



Lecture 2: Self-Driving Cars

Self-Driving Cars

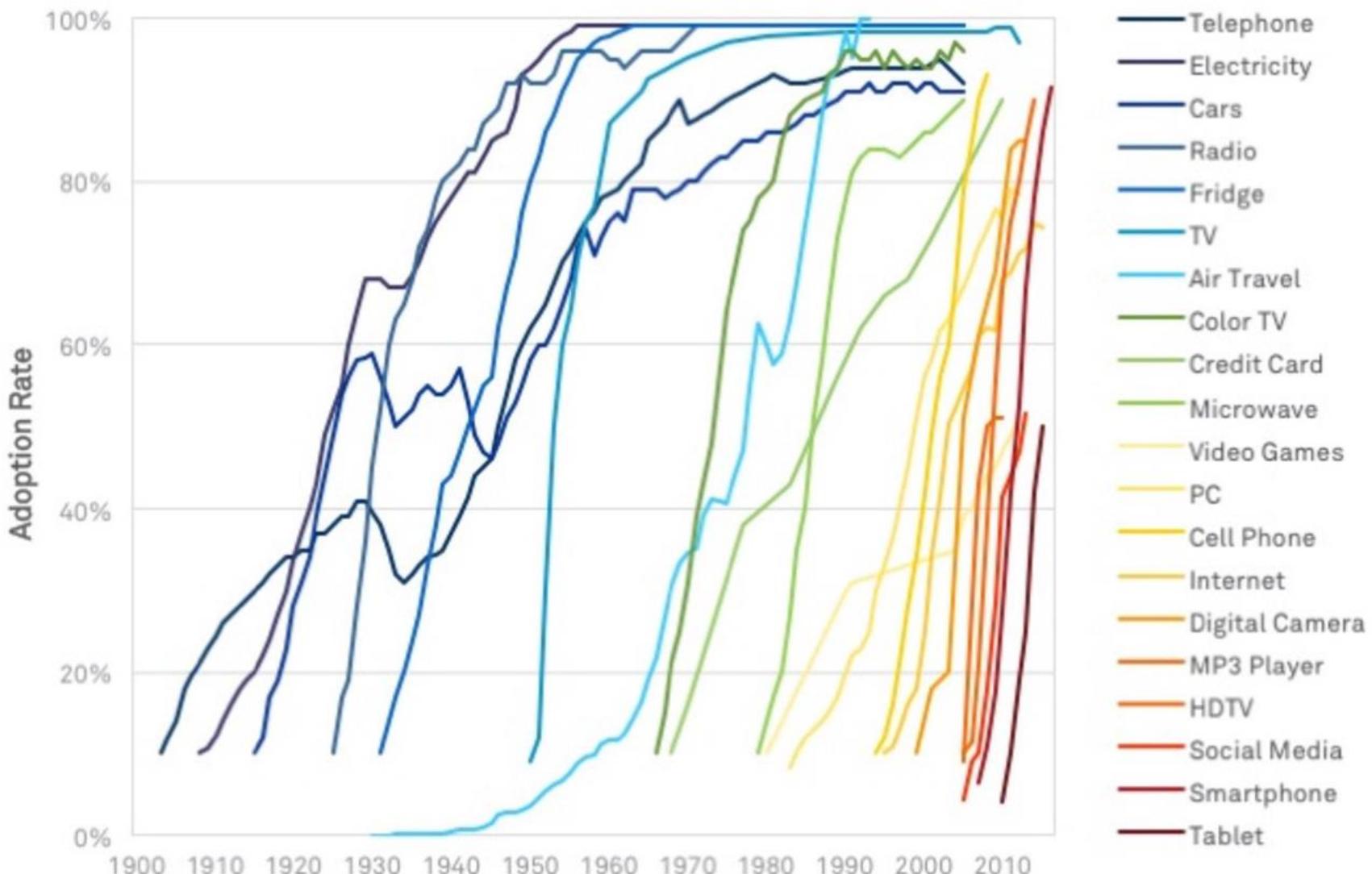
(aka driverless cars, autonomous cars, robocars)

- Utopian view
 - Save lives (1.3 million die every year in manual driving)
 - 4D's of human folly: drunk, drugged, distracted, drowsy driving
 - Eliminate car ownership
 - Increase mobility and access
 - Save money
 - Make transportation personalized, efficient, and reliable
- Dystopian view
 - Eliminate jobs in the transportation sector
 - Failure (even if much rarer) may not depend on factors that are human interpretable or under human control
 - Artificial intelligence systems may be biased in ways that do not coincide with social norms or be **ethically grounded**
 - Security

Self-Driving Cars: Grain of Salt

- Our intuition about what is hard or easy for AI is flawed (*see first lecture*)
- Carefully differentiate between:
 - **Doubtful:** Promises for future vehicles (in 2+ years)
 - **Skeptical:** Promises for future vehicles (in 1 year)
 - **Possible:** Actively testing vehicles on public roads at scale
 - **Real:** Available for consumer purchase today
- Rodney Brooks prediction in “My Dated Predictions”:
 - **>2032:** A driverless “taxi” service in a major US city with arbitrary pick and drop off locations, even in a restricted geographical area.
 - **>2045:** The majority of US cities have the majority of their downtown under such rules.

Self-Driving Cars

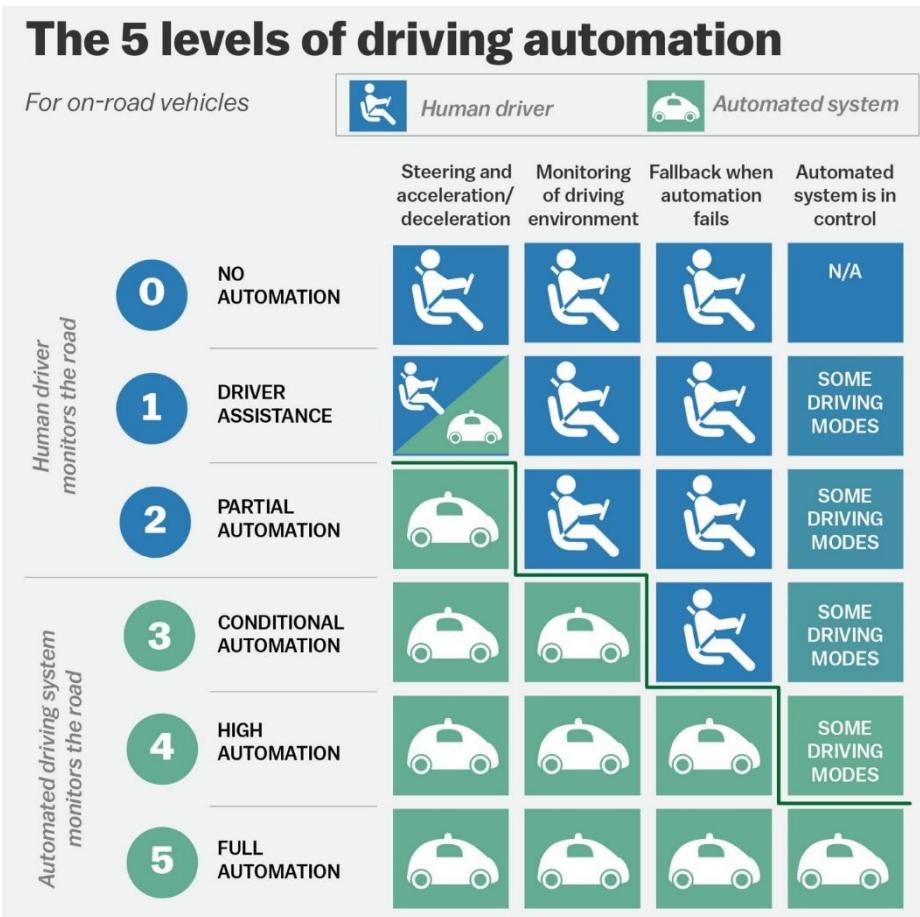


Overview

- **Different approaches autonomy**
- Sensors
- Companies doing it
- Opportunities for AI and deep learning

Levels of Automation (SAE J3016)

- Useful for initial discussion (especially for policy making), but **not useful** for design and engineering of the underlying intelligence and the holistic system performance:



Beyond Traditional Levels: Two AI Systems

- **Starting point:**

- All cars are manually controlled until the AI system shows itself to be **available** and is elected to be **turned on** by the human.

- **A1: Human-Centered Autonomy**

- **Definition:** AI is not fully responsible
 - Feature axis:
 - Where/how often is it “available”? (traffic, highway, sensor-based, etc.)
 - How many seconds for take-over? (0, 1, 10, etc)
 - Teleoperation support

- **A2: Full Autonomy**

- **Definition:** AI is fully responsible
 - Notes:
 - No teleoperation
 - No 10-second rule: It's allowed to ask for human help, but not guaranteed to ever receive it.
 - Arrive to a **safe** destination or safe harbor.
 - Allow the human to take over **when they choose to**.

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Beyond Traditional Levels: Two AI Systems

L0



- **Starting point:**

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L1, L2, L3



- **A1: Human-Centered Autonomy**

- **Definition:** AI is not fully responsible

L4, L5



- **A2: Full Autonomy**

- **Definition:** AI is fully responsible

Two AI Systems:
A2: Full Autonomy



Two AI Systems:
A1: Human-Centered Autonomy



Jukin Media

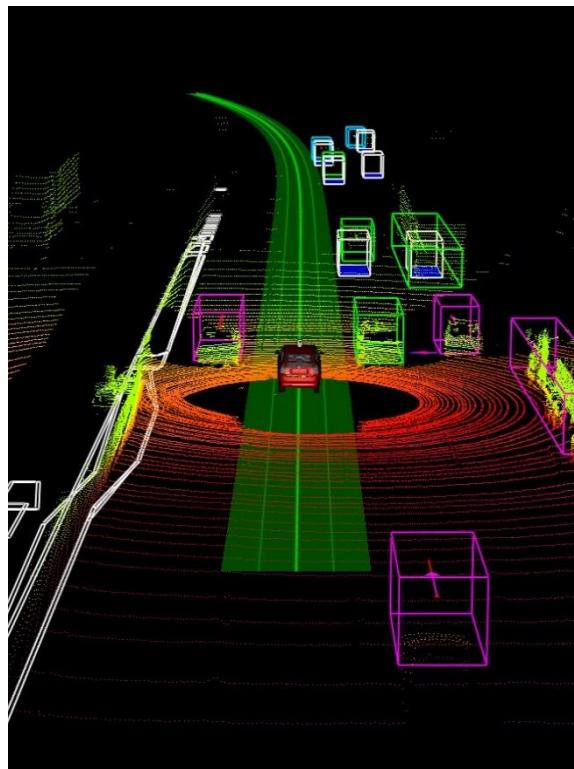
Two Paths to an Autonomous Future

A1:

Human-Centered Autonomy

- **Localization and Mapping:** Where am I?
- **Scene Understanding:** Where/who/what/why of everyone else?
- **Movement Planning:** How do I get from A to B?
- **Human-Robot Interaction:** What is the physical and mental state of the driver?
- **Communicate:** How to I convey intent to the driver and to the world?

Blue Text: Easier
Red Text: Harder



A2:

Full Autonomy

- **Localization and Mapping:** Where am I?
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Is partially automated driving a bad idea? Observations from an on-road study

Article · April 2018 with 447 Reads

DOI: 10.1016/j.apergo.2017.11.010

 Cite this publication



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✉ 11.13 · Swedish National Road and Transport Research Inst...



Jim O'donoghue



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✉ 43.23 · University of Southampton



