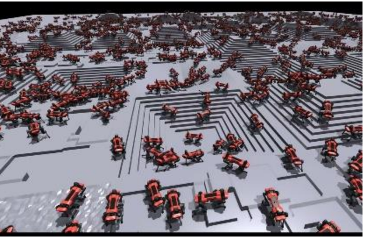
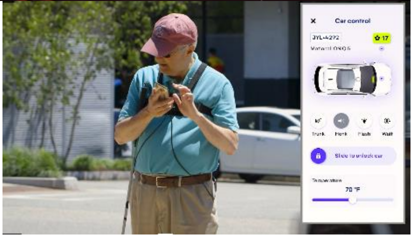
EC500: Robot Learning and Vision for Navigation



Eshed Ohn-Bar



January 25, 2023

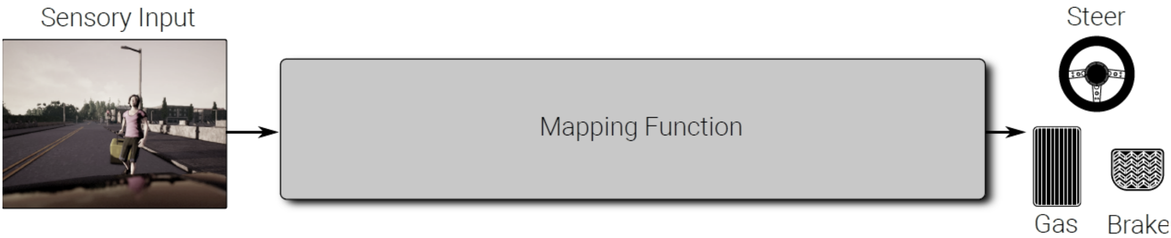
Questions About Class?

Questionnaire:

bit.ly/3XEZA3F

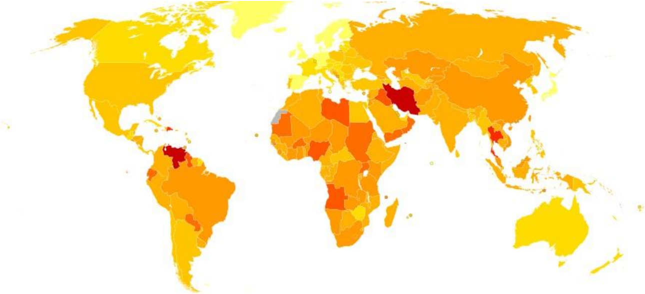
Last Time

Robot Learning and Vision for Navigation

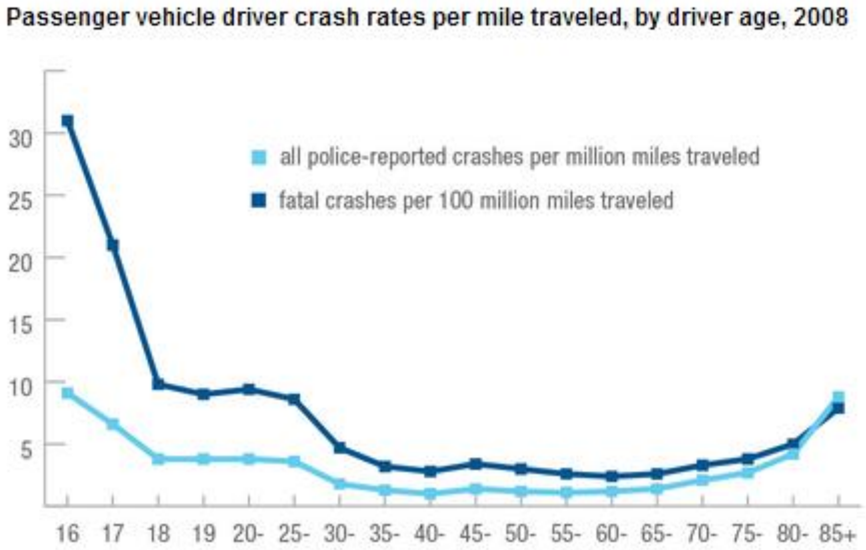


- Last Time:
- Interactive intelligence, system can ***act and move***
- ***How*** to design this mapping function?

