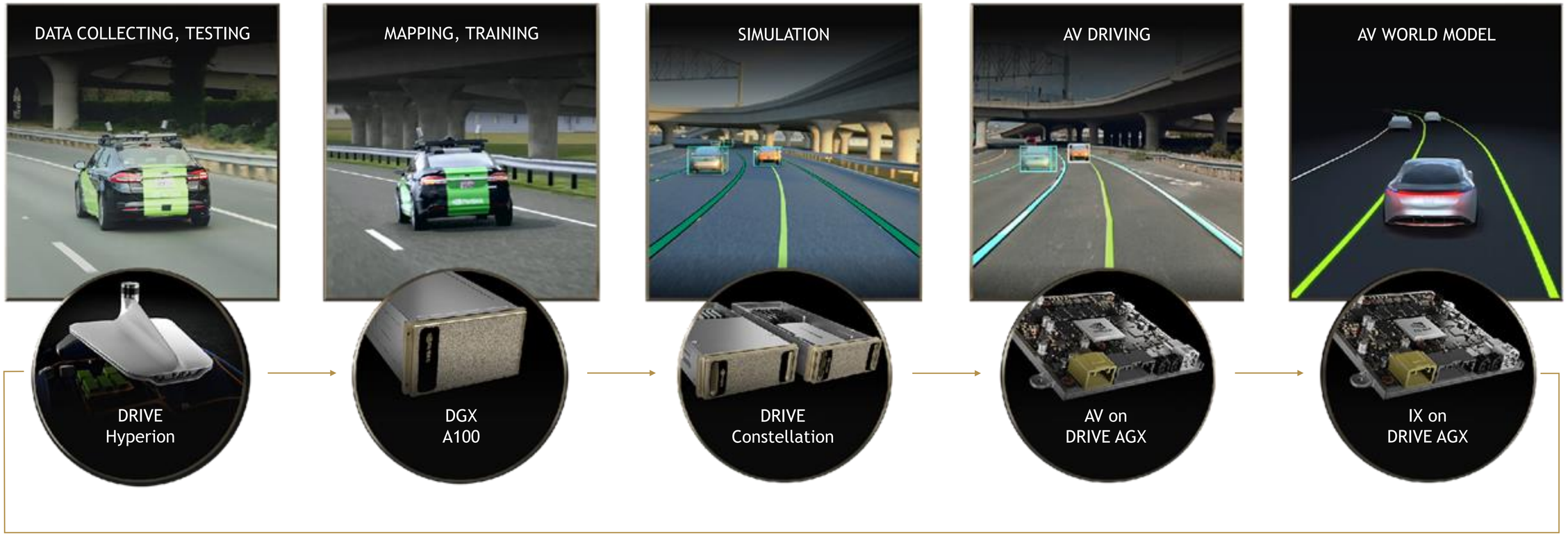
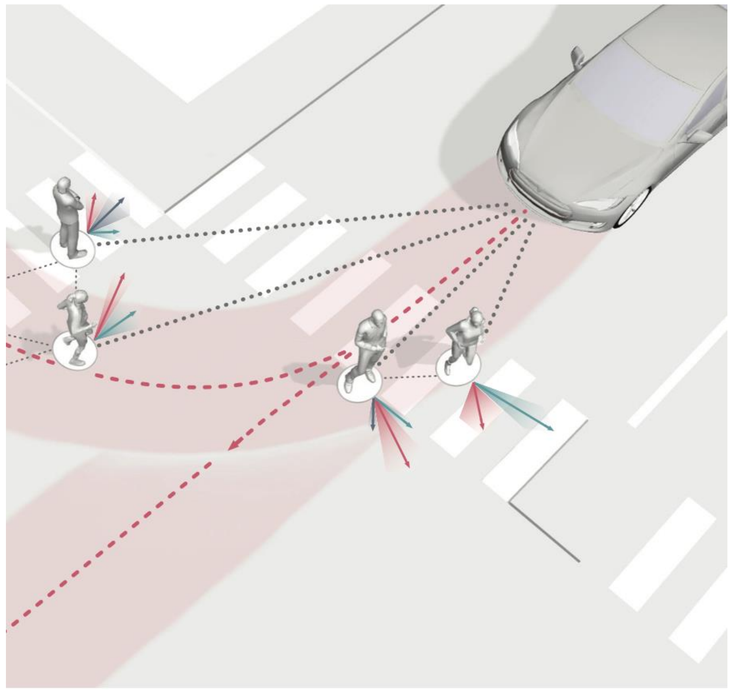
NVIDIA DRIVE AV PLATFORM

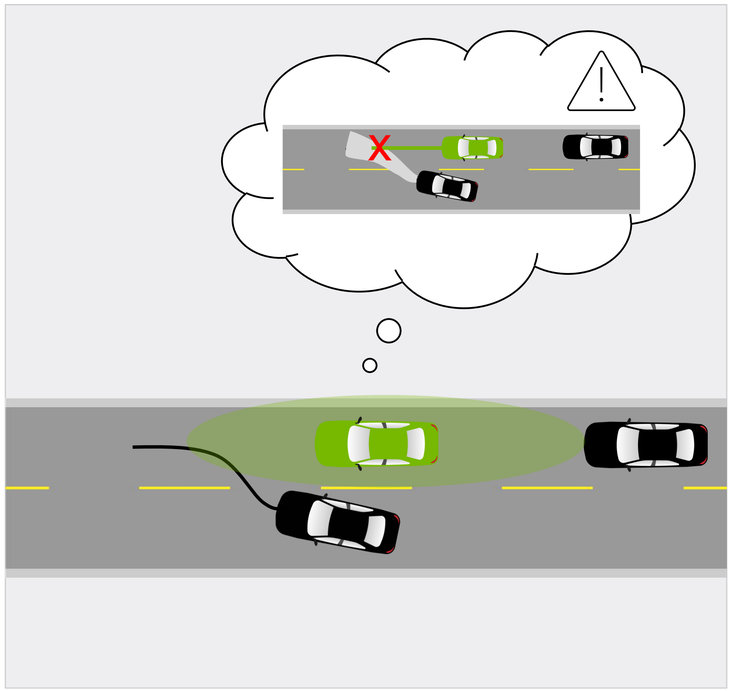


DESIGN OF AI-BASED AV STACK

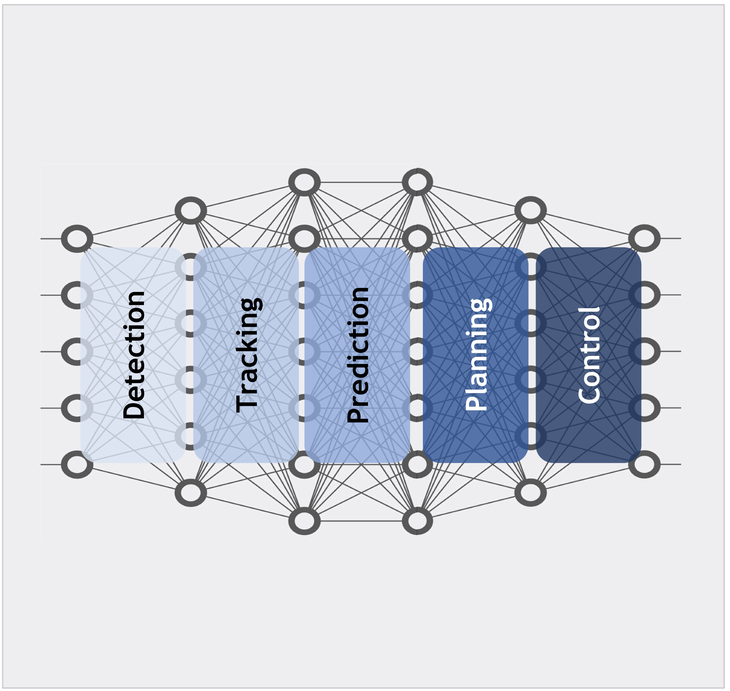
Insights on some key open research problems



