

NA 565 Fall 2024

Self-Driving Cars: Perception and Control

Introduction

08/26/2024

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Instructional Team



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Why are you here?

Why do you take the self-driving course?

Why self-driving

- Societal benefits
- Economic returns
- Technical readiness
- The industry and the academia are actively working on it.
- Helps me find a good job! (or a research career)
- Happening soon (???)

(Potential) societal benefits of self-driving: safety

- Traffic accidents are more frequent than you think.
- 2022 United States statistics:
- 46,027 deaths = 1.38 deaths per 10,000 people = 1.44 deaths per 100 million miles.
- 5.2 million injuries = 1.56 injuries per 100 people = 1.63 injuries per 1 million miles.
- 22.8 million drivers involved in crashes = 6.84 drivers per 100 people.

<https://www.iihs.org/topics/fatality-statistics/detail/state-by-state>
<https://injuryfacts.nsc.org/motor-vehicle/overview/introduction/>

(Potential) societal benefits of self-driving: safety



Health Topics ▾

Countries ▾

Newsroom ▾

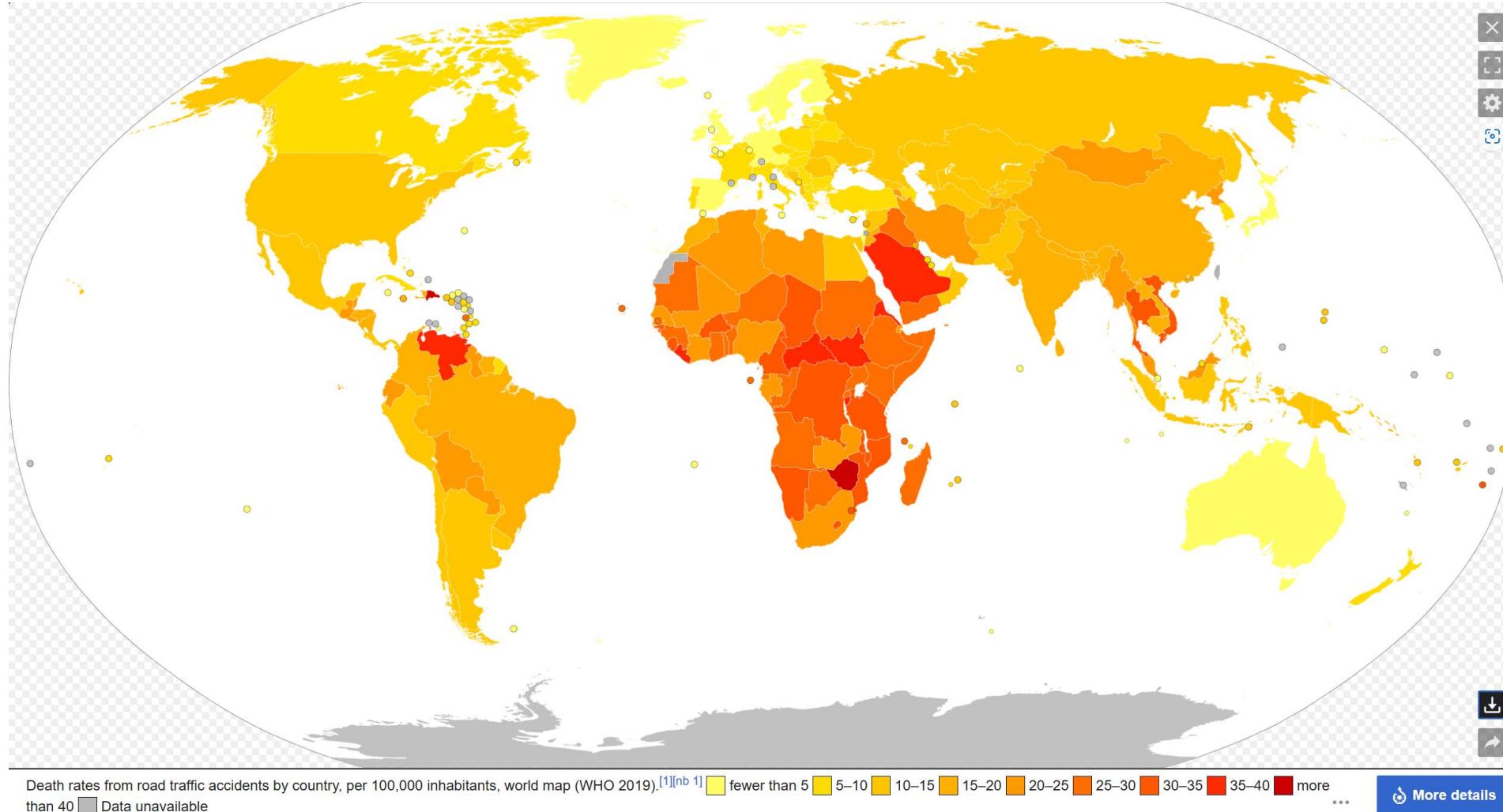
Emergencies ▾

Key facts

- Approximately 1.19 million people die each year as a result of road traffic crashes.
- Road traffic injuries are the leading cause of death for children and young adults aged 5–29 years.
- 92% of the world's fatalities on the roads occur in low- and middle-income countries, even though these countries have around 60% of the world's vehicles.
- More than half of all road traffic deaths are among vulnerable road users, including pedestrians, cyclists and motorcyclists.
- Road traffic crashes cost most countries 3% of their gross domestic product.
- The United Nations General Assembly has set an ambitious target of halving the global number of deaths and injuries from road traffic crashes by 2030 (A/RES/74/299).

(Potential) societal benefits of self-driving: safety

- Global fatality rate: ~1.5 deaths per 10,000 people.



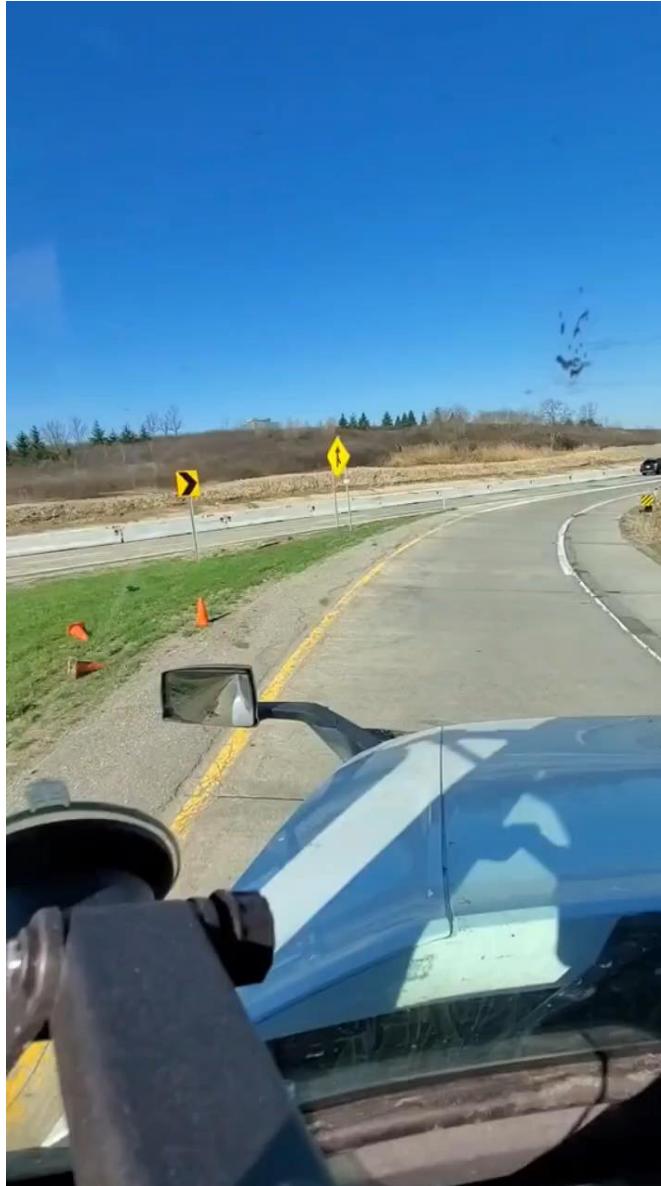
(Potential) societal benefits of self-driving: safety

- More than 90% of crashes in the U.S. involve human errors.
 - * A critical reason is not the only reason that caused an accident.