Chris Urmson

Public Perception of What Drivers Do in Semi-Autonomous Vehicles



MIT-AVT Naturalistic Driving Dataset

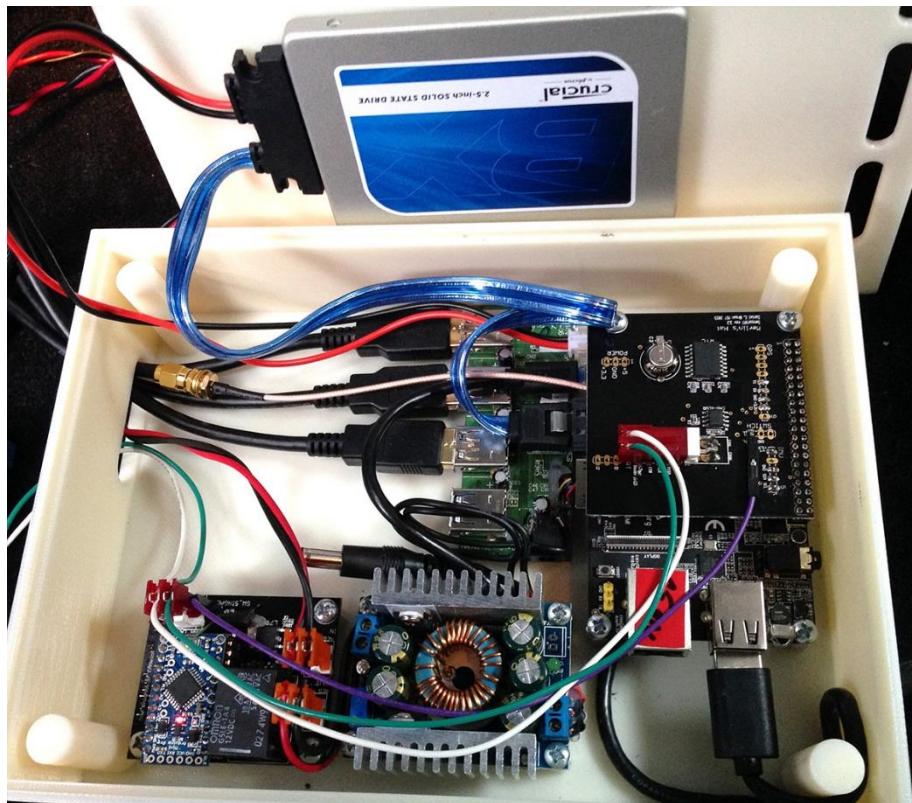
Vehicles instrumented: 25

Distance traveled: 275,000+ miles

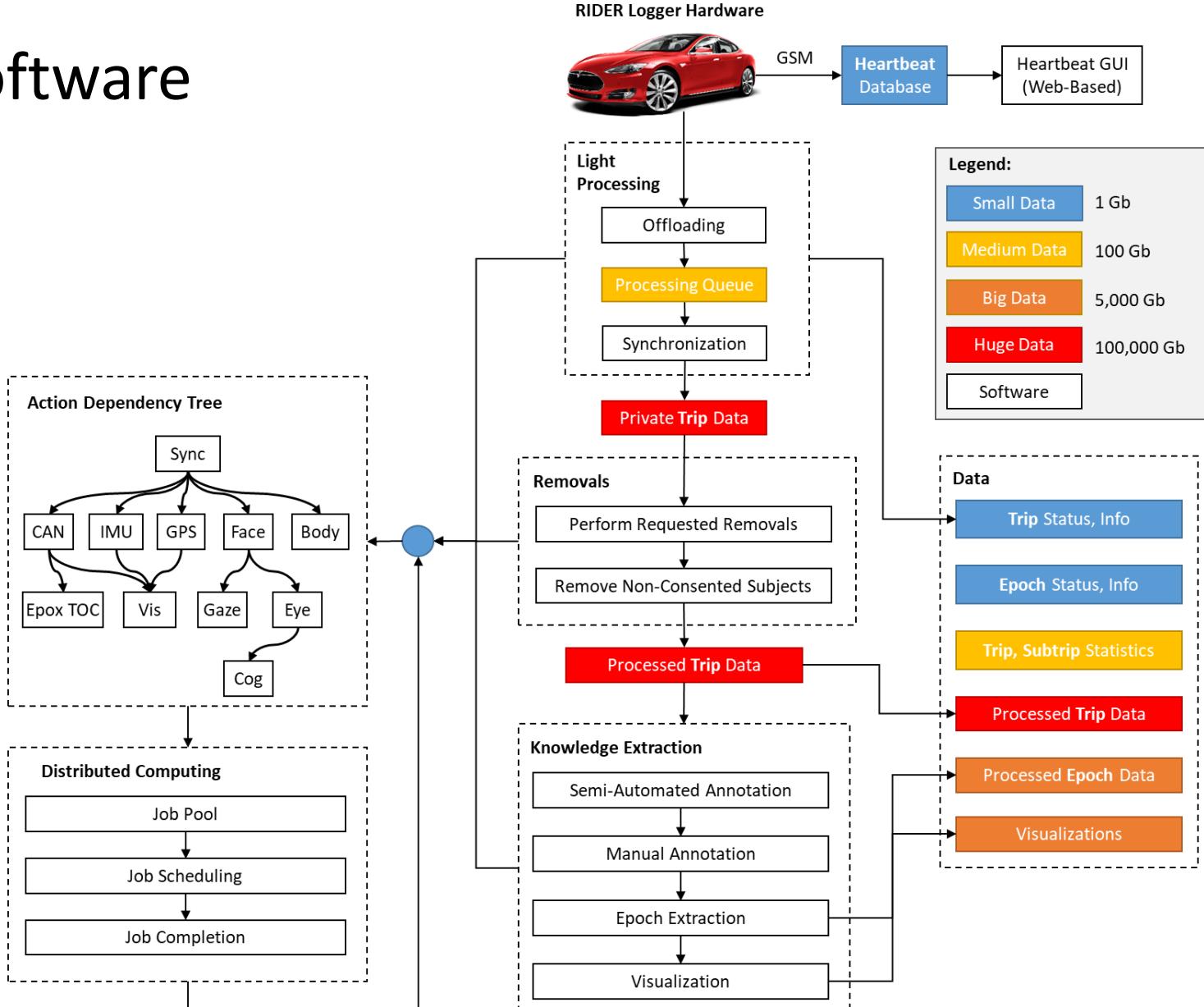
Video frames: 4.7+ billion



Hardware



Software





Total Time Driving: 0 mins
Autopilot Available: 0 mins
Autopilot Engaged: 0 mins





Human Behavior

Shared Autonomy

Understand
Behavior

Assist
Behavior

Share
Control

Semi-Supervised Learning



Large-Scale Naturalistic Data

MIT-AVT Naturalistic Driving Dataset

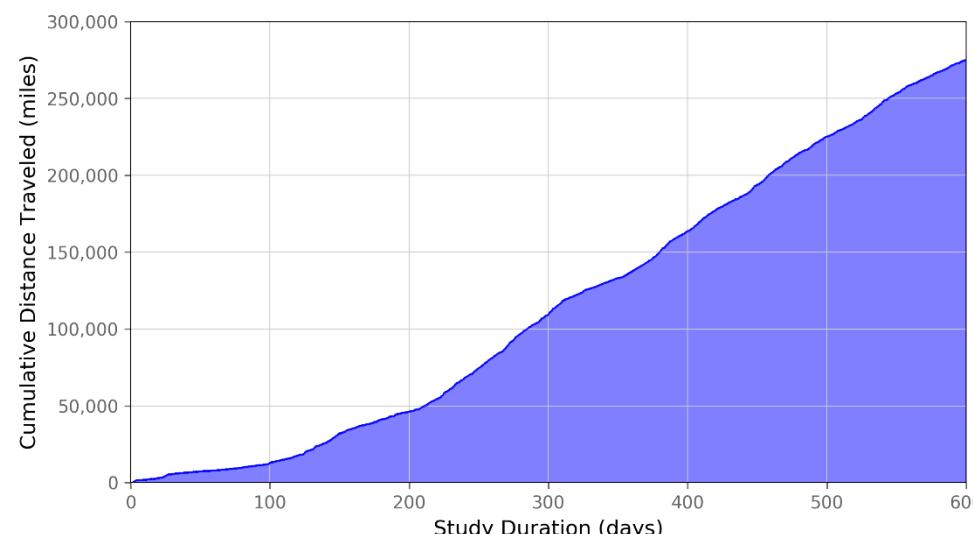
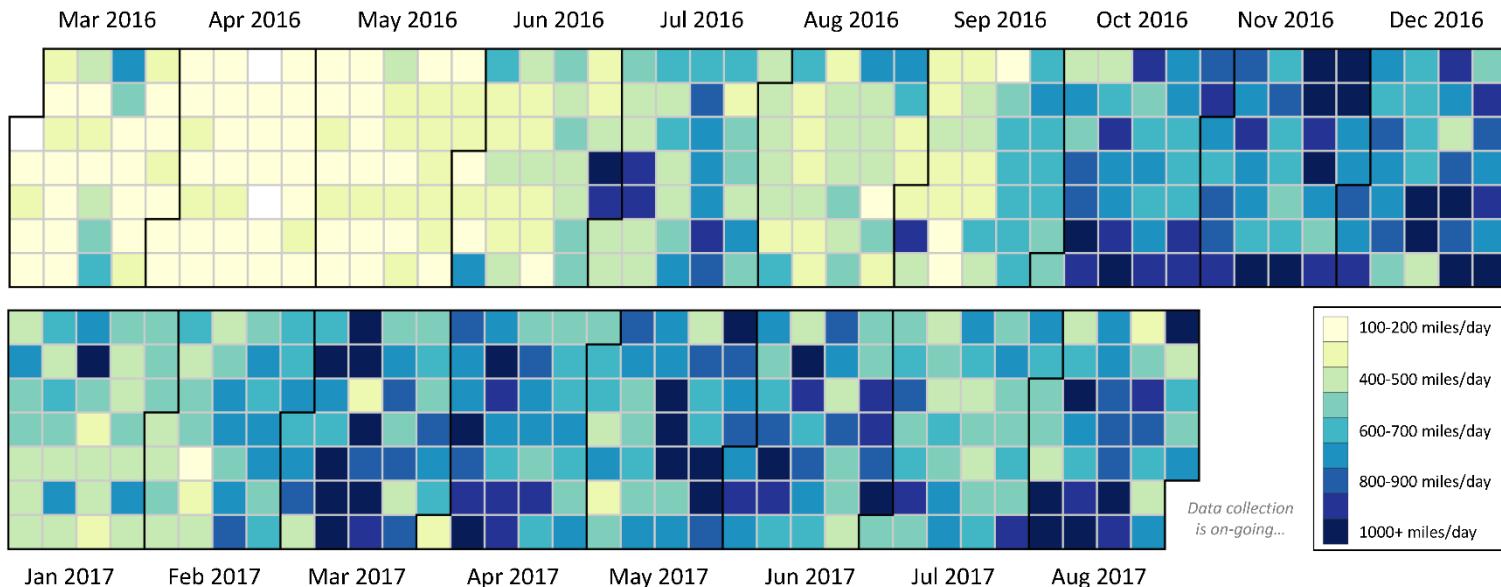
MIT Autonomous Vehicle Technology Study

Study months to-date: 21
Participant days: 7,146
Drivers: 78
Vehicles: 25
Miles driven: 275,589
Video frames: 3.48 billion

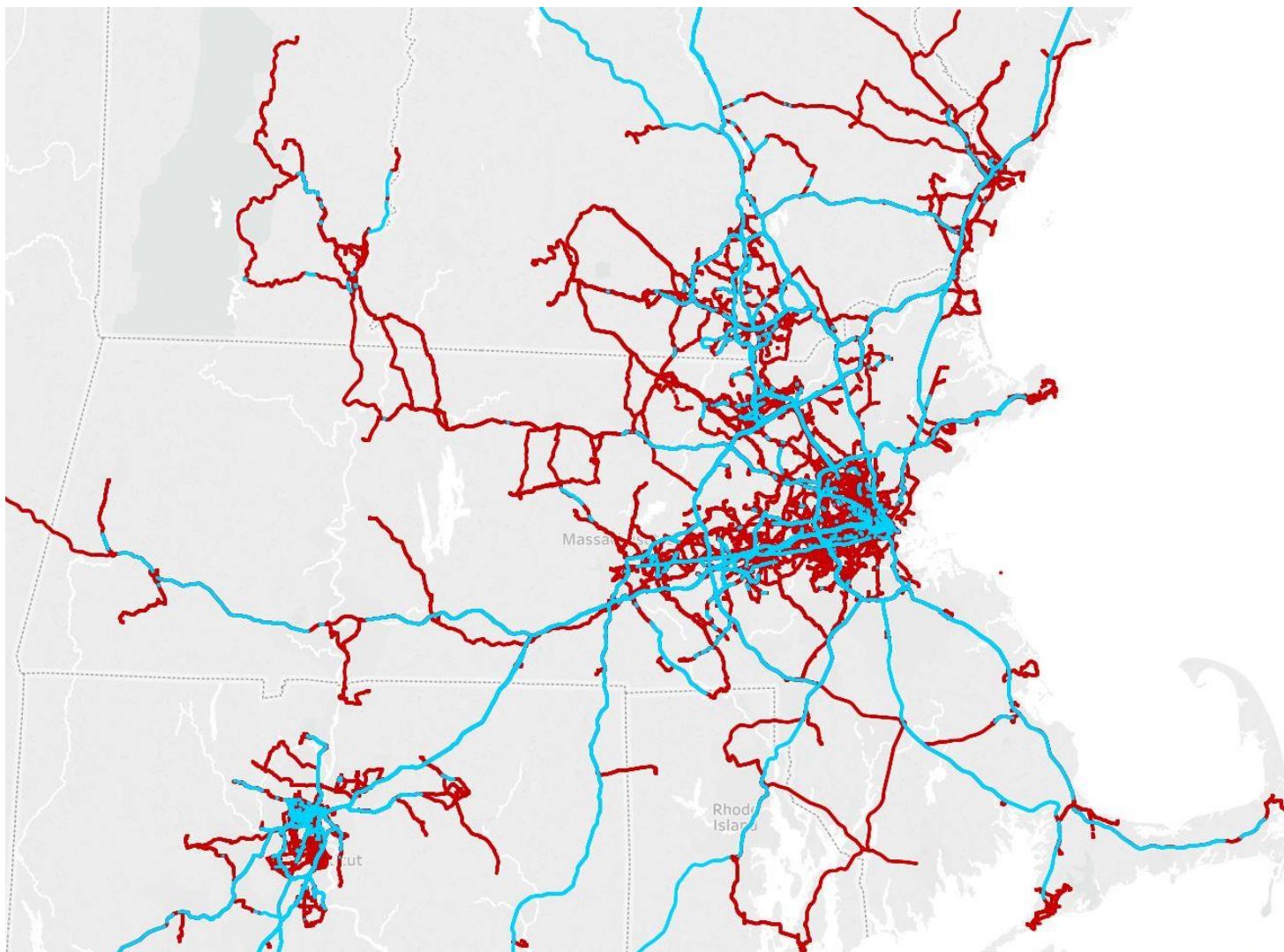
*Study data collection is ongoing.
Statistics updated on: Oct 23, 2017.*

	Tesla Model S 24,657 miles 588 days in study		Tesla Model X 22,001 miles 421 days in study		Tesla Model S 18,896 miles 435 days in study
	Tesla Model S 18,666 miles 353 days in study		Range Rover Evoque 18,130 miles 483 days in study		Tesla Model S 15,735 miles 322 days in study
	Tesla Model X 15,074 miles 276 days in study		Range Rover Evoque 14,499 miles 440 days in study		Tesla Model S 14,410 miles 371 days in study
	Tesla Model S 14,117 miles 248 days in study		Volvo S90 13,970 miles 325 days in study		Tesla Model S 12,353 miles 321 days in study
	Tesla Model X 10,271 miles 366 days in study		Tesla Model S 9,188 miles 183 days in study		Tesla Model S 8,319 miles 374 days in study
	Tesla Model S 5,186 miles 91 days in study		Tesla Model X 5,111 miles 232 days in study		Tesla Model S 4,596 miles 132 days in study
	Tesla Model X 3,719 miles 133 days in study		Tesla Model S 3,006 miles 144 days in study		Tesla Model X 1,306 miles 69 days in study
					Tesla Model S (Offload pending)