Human-centered & Robust Autonomy



Offline and Online
Safety Assurances



Novel AV Stacks Optimizing
End-to-End Performance

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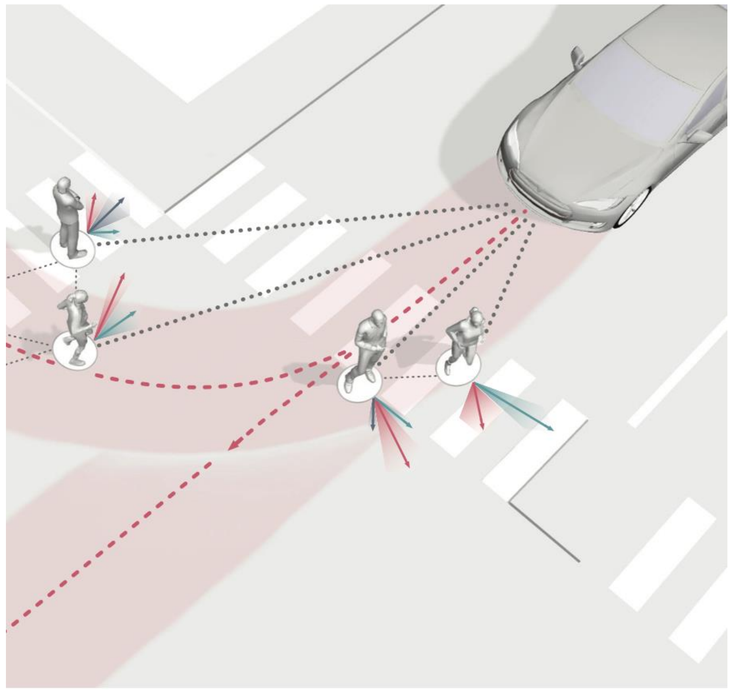
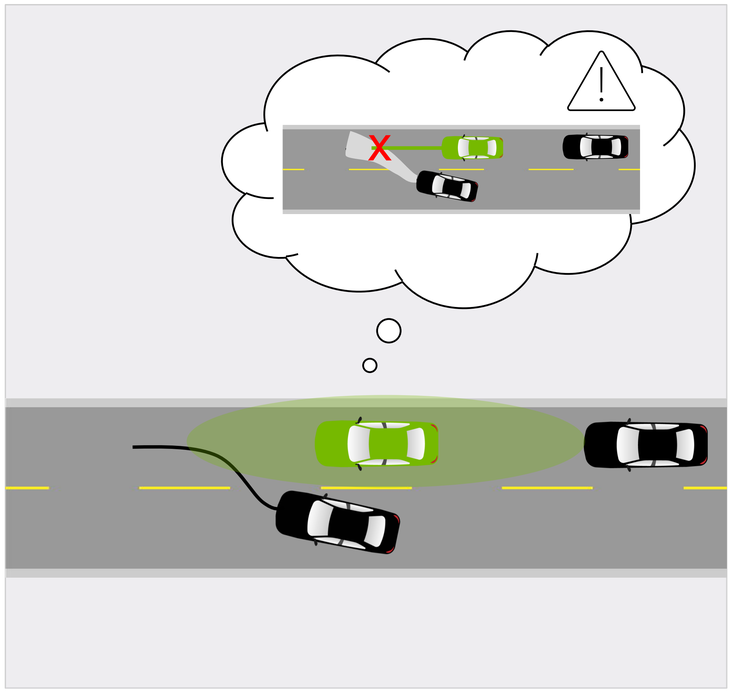
DESIGN OF AI-BASED AV STACK

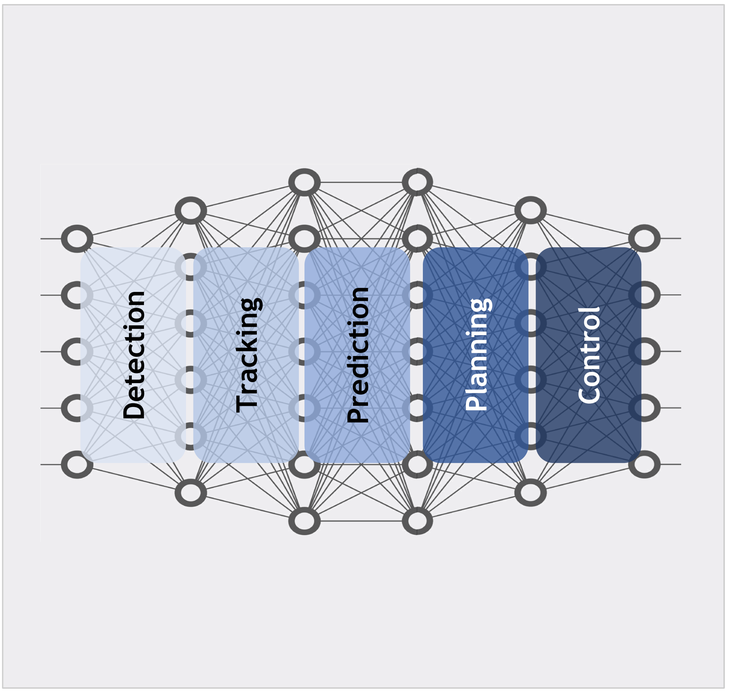
Insights on some key open research problems



Human-centered & Robust Autonomy



Offline and Online
Safety Assurances



Novel AV Stacks Optimizing
End-to-End Performance

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HUMAN-CENTERED & ROBUST AUTONOMY

“Merging into traffic during rush hour is an exercise in negotiation."

— Google Report, 2016

From https://www.youtube.com/watch?v=_aKLwYgUj4A

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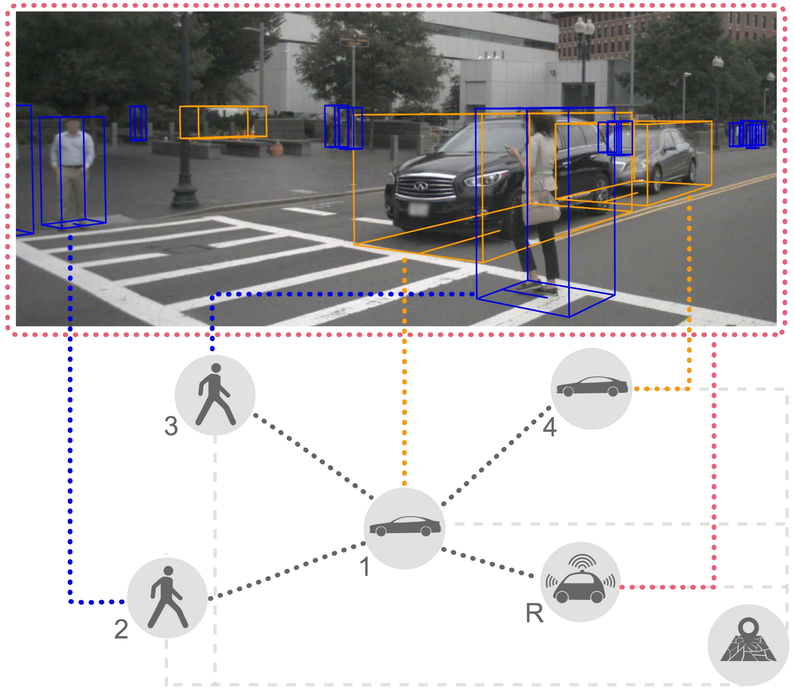
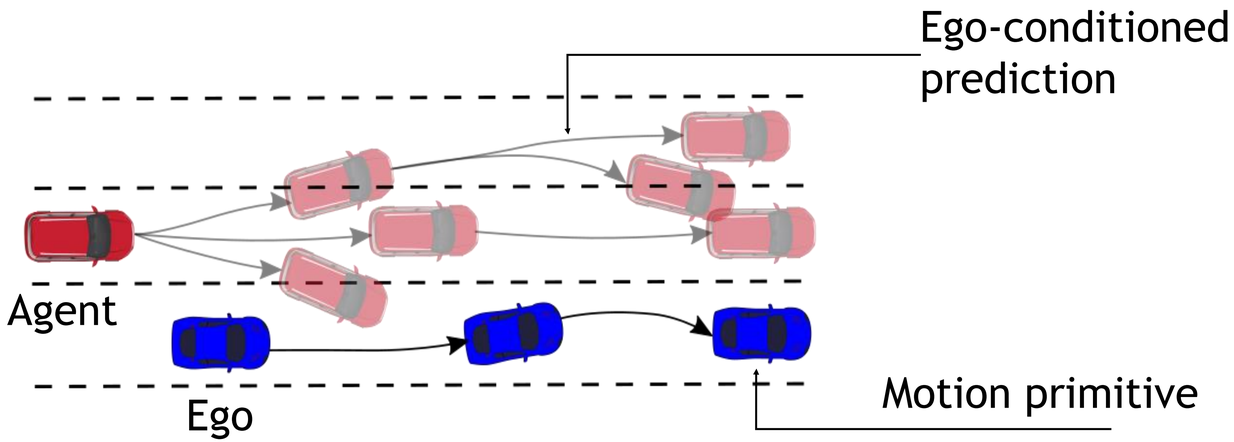
GENERAL MULTI-AGENT TRAJECTORY MODELING