Specific Application – Autonomous Driving
Road Fatalities in 2021



- World: 1,350,000
- Main factors: speeding, intoxination, distraction


Passenger vehicle driver crash rates per mile traveled, by driver age, 2008
30
25
20
15
10
5
all police-reported crashes per million miles traveled
fatal crashes per 100 million miles traveled
16
17
18
19
20-
25-
30-
35-
40-
45-
50-
55-
60-
65-
70-
75-
80-
85+

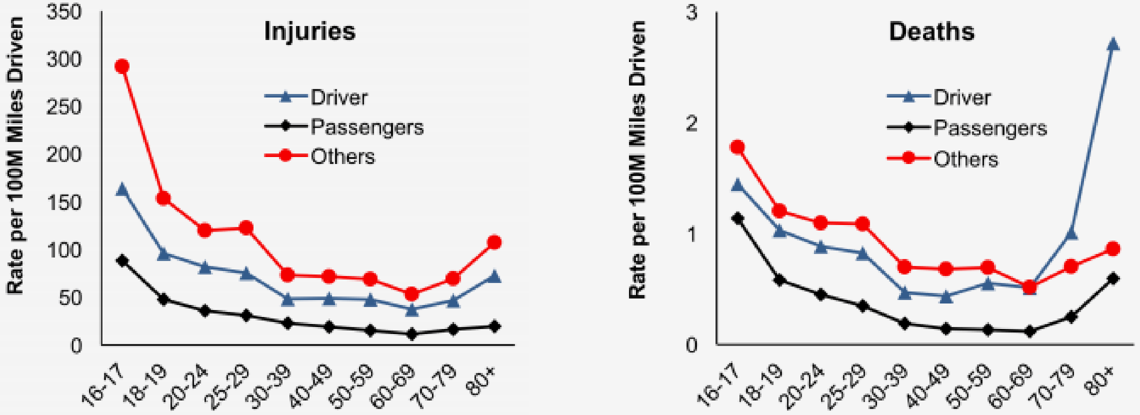


Figure 2. Injuries (left) and deaths (right) in crashes involving a driver of age shown per 100 million miles driven by drivers of that age, by role of person injured or killed, United States, 2014-2015.

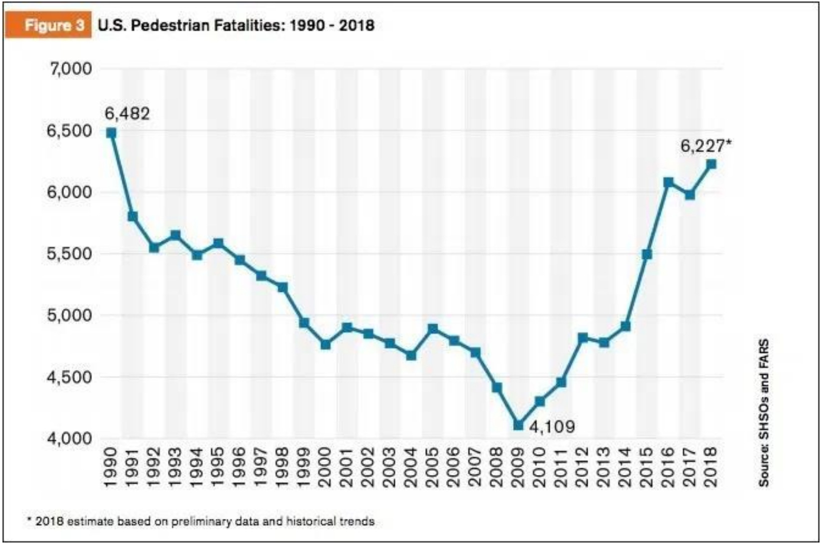
National Highway Traffic Safety Administration