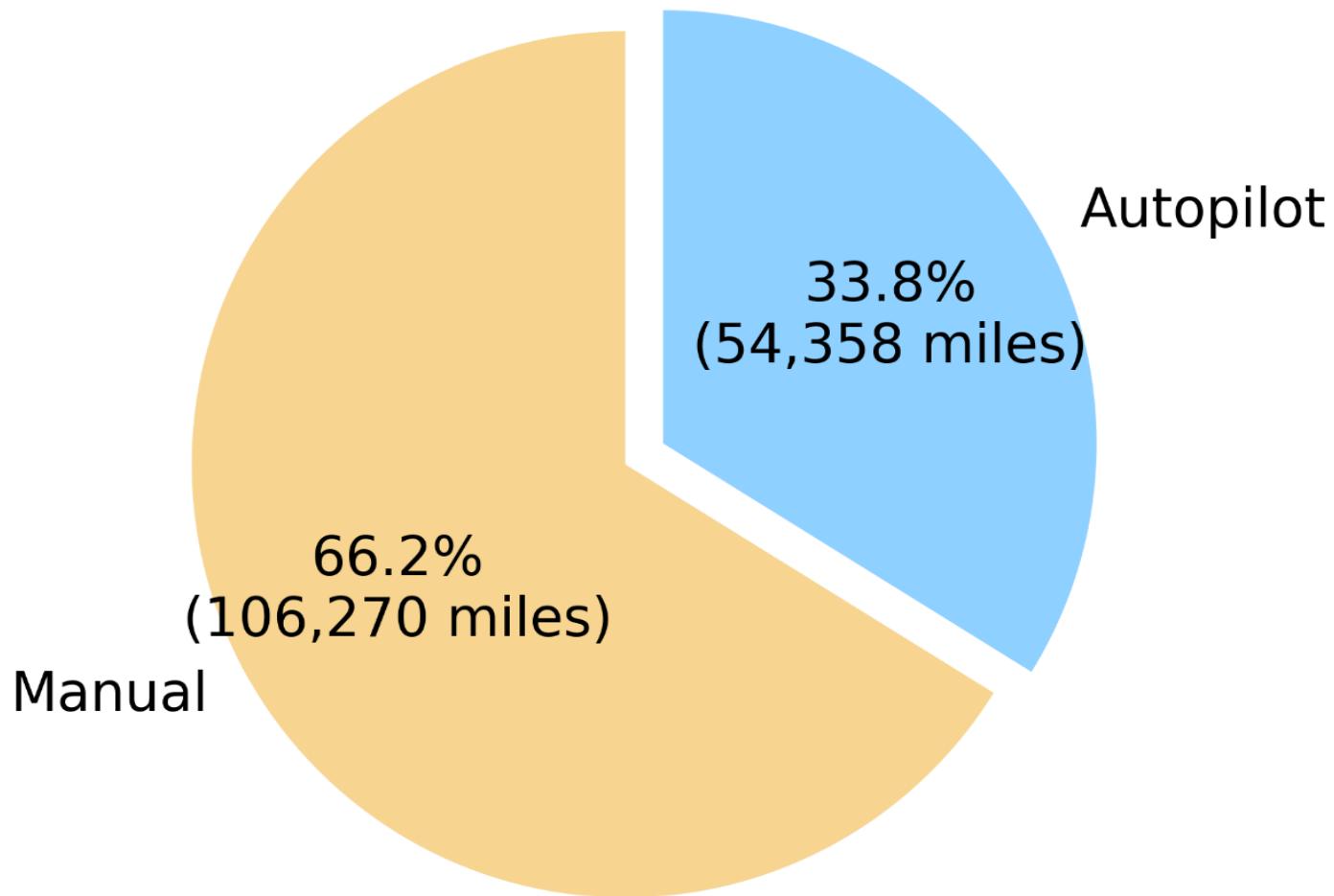
500+ Miles / Day and Growing



MIT-AVT Naturalistic Driving Dataset

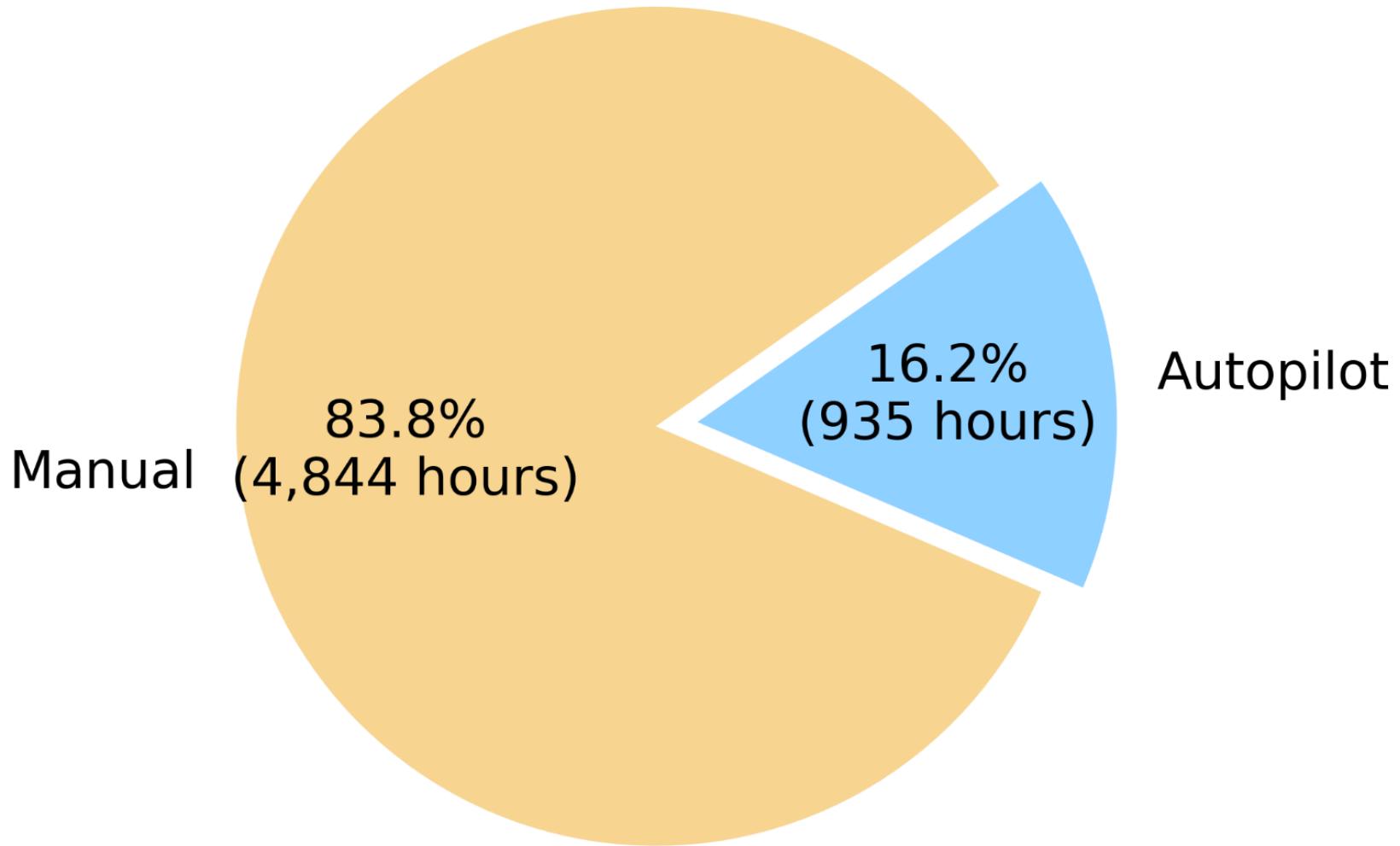


Tesla Autopilot: Patterns of Use



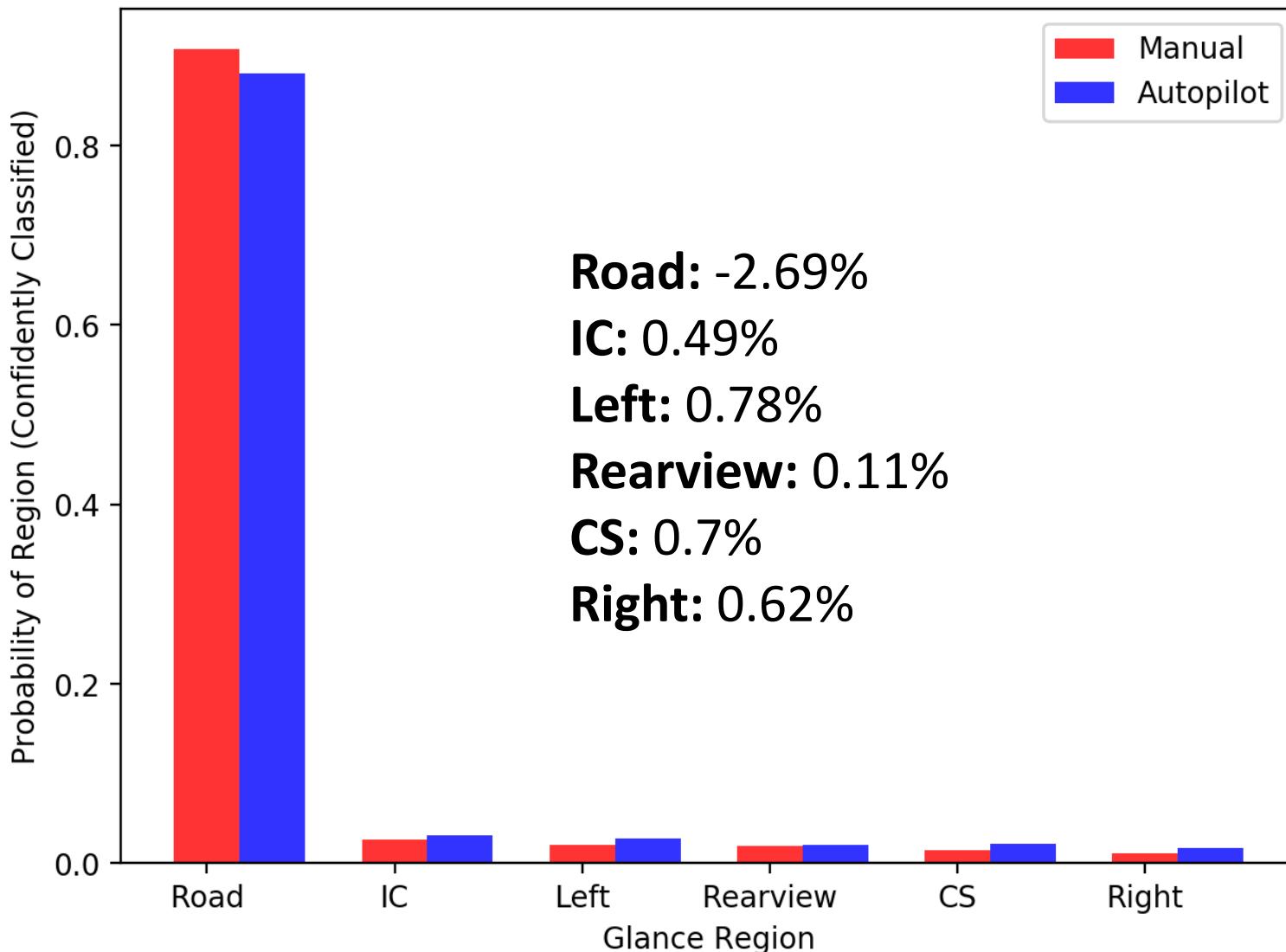
33.8% of the miles driven are with Autopilot engaged

Tesla Autopilot: Patterns of Use



16.2% of the hours driven are with Autopilot engaged

Physical Engagement: Glance Classification



Tesla Autopilot: Observed Patterns of Behavior

- **Usage:** People use autopilot a lot (% miles, % hours)
- **Road Type:** People use it on highway (using speed limit)
- **Mental Engagement:** 8,000 transfers of control from machine show that they remain vigilant to cases when Autopilot creates risk.
- **Physical Engagement:** Glance profile remains the same (% glance in manual vs autopilot by same road type)
- The “how” of successful human-robot interaction:

Use but Don't Trust.

- The “why” of successful human-robot interaction:

Learn Limitations by Exploring.

Self-Driving Cars: Personal Robotics View

- First wide reaching and profound integration of **personal robots** in society.
 - **Wide reaching:** 1 billion cars on the road.
 - **Profound:** Human gives control of his/her life directly to robot.
 - **Personal:** One-on-one relationship of communication, collaboration, understanding and trust.



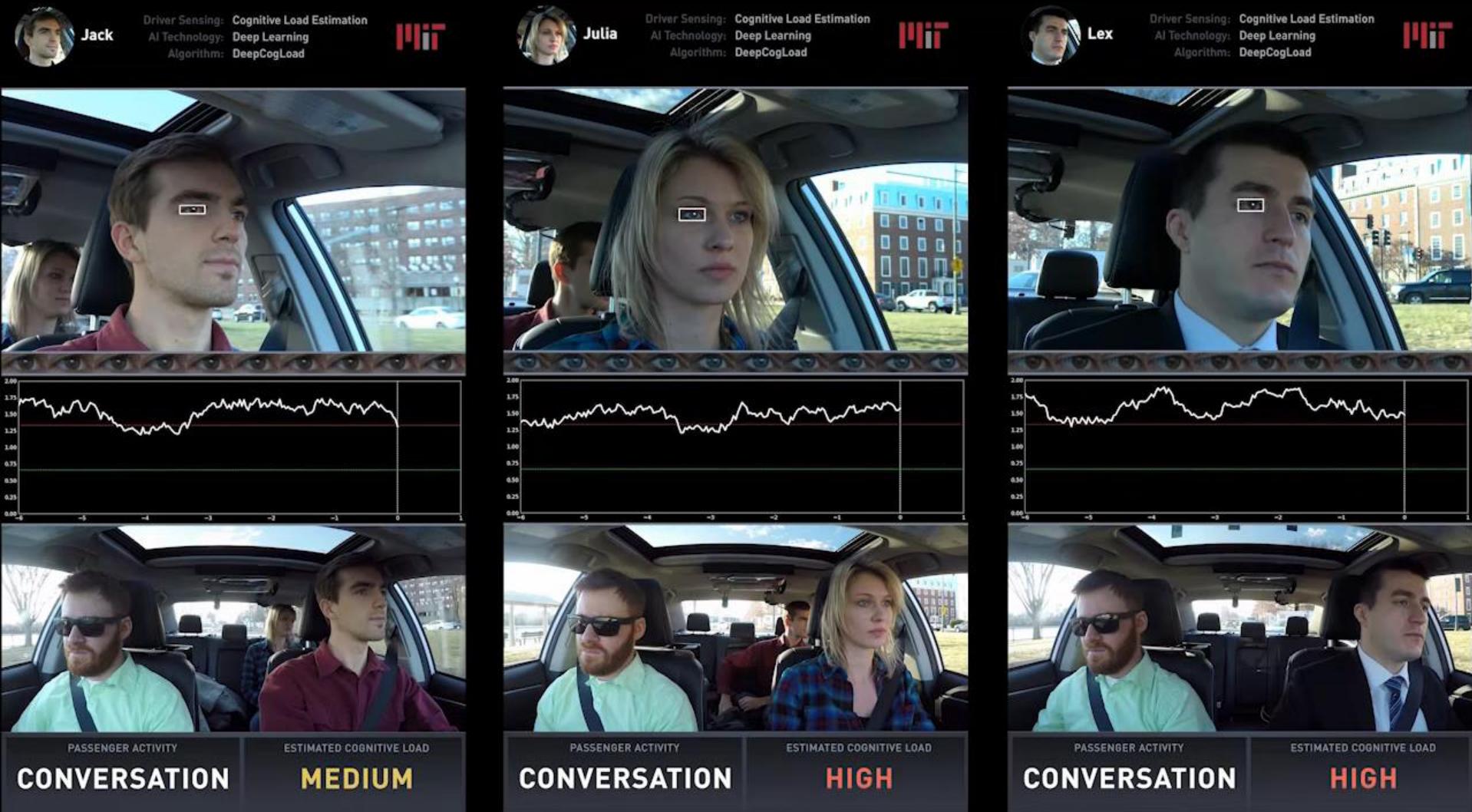
A self-driving car may be more a **Personal Robot** and less a perfect **Perception-Control** system. Why:

- **Flaws need humans:**

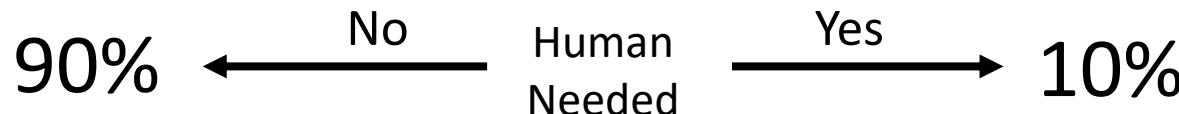
The scene understanding problem requires much more than pixel-level labeling

- **Exist with humans:**

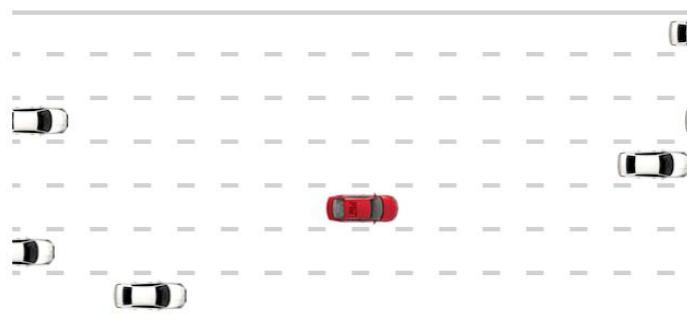
Achieving both an enjoyable and safe driving experience may require “driving like a human”.