Learn phenomenological action distributions directly from data

- Predictions for any kind of agent
- Accounting of dynamics constraints
- Conditioning on heterogenous data





Trajectron++

References: Ivanovic, Pavone, ICCV ’19; Salzmann, Ivanovic, Chakravarty, Pavone, ECCV ’20; Chen, Ivanovic, Pavone, CVPR '22.

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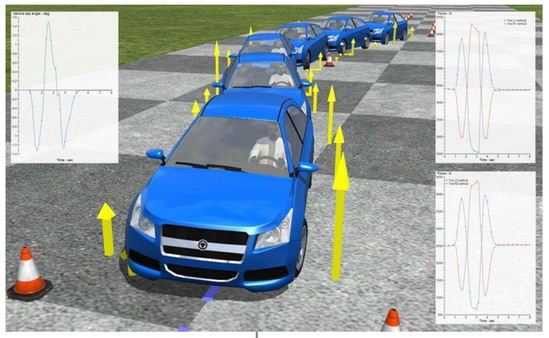
HISTORY OF DRIVING SIMULATORS

CarSim
High-fidelity vehicle dynamic simulator



Virtual KITTI
Synthetic sensor image

CARLA
Urban driving simulation with UE4

Nvidia DriveSim
Photo-realistic rendering as part of Omniverse

1990 — 2016 — 2017 — 2021

✓high-fidelity physics simulation
✓high-fidelity rendering (UE, Omniverse)
? intelligence that generates realistic, human-like driving behavior

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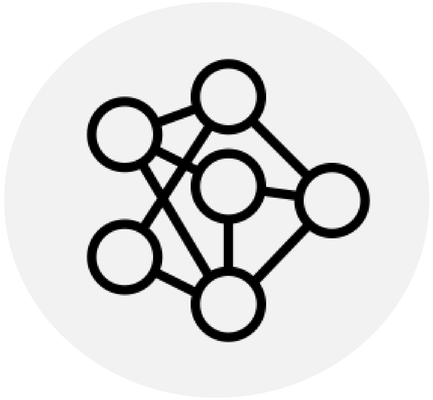
TOWARDS BETTER DRIVING SIMULATION

Grounding traffic behavior synthesis in real human driving behaviors

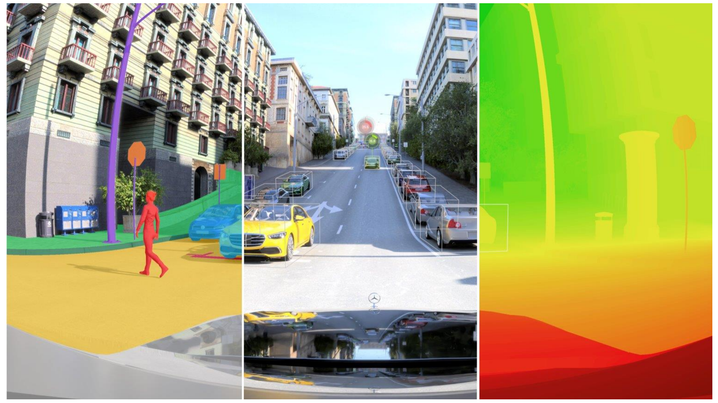
Real-world driving log

Learn



ML-based behavior model

Deploy



High-fidelity simulator

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TOWARDS BETTER DRIVING SIMULATION

Grounding traffic behavior synthesis in real human driving behaviors

Desiderata

Fidelity: can we synthesize agent group behaviors that resemble real-world traffic?

Diversity: can we generate a wide range of realistic traffic patterns?

Controllability: can we steer the traffic model to generate a specific scenario?

Challenges

Stability: prevent the simulation from diverging out of “reasonable” behaviors

Long-horizon: run simulation with horizon much longer than training data horizon

Adaptivity: adapt to new regions / traffic patterns with little to no tuning

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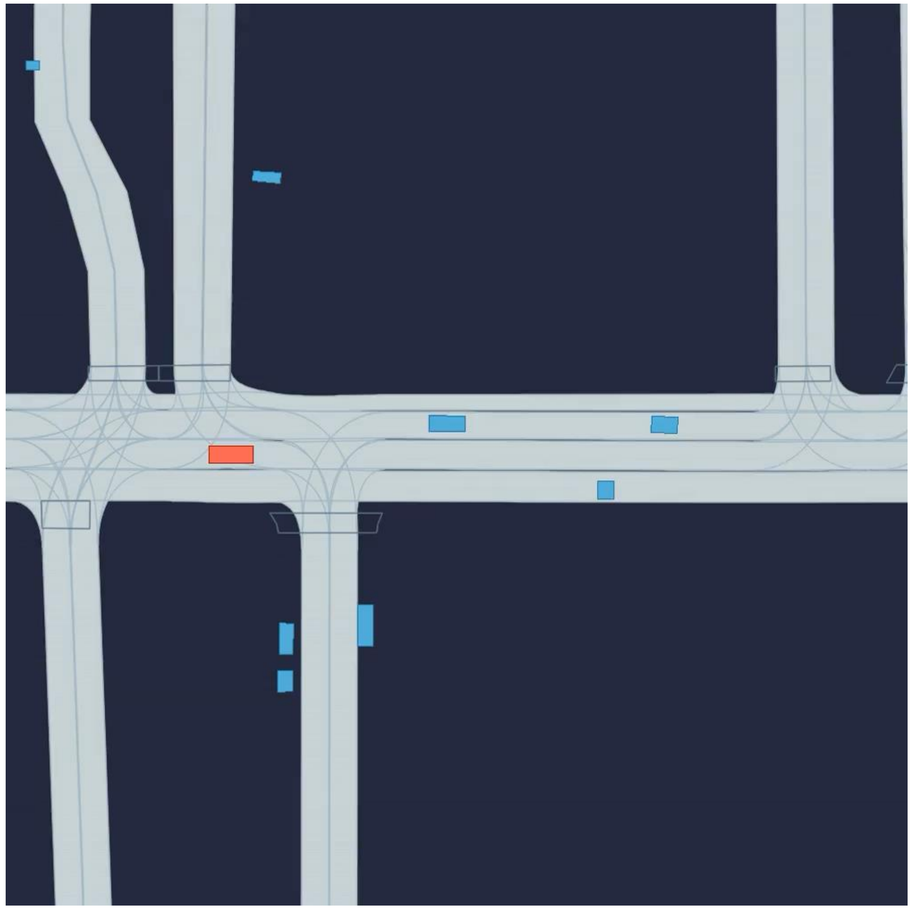
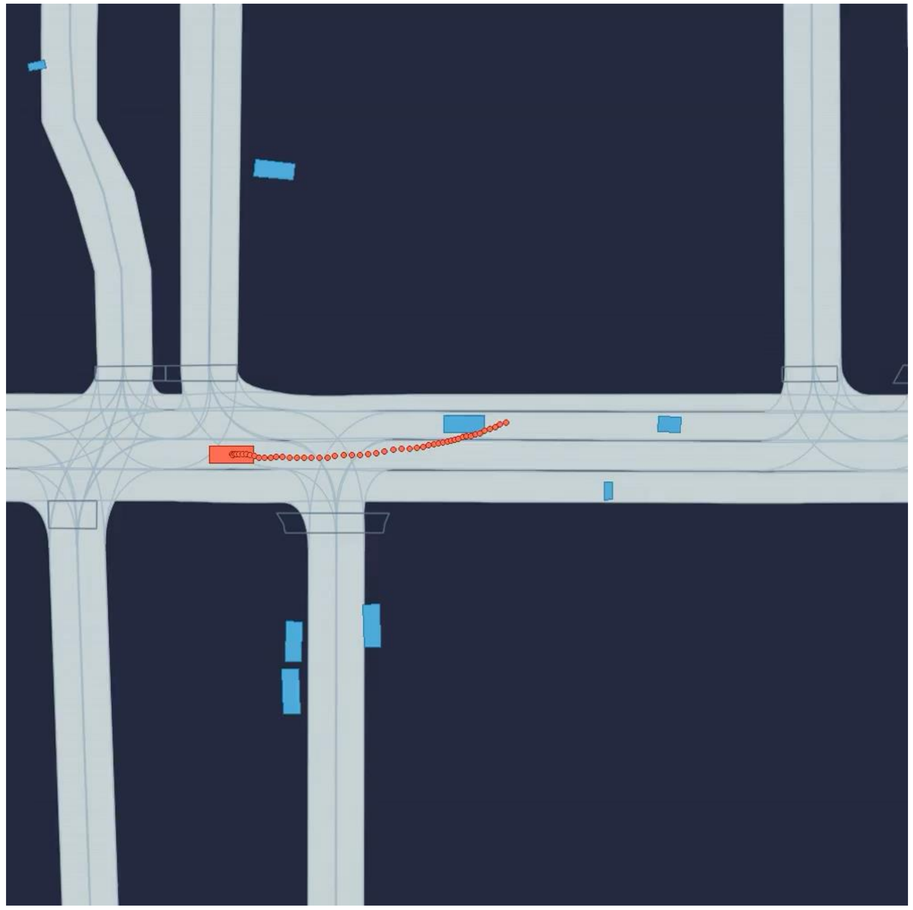
MODELING HUMAN BEHAVIORS BEYOND PREDICTION