Table 1. Driver-, Vehicle-, and Environment-Related Critical Reasons

Critical Reason Attributed to	Estimated	
	Number	Percentage* ± 95% conf. limits
Drivers	2,046,000	94% ±2.2%
Vehicles	44,000	2% ±0.7%
Environment	52,000	2% ±1.3%
Unknown Critical Reasons	47,000	2% ±1.4%
Total	2,189,000	100%

(Potential) societal benefits of self-driving: safety



https://www.youtube.com/watch?v=BDY3I_vofuM&t=1s

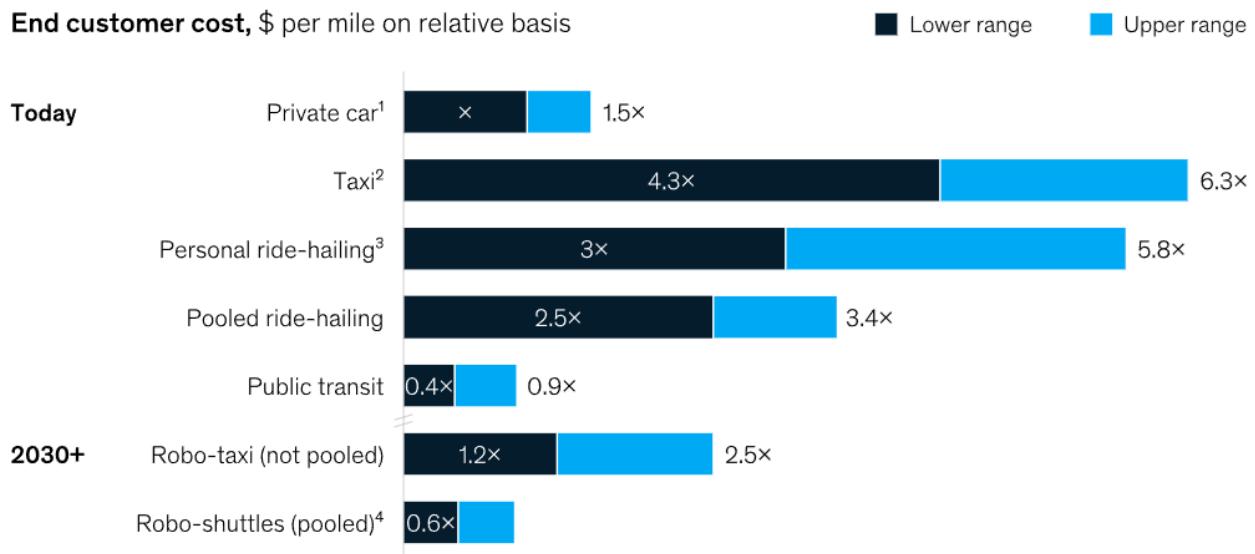
(Potential) societal benefits of self-driving: safety

- Driving can be easy, or nasty... The reality is complicated.
- Self-driving could be part of the solution.

(Potential) societal benefits of self-driving: mobility

- Lower mobility costs.
- Access to the disabled and the elderly.
- Reduce traffic congestions.

Mobility costs could decline in the coming decade as robo-taxi services emerge at scale.



¹Depending on car type for 10,000 miles per year.

²Estimation based on a five-mile trip with a five-minute waiting time in Dallas and Los Angeles.

³Estimation based on a five-mile, 15-minute trip in New York and Dallas.

⁴Assuming three passengers on average and 10 percent additional miles.

Source: McKinsey Center for Future Mobility; Uber fare data; US Department of Transportation mileage data

(Potential) societal benefits of self-driving: sustainability

- Less parking space needed.
- Higher lane capacity.
- Reduced energy consumption.

Cars are parked **95%** of the time.

In the U. S., there are **8** parking spots for every car, and they cover more than **5%** of all urban land.

Parking Lots in the Midwest, United States

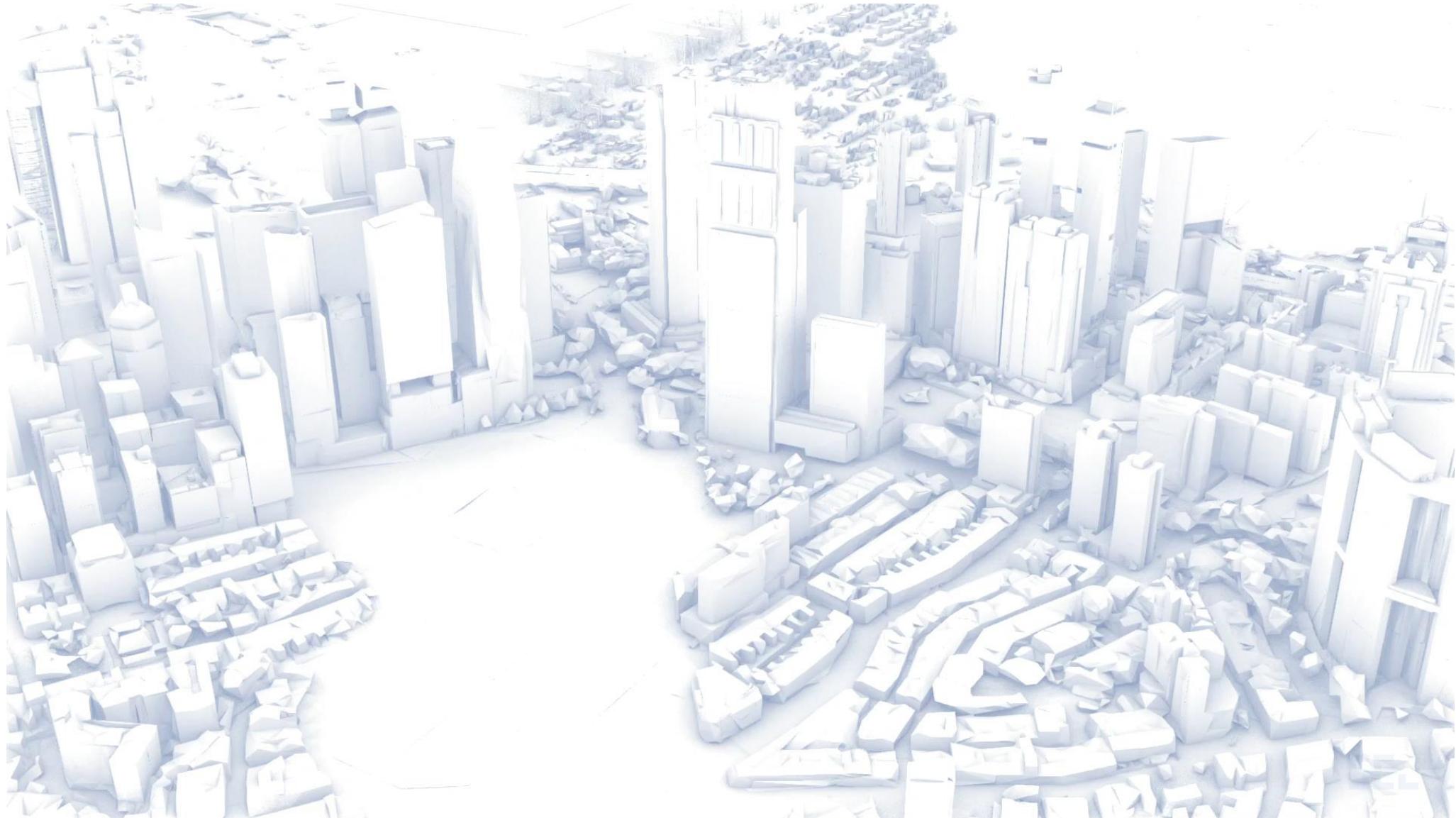


<https://www.reinventingparking.org/2013/02/cars-are-parked-95-of-time-lets-check.html>

