L1.1 Introduction and Overview

Zonghua Gu, Umeå University

Nov. 2023

Course Logistics

- Lectures Mon & Wed 15:30-17:00 via Zoom.
  - Link: https://umu.zoom.us/j/62818040552
- Instructor: Zonghua Gu, zonghua.gu@umu.se
- Course info (Welcome Letter, Syllabus, etc.):
  - https://www.umu.se/en/education/courses/algorithms-and-systems-for-autonomous-vehicles/

My Instruction Style

- No textbook. Will discuss classic techniques as well as latest research advances
- I provide detailed, self-contained PowerPoint slides
  - All exam questions come from these slides. Some slides may be verbose for the sake of completeness
- In-class questions and discussions are welcome
  - You can either speak up during lecture, or type in the chat window. For questions after class, please use the Canvas discussion board so everyone can see the discussions
- Lecture videos are recorded and put in UmU Play after each class, so in-class attendance is not mandatory

Course Materials

- I will put lecture materials here instead of on Canvas. Please bookmark this link
  - https://guzonghua.github.io/saav/
  - Canvas used for discussions, submission of labs and final exam
  - Since slides may be updated slightly after each class, it is more convenient to put them on GitHub
- Previous course contents available:
  - https://guzonghua.github.io/saav2022/
  - https://guzonghua.github.io/saav2021/
  - Contents updated every year

Lecture Schedule

Lec Date	Lecture Notes	Topics Discussed
W1	L1.1 Introduction and Overview PPTX, PDF L1.2 AV Sensors HD Map PPTX, PDF	Background, history, AD processing pipeline
W2	L1.3 HWSW Platforms V2X PPTX, PDF	Sensors and perception, HD maps, HW platforms, SW platforms, V2X communication
W2	L2 Intro to Machine Learning PPTX, PDF	Activation functions, Cross-Entropy Loss, SoftMax, ROC and AUC, NN training issues
W3	L3.1 CNN for Computer Vision PPTX, PDF	Intro to CNN, case studies (LeNet, AlexNet, VGGNet, GooLeNet, ResNet...)
W4	L3.2 Adversarial Attacks PPTX, PDF	Adversarial attacks
W5	L4 Object Detection and Segmentation PPTX, PDF	Object detection (R-CNN, Fast R-CNN, Faster R-CNN, Single-Stage Detectors), object segmentation
W6	L5 Planning PPTX, PDF	Route planning, behavior planning, local planning, Responsibility Sensitive Safety (RSS)
W7	L6 Control Theory PPTX, PDF	PID, MPC, Udacity racetrack control, PID tuning with twiddle()
W8	L7.1 MDP Planning, PPTX, PDF	Markov Decision Process (MDP), Bellman Equations, Policy Iteration, Value Iteration
W8	L7.2 Q-Learning, PPTX, PDF	Q-learning
W9	L8 Latest Research Advances	TBD
W10	Final Exam, Date TBD, Online on Zoom, Sample Exam Questions	

Lab Sections

- Lab materials: https://github.com/guzonghua/saavlabs
- We will keep the programming workload relatively low, e.g., you may be given a semi-complete program, and asked to fill in a few lines of missing code (no large-scale coding)
- We will keep the computing demands low, so you can use Google Colab, or work on your own computer without a powerful GPU (Programming language is Python)

Assign Date	Assignment	Due Date
W4	Lab1. Adversarial Attacks on a CNN for Traffic Sign Classification LabX. Bonus project proposal	TBD
W6	Lab2. PID Control	TBD
W8	Lab3. DQN RL for Highway Driving, PPTX, PDF, Video Lecture	TBD
W10	LabX. Bonus project	TBD

LabX. Optional Bonus Project

- Please submit a proposal (on Canvas) before the end of W4 (Nov. 24), if you plan to work on a bonus project
  - The proposal should be at most 2 pages long, and describe the background, proposed work and why it is relevant to the course
  - The goal is to give you a chance to explore your own interests based on what you have learned in the course
- Submit the project report before the end of term (Jan. 14)
  - The report should be at most 6 pages long

Final Exam

- Friday, Jan. 12, 2024, 15:00 – 17:30, online on ZOOM
- Covers lecture PPTs. Held as a quiz on Canvas
  - Multiple choice questions
  - Simple calculation questions
  - Sample Exam Questions
- Open book, honor system
  - You may search online, but should not talk with your friends

Grading Rules

- Maximum 100 points:
  - Final exam (open-book): 60 points
  - Lab sections: 40 points
  - LabX: 10 points (if total number of points exceeds 100, then it is set to 100)
- One of the grades Fail (U), Pass (3), Pass with Credit (4) or Pass with Distinction (5) is given
  - To obtain grade (3), at least 50 points are required
  - For grade (4), at least 65 points
  - For grade (5), at least 80 points
- For students who have not obtained the grade Pass (3+), other examination sessions will be arranged

Pass or Fail?

- In the past, vast majority of students who finished the course have passed the course
  - Those who submitted all labs on time, and took the exam
- Course workload is not very high. Most students find it managable
  - Use the anonymous feedback link (bottom of course page) to provide comments on course pace, level of difficulty, etc.

Overview of AV Technology

https://www.hollywoodreporter.com/news/general-news/driving-cars-could-add-billions-905966/

Autonomous Vehicles (AVs)

- Can refer to any type of Autonomous Mobile Robot.
  - Not just Self-Driving Cars (SDCs)
- Techniques covered in this course are generally applicable to all types of AVs.


Self-Driving Cars


Drones


Warehouse Robots


Indoor-Cleaning Robots

Why Autonomous Driving?

- Reduced traffic accidents and fatalities
    - In 2019, an estimated 38,800 people lost their lives to car crashes in the US. About 4.4 million people were injured seriously enough to require medical attention in crashes.
- Reduced congestion and pollution
- More productive time spent on the road
- Autonomous Mobility-on-Demand (AMoD) with a fleet of robotaxis
    - Low-cost, safe and efficient mode of transportation that may make vehicle ownership obsolete.
    - The dream of Uber (and many other companies)

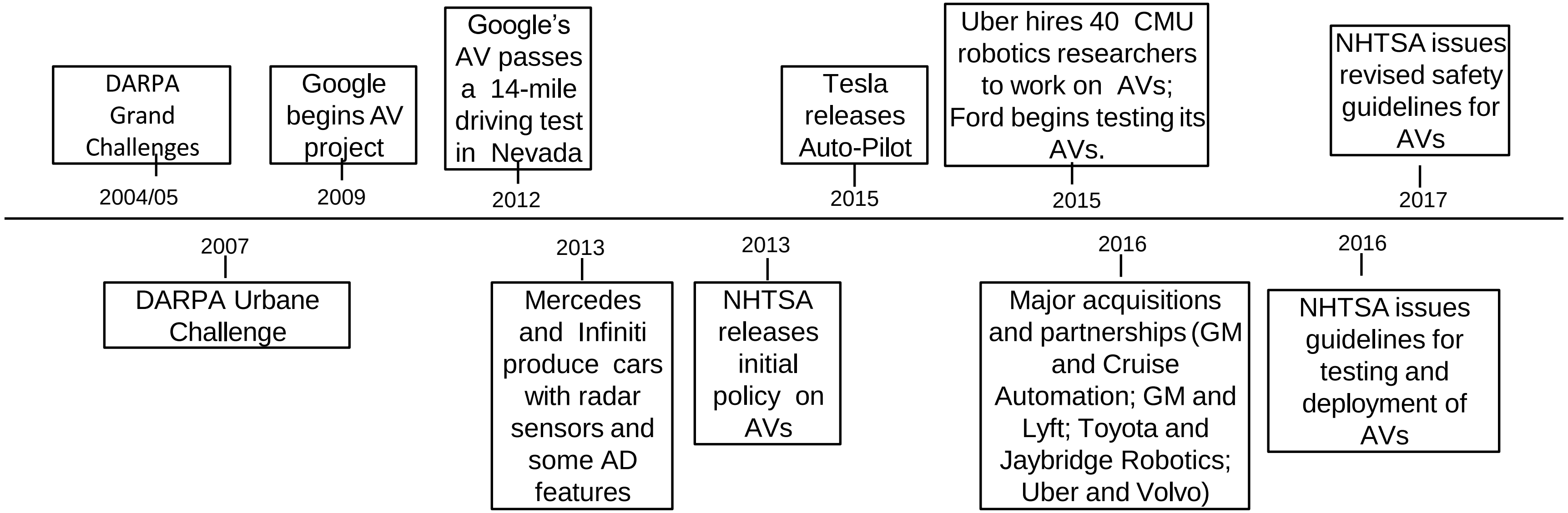
Advanced Driver Assistance (ADAS)