Closed-loop decision making requires rethinking behavior modeling

Ground truth trajectory



Rolling out a prediction model



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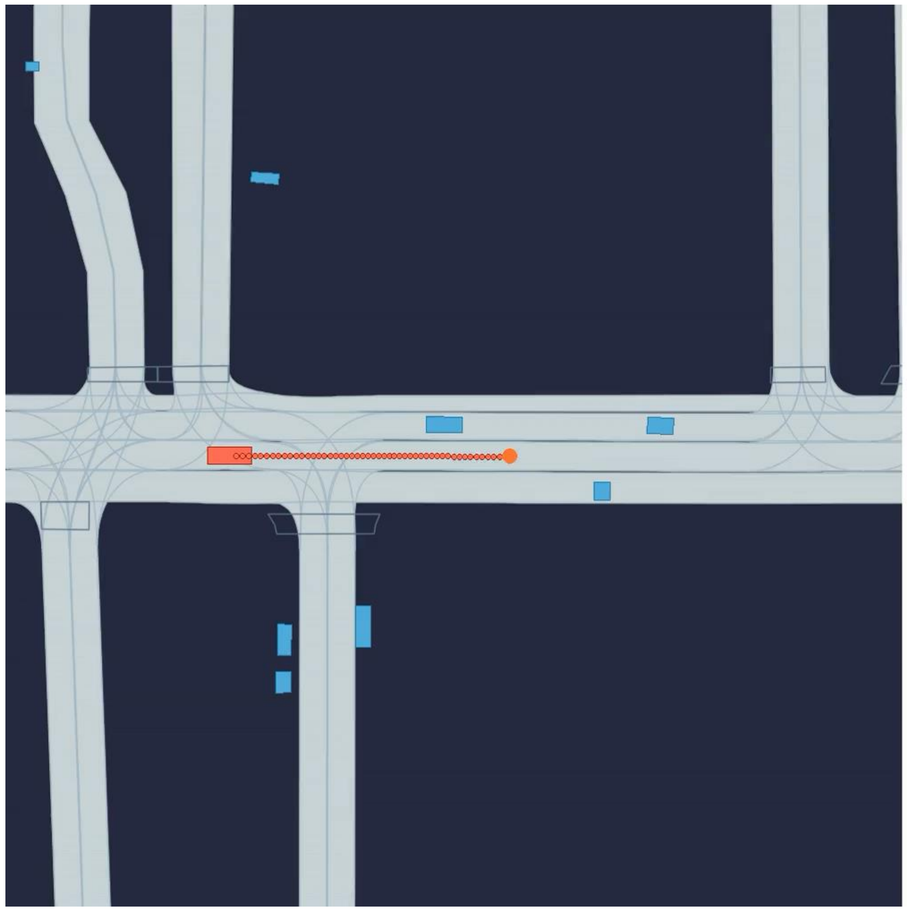
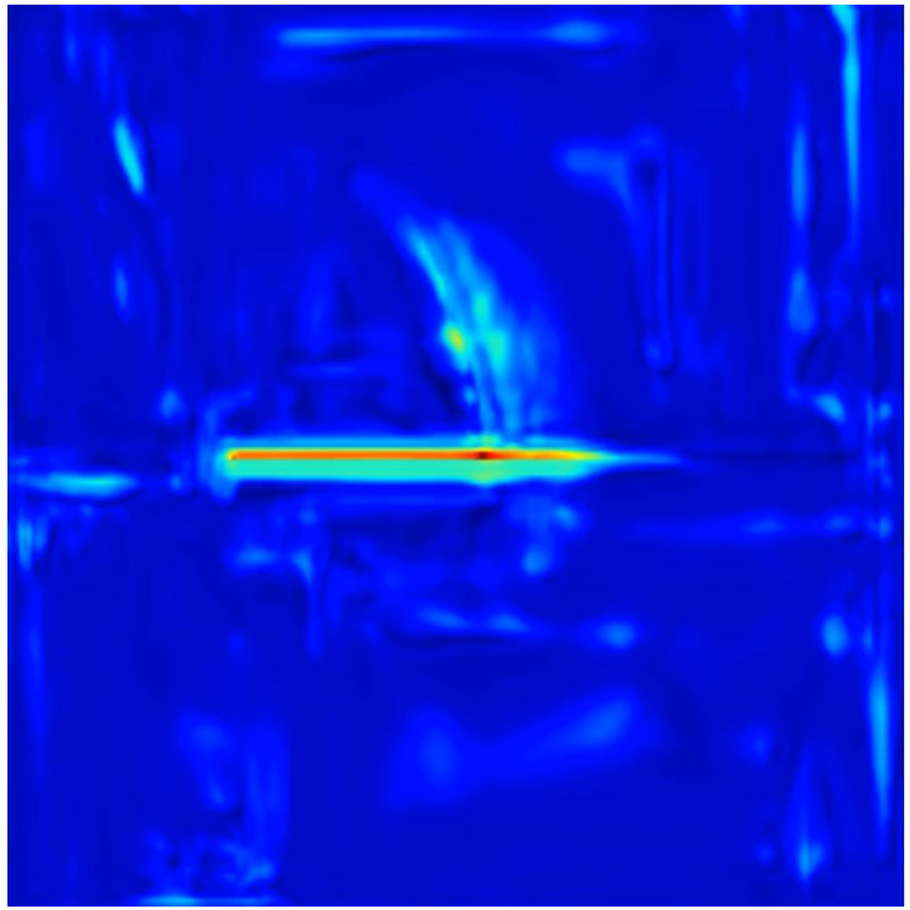
CLOSED-LOOP DRIVING BEHAVIOR SIMULATION

Hierarchical decision making: decoupling where from how

Hierarchical Policy = Spatial Map Planner + Goal-conditional Controller



Rollout



Spatial Probability Map

References: Xu, Chen, Ivanovic, Pavone, ICRA 23 (submitted).