Human-Centered Artificial Intelligence Approach



Solve the perception-control problem where **possible**:



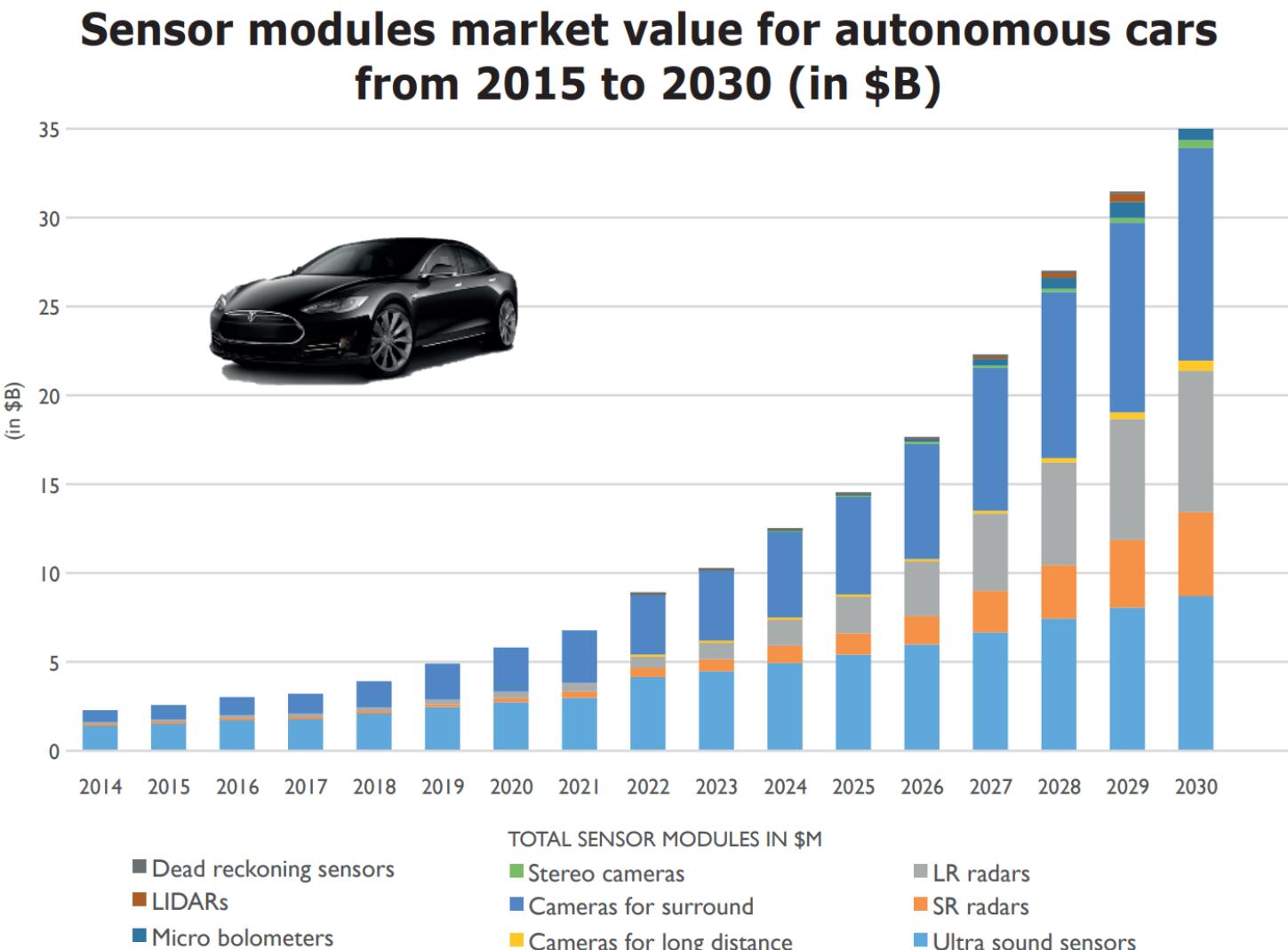
And where **not possible**: involve the human



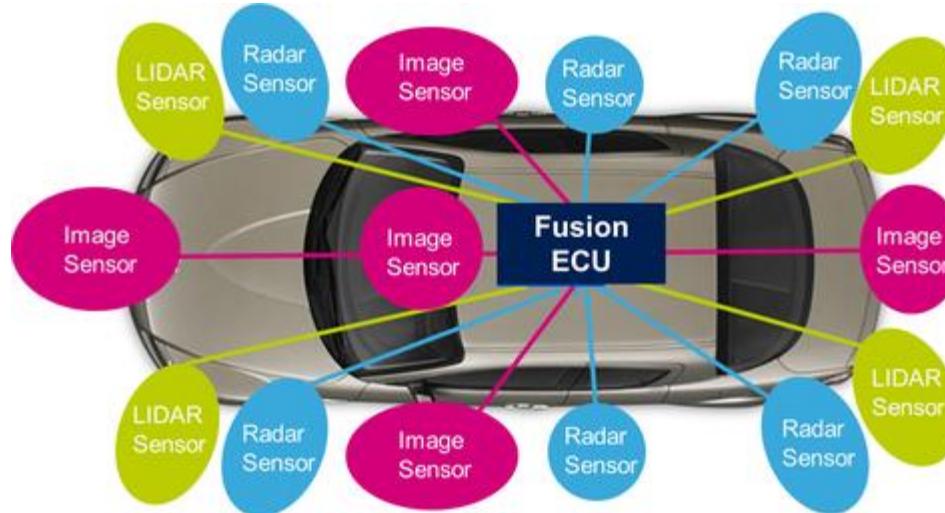
Overview

- Different approaches autonomy
- **Sensors**
- Companies doing it
- Opportunities for AI and deep learning

By 2030: Sensor Market Estimated at \$36 Billion



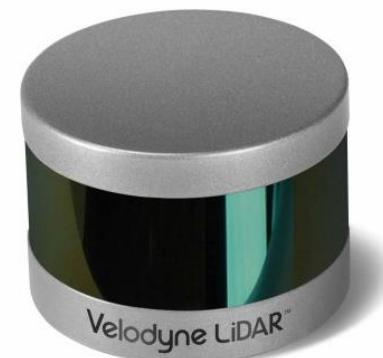
Automotive AI Sensors



Camera

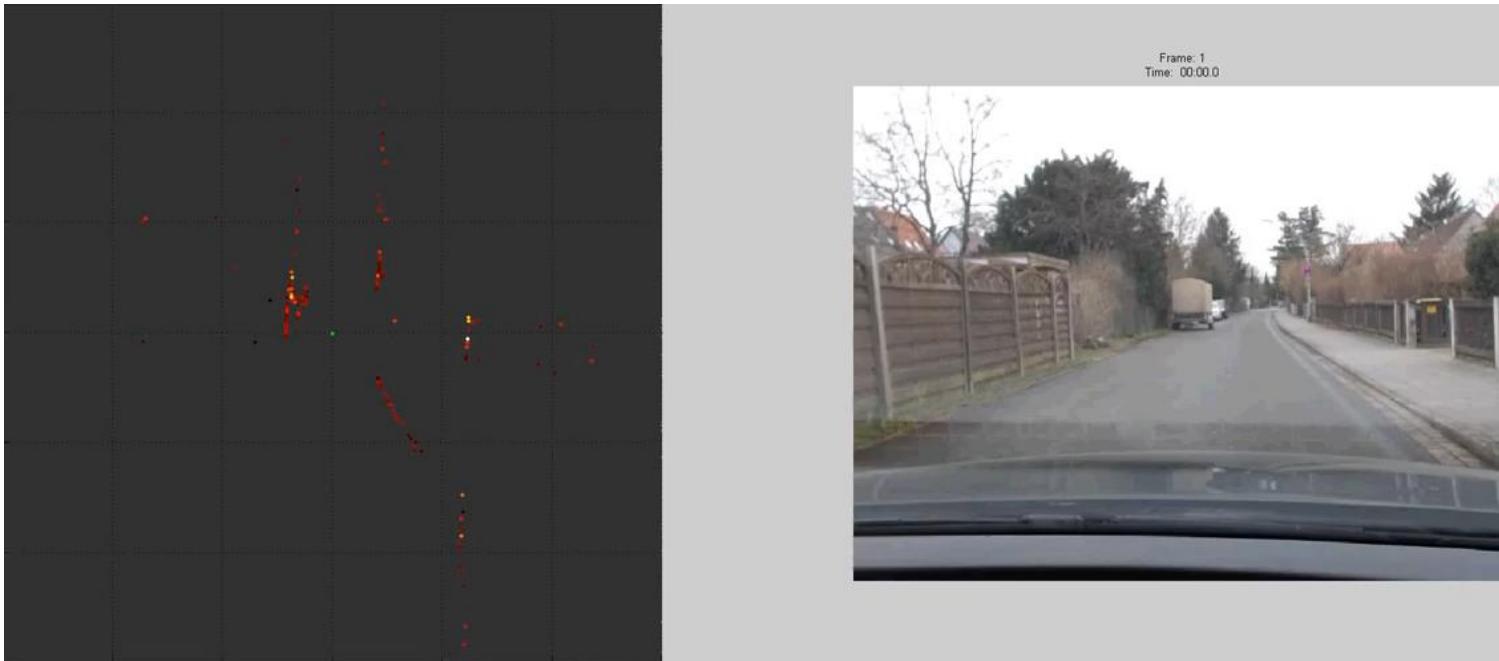


Radar



LIDAR

Radar

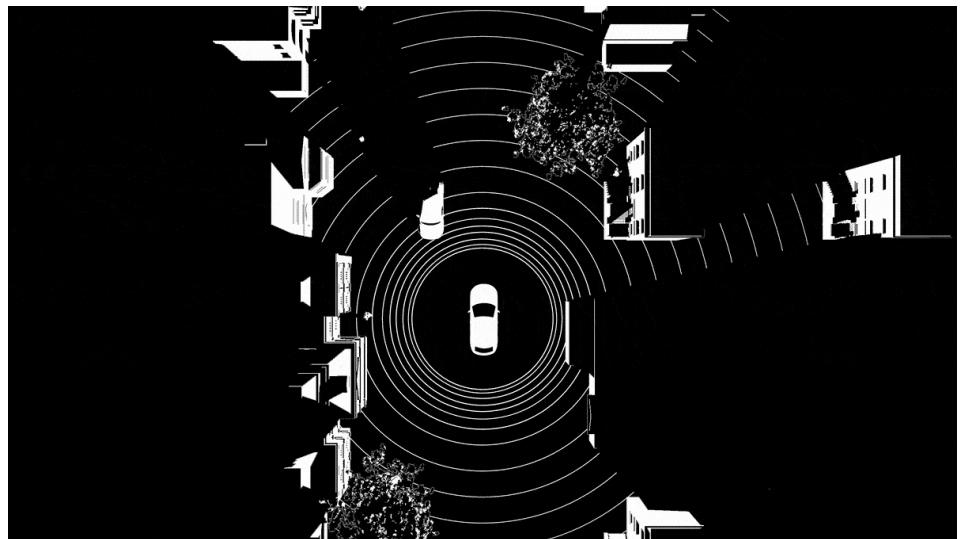
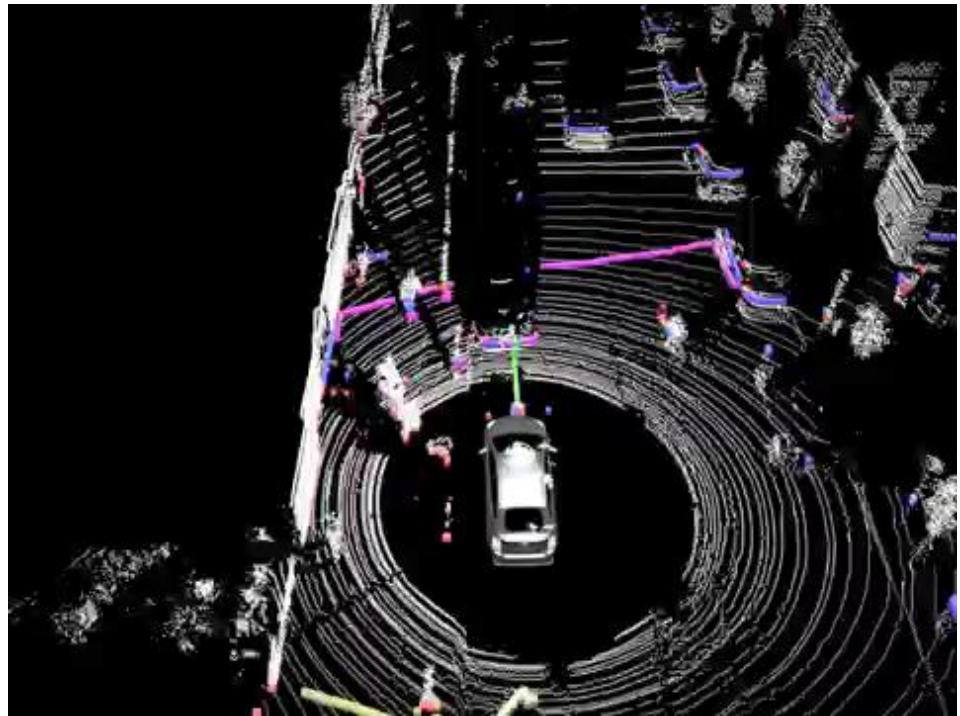