- Since the initial introduction of Cruise Control in 1948, ADAS functions are increasingly prevalent in modern vehicles.
  - Adaptive cruise control (ACC), Anti-lock braking system, Collision avoidance system (Pre-crash system), Driver Monitoring System (DMS), Electronic Stability Control (ESC), Forward Collision Warning (FCW), Lane Departure Warning (LDW), Lane Change Assistance, Surround View…

DARPA Grand Challenges

- 2004 challenge
  - Held in the Mojave Desert region of the USA, along a 150-mile route.
  - None of the robot vehicles finished the route. No winner was declared, and the cash prize was not given.
- 2005 challenge
  - Vehicles passed through three narrow tunnels and negotiated more than 100 sharp left and right turns.
  - Five vehicles successfully completed the 132 mi course. Stanford’s Stanley won the $2M top prize.
- 2007 challenge
  - The course involved a 60 mi urban area course to be completed in less than 6 hours. Rules included obeying all traffic regulations while negotiating with other traffic and obstacles and merging into traffic.
- The 3 Grand Challenge races jump-started the Self-Driving Car industry. Faculty and students from winning teams such as Stanford and CMU later became leaders in SDC projects at companies like Google/Waymo and Uber and numerous startups.

Brief History of AVs



https://www.mcca.com/wp-content/uploads/2018/04/Autonomous-Vehicles.pdf

Highway vs. City Driving

- Highway driving is perceived as an easier problem than city driving.
  - Has potential of massive displacement of truck driver jobs
  - But traffic merging is tricky and may require human operator assistance

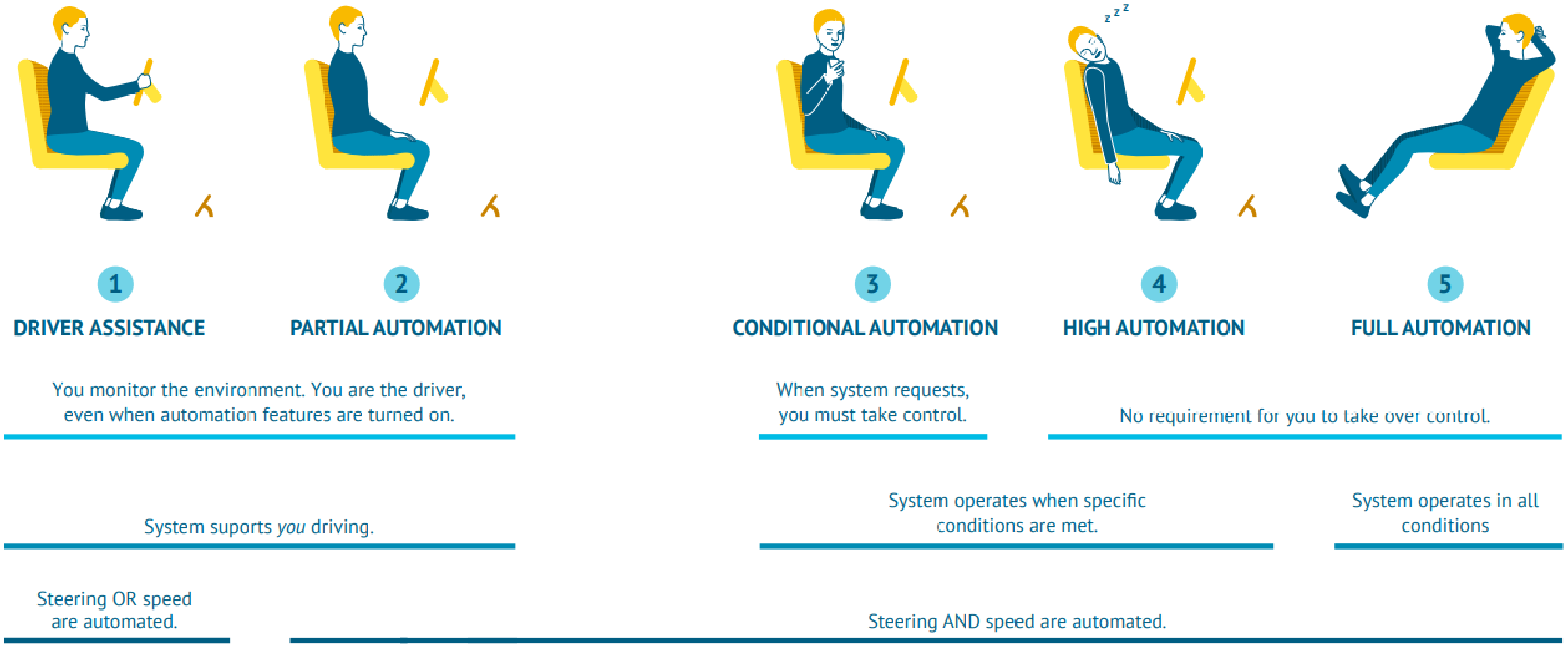
	Highway Driving	**City Driving**
Travel Speed	High	Low to medium
Traffic Volume	High	Medium to high
Number of Lanes	Large (6-8)	Small (2-4)
Others	Entry and exit points for traffic merging	Many intersections with traffic lights

Operational Design Domain (ODD)

- The ODD defines the conditions under which a vehicle is designed to function and is expected to perform safely. The ODD includes (but isn't limited to) environmental, geographical, and time-of-day restrictions, as well as traffic or roadway characteristics.
  - e.g., an autonomous freight truck might be designed to transport cargo from a seaport to a distribution center 30 Km away, via a specific route, in day-time only. This vehicles ODD is limited to the prescribed route and time-of-day, and it should not operate outside of it