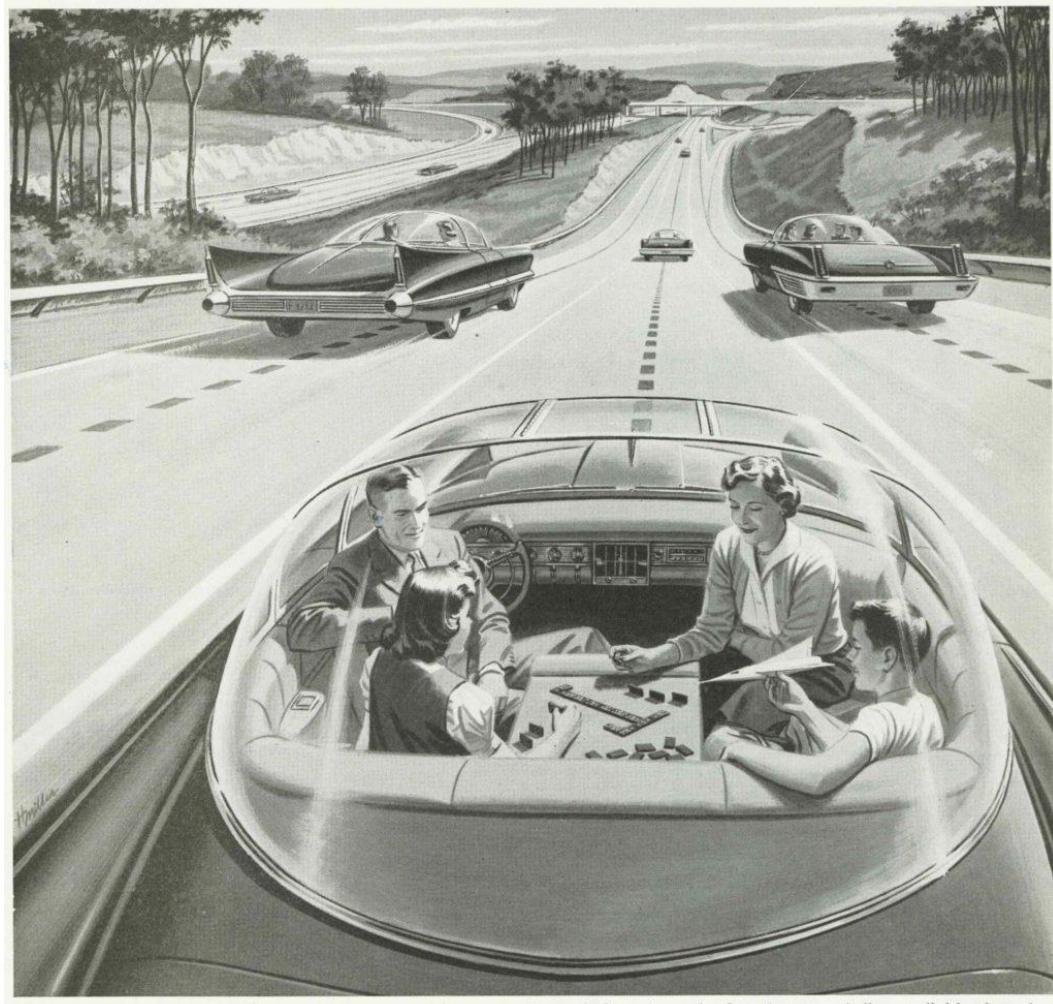
<https://www.archdaily.com/976069/when-5-percent-of-the-united-states-is-covered-by-parking-lots-how-do-we-redesign-our-cities>

<https://www.strongtowns.org/journal/2019/11/27/parking-dominates-our-cities-but-do-we-really-see-it>

(Potential) societal benefits of self-driving: sustainability



(Potential) societal benefits of self-driving: convenience



ELECTRICITY MAY BE THE DRIVER. One day your car may speed along an electric super-highway, its speed and steering automatically controlled by electronic devices embedded in the road. Travel will be more enjoyable. Highways will be made safe—by electricity! No traffic jams . . . no collisions . . . no driver fatigue.



<https://computerhistory.org/blog/where-to-a-history-of-autonomous-vehicles/>

<https://www.notateslaapp.com/software-updates/upcoming-features/id/1058/zoom-announces-its-video-conferencing-app-is-coming-to-tesla>

<https://news.zoom.us/zoom-for-android-auto/>

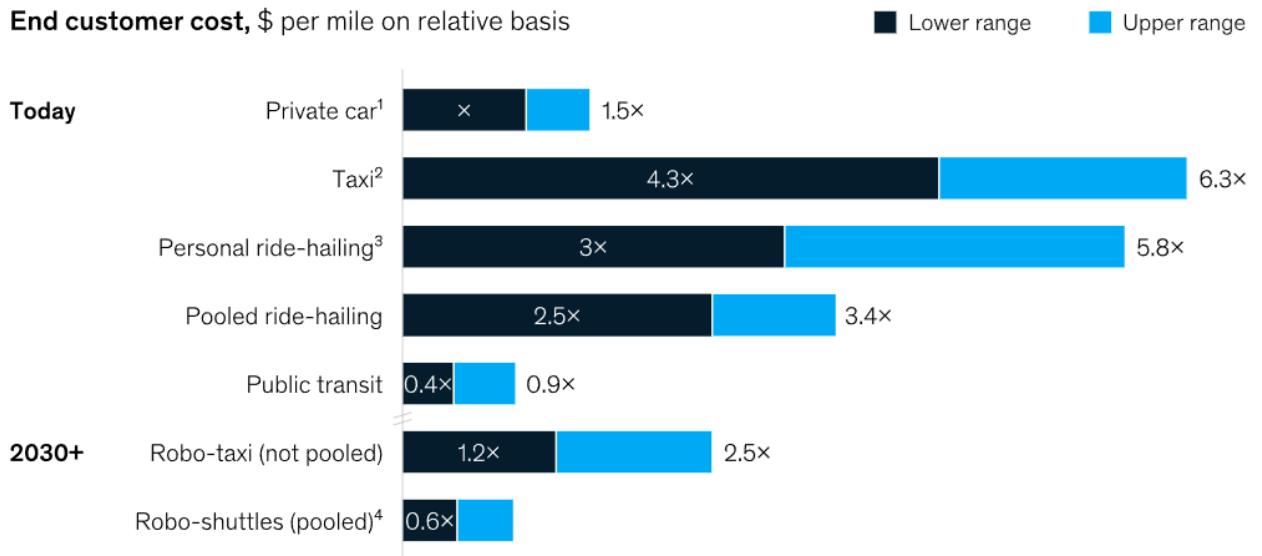
(Potential) economic benefits of self-driving

- Reduced cost for medical care and damage repair from crashes.

- Private-owned cars.

Mobility costs could decline in the coming decade as robo-taxi services emerge at scale.

- Robo-taxi.



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(Potential) economic benefits of self-driving

- Reduced cost for medical care and damage repair from crashes.

- Private-owned cars.

- Robo-taxi.

- Autonomous truck.

- Solve driver shortage.

- Lower logistic cost.

- Higher capacity.

Global logistics by area, 2018 (\$ in billions)