- Cheap
- Does well in extreme weather
- Low resolution
- Most used automotive sensor for object detection and tracking

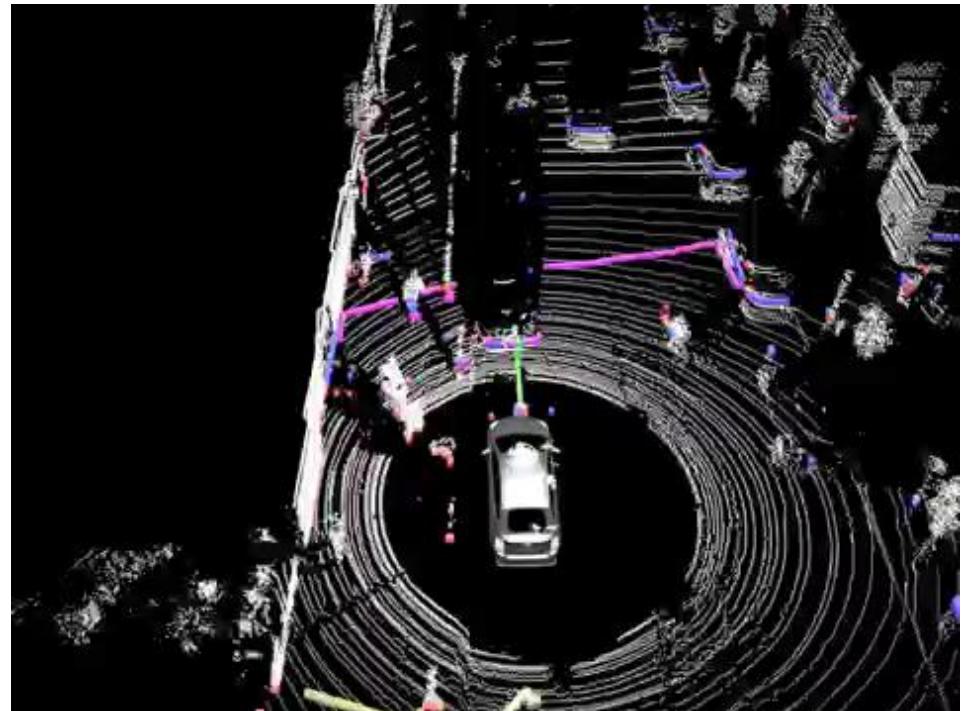
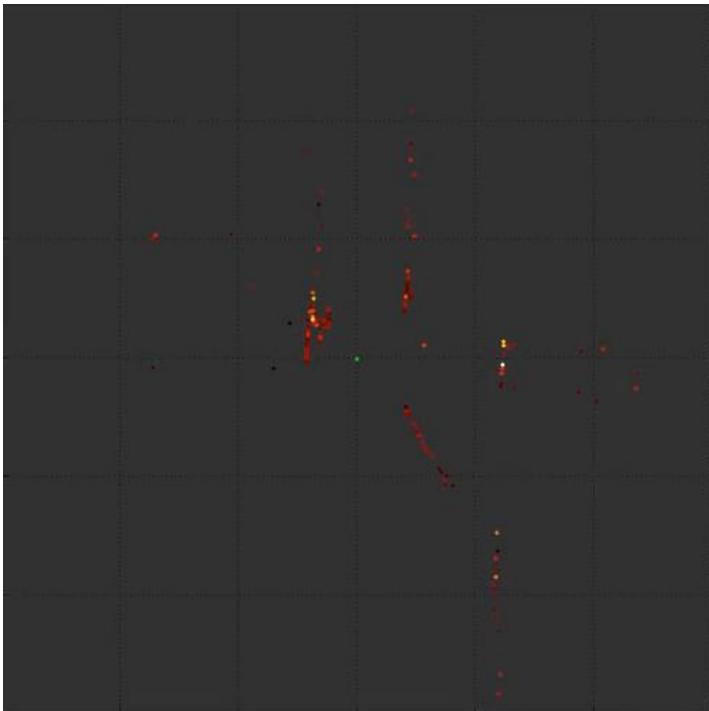
LIDAR



- Expensive
- Extremely accurate depth information
- Resolution much higher than radar
- 360 degrees of visibility

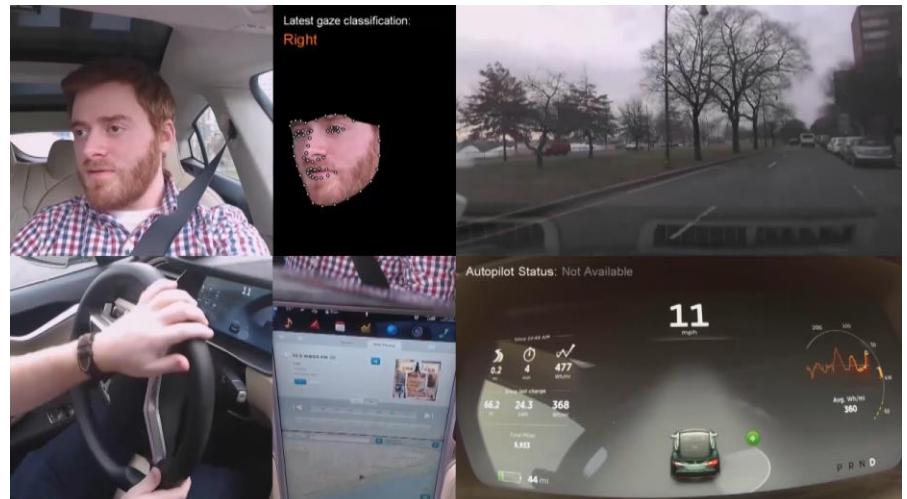


Resolution: LIDAR vs Radar

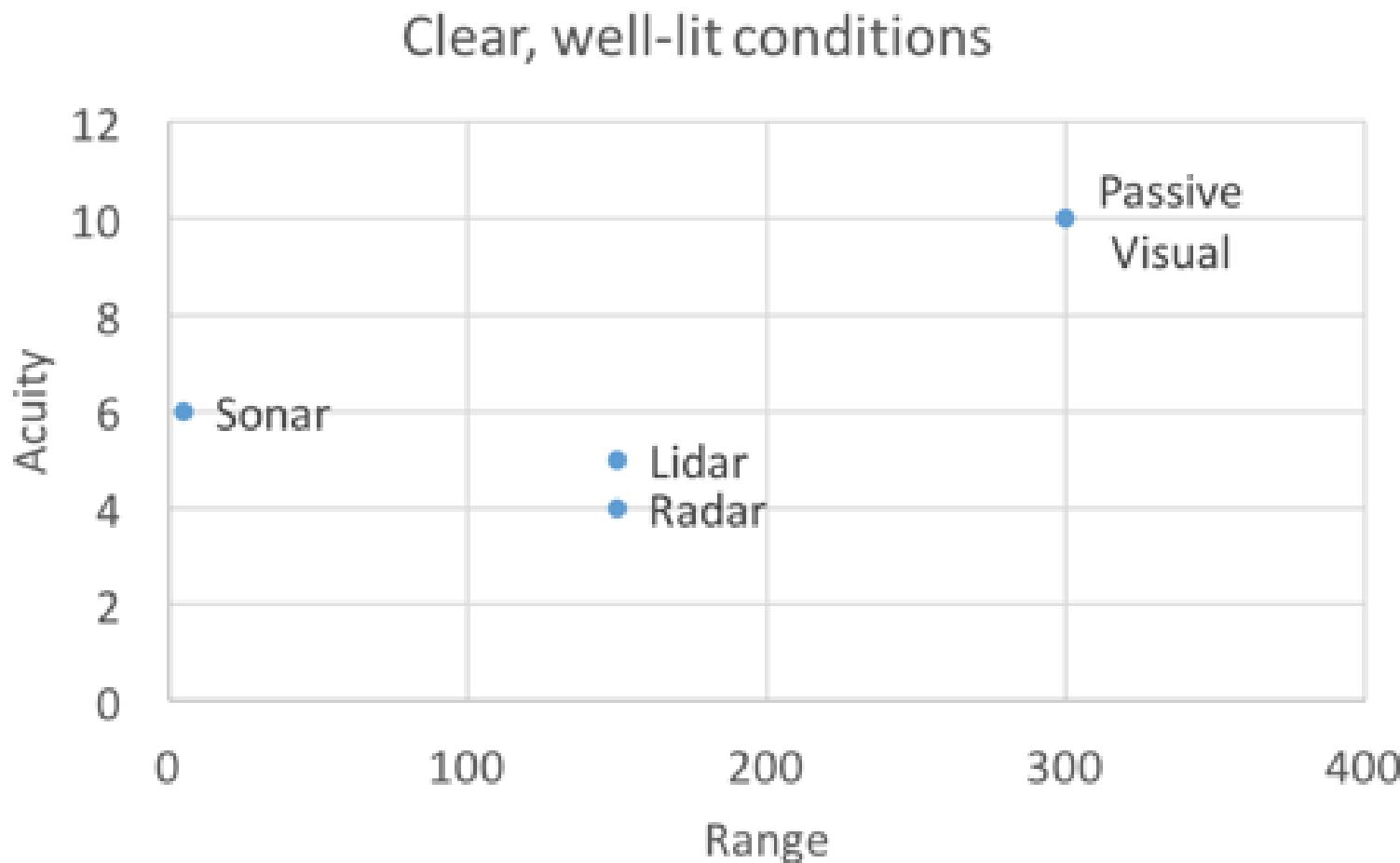


Camera

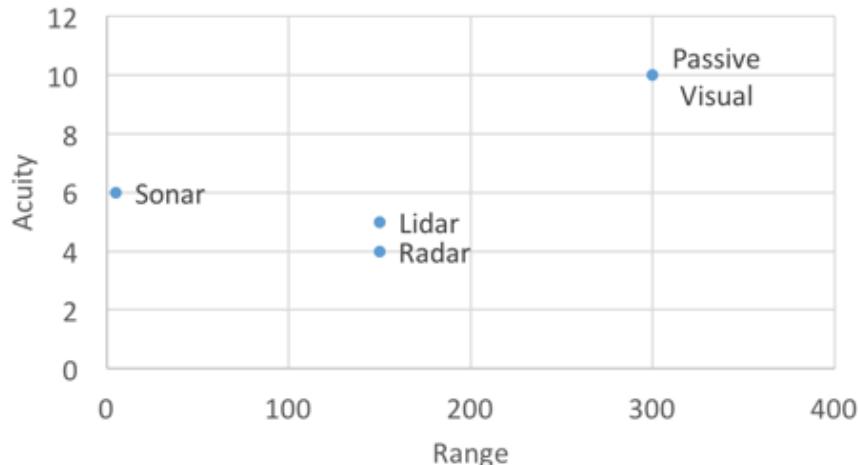
- Cheap
- Highest resolution
- Huge data = deep learning
- Human brains use similar sensor technology for driving
- Bad at depth estimation
- Not good in extreme weather