Five Levels of Automation

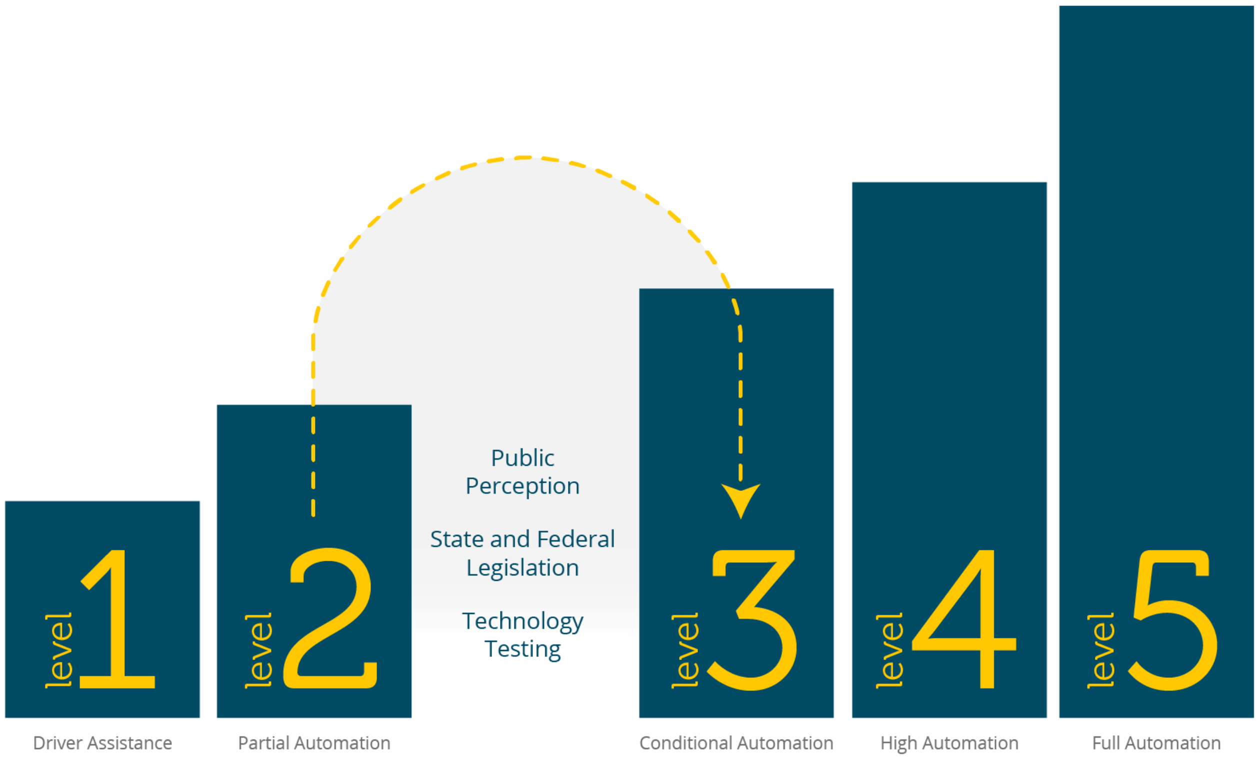
- L1: ADAS features that either control steering or speed to support the driver.
- L2: both steering and acceleration are simultaneously handled by AD system. The human driver still monitors the environment and supervises the support functions.
- L3: Conditional automation: the system can drive without the need for a human to monitor and respond. However, the system might ask a human to intervene, so the driver must be able to take control at all times.
- L4: These systems have high automation and can fully drive themselves under certain conditions. The vehicle won't drive if not all conditions are met.
- L5: Full automation, the vehicle can drive wherever, whenever, with unlimited ODD.



https://www.wevolver.com/article/2020.autonomous.vehicle.technology.report

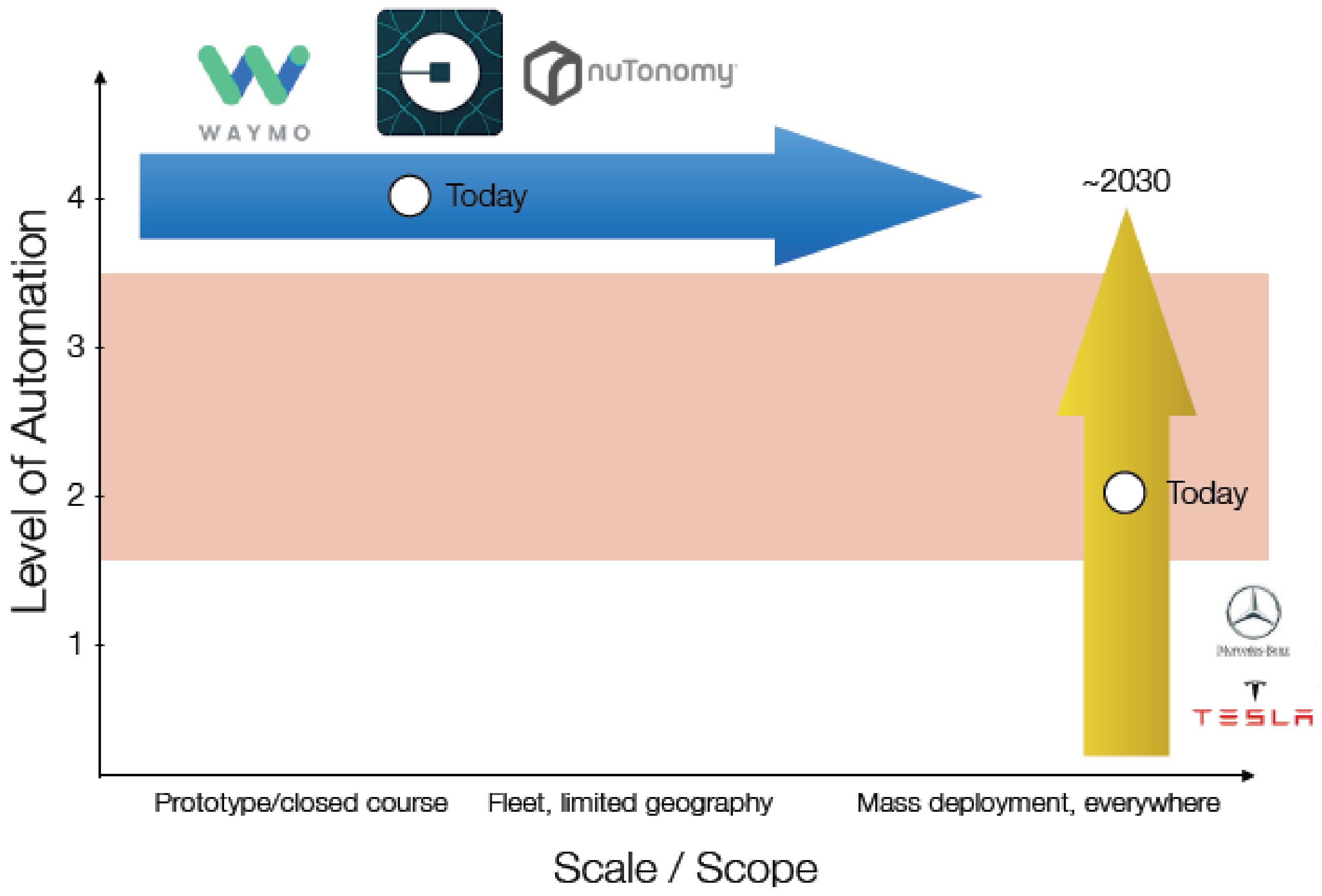
State of the Art

- Current commercial products are at most L2 (e.g., Tesla Autopilot)
- L2 to L3 is perceived to be a giant leap
- Automakers keep pushing the timeline of L3 and above to the future…



Two Different Paths to L4/5

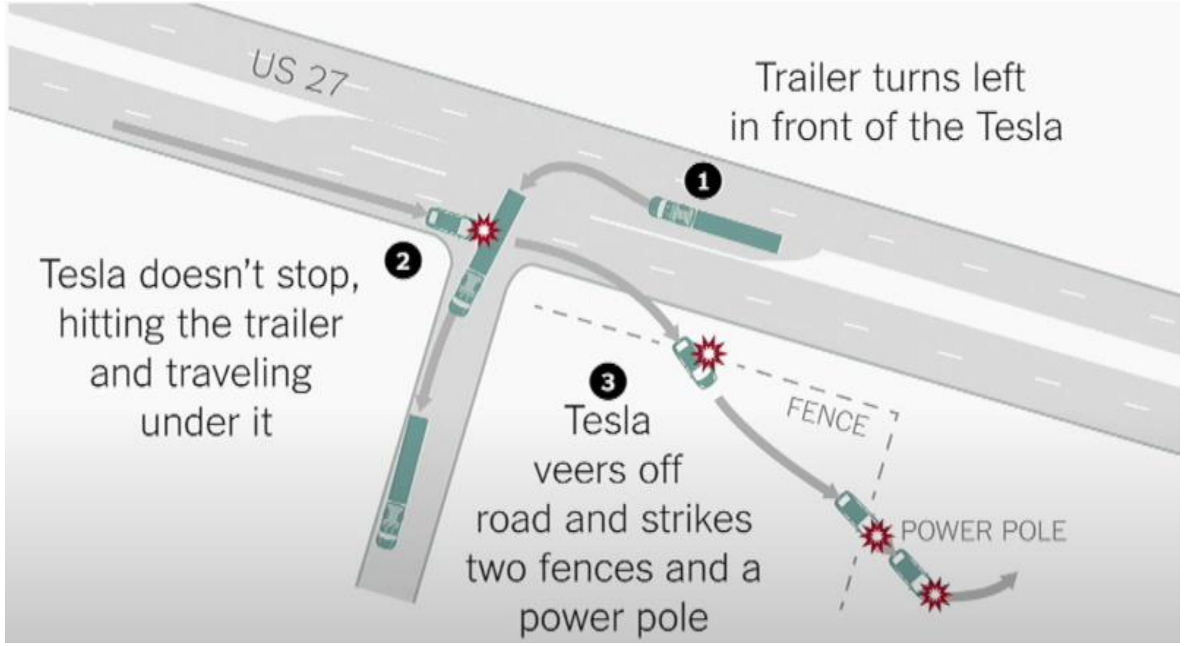
- Tesla starts from L2 and mass deployment, and gradually moves to L4/5.
- Waymo, nuTonomy…starts from L4 in limited ODD, and gradually expands deployment