Additionally, the traffic fatalities in the following categories showed relatively large increases in 2021, as compared to 2020:

- Fatalities in multi-vehicle crashes up 16%
- Fatalities on urban roads up 16%
- Fatalities among drivers 65 and older up 14%
- Pedestrian fatalities up 13%
- Fatalities in crashes involving at least one large truck up 13%
- Daytime fatalities up 11%
- Motorcyclist fatalities up 9%
- Bicyclist fatalities up 5%
- Fatalities in speeding-related crashes up 5%
- Fatalities in police-reported, alcohol-involvement crashes up 5%

https://www.nhtsa.gov/press-releases/early-estimate-2021-traffic-fatalities

U.S. Pedestrian Fatalities Reach Highest Level in 40 Years (in 2022, NHTSA)



Benefits of Autonomous Driving

- Lower risk of accidents

- Provide mobility for elderly and people with diabilities

- Decrease pollution

- Reduce number of cars (95% of the time a car is parked)

Objective for This Lecture

- Historical Perspective

- Frameworks for Sensorimotor Algorithms


Bush
1500
FRANKLIN
1500
FRANKLIN
Franklin
ACURA
coffee
68
68
5:28

How Did We Get Here?

1886 – First Automobile

Benz Patent-Motorwagen Nummer 1

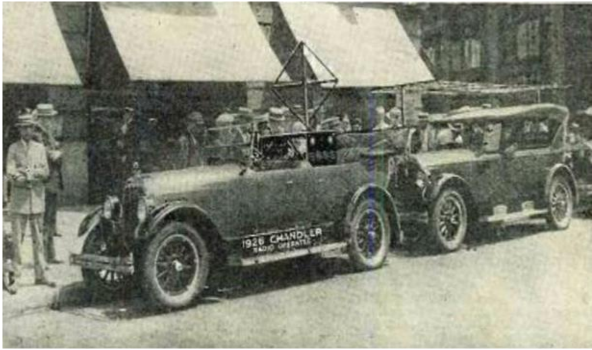
1886: Benz Patent-Motorwagen Nummer 1

- ►Benz 954 cc single-cylinder four-stroke engine (500 watts)
- ►Weight: 100 kg (engine), 265 kg (total)
- ►Maximal speed: 16 km/h
- ►Consumption: 10 liter / 100 km (!)

1886: Benz Patent-Motorwagen Nummer 1

- ►First long distance trip (106 km / 66 miles) by ***Bertha Benz*** in 1888 with Motorwagen Nummer 3 (without knowledge of her husband) fostered commercial interest

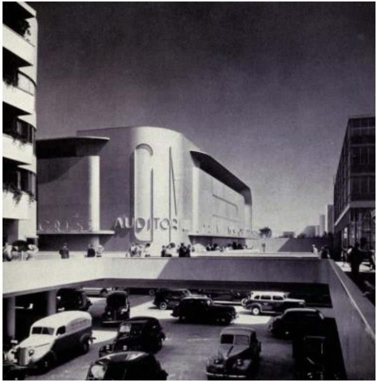
1925: Phantom Auto – “American Wonder” (Houdina Radio Control)



Houdina’s driverless car, called the American Wonder, traveled along Broadway in New York City—trailed by an operator in another vehicle—and down Fifth Avenue through heavy traffic. It turned corners, sped up, slowed down and honked its horn. Unfortunately, the demonstration ended when the American Wonder crashed into another vehicle filled with photographers documenting the event.