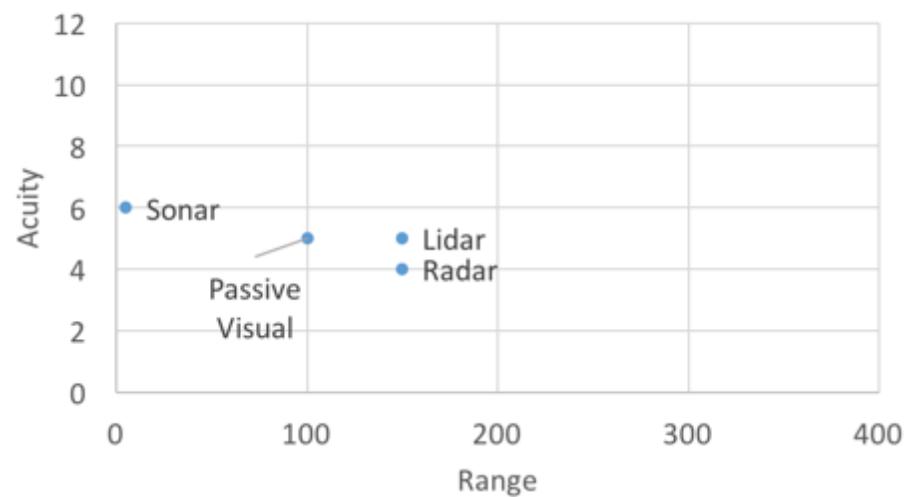
Range Comparison



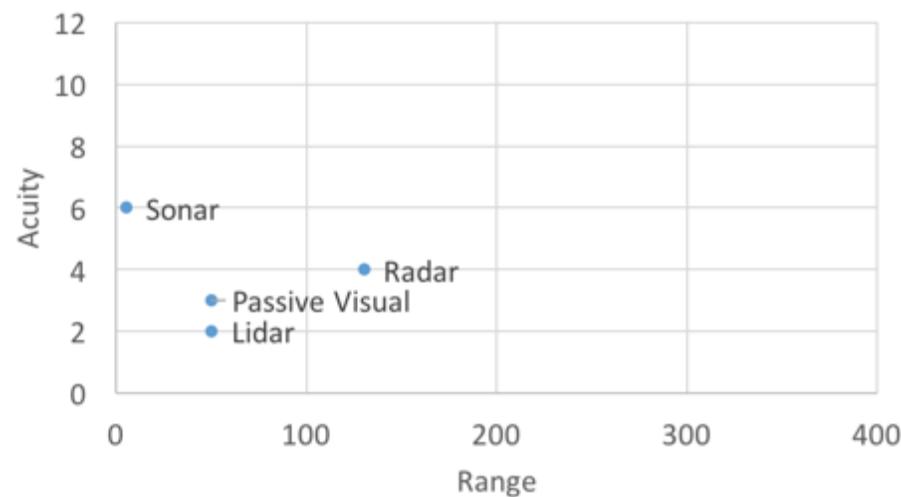
Clear, well-lit conditions



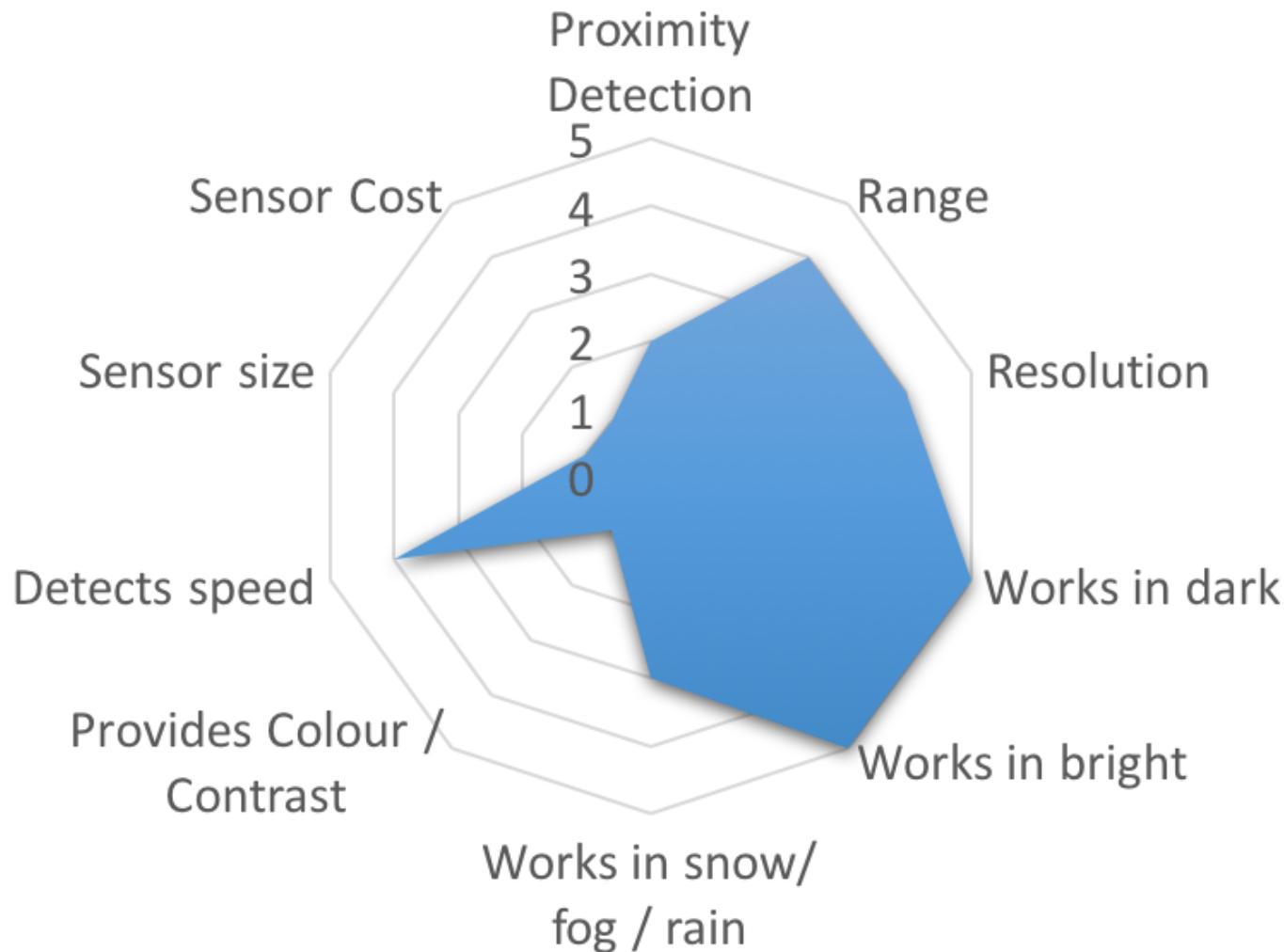
Clear, dark conditions



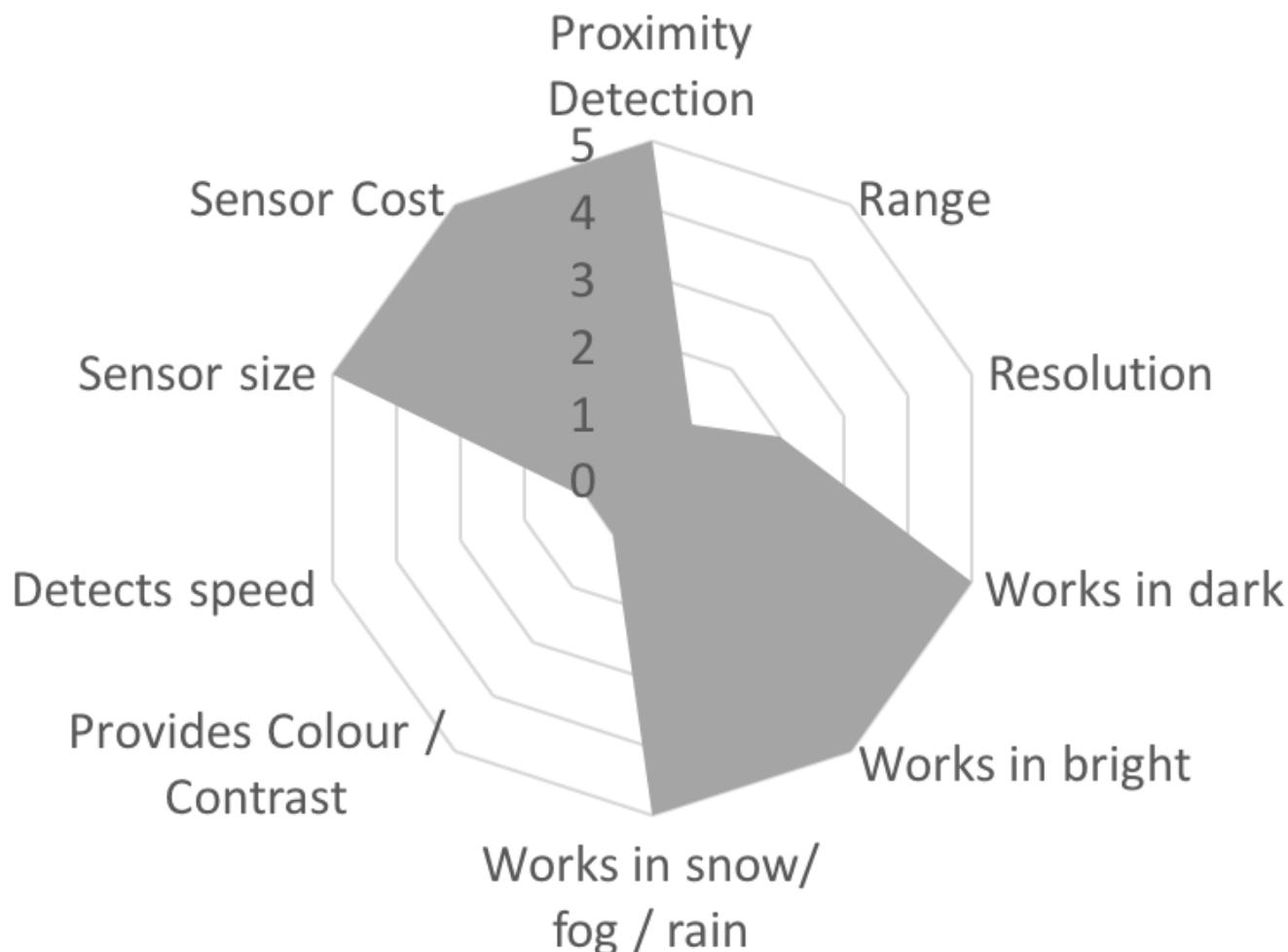
Heavy rain, snow or fog



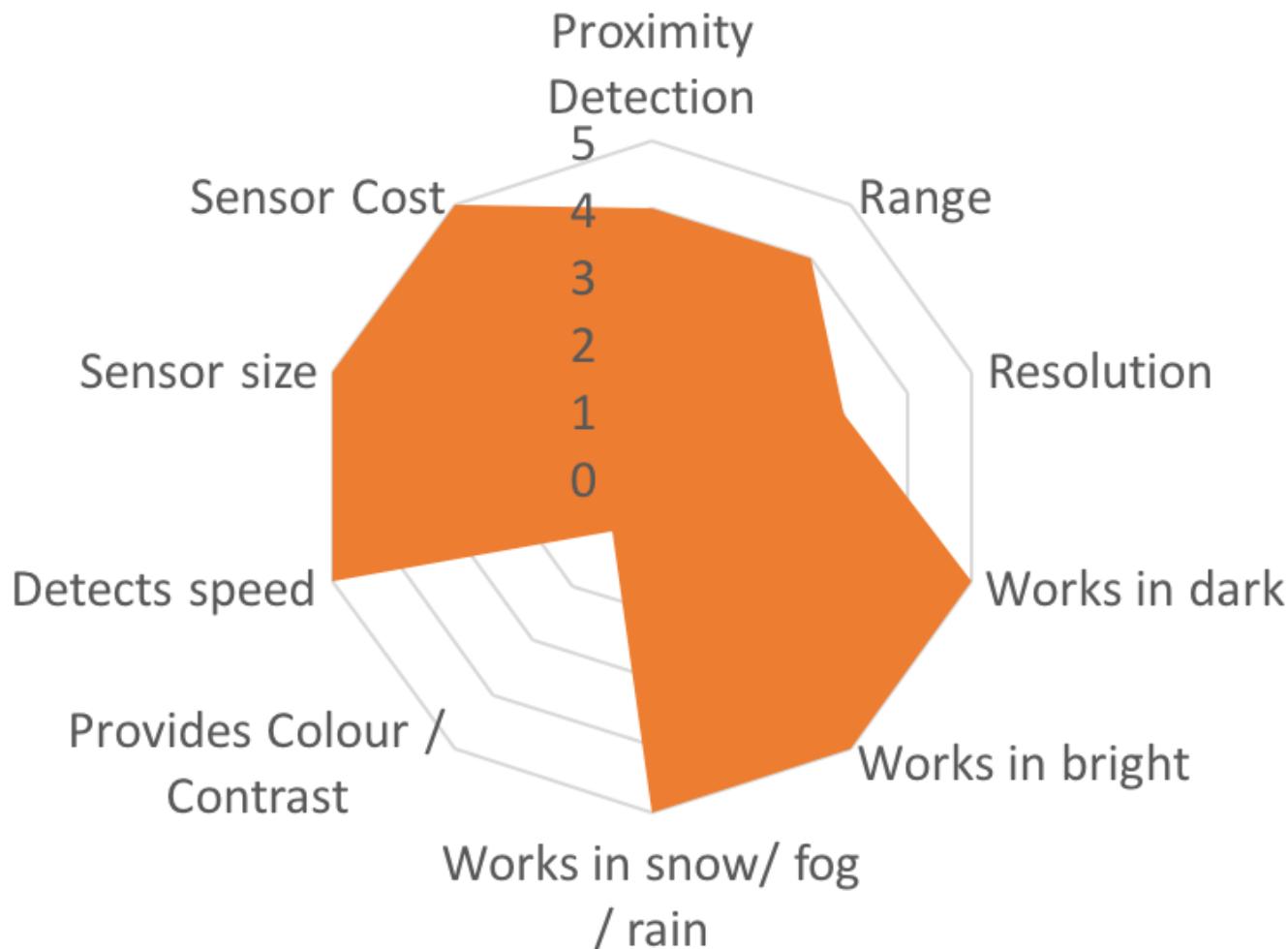
Lidar



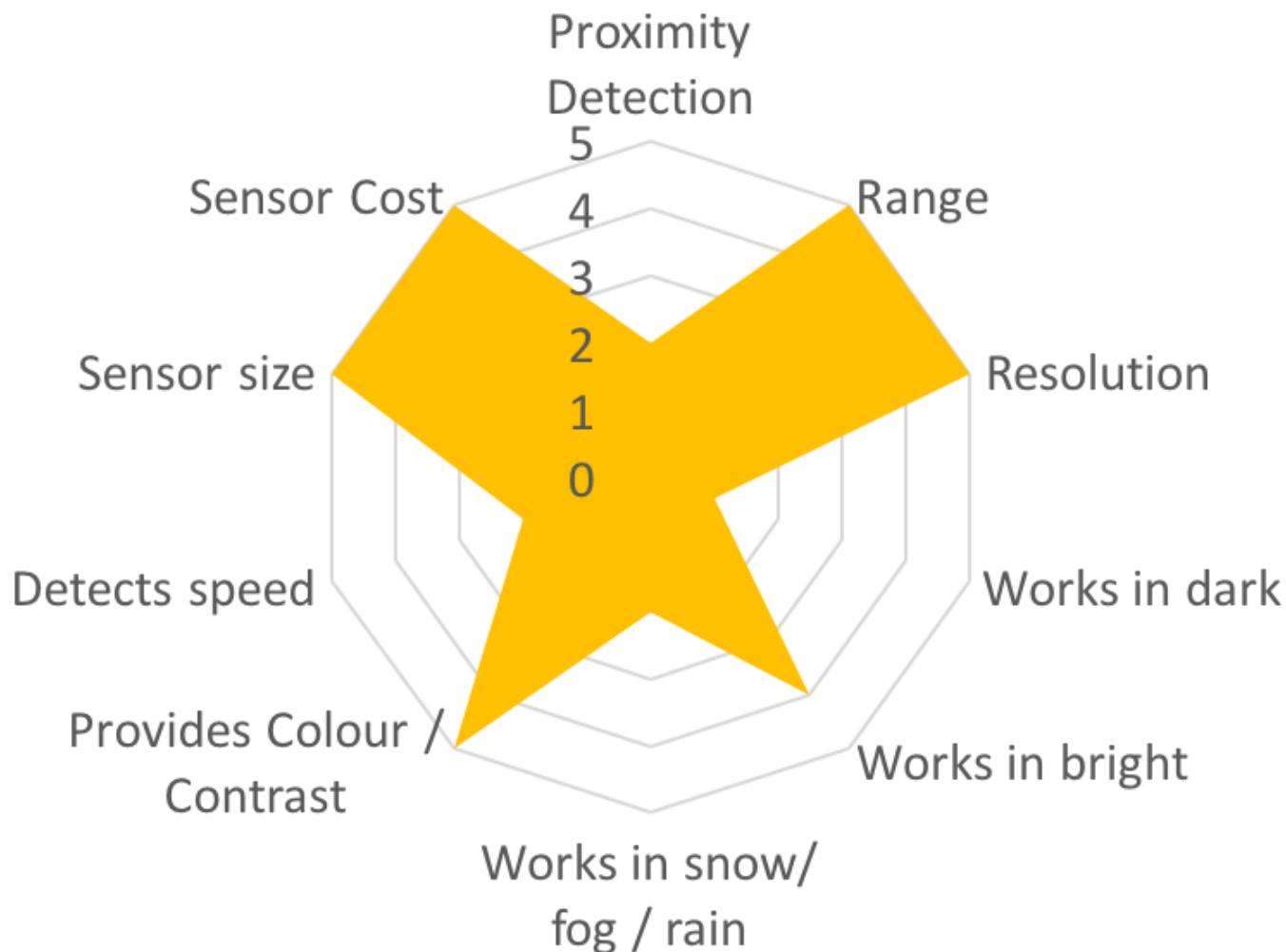
Ultrasonic



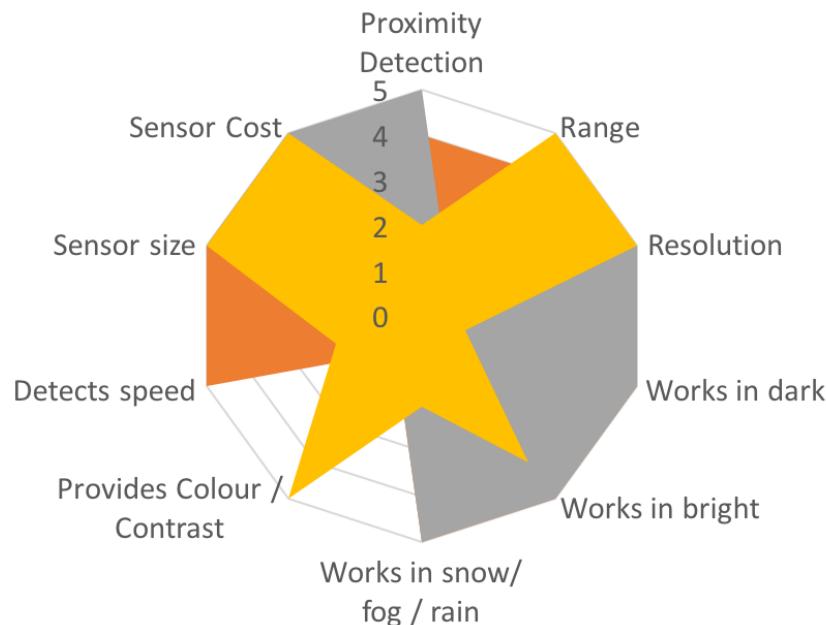
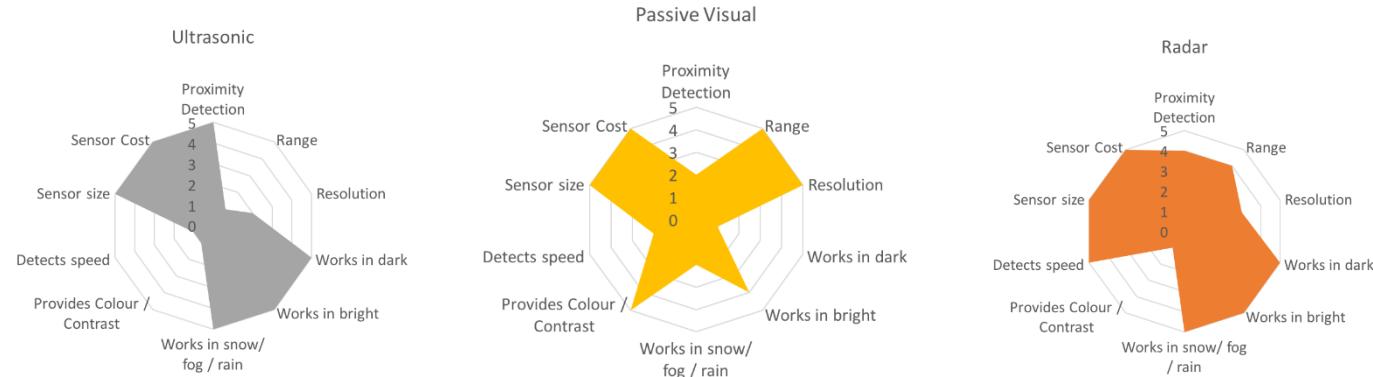
Radar



Passive Visual



Sensor Fusion



Future of Sensor Technology: Camera vs LIDAR

- **Radar and Ultrasonic:**

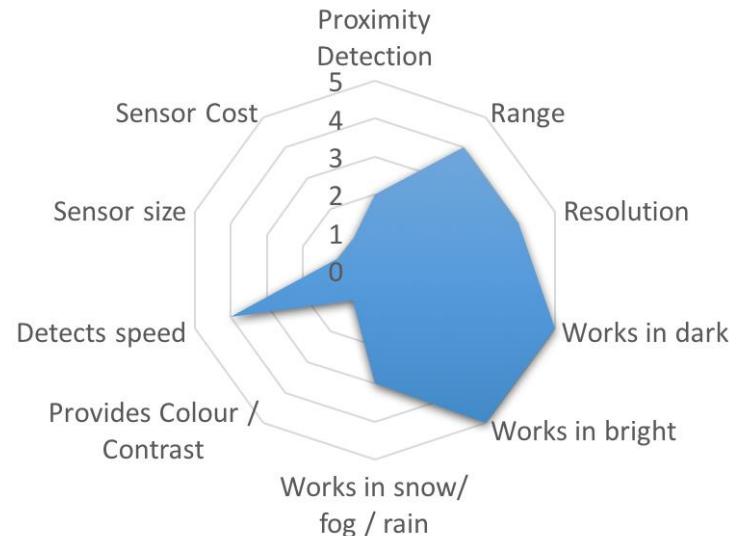
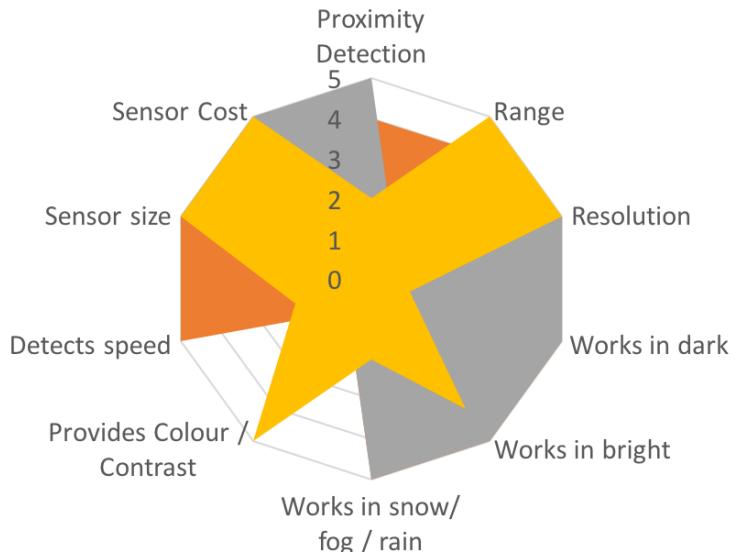
- Always there to help

- **Camera:**

- Annotated driving data grows
- Deep learning algorithms improve

- **LIDAR:**

- Range increases
- Cost drops (solid-state LIDAR)



Overview

- Different approaches autonomy
- Sensors
- **Companies doing it**
- Opportunities for AI and deep learning

Waymo



Notable:

- April 2017: Exits testing: first rider in Phoenix
- November 2017: 4 million miles driven autonomously
- December 2017: No safety driver in Phoenix

Uber



Notable:

- December 2017: 2 million miles driven autonomously

Tesla



Notable:

- Sep 2014: Released Autopilot
- Oct 2016: Started Autopilot 2 from scratch.