Emilio Frazzoli, nuTonomy

The Tesla Fatality (May 2016)

- A Tesla Model S was driving 74 mph on the highway when it was struck by a truck
- Tesla: "Neither Autopilot nor the driver noticed the white side of the truck against a brightly lit sky, so the brake was not applied."
  - A failure of computer vision algorithm for object detection



The Tesla Fatality (Mar 2018)

- In 2018, a man died from a high-speed crash because his Tesla Autopilot system steered the car into a median on Highway 101 in CA.
  - Limitations on Tesla's Autopilot Lane-Keeping Assistance (LKA) caused the vehicle to veer into the median and failed to provide an alert to the driver in the seconds leading to the crash.
  - The collision avoidance system was not designed to detect a crash attenuator, which resulted in a severe crash in which the automatic braking and collision warning systems failed to activate.
  - A failure of computer vision algorithm for lane tracking.
- Tesla Autopilot 2 almost crashes Into Barrier (similar to this crash)
  - https://www.youtube.com/watch?v=TIUU1xNqI8w

https://www.mv-voice.com/news/2020/02/25/ntsb-teslas-autopilot-steered-model-x-into-highway-median-causing-fatal-mountain-view-crash

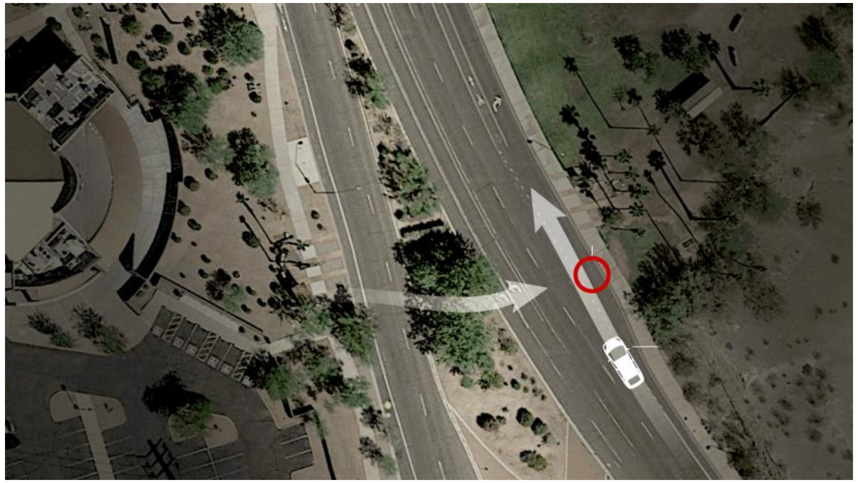
Tesla vs. Truck (Jun 2020)

- Tesla crashes into overturned truck on a busy highway in Taiwan
- Video: https://taiwanenglishnews.com/tesla-on-autopilot-crashes-into-overturned-truck/

Tesla on autopilot crashes into overturned truck

The Uber Pedestrian Fatality (Mar 2018)

- Video of Uber collision that killed pedestrian
  - https://www.youtube.com/watch?v=q7d90ZFhg28
- After the woman was detected on the road (6 sec before crash), she was:
  - first classified as unknown object
  - then misclassified as a vehicle
  - then as a bicycle
- 1.3 sec before, the Volvo system tried to do emergency braking maneuver
  - but Uber had disabled it for testing
- The safety driver was not watching the road moments before crash
  - It was probably too dark for the driver to see her in time
- The AV was equipped with both Lidar and Radar
  - “This is exactly the type of situation that Lidar and radar are supposed to pick up. This is a catastrophic failure that happened with Uber’s technology.” – Prof. David King.



Tesla Wins in Court (Oct 2023)

- Tesla won the first U.S. trial over allegations that its Autopilot driver assistant feature led to a death
  - In 2019, a Tesla Model 3 suddenly veered off a highway at 65 MPH, struck a palm tree and burst into flames, killing the driver and seriously injuring two passengers
  - Tesla argued that the crash, which resulted in the death of the driver Micah Lee, was the result of human error — the same stance it’s taken in other Autopilot lawsuits
    - https://www.reuters.com/business/autos-transportation/tesla-wins-autopilot-trial-involving-fatal-crash-2023-10-31/

AD Safety Evaluation by California DMV

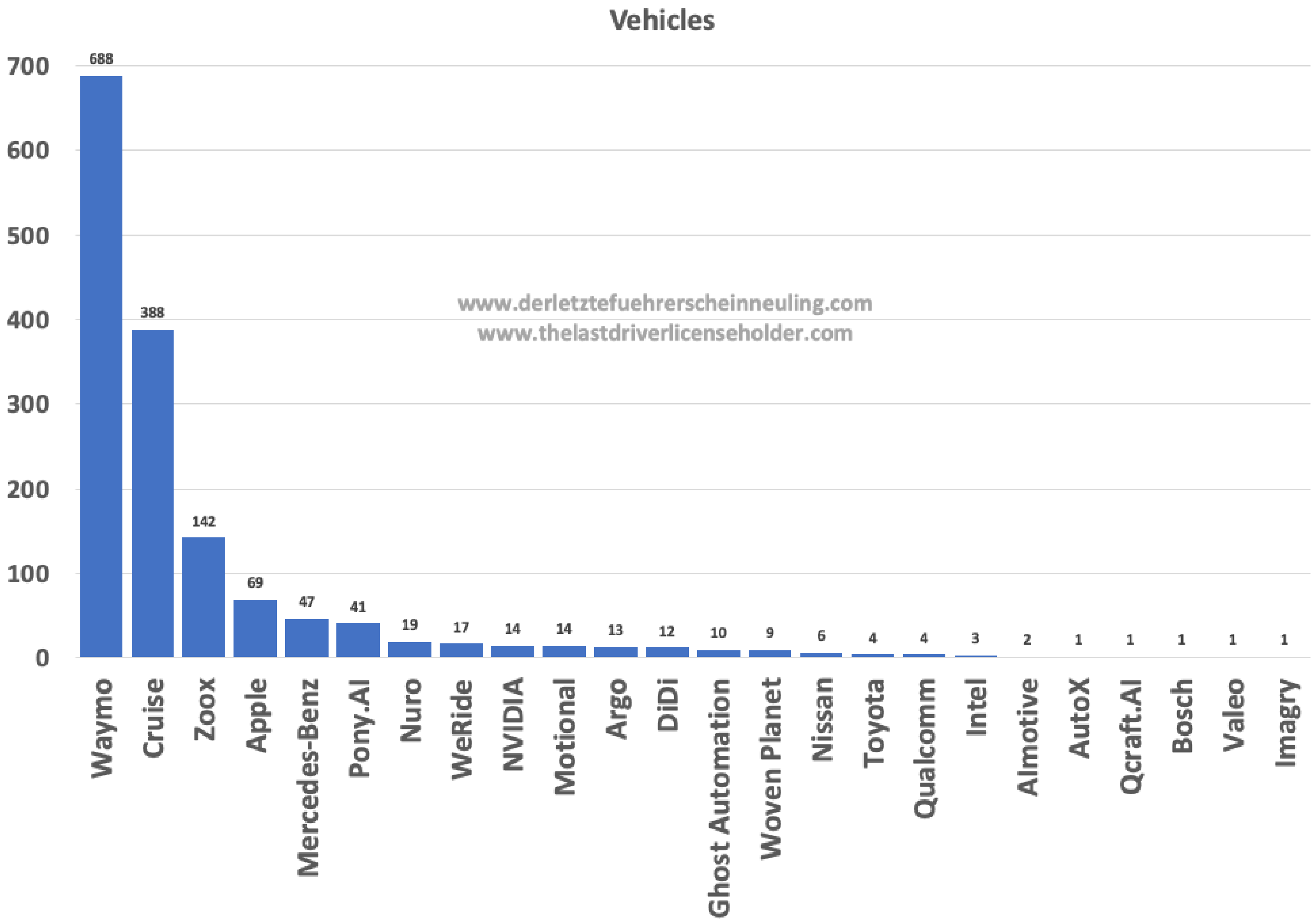
- A disengagement report is required from the 43 companies currently licensed to test autonomous cars on public roads in California.
  - California is currently the only region in the world where we have such data publicly available.
- A disengagement can be described as the event when the AV either got stuck and handed over control to a safety driver present in the vehicle, or when a safety driver took control himself.