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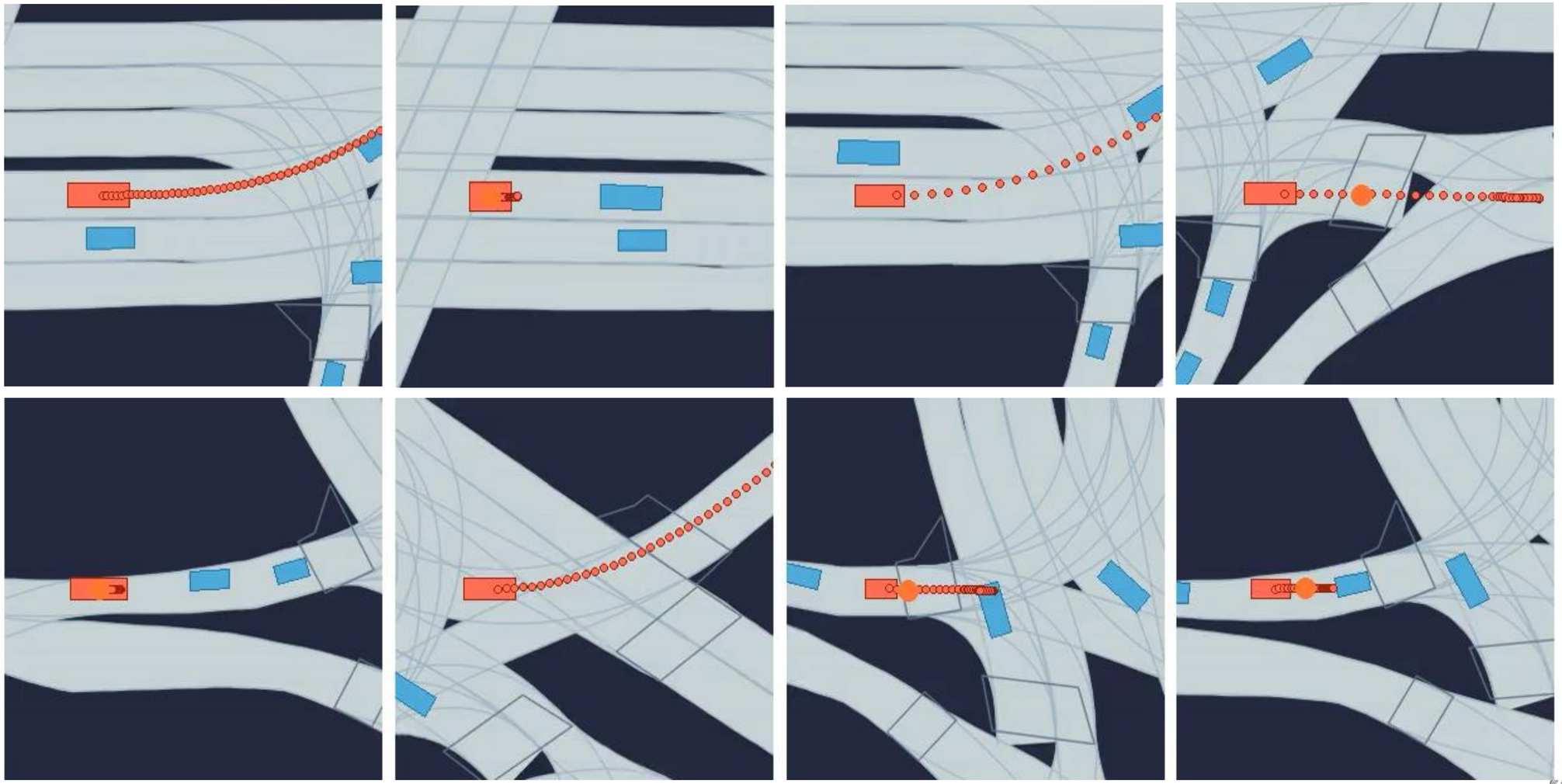
SYNTHESIZE NEW AND DIVERSE TRAFFIC BEHAVIORS

Decentralized decision making: Emergence of complex interactive behaviors

All agents in the scene are controlled by a learned traffic model



References: Xu, Chen, Ivanovic, Pavone, ICRA 23 (submitted).

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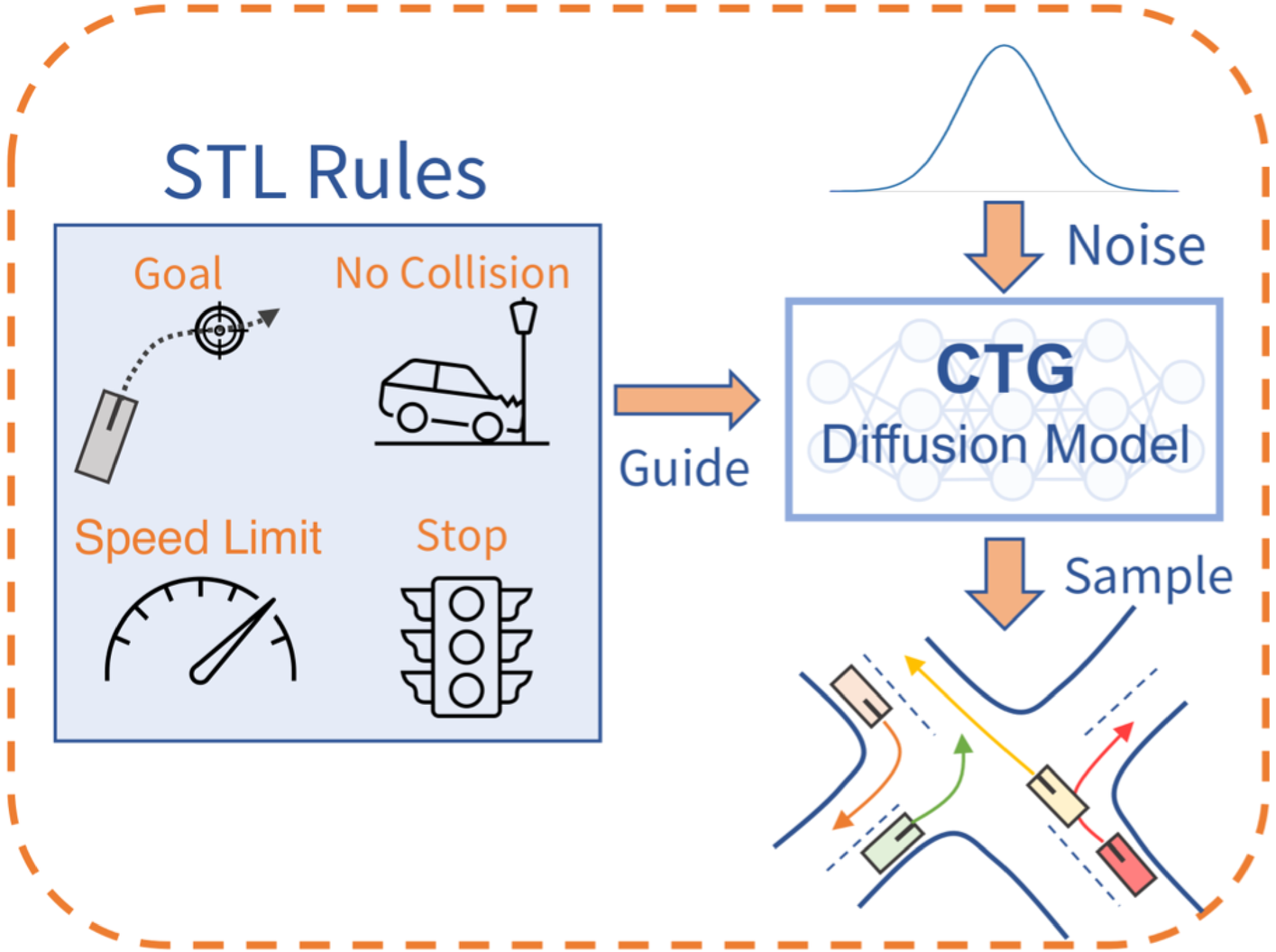
NEXT: CONTROLLABLE, DATA-DRIVEN TRAFFIC SIMULATION