- Jan 2018: ~1 billion miles driven in Autopilot
- Jan 2018: ~300,000 Autopilot equipped vehicles

Audi A8

(Released end of 2018)



- Thorsten Leonhardt, head of Automated Driving, Audio:
“When the function is operated as intended, if the customer turns the traffic jam pilot on and uses it as intended, and the car was in control at the time of the accident, the driver goes to his insurance company and the insurance company will compensate the victims of the accident and in the aftermath they come to us and we have to pay them,” he said.

Notable Progress

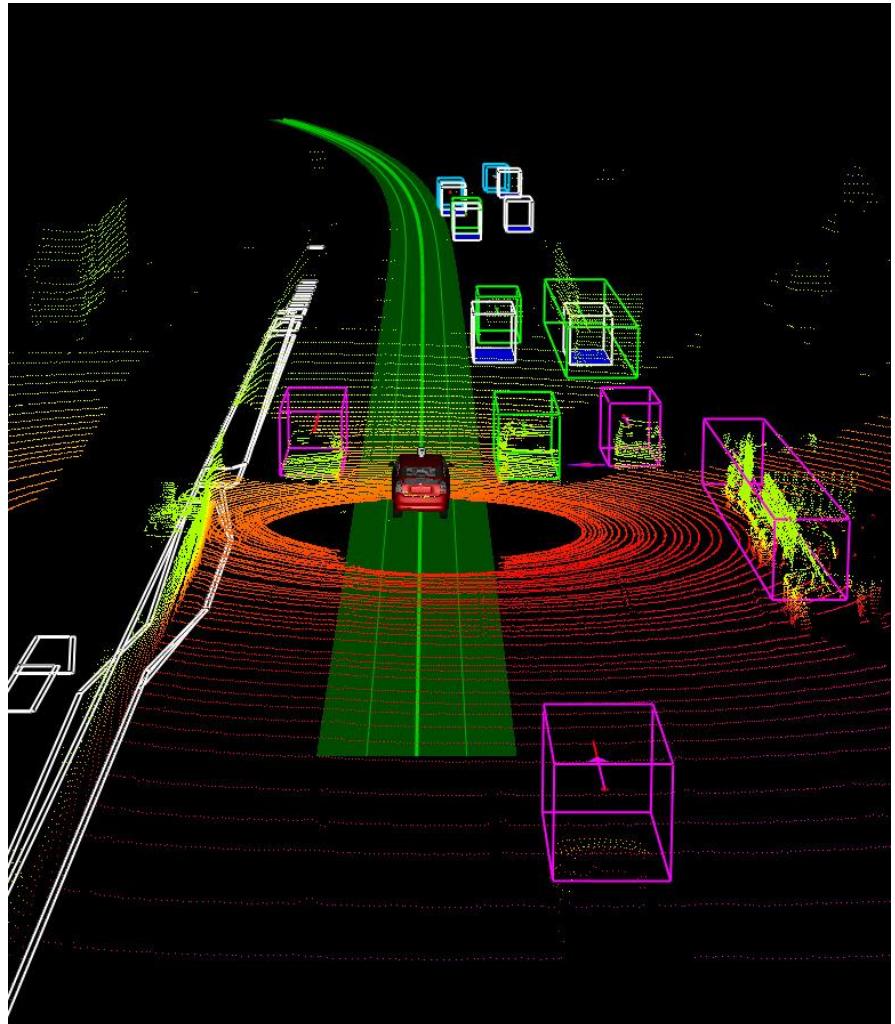
- Full autonomy (A2)
 - Waymo
 - Uber
 - GM Cruise
 - nuTonomy
 - OptimusRide
 - Zenuity
 - Voyage
 - ...
- Human-centered autonomy (A1)
 - Tesla Autopilot - Model S/3/X
 - Volvo PilotAssist - S90/XC90/XC60/V90
 - Audi Traffic Jam Assist - A8
 - Mercedes-Benz Drive Pilot Assist - E-Class
 - Cadillac Super Cruise - CT6
 - Comma.ai openpilot
 - ...

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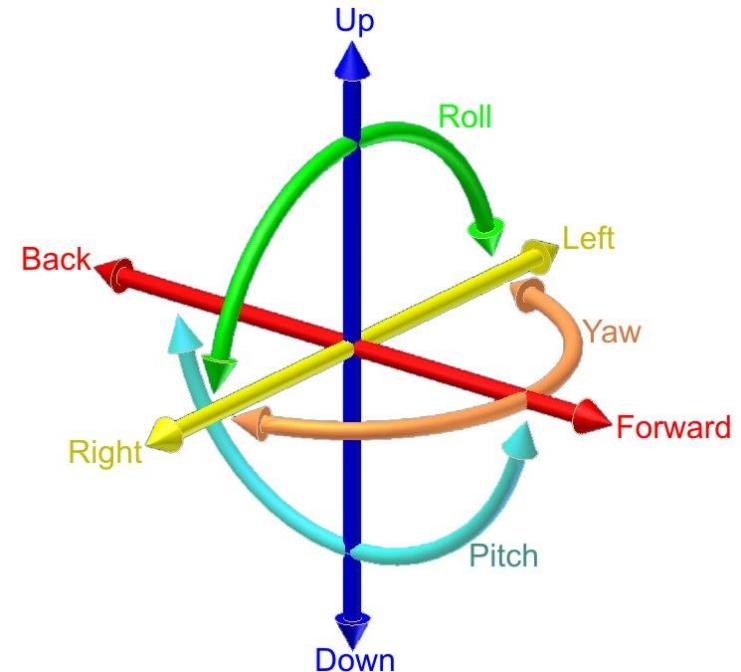
Self-Driving Car Tasks

- **Localization and Mapping:**
Where am I?
- **Scene Understanding:**
Where is everyone else?
- **Movement Planning:**
How do I get from A to B?
- **Driver State:**
What's the driver up to?