(Discovery Magazine)

1939: Futurama – New York World's Fair

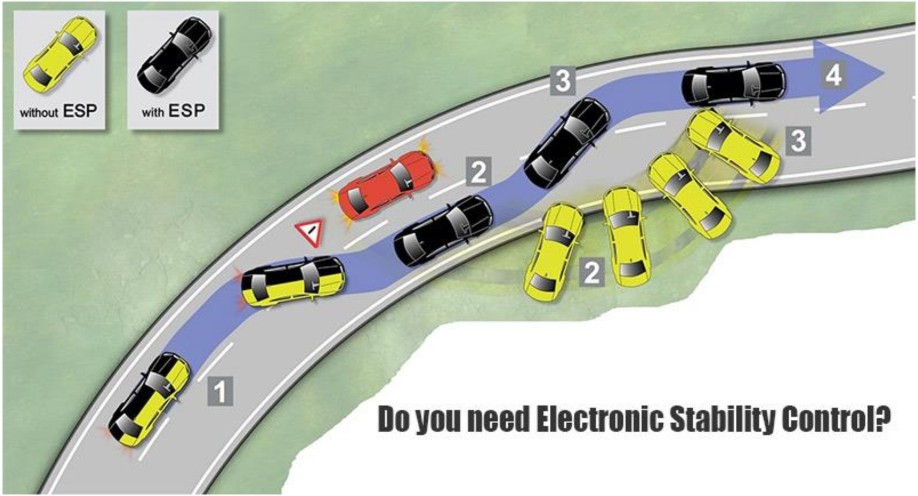


- ► Exhibit at the New York World's Fair in 1939 sponsored by **General Motors**
- ► Designed by Norman Bel Geddes' -his vision of the world 20 years later (1960)
- ► Radio-controlled electric cars, electromagnetic field via circuits in roadway
- ► #1 exhibition, very well received (great depression), prototypes by RCA & GM

1956: General Motors Firebird II


1,450
°F
INLET TEMP
GAS TURBINE

1983-Now: Driver Assistance Systems



ESP – Electronic Stability Program

1983-Now: Driver Assistance Systems

ESC Prevents

- 40% of single vehicle crashes
- 43% of all crash fatalities
- 56% of single vehicle fatalities
- 80% of rollover fatalities

Insurance Institute of Highway Safety - 2006

1986-1994: The invention of the self-driving car

- Developed by Ernst Dickmanns, Longitudinal & lateral guidance with lateral acceleration feedback
- 1678 km autonomous ride Munich to Odense, 95% autonomy (up to 158 km)
- Autonomous driving speed record: 180 km/h (lane keeping)

Dickmanns and Mysliwetz: Recursive 3-D Road and Relative Ego-State Recognition. PAMI, 1992.

1986-1995: Navlab

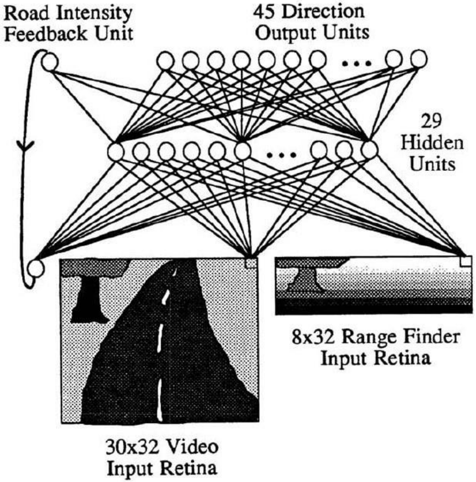
Jochem, Pomerleau, Kumar and Armstrong: PANS: A Portable Navigation Platform. IV, 1995.