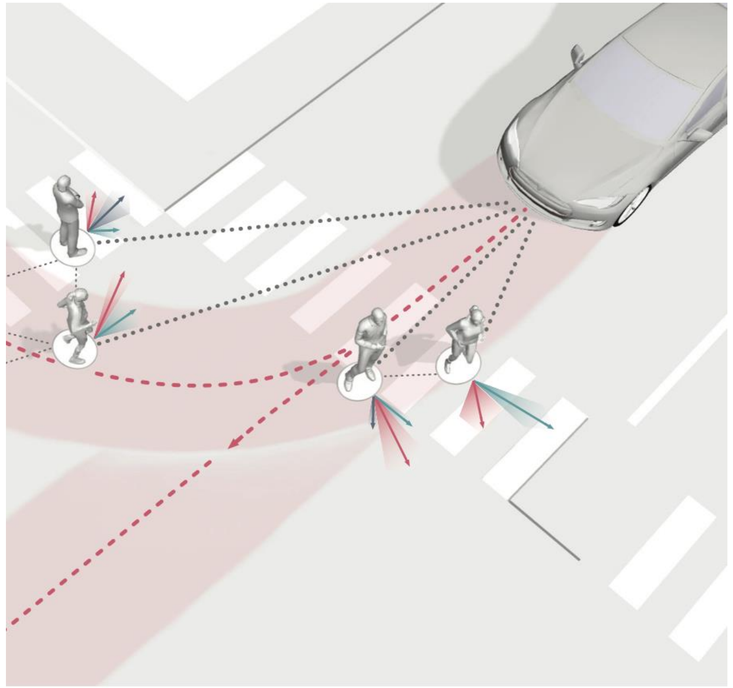


Takeaway message: closed-loop simulation will play an increasingly major role in AV development and V&V

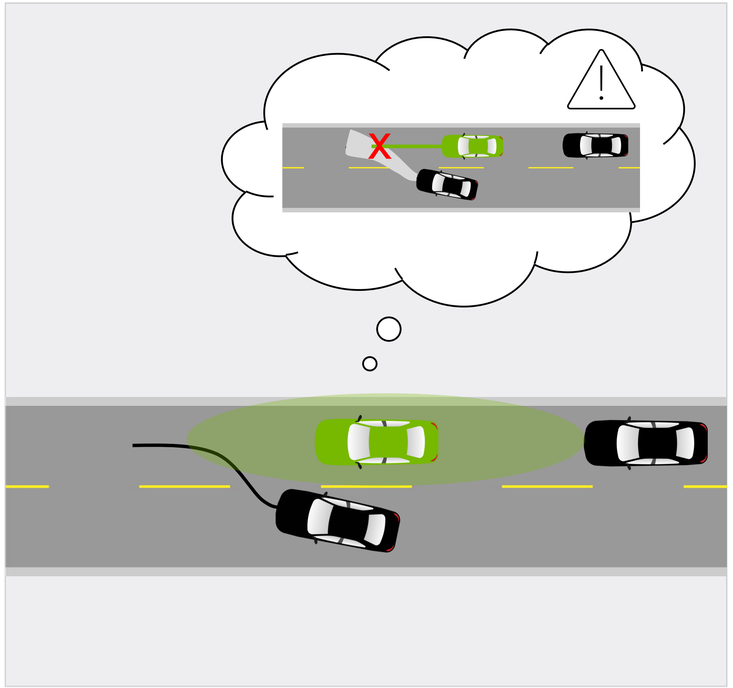
References: Xu, Chen, Ivanovic, Pavone, ICRA 23 (submitted).

DESIGN OF AI-BASED AV STACK

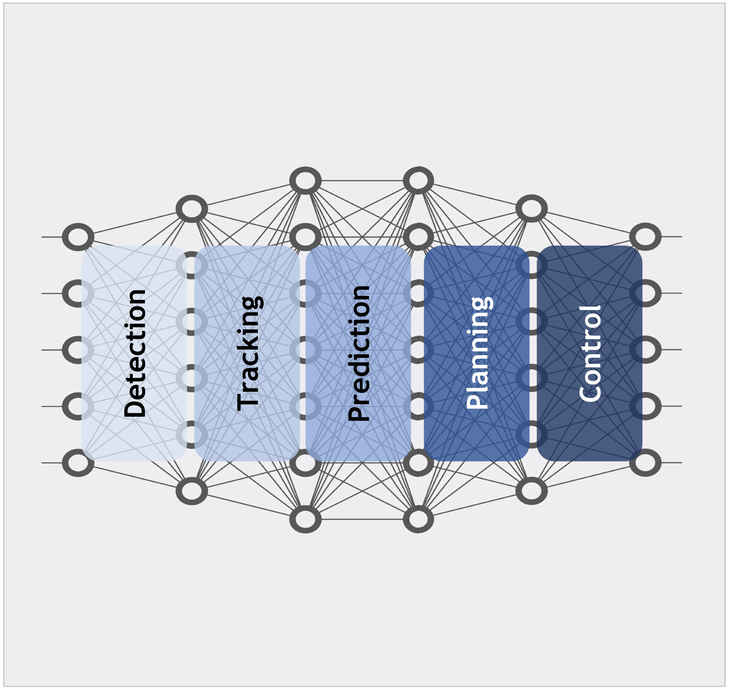
Insights on some key open research problems



Human-centered & Robust Autonomy



Offline and Online
Safety Assurances



Novel AV Stacks Optimizing
End-to-End Performance

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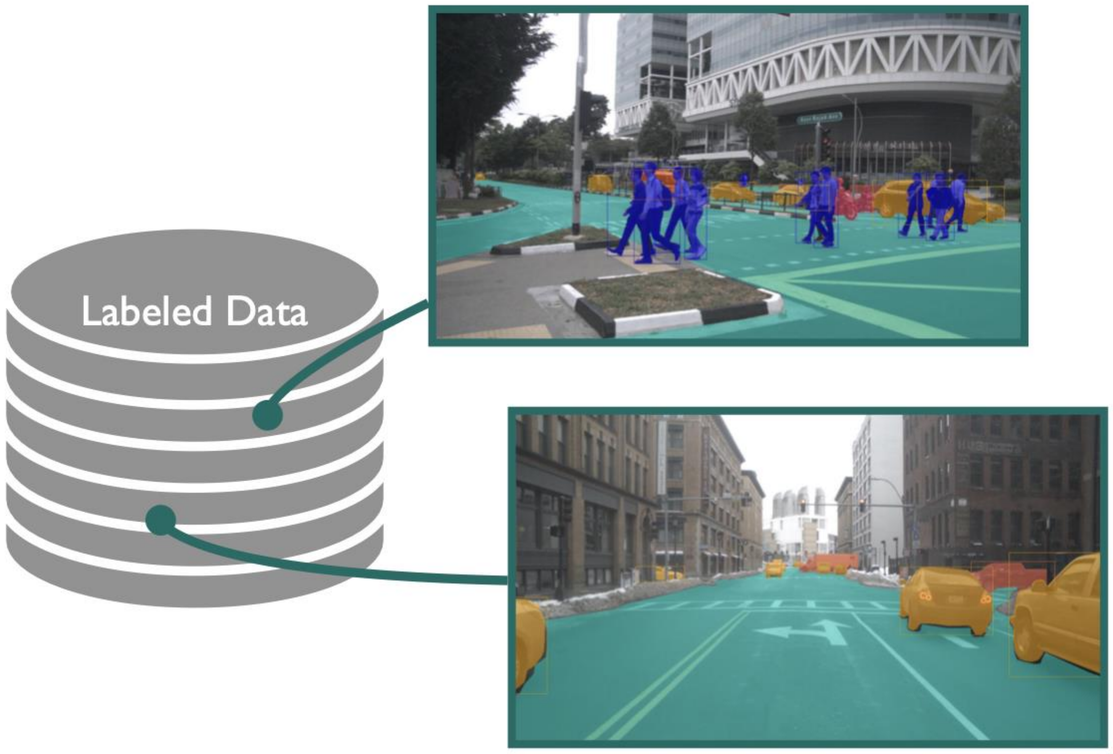
DATA-DRIVEN MODELS ARE AT THE CORE OF MODERN AV STACKS