Number of vehicles deployed per manufacturer in the 2022 reporting period

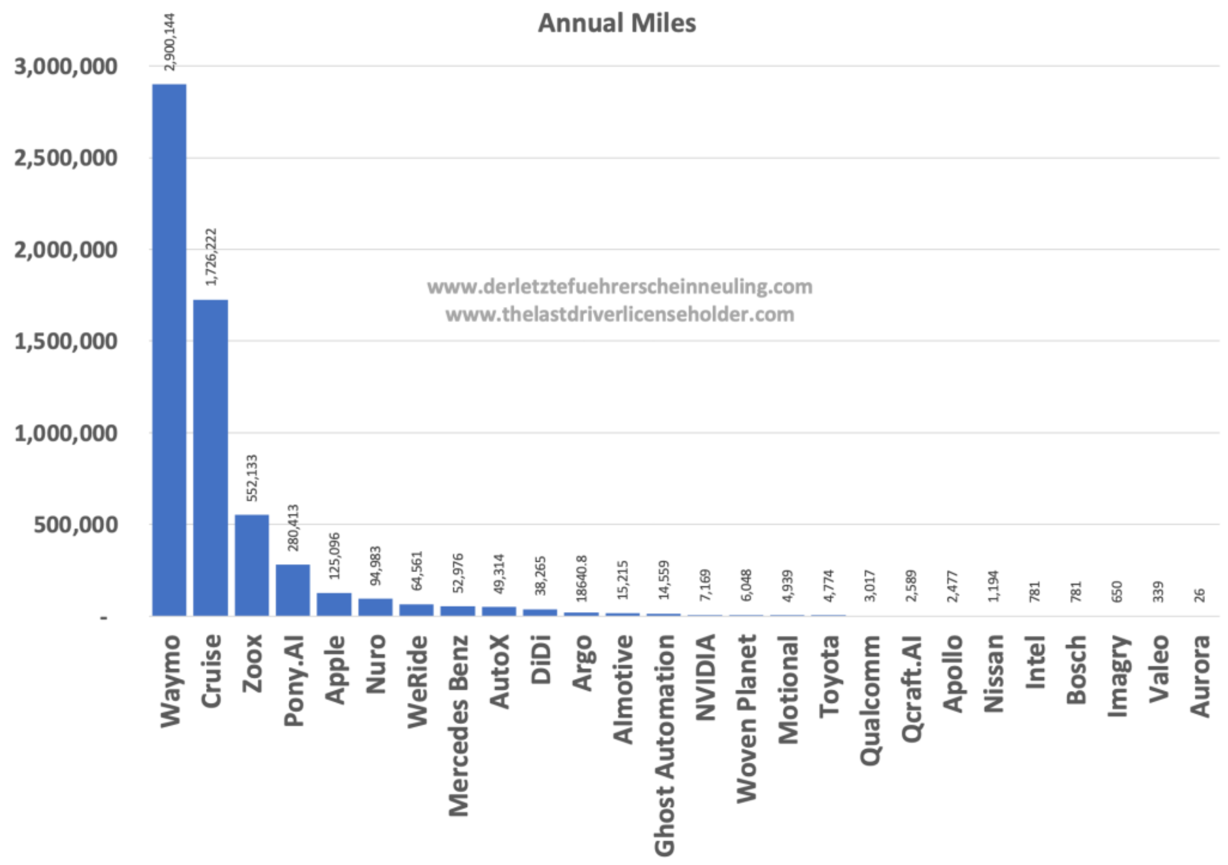
https://thelastdriverlicenseholder.com/2023/02/17/2022-disengagement-report-from-california/

Reports with Safety Drivers (2022)

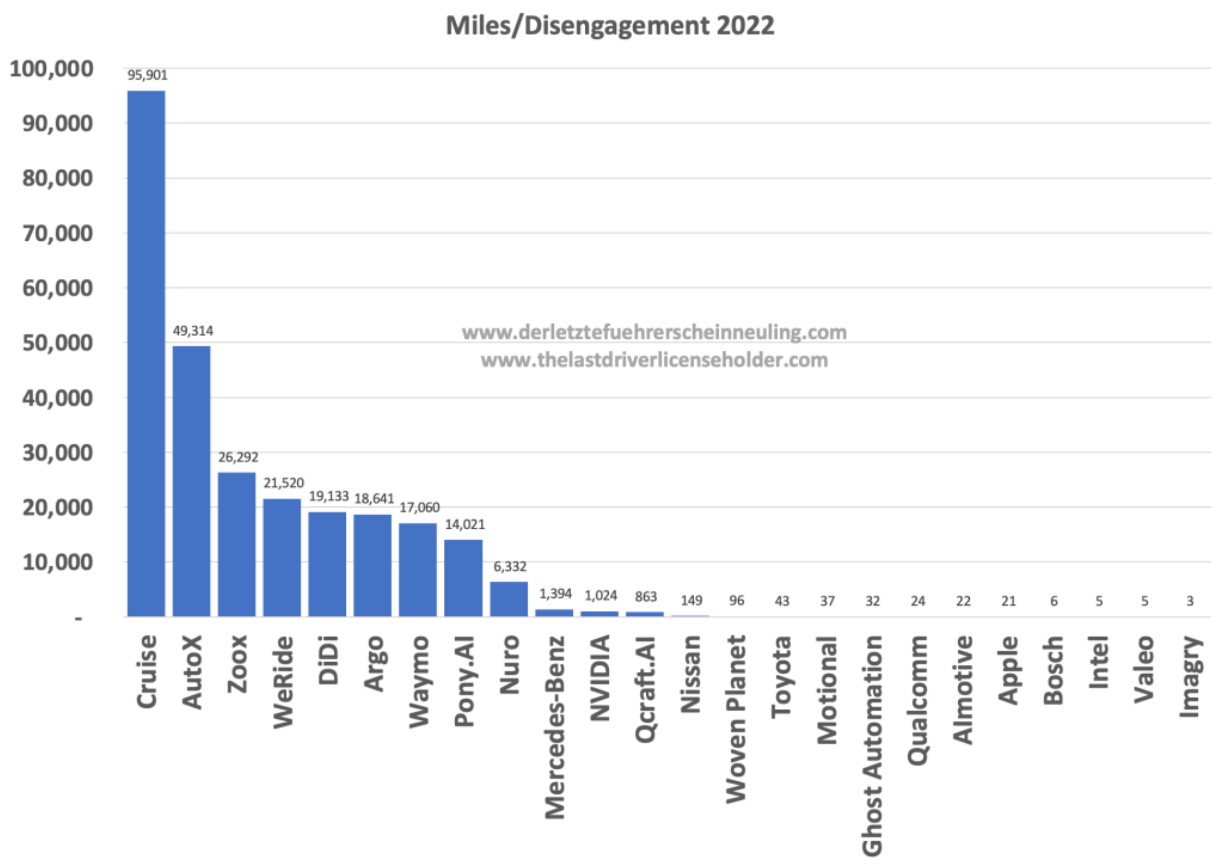
- Number of vehicles deployed per manufacturer in the 2022 reporting period



Reports with Safety Drivers (2022)