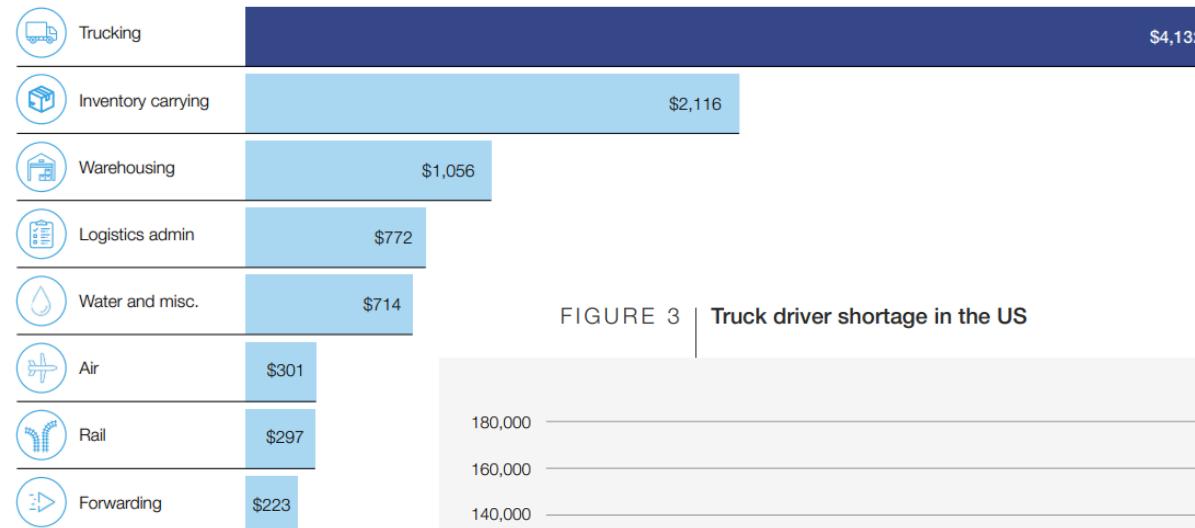
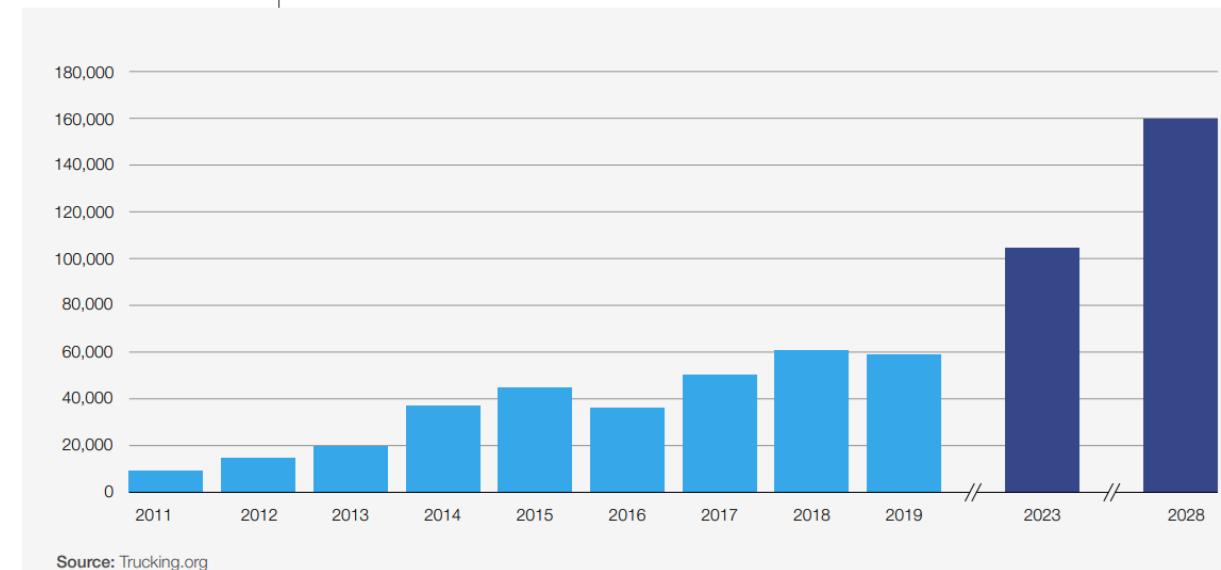


FIGURE 3 | Truck driver shortage in the US



- All the benefits are “potential” until they are realized...
- People have been working hard towards this goal!

Historical efforts

- Smart roads



Autonomous Highway System tests, 1950s GM and RCA developed automated highway prototypes with radio control for speed and steering.

Magnets in the car tracked a steel cable embedded in the road; control towers managed overall traffic flow.

Credit: Radio Corporation of America (RCA)

Historical efforts

- Smart cars



https://www.youtube.com/watch?v=_HbVWm7wdmE

<https://computerhistory.org/blog/where-to-a-history-of-autonomous-vehicles/>

Recent efforts

- 2004, the first DARPA Grand Challenge.
- 2007, DARPA Urban Challenge.
- 2009, Google started self-driving car project.
- 2011, Nevada first adopted self-driving legislation.
- 2015, first public road self-driving ride by Google.
- 2015, Tesla AutoPilot available for Model S.
- ...



Recent efforts

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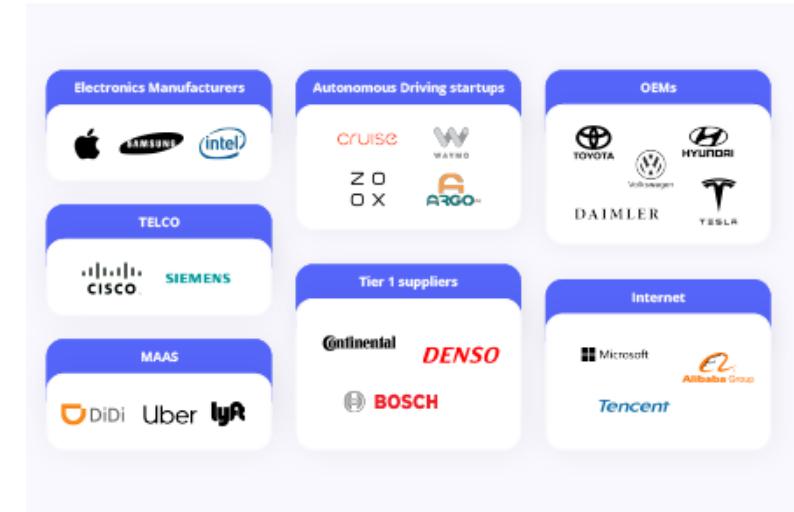


https://www.youtube.com/watch?v=X_d3MCklvg8

<https://www.youtube.com/watch?v=uHbMt6WDhQ8>

Recent efforts: huge investments since mid-2010s

- GM:
 - 2016: spent \$581 million to acquire Cruise Automation.
 - 2016: invest \$500 million in Lyft to built robotaxi fleet.
- Ford:
 - 2017: invest \$1 billion in Argo AI.
- Honda:
 - 2018: invest \$750 million in Cruise, joining forces with GM.
- Toyota:
 - 2015: invest \$1 billion in Toyota Research Institute to develop robotics and AI technology.
- Volvo:
 - 2016: joined a \$300 million venture with Uber.
- ...

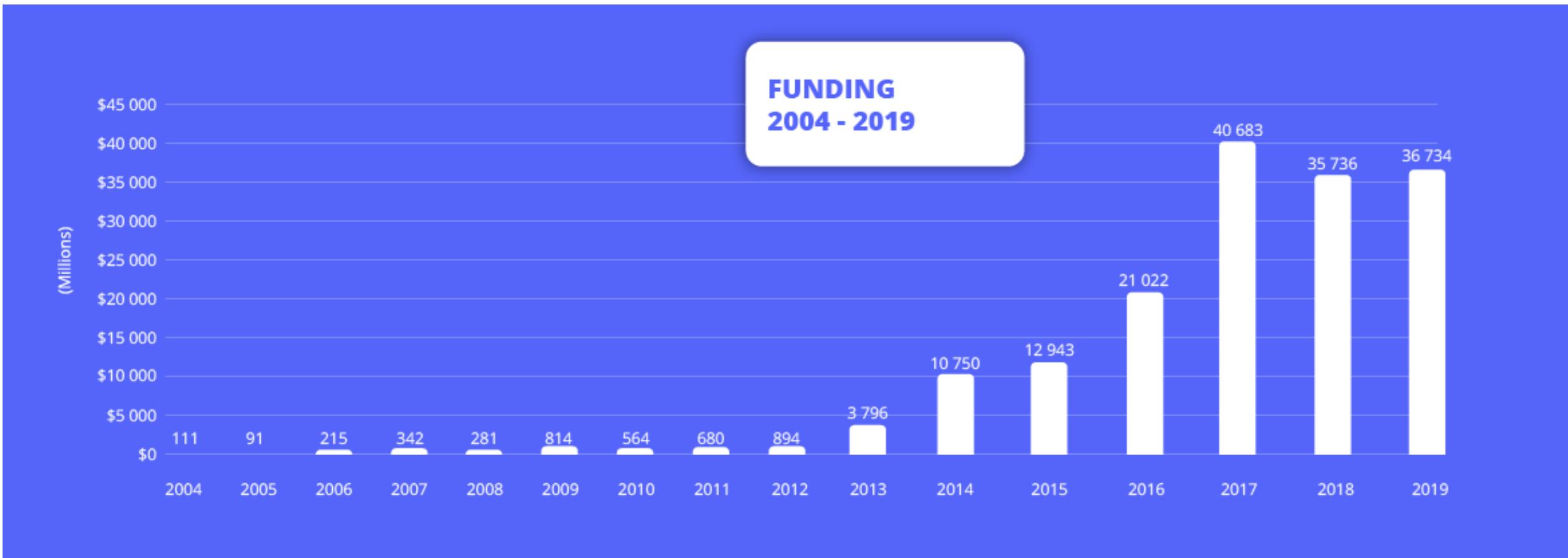


<https://emerj.com/ai-adoption-timelines/self-driving-car-timeline-themselves-top-11-automakers/>

<https://www.theverge.com/2016/1/6/10719414/uber-lyft-gm-driverless-cars-ridesharing>

<https://global.honda/en/newsroom/news/2018/c181003eng.html>

Recent efforts: huge investments since mid-2010s



- Funding in autonomous driving exploded to reach about \$150 billion by 2020.