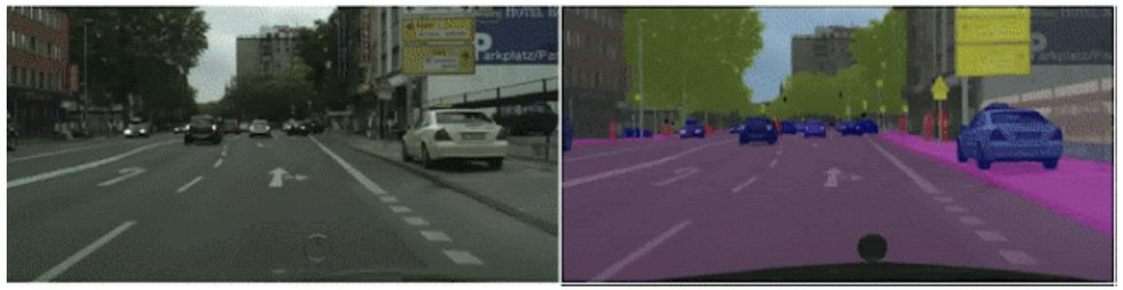
Sidestep brittle modeling assumptions by learning directly from data

Design time



NuScenes

Deployment time



Cheng et al., Panoptic-Deeplab, CVPR 2020

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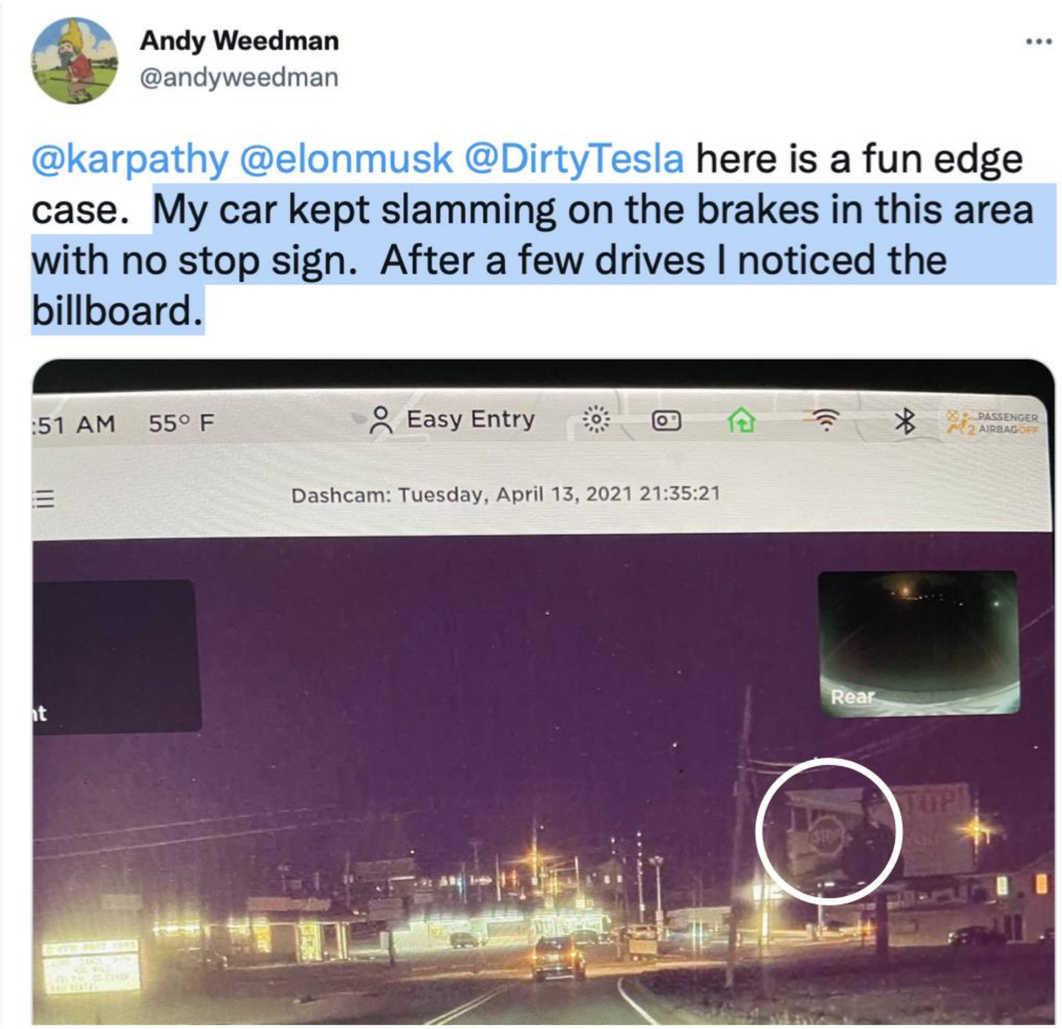
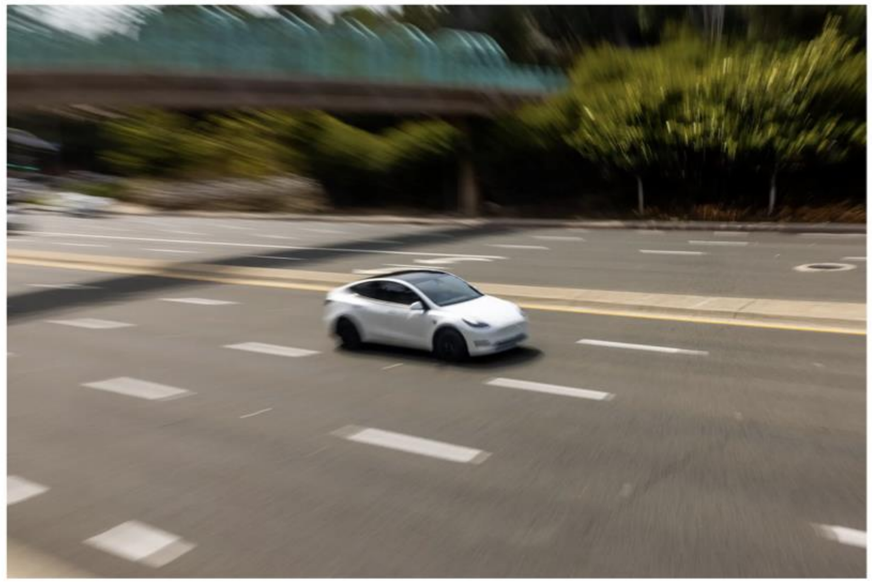
...BUT THEY CAN BE UNRELIABLE AND ERRATIC



The New York Times

Regulators open an investigation into 'phantom braking' by Teslas.

Some drivers have complained that cars using the company's Autopilot system have been slowing down suddenly even when there are no hazards ahead.



The investigation focuses on Tesla Model 3 compact sedans and Model Y hatchbacks that were made in 2021 and 2022 and sold in the United States. Roger Kisby for The New York Times