Number of miles driven per manufacturer



Number of miles driven per disengagement

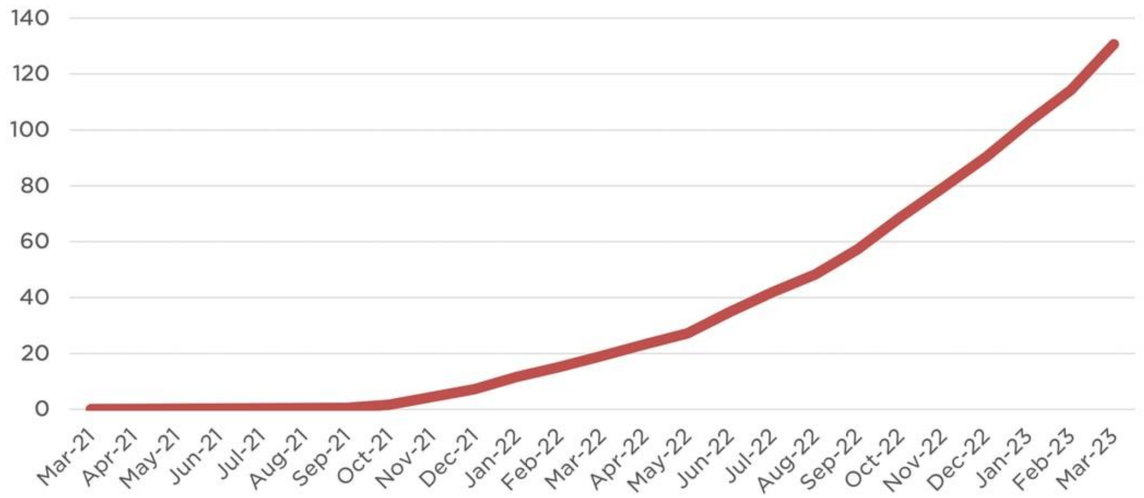
Driverless Reports (2022)

- Seven companies (Apollo, AutoX, Cruise, Nuro, Waymo, WeRide, and Zoox) have driverless licenses in California.
- Cruise completed the majority of driverless driving with 546,492 mi in San Francisco.
- No disengagements are given by the manufacturers because, according to the definition, they require the intervention of a safety driver on board.

	Miles	**Vehicles**
Apollo (Baidu)	21,774	4
Cruise	546,492	222
Nuro	924	9
Waymo	51,639	317
WeRide	2,859	3
	623,689	**555**

Where is Tesla?

- Tesla does not appear in the 2022 report
  - “Tesla’s current interpretation of the FSD Beta, which is now in use in more than 300,000 customer vehicles, is that it is a driver assistance system that does not require reporting to the DMV.”
- Tesla Surpasses 150 Million Miles Driven with FSD Beta (Apr. 2023)



Cumulative miles driven with FSD Beta (millions)

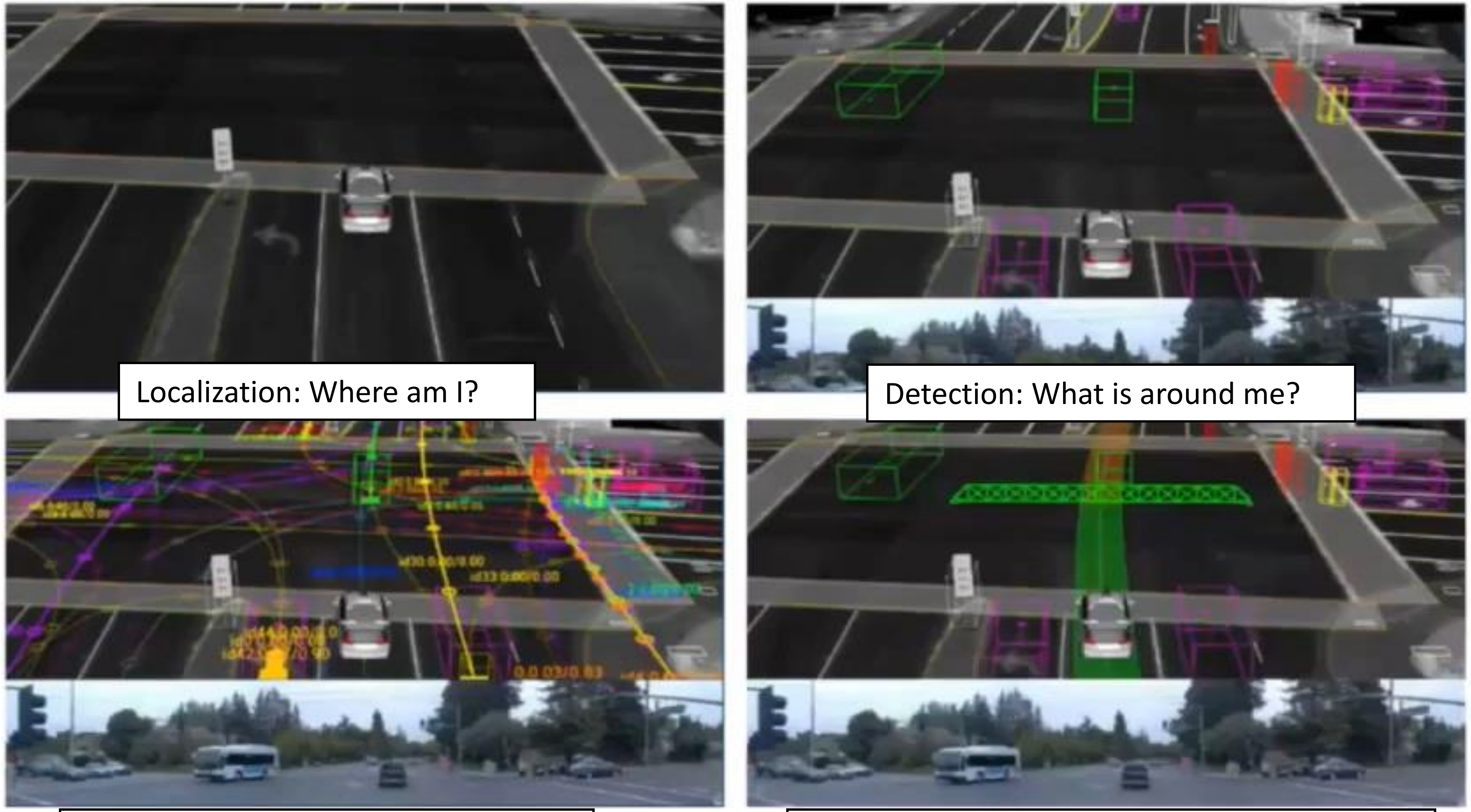
Is Miles Driven a Good Metric?

- Not All Miles are Equal.
  - Driving conditions may be dramatically different.
  - Companies may be incentivized to avoid difficult driving conditions.

When will L5 AD Arrive?

- Chris Urmson, CEO of Aurora:
  - “In 5 years” - 2009
  - “In 5 years” - 2012
  - “In 5 years” - 2015
  - “In 5 years” - 2018

Four Major Tasks of an AV



Localization: Where am I?

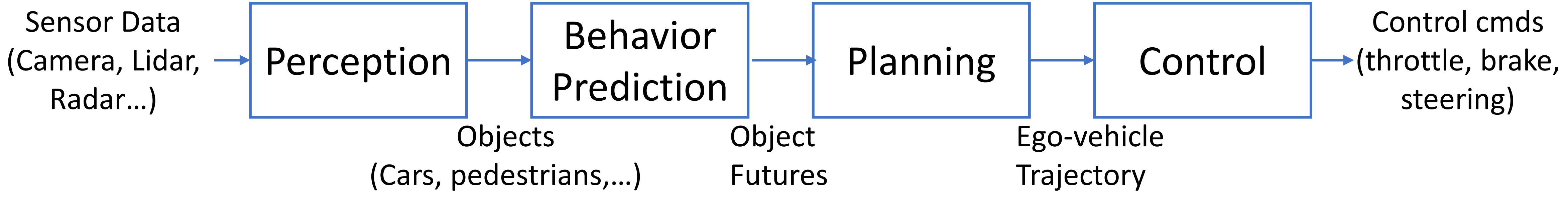
Detection: What is around me?