Visual Odometry

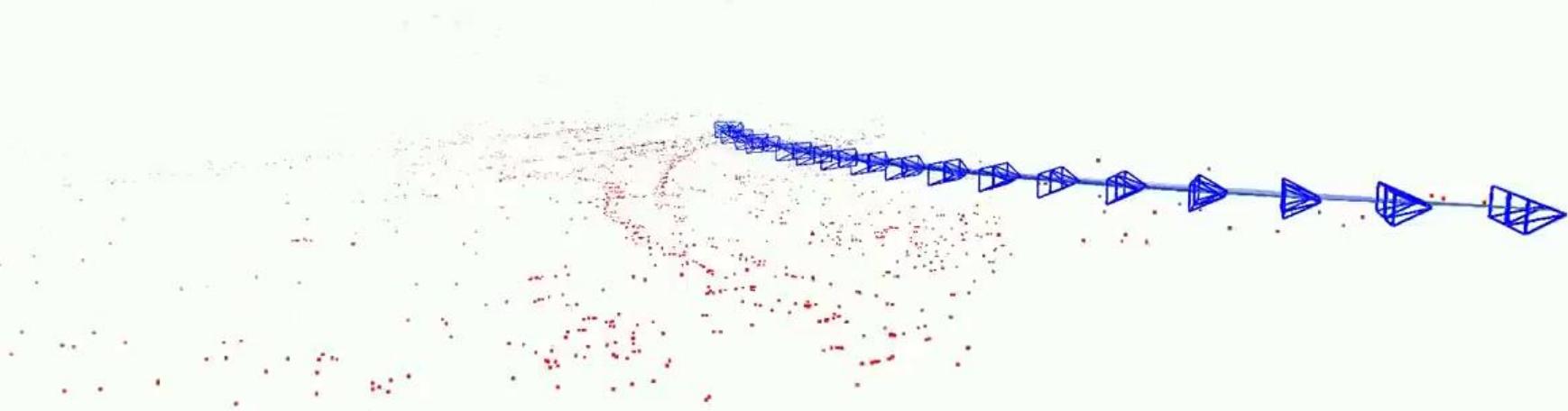
- 6-DOF: freedom of movement
 - Changes in position:
 - Forward/backward: surge
 - Left/right: sway
 - Up/down: heave
 - Orientation:
 - Pitch, Yaw, Roll
- Source:
 - **Monocular:** I moved 1 unit
 - **Stereo:** I moved 1 meter
 - Mono = Stereo for far away objects
 - PS: For tiny robots everything is “far away” relative to inter-camera distance



SLAM: Simultaneous Localization and Mapping

What works: SIFT and optical flow

x2



Visual Odometry in Parts

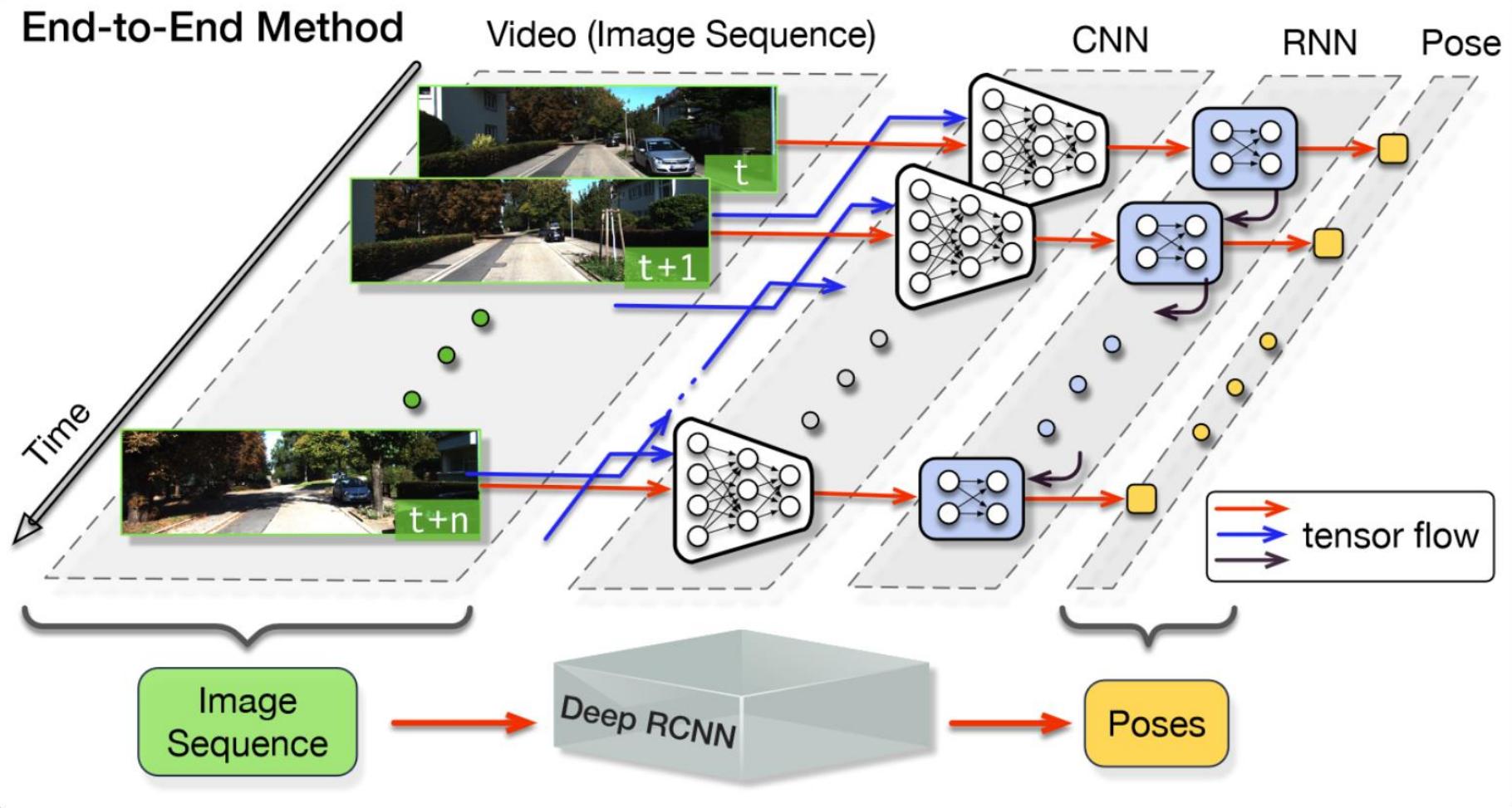


- (Stereo) Undistortion, Rectification
- (Stereo) Disparity Map Computation
- Feature Detection (e.g., SIFT, FAST)
- Feature Tracking (e.g., KLT: Kanade-Lucas-Tomasi)
- Trajectory Estimation
 - Use rigid parts of the scene (requires outlier/inlier detection)
 - For mono, need more info* like camera orientation and height off the ground

* Kitt, Bernd Manfred, et al. "Monocular visual odometry using a planar road model to solve scale ambiguity." (2011).

DeepVO: Deep Learning Based Visual Odometry

End-to-End Method

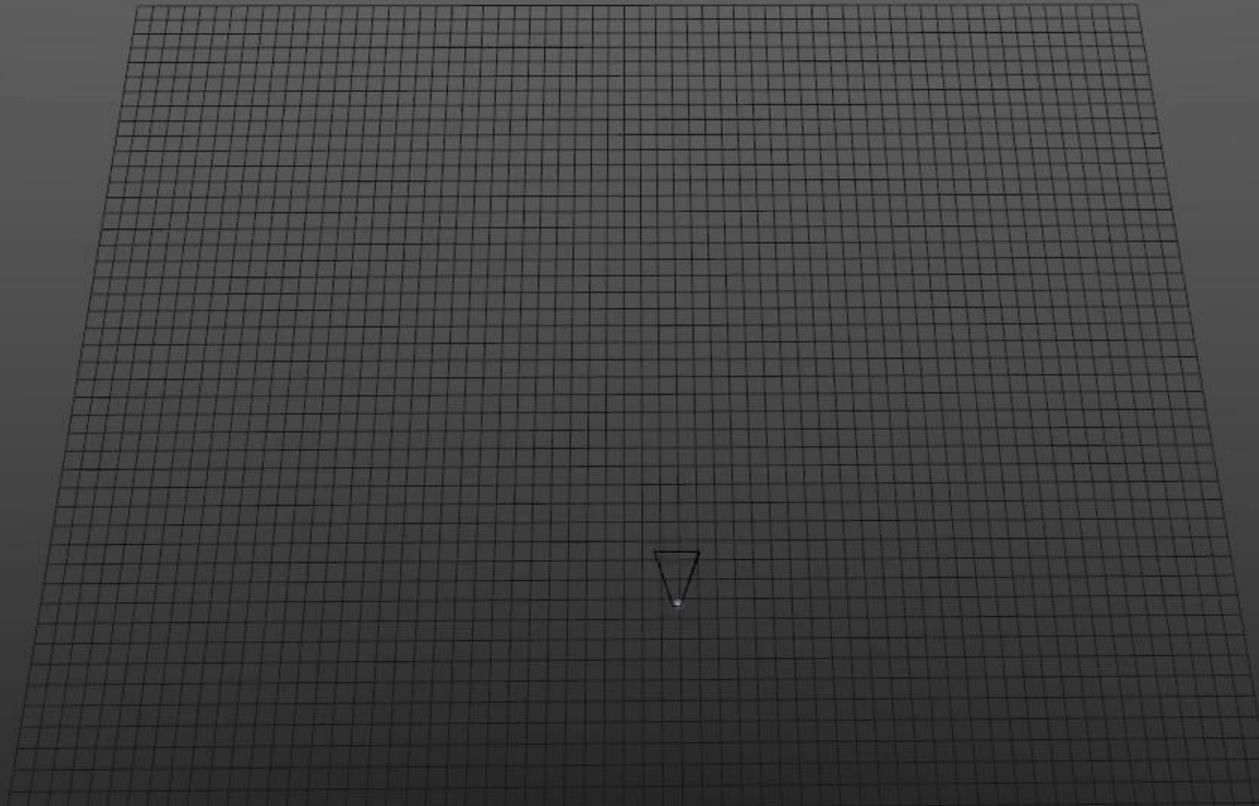


DeepVO: Deep Learning Based Visual Odometry

Ground-Truth
Deep-VO



Train: 00 01 02 08 09
Test: 05 (This video)



Self-Driving Car Tasks

- **Localization and Mapping:**

Where am I?

- **Scene Understanding:**

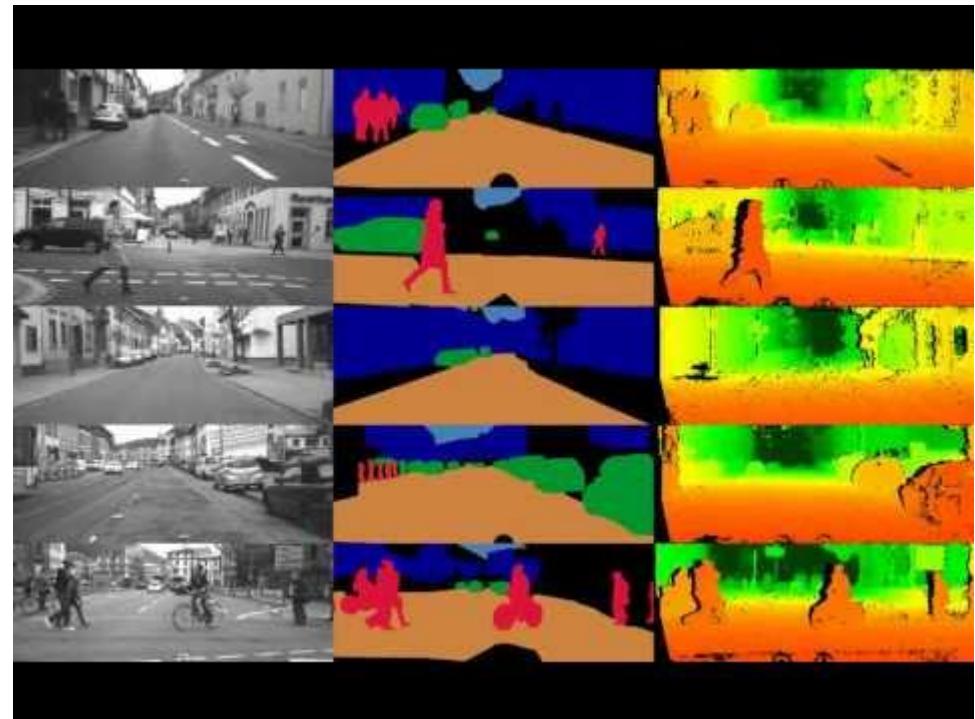
Where is everyone else?

- **Movement Planning:**

How do I get from A to B?

- **Driver State:**

What's the driver up to?



Object Detection

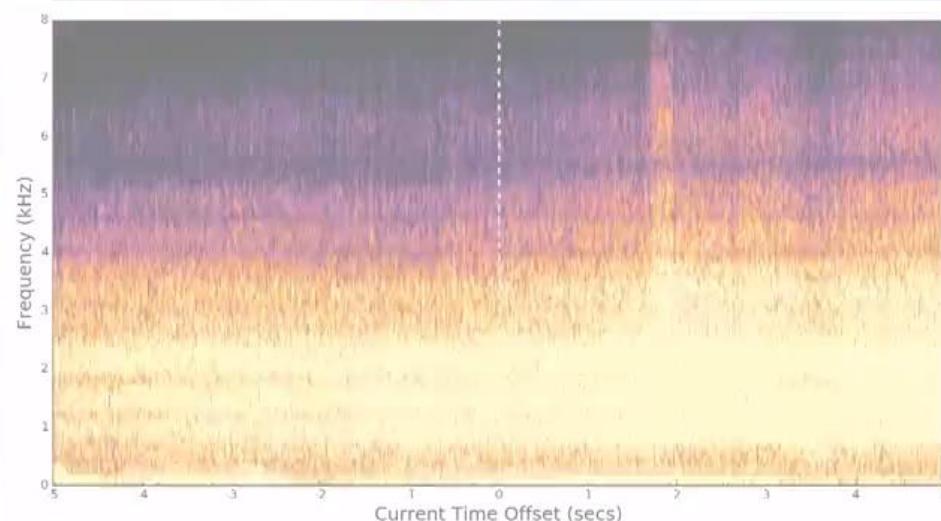
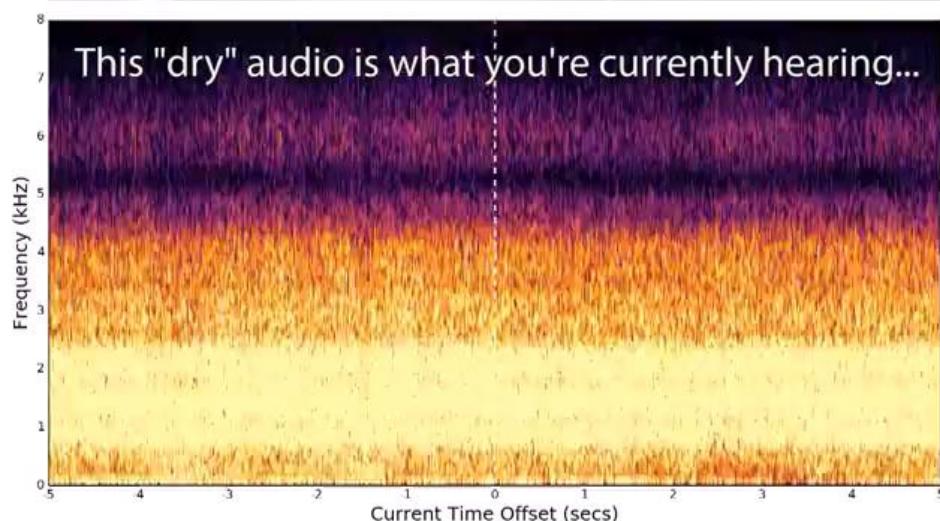


- Past approaches: cascades classifiers (Haar-like features)
- Where deep learning can help:
recognition, classification, detection

Driving Scene Segmentation