Why mid-2010s? The booming of artificial intelligence

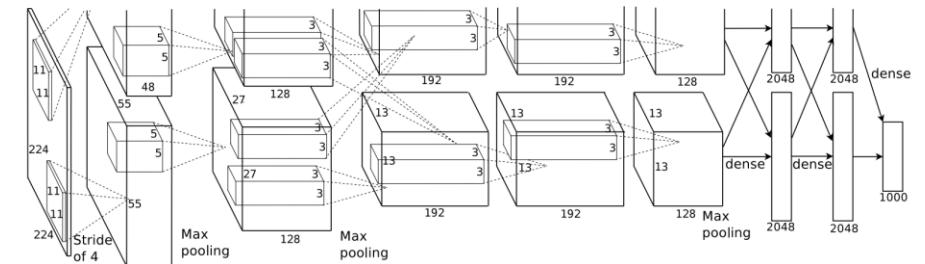
- 2007 • **CUDA** was created, allowing GPUs to be used for general-purpose computing.
- 2009 • **ImageNet** was introduced, containing more than 14 million annotated images.
- 2012 • **AlexNet** won the ImageNet competition by a large margin, showing the power of deep convolutional neural networks trained with GPUs without feature engineering.



Hardware



Data



Algorithm

Why mid-2010s? The booming of artificial intelligence

- 2007 • **CUDA** was introduced, allowing GPUs to be used for general-purpose computing.
- 2009 • **ImageNet** was introduced, containing more than 14 million annotated images.
- 2012 • **AlexNet** won the ImageNet competition by a large margin, showing the power of deep convolutional neural networks trained with GPUs without feature engineering.
- 2014 • **GAN** was introduced, marking a new paradigm of generative models.
- 2015 • **ResNet** was introduced, enabling the training of very deep neural networks.
- 2016 • **AlphaGo** won over world champion Go player Lee Sedol, marking the success of reinforcement learning.
- ... • ...

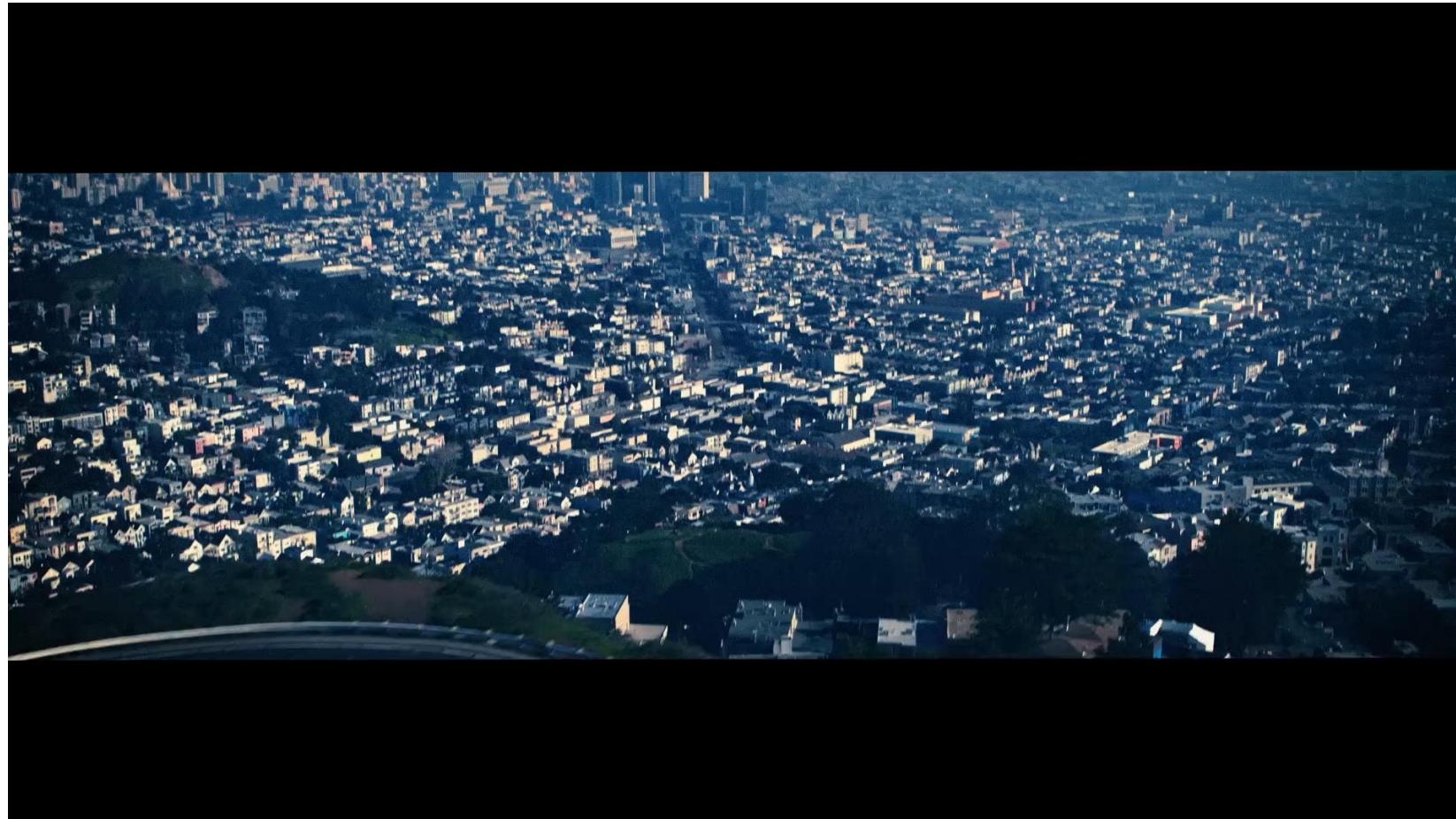
Self-driving is one of the most representative applications of AI.