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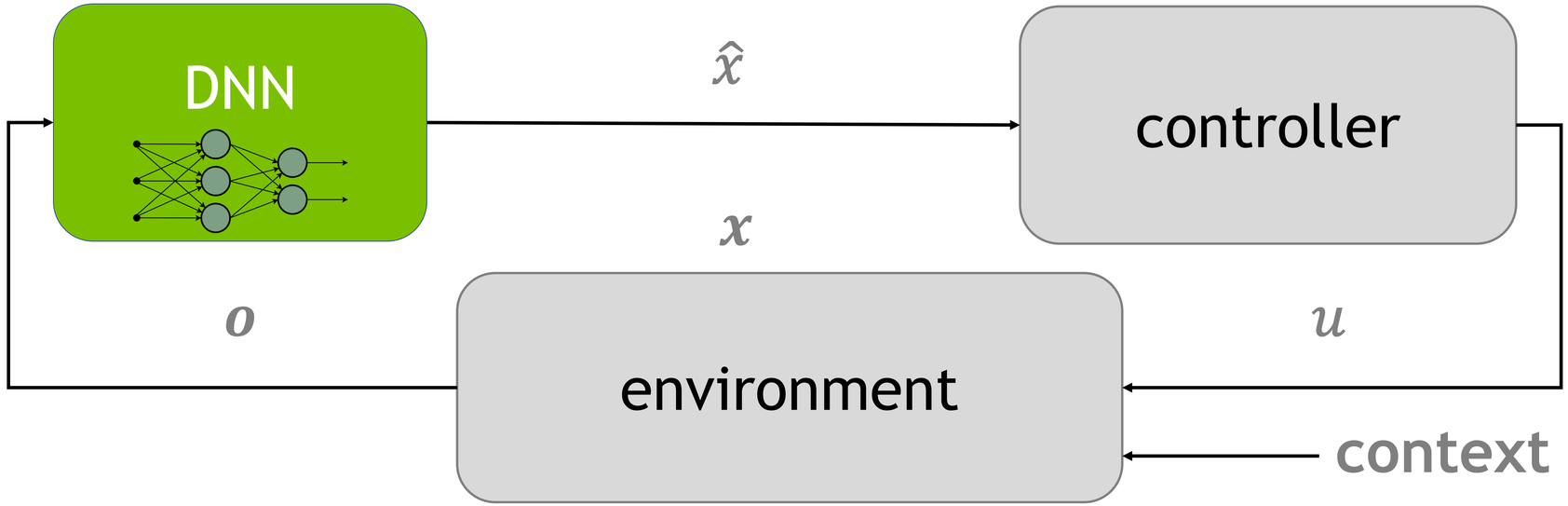
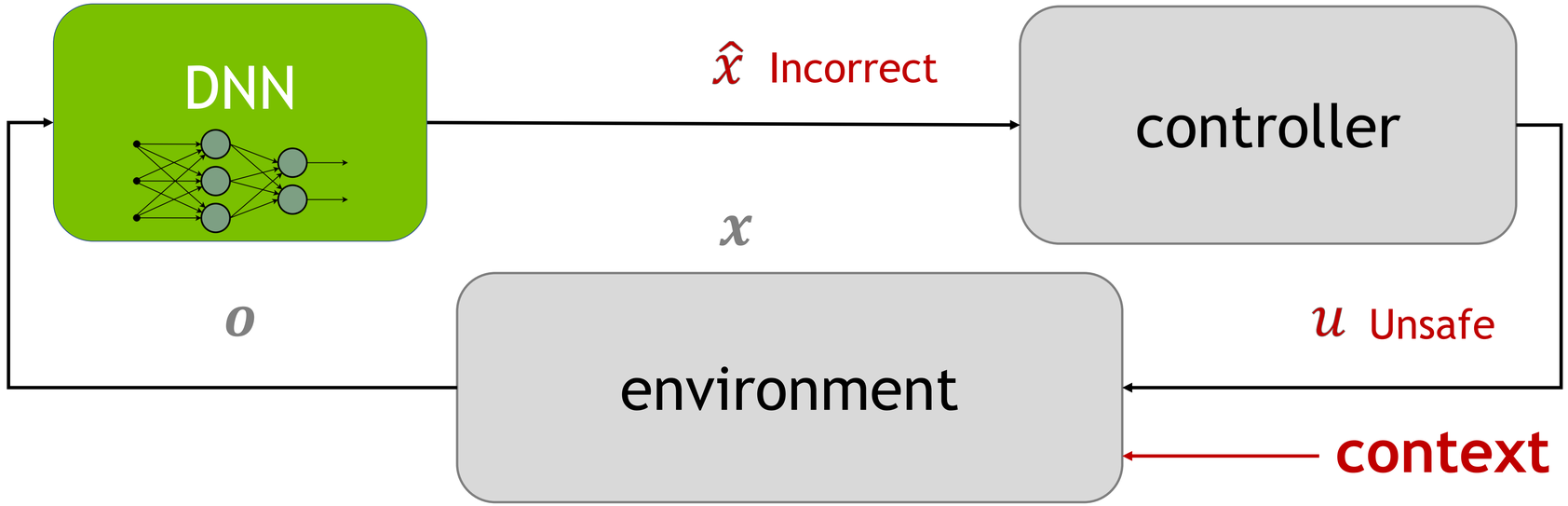
DNNS ARE ONLY AS GOOD AS THEIR DATASETS



DNN trained on $(o, x) \sim p_{\text{train}}(o, x)$

These examples come from specific contexts (e.g., weather, time of day)

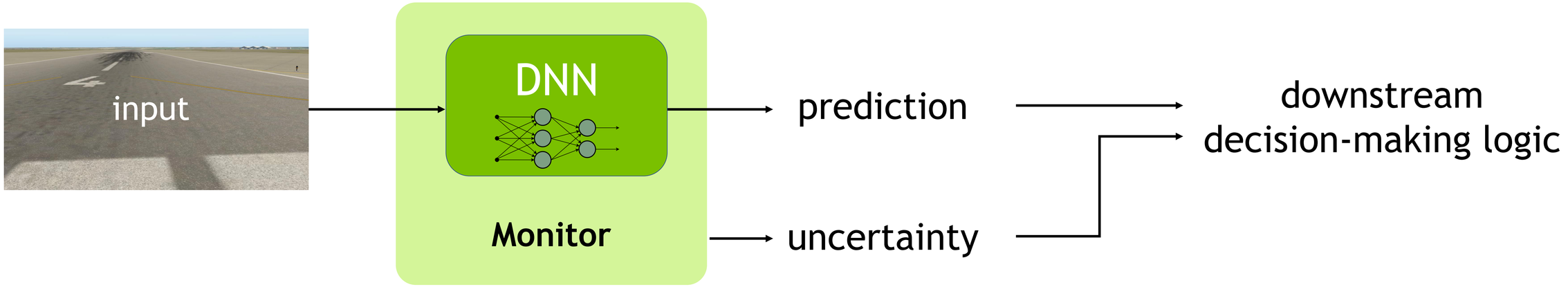
DNNS ARE ONLY AS GOOD AS THEIR DATASETS

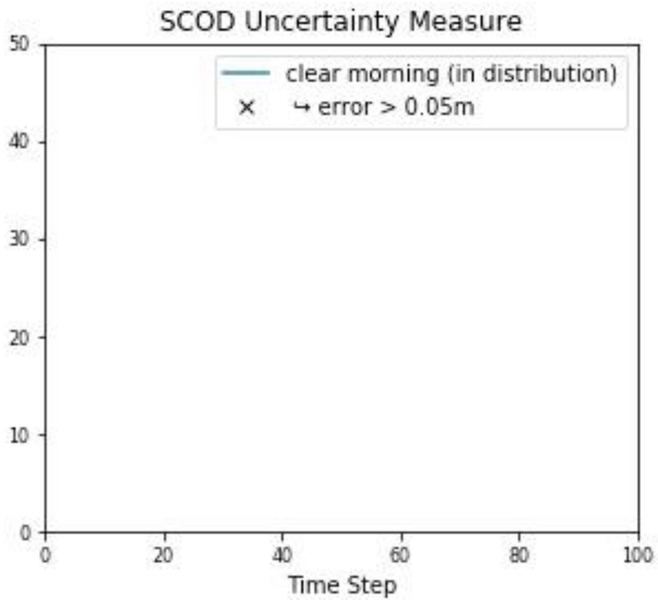


DNN trained on $(o, x) \sim p_{\text{train}}(o, x)$

Out-of-distribution observations can lead to **faults in perception**, and impact **closed-loop performance**

RUN-TIME MONITORS FOR ANOMALY DETECTION





Takeaway message: run-time monitors are key to build high-confidence ML systems

Reference: Sharma, Azizan, Pavone, UAI '21.

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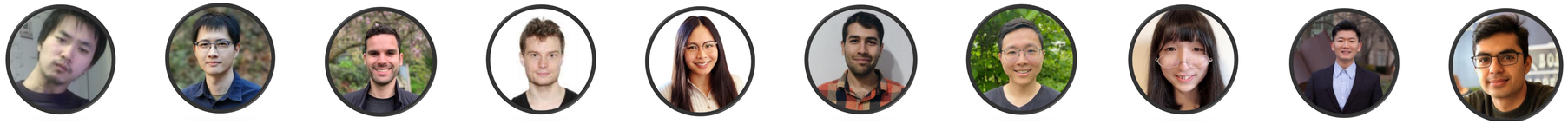
Acknowledgements: ASL group@Stanford (https://stanfordasl.github.io/) &
AVG group@NVIDIA (https://nvr-avg.github.io/)

ASL

AVG



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