Prediction: Where are they going?

Planning and Control: Where should I go?

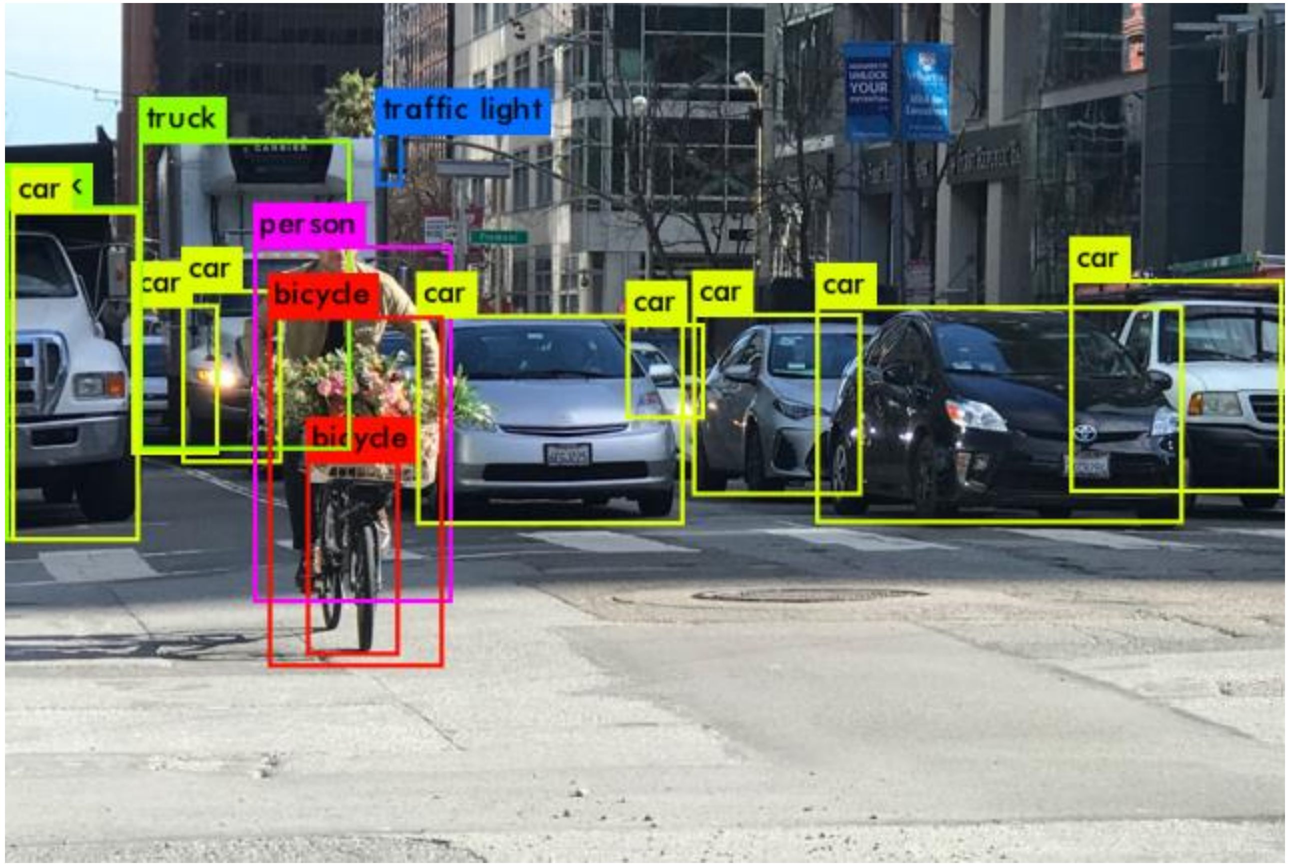
AV Processing Pipeline

- Perception:
  - Understanding the surrounding environment, incl. localization, object detection and tracking, etc.
- Behavior prediction:
  - Predict objects' future movements
- Planning:
  - Plan a path/trajectory for the ego-vehicle in the context of other road users
- Control:
  - Moving the vehicle to follow the planned trajectory



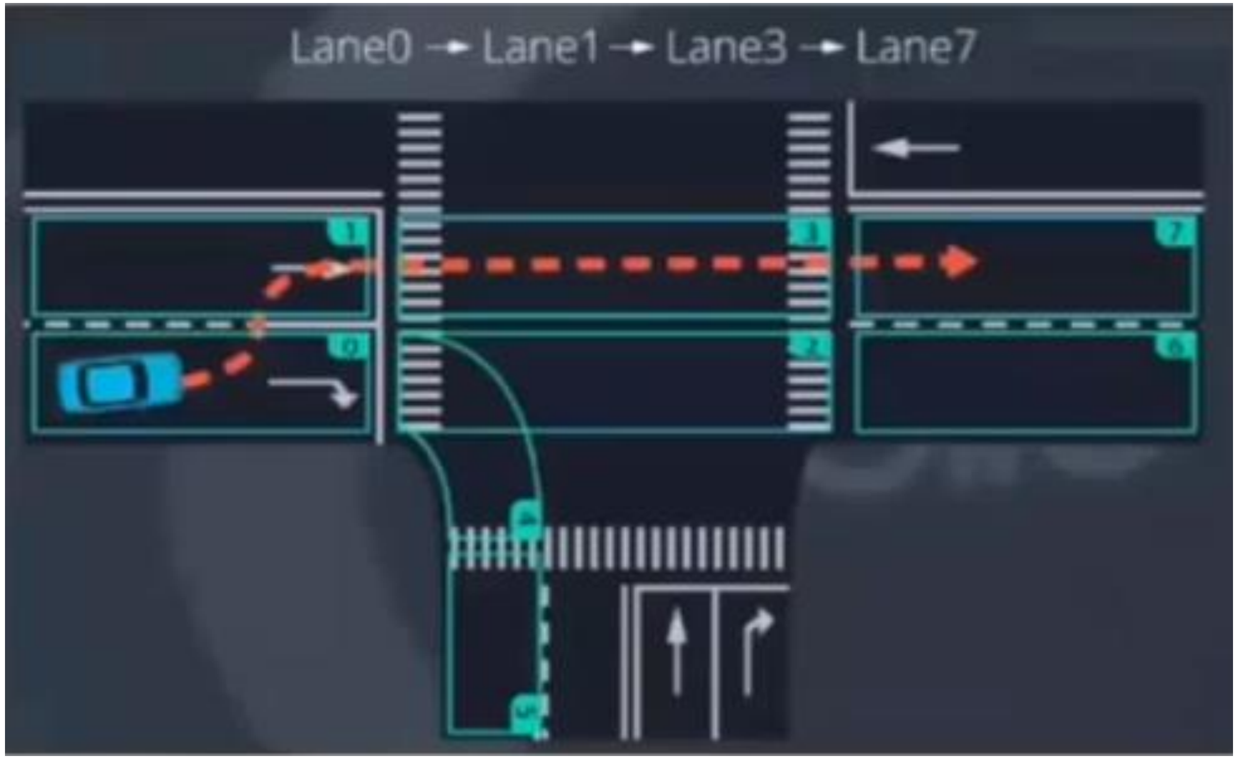
Perception

- Localization
- Static object detection
- Dynamic object detection and tracking



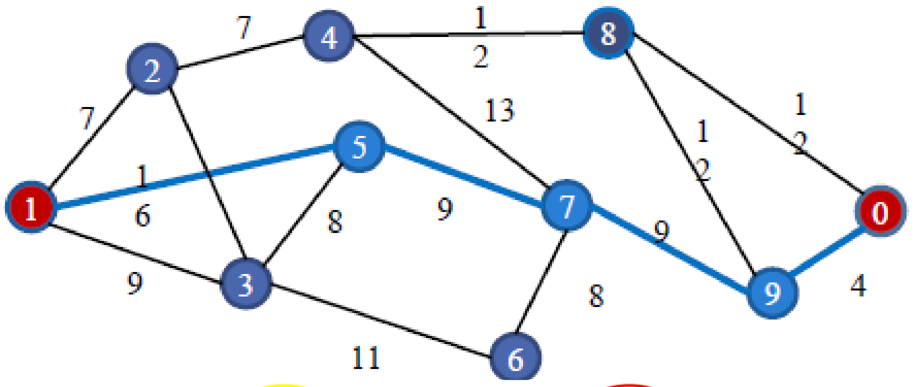
Behavior Prediction

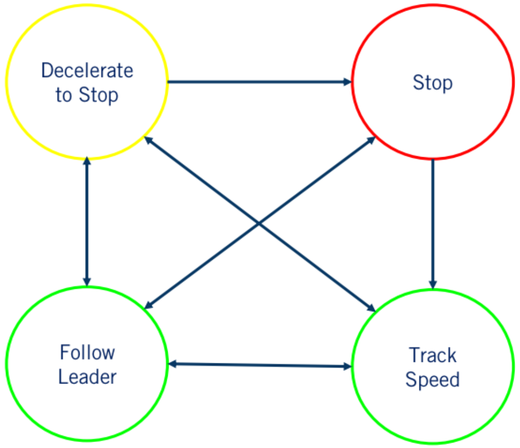
- Based on state
  - Kalman filter
  - Particle filter
- Data-driven
  - ML-based classification
- Pedestrian intention prediction
  - Based on visual cues such as pose, etc.

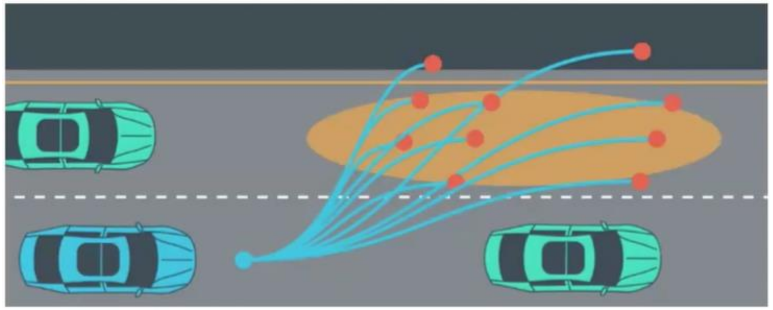


Planning

- Mission Planning: use graph search to find a path from source to destination on the map
- Behavior Planning: plan the set of high-level driving actions or maneuvers to safely achieve the driving mission under various driving conditions
- Local Planning: plan a safe and smooth trajectory (vehicle pose as function of time)

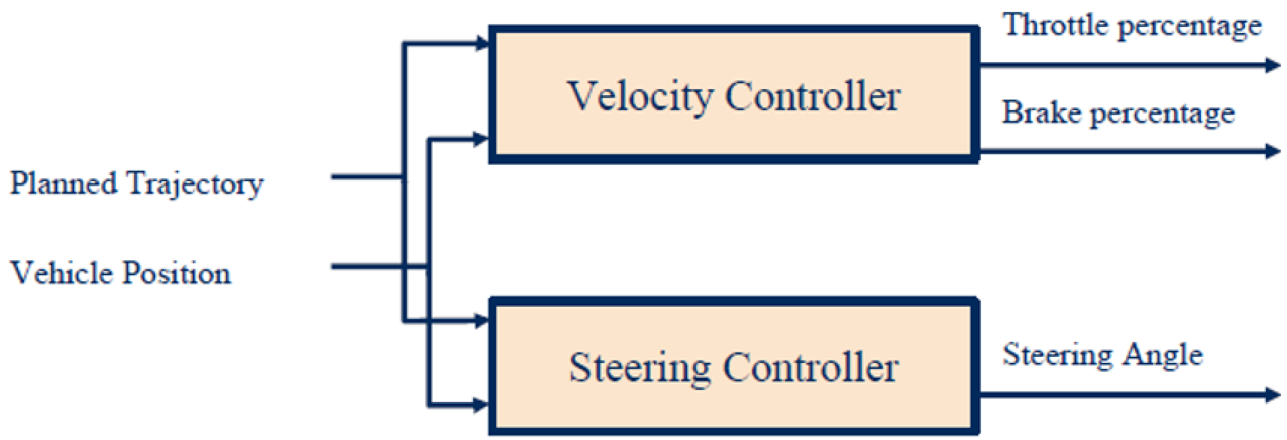






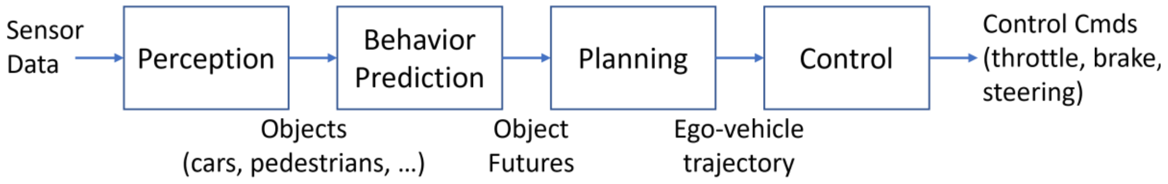
Control

- Velocity controller for longitudinal speed control
- Steering controller for lateral speed control

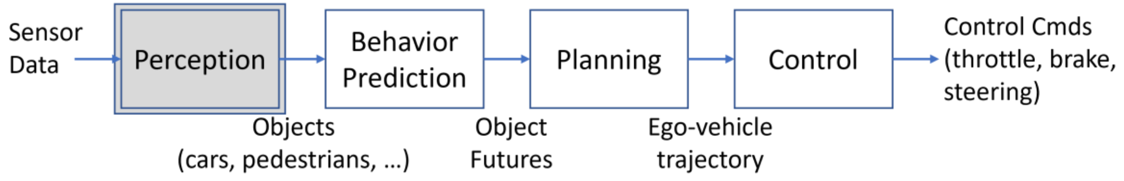


ML/DL Applied in the AV Pipeline

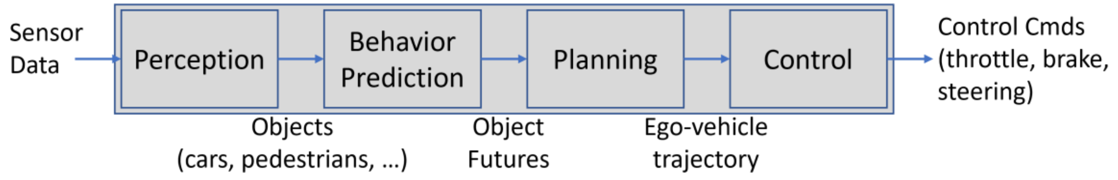
- Classic AD processing pipeline: separate algorithms for each processing stage
- ML, esp. Deep Neural Networks, may be deployed at different stages of the AD processing pipeline
  - (b): DNNs deployed in the Perception stage only, the prevalent approach in industry practice.
  - (c): end-to-end control, e.g., mapping from input images to control, trained with Imitation Learning or Reinforcement Learning.
  - (d): mid-to-mid approach, e.g., a separate perception module outputs Bird's Eye View as input to downstream modules.



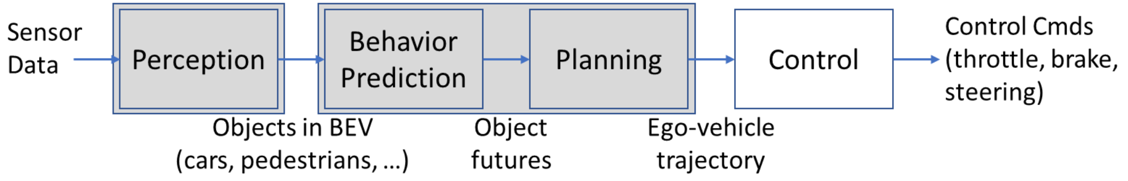
(a) The typical processing pipeline of an AV.



(b) DNN used in the Perception stage.



(c) DNN used for end-to-end control.



(d) DNN used in the mid-to-mid approach.