- Perception



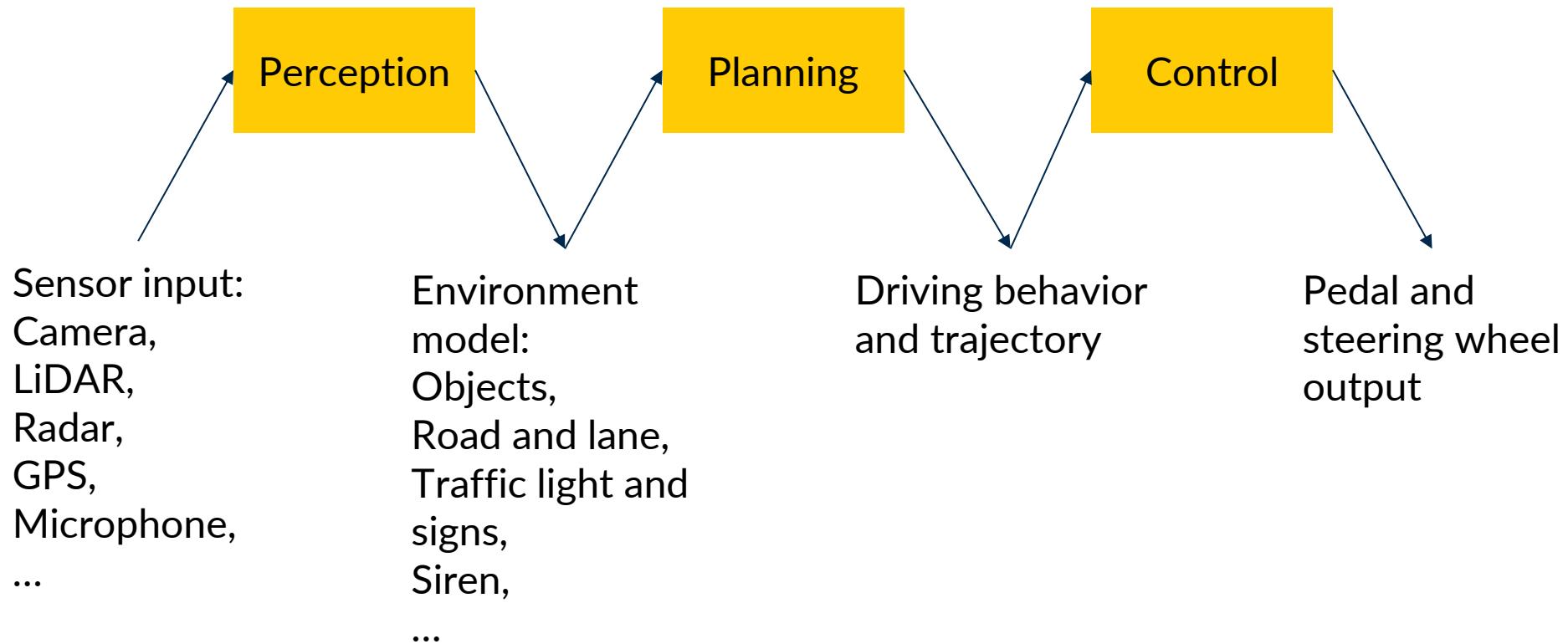
Self-driving is one of the most representative applications of AI.

- A typical framework:



Self-driving is one of the most representative application of AI.

- A typical framework:

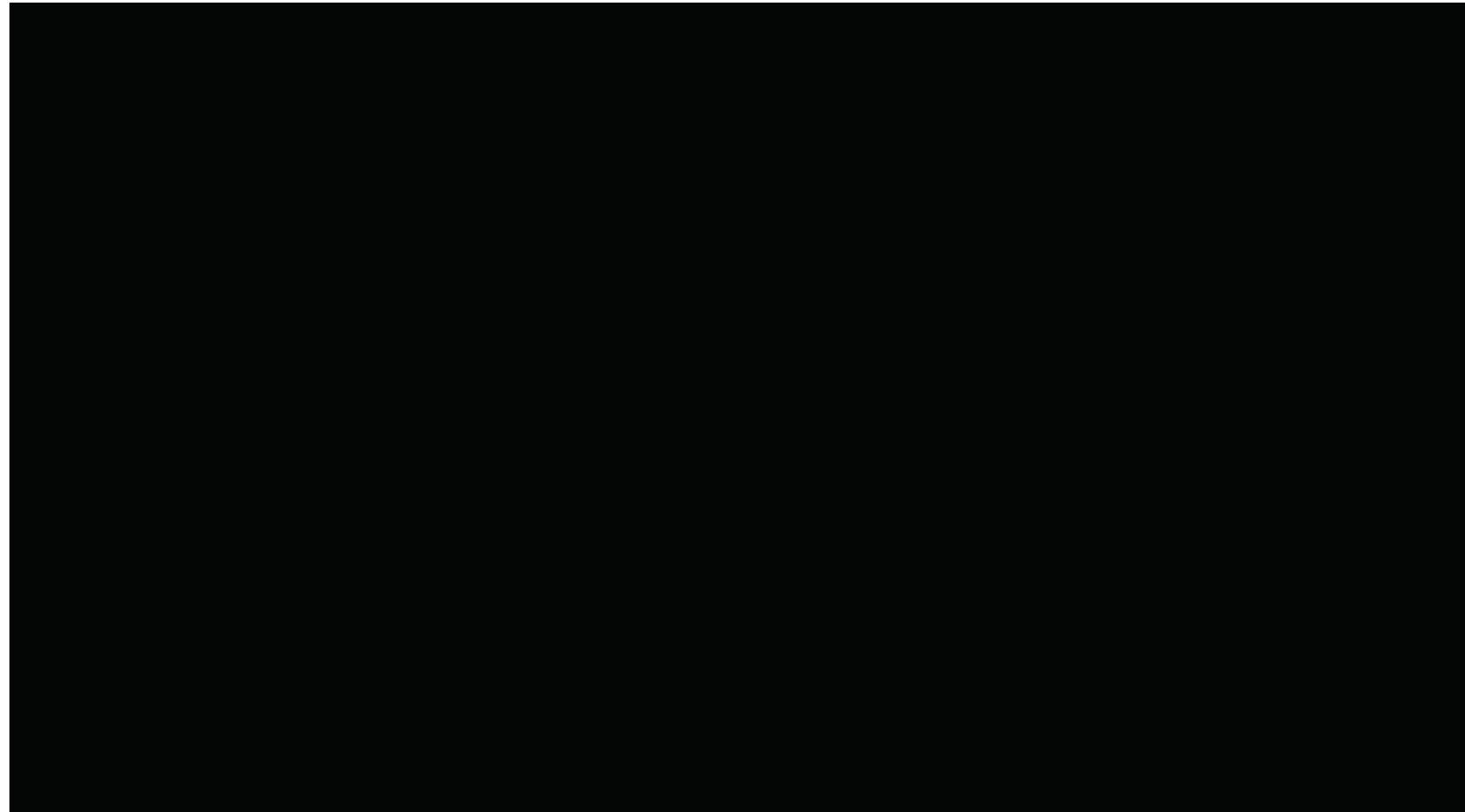


Self-driving is embodied AI.

- It works in a physical environment.



- Pushing the limit of self-driving control:



Optimism

ALEX DAVIES GEAR MAY 18, 2015 7:00 AM

Google's Plan to Eliminate Human Driving in 5 Years

Google wants to take the human out of driving.

Autonomous vehicles will transform urban life by 2020, if Waymo's

TECH / TRANSCO / CARS

Lyft's president says 'majority' of rides will be in self-driving cars by 2021

Ford's self-driving car 'coming in 2021'

ARIAN MARSHALL TRANSPORTATION JUL 1, 2016 4:55 PM

BMW's Bold Plan to Make a Fully Self-Driving Car by 2021

A partnership between the German carmaker and tech companies promises a totally autonomous car by 2021.

GM

GM moves to deploy driverless car fleet in 2019

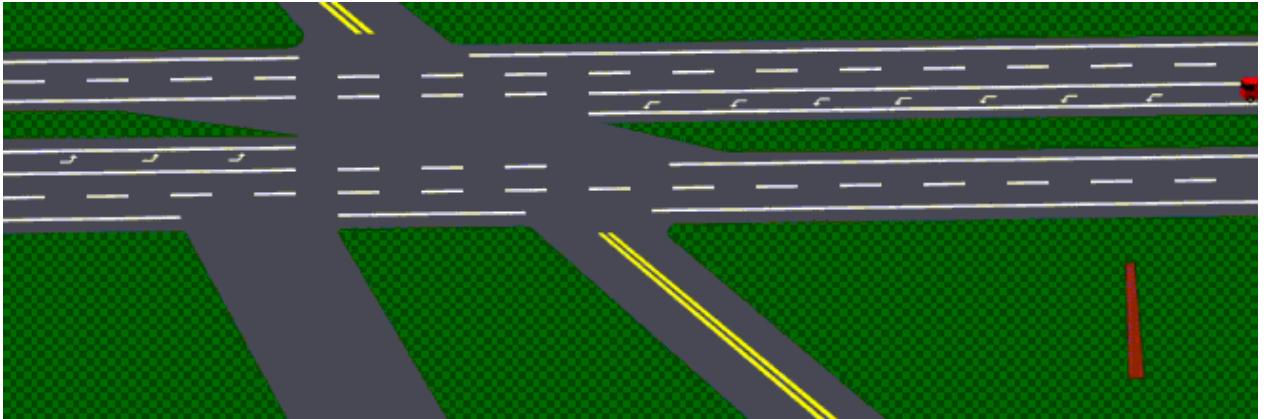
Nora Naughton The Detroit News

Published 12:01 a.m. ET Jan. 12, 2018 | Updated 12:23 a.m. ET Jan. 12, 2018

Elon Musk says Tesla autonomous driving will happen 'this year' – for the fourth year in a row

Setbacks

- 2016: first fatal Tesla Autopilot crash.