1986-1995: Navlab

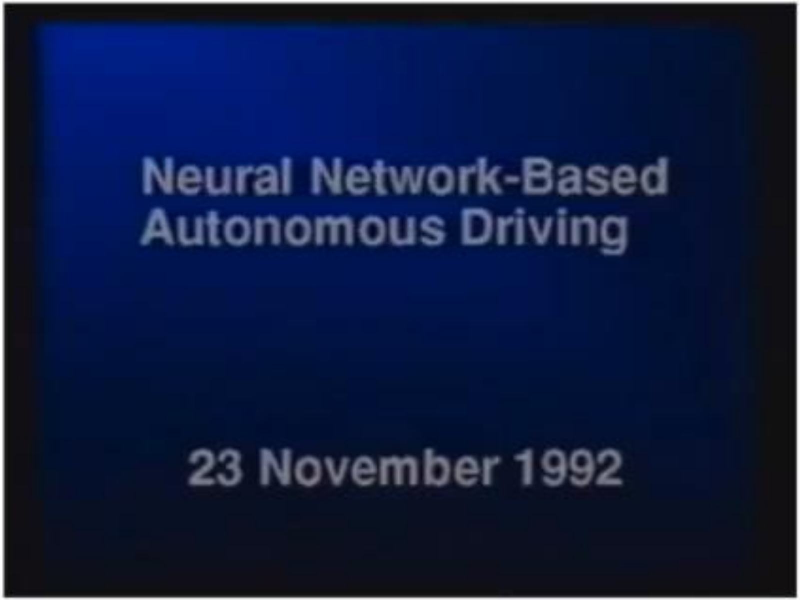
Using computer vision, the **Navlab 5** steered 98.2% of the distance from Washington, D.C. to San Diego CA. (2797 miles out of 2849)

1988: ALVINN An Autonomous Land Vehicle in a Neural Network

- ► Forward-looking, vision based driving
- ► Fully connected neural network maps road images to vehicle turn radius
- ► Directions discretized (45 bins)
- ► Trained on simulated road images
- ► Tested on unlined paths, lined city streets and interstate highways
- ► 90 consecutive miles at up to 70 mph



Pomerleau: ALVINN: An Autonomous Land Vehicle in a Neural Network. NIPS, 1988.

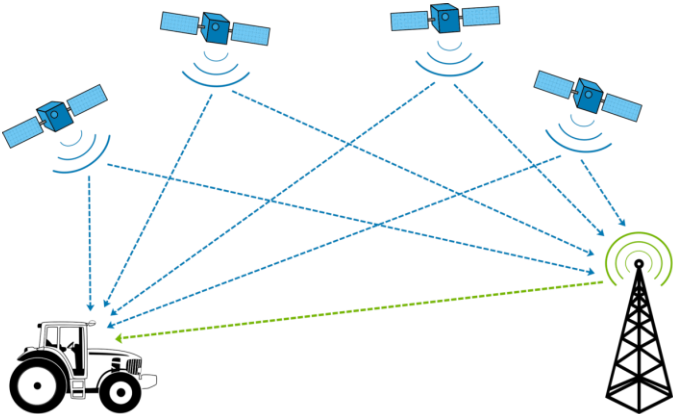


[Courtesy of Dean Pomerleau]

1995: Invention of Adaptive Cruise Control (ACC)

- ► 1992: Lidar-based distance control by Mitsubishi (throttle control & downshift)
- ► 1997: Laser adaptive cruise control by Toyota (throttle control & downshift)
- ► 1999: Distronic radar-assisted ACC by Mercedes-Benz (S-Class), level 1 autonomy

2000: "**Main Breakthrough #1**": GPS, IMUs & Maps



- NAVSTAR GPS available with 1meter accuracy, IMUs improve up to 5 cm
- Navigation systems and road maps available
- Accurate self-localization and ego-motion estimation algorithms

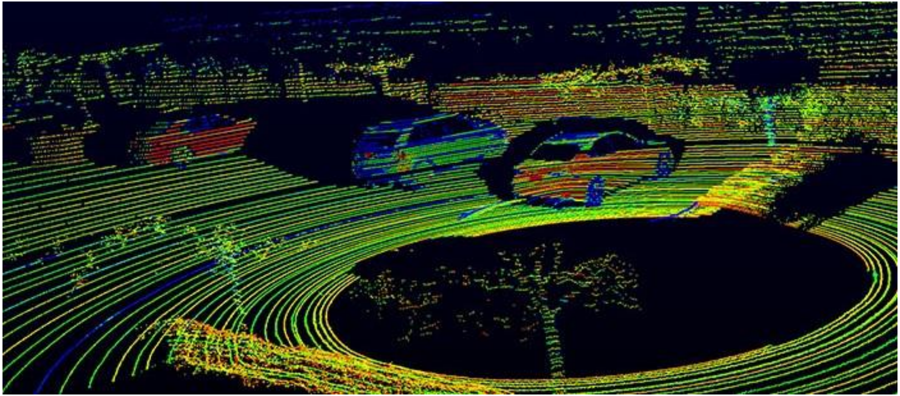
2004: Darpa Grand Challenge 1

- 1st competition in the Mojave Desert along a 240 km route, $1 mio prize money
- No traffic, dirt roads, driven by GPS (2935 points, up to 4 per curve).
- None of the robot vehicles finished the route. CMU traveled the farthest distance, completing 11.78 km of the course **before hitting a rock**.

2005: Darpa Grand Challenge 2

- 2nd competition in the Mojave Desert along a 212 km route, \$2 mio prize money
- Five teams finished (Stanford team 1st in 6:54 h, CMU team 2nd in 7:05 h)

2006: **Main Breakthrough #2**: Lidars & High-res Sensors



- High-resolution Lidar
- Camera systems with increasing resolution
- Accurate 3D reconstruction, 3D detection & 3D localization

2007: Darpa Urban Challenge

- 3nd competition at George Air Force Base, 96 km route, urban driving, $2 mio
- Rules: obey traffic law, negotiate, avoid obstacles, merge into traffic
- 11US teams received $1 mio funding for their research
- Winners: CMU 1st (4:10), Stanford's Stanley 2nd (4:29).


START

2009: Google starts working on Self-Driving Car

- ► Led by Sebastian Thrun, former director of Stanford AI lab and Stanley team
- ► Others: Chris Urmson, Dmitri Dolgov, Mike Montemerlo, Anthony Levandowski
- ► Renamed "Waymo" in 2016

2012: **Breakthrough #3**: Benchmarks and Methods

Geiger, Lenz and Urtasun: Are we ready for Autonomous Driving? The KITTI Vision Benchmark Suite. CVPR, 2012.

Still Ongoing: New Benchmarks and Methods

Dosovitskiy et. al.: CARLA: An open urban driving simulator. CoRL, 2018.

Still Today: Third Technological Revolution: New Benchmarks and Methods

Dosovitskiy et. al.: CARLA: An open urban driving simulator. CoRL, 2018.

2013: Mercedes Benz S500 Intelligent Drive

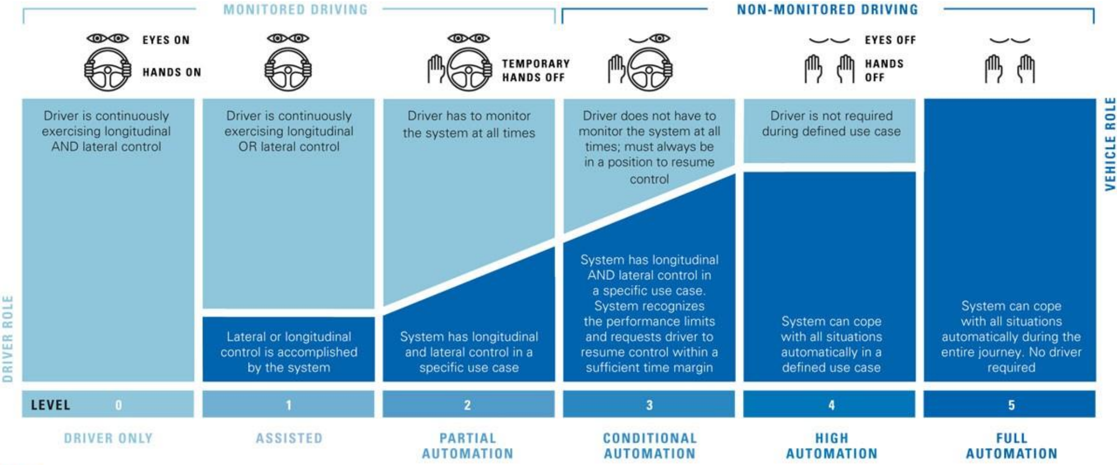
- ► Autonomous ride on historic Bertha Benz route by Daimler R&D and KIT/FZI
- ► Novelty: close to production stereo cameras / radar (but also HD maps)

2014: Mercedes S Class

Advanced ADAS (Level 2 Autonomy):

- Autonomous steering, lane keeping, acceleration/braking, collision avoidance, driver fatigue monitoring in city traffic and highway speeds up to 200 km/h

2014: Society of Automotive Engineers: SAE Levels of Autonomy



Mike Lemanski

2015: Tesla Model S Autopilot

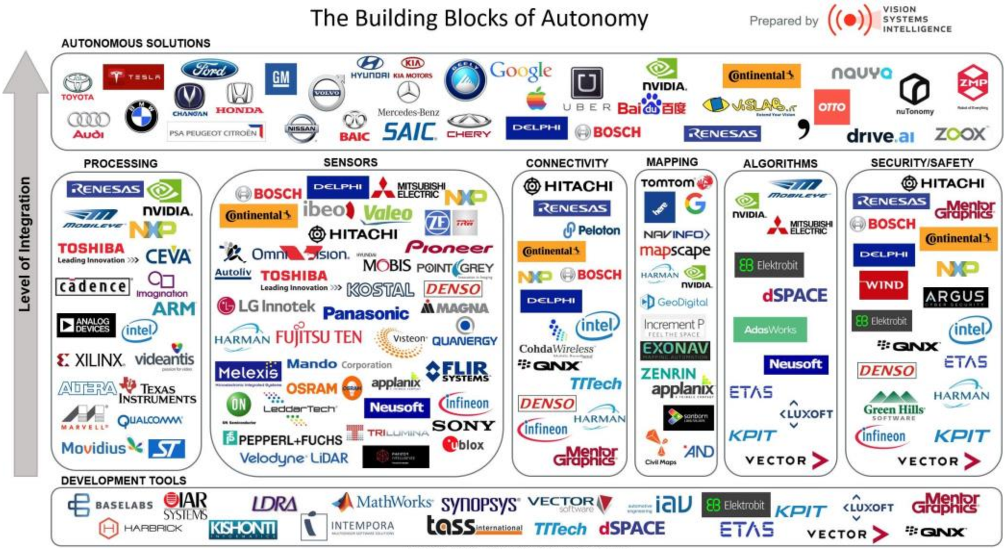
Tesla Autopilot (Level 2 Autonomy):

- ► Lane keeping for limited-access highways (hands off time: 30-120 seconds)
- ► Doesn’t read traffic signals, traffic signs or detect pedestrians/cyclists

2016: Tesla Model S Autopilot: Fatal Accident 1

2018: Tesla Model X Autopilot: Fatal Accident 2

Self-Driving Industry



Business Models

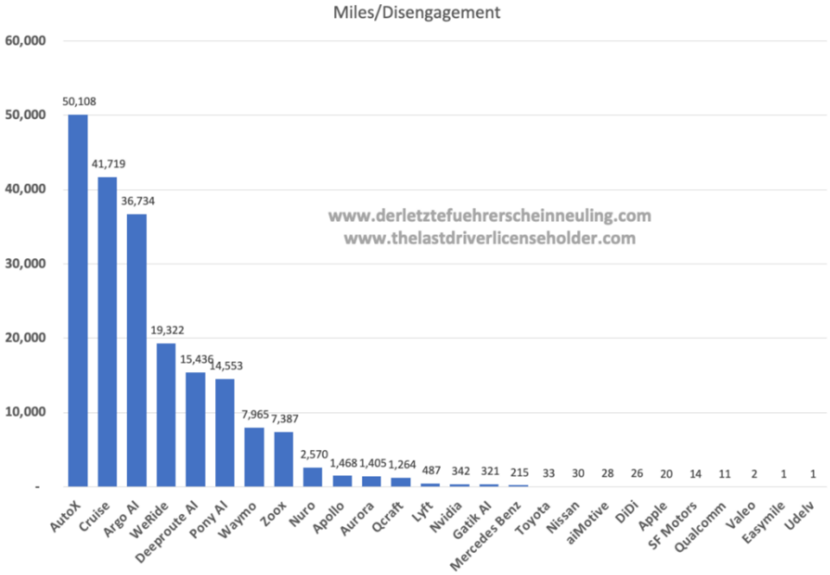
Autonomous or nothing (Google, Apple, Uber)

- ► Very risky, only few companies can do this
- ► Long term goals

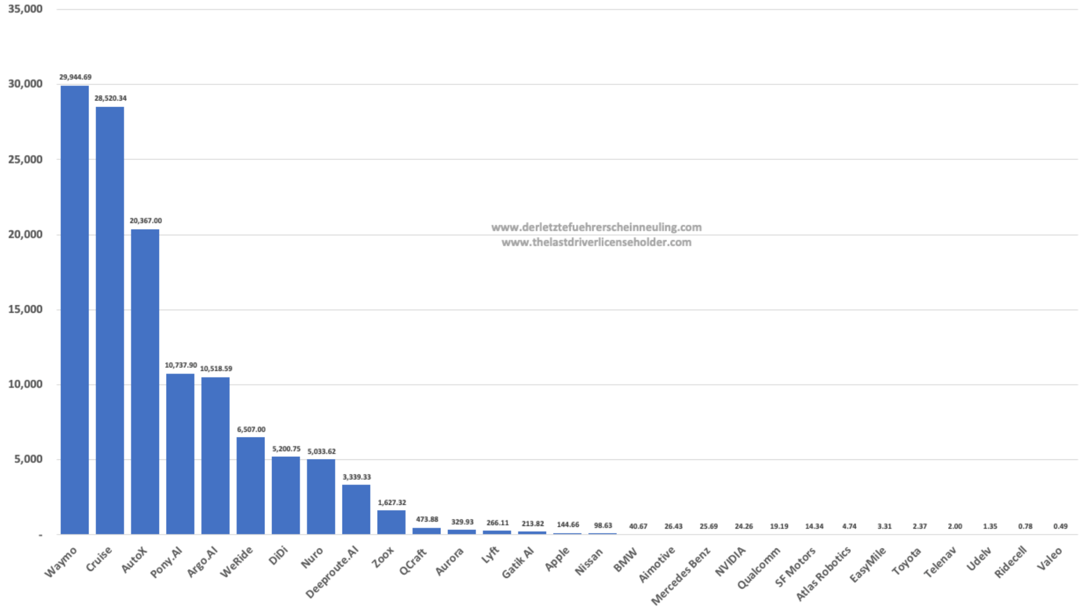
Introduce technology little by little (all car companies)

- ► Car industry is very conservative
- ► ADAS as intermediate goal
- ► Sharp transition: how to maintain the driver engaged?

Miles per disengagement (California Dept. of Motor Veh., 2021)



Miles per disengagement (California Dept. of Motor Veh., 2020)



Summary

- Self-driving has a ***long history***
- Highway lane-keeping of today was developed 30 years ago
- Increased robustness $\Rightarrow$ introduction of ***level 3 for highways in 2019***
- Increased interest after DARPA challenge and new benchmarks (e.g., KITTI)
- Many claims about full self-driving (e.g., Elon Musk), but level 4/5 stays hard
- Waymo seems ahead of competition in fully self-driving, also largest investments
- But several setbacks (Uber, Tesla accidents)
- Existing systems require laser scanners and HD maps
- Key technological challenges remain – autonomous driving is a research problem.