- 2018: Uber's self-driving car caused the first pedestrian fatality.



- More crashes...

[https://en.wikipedia.org/wiki/List_of_Tesla_Autopilot_crashes#Williston,_Florida,_USA_\(May_7,_2016\)](https://en.wikipedia.org/wiki/List_of_Tesla_Autopilot_crashes#Williston,_Florida,_USA_(May_7,_2016))

<https://www.digitimes.com/news/a20231121PR201/autonomous-driving-av-tesla-waymo.html>

Setbacks

Uber is selling its self-driving car business to Aurora

By Matt McFarland, CNN Business
Published 6:45 PM EST, Mon December 7, 2020

Transportation

Lyft sells self-driving unit to Toyota's Woven Planet for \$550M

Kirsten Korosec @kirstenkorosec 4:05 PM EDT • April 26, 2021

Comment

Technology

Ford, Volkswagen-backed Argo AI to shut down- TechCrunch

Reuters

October 26, 2022 3:56 PM EDT - Updated 10 months ago



TOTAL INVESTMENT, \$B



Setbacks

- Cruise:
 - 08/10/2023, San Francisco approved 24/7 robotaxi services.
 - 08/18/2023, SF regulator orders Cruise to cut robotaxi fleet by half, after its robotaxis were involved in a series of crashes, including one in which a Cruise vehicle collided with a fire truck that ran a red light on the way to an emergency.
 - 10/02/2023, a Cruise car dragged a hit-by-human-driver pedestrian for 20 feet on a San Francisco street, causing severe injuries.
 - 10/24/2023, California DMV suspended Cruise's driverless vehicles operation in SF.

Setbacks

- Cruise:



Challenges

- “Long-tail problem”

- Rare
- Diverse
- Combinatorial complexity



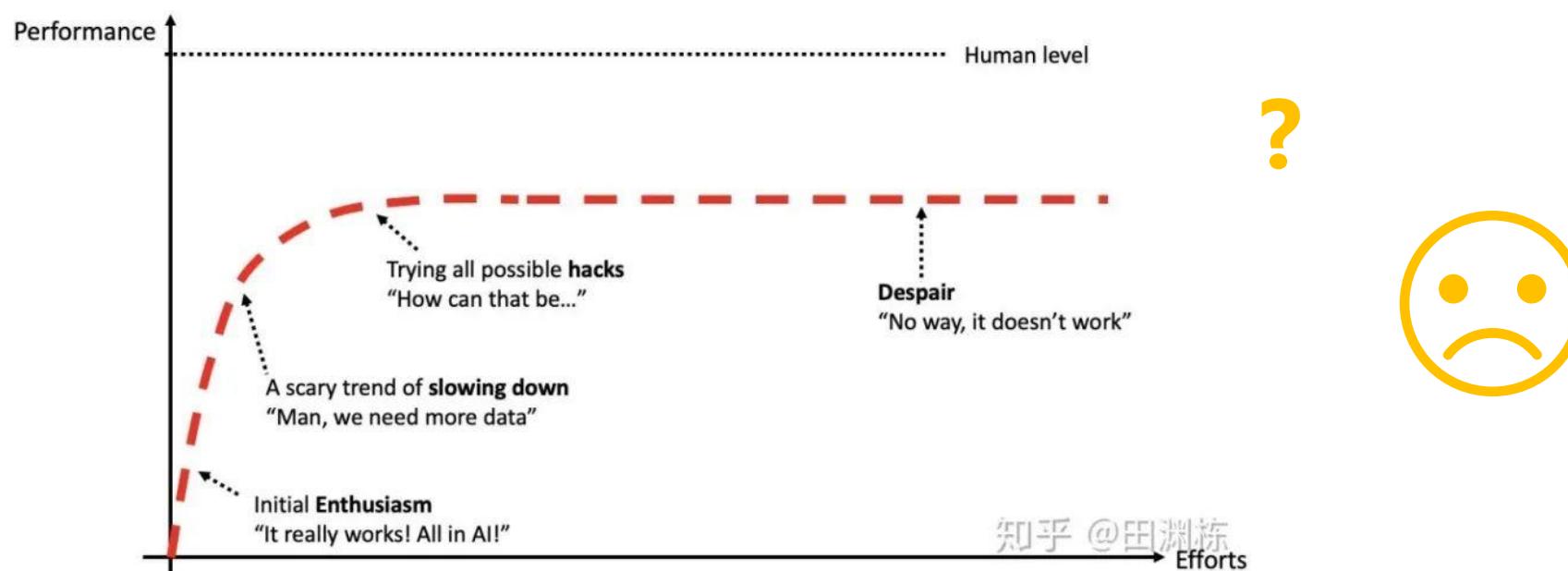
https://www.youtube.com/watch?v=oeGis1cz_zM

<https://www.youtube.com/watch?v=U0QAFqTrl6A>

<https://yuhuang-63908.medium.com/how-to-build-a-data-closed-loop-platform-for-autonomous-driving-4b0faa93d592>

Challenges

- “Long-tail problem”
 - Rare → hard to collect enough data
 - Diverse → hard to enumerate all concepts
 - Combinatorial complexity → hard to build a holistic understanding



A new wave of AI boom



ChatGPT



SAM

<https://imagen.research.google/>
<https://segment-anything.com/>
<https://openai.com/index/sora/>
<https://repo-sam.inria.fr/fungraph/3d-gaussian-splatting/>



Imagen



3D GS



Sora

A new wave of AI boom

Large Language Models

Neural Rendering

Foundation Models

...

World Models

Generative Models

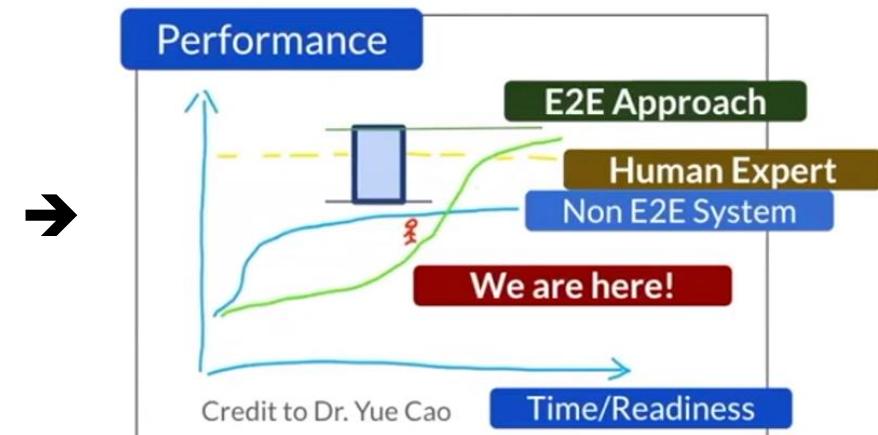
Challenges and new solutions?

- Long-tail problem
 - Rare → hard to collect enough data
 - Diverse → hard to enumerate all concepts
 - Combinatorial complexity → hard to build a holistic understanding

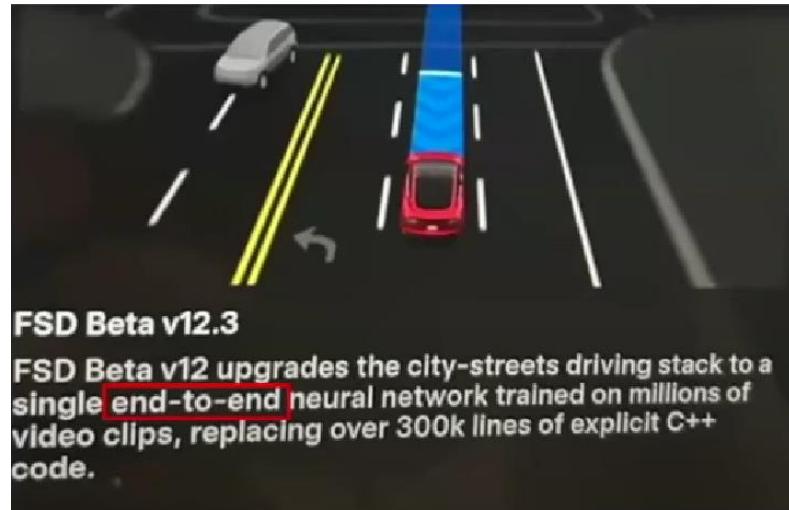
Large Language Models
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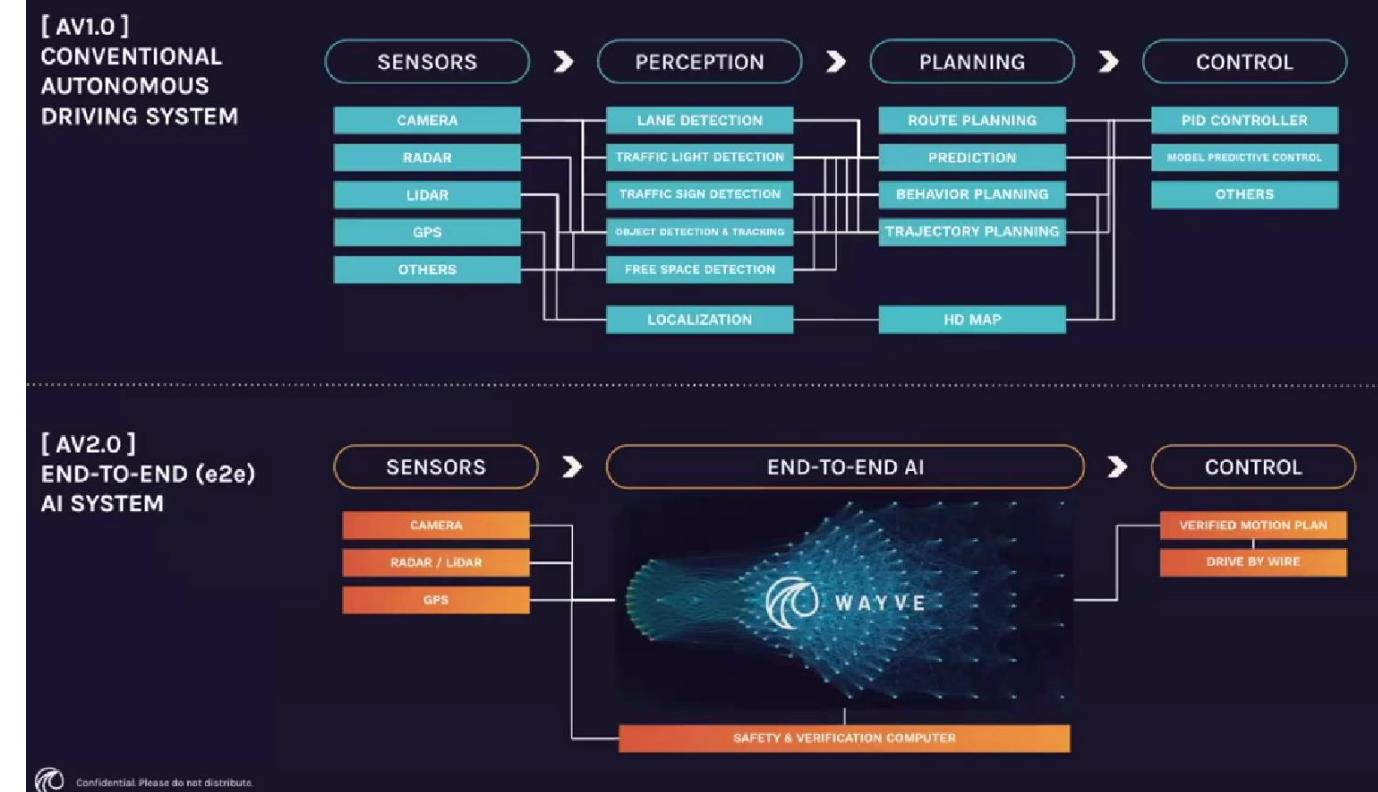
Internet-scale data pretraining
Open-set concept modeling
Common-sense awareness
Complex situation reasoning
Neural simulation
End-to-end learning
...



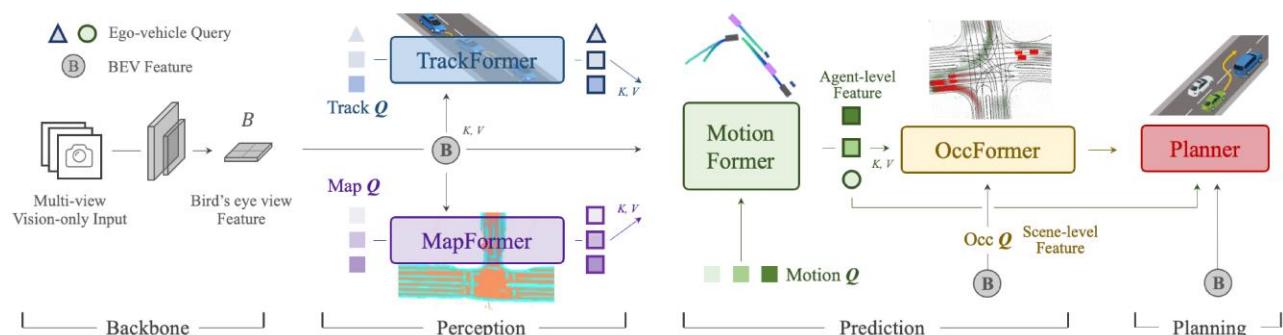
New solutions to self-driving



Tesla



Wayve



UniAD [CVPR 2023 best paper award]

New solutions to self-driving



Still an open problem

- Evaluation and diagnosis
- Making sure solving existing problems does not bring new problems.
- Grounding reasoning in complex physical environment.
- ...

The party is still on!

About this course

Syllabus

- Self-driving cars: perception and control.



Second half of this
course

- Sensor geometry
- Basic deep learning
- Segmentation and detection
- End-to-end driving
- ...

First half of this
course

- State space models
- Vehicle dynamics and control
- Trajectory optimization
- Vehicle routing
- ...

Coursework

- Homework x 4 (60%) → Individual
- Paper presentation (10%)
- Final project (25%)
- Participation (5%)



Individual

Teamwork

Coursework

- Individual: 4 homeworks (60%)
 - 2 for control + 2 for perception.
 - Encouraged to work together in groups, but everyone must write up their own solutions, which should list all of your collaborators.
 - Submission via Gradescope.
- NO LATE HOMEWORK
 - Your lowest homework grade will be dropped.
 - Deadlines are on Fri at 11:55 pm (EST) - Gradescope submission remains open until Monday 9 am (EST) with no penalty.

Coursework

- Teamwork (maximum of 3 people):
 - For the perception part of this course. But you can start forming your team now.
 - Paper presentation (10%):
 - Choose a paper from a list which we will release after the first homework due date.
 - Introduce the paper you select to the class.
 - 7 min talk & 3 min Q&A (subject to minor change). Every member should be present.
 - Slides need to be uploaded the day before class.
 - Presentations are scheduled between Nov. 4 – Nov. 25. Dec. 2 for backup.

Coursework

- Teamwork (maximum of 3 people):
 - Final project (25%):
 - Share the same team as the paper presentation.
 - Submit 1-page proposal mid-semester related to self-driving perception or end-to-end learning.
 - We will host a poster session at the last lecture of this course for every team to show their work and learn from others.
 - Every team writes a final report (max 4-page) summarizing their work.

Coursework

- Participation (5%)
 - Interaction with instructors and GSIs or activities on Piazza (3%)
 - Mid-term and final teaching evaluations (2%)

Infrastructure

- Canvas
 - Syllabus, files, lecture recordings, and the entrance to other course websites.
- Gradescope
 - Coursework submission and grading.
- Piazza
 - All Q&A, discussions, and announcements.
 - Make your posts public if possible, so that others can benefit from the discussion.
 - DO NOT EMAIL TECHNICAL/LOGISTICS QUESTIONS. THEY WILL BE IGNORED.

Lecture recordings

- All lectures will be recorded and posted on Canvas for your convenience.
- No live streaming.

Q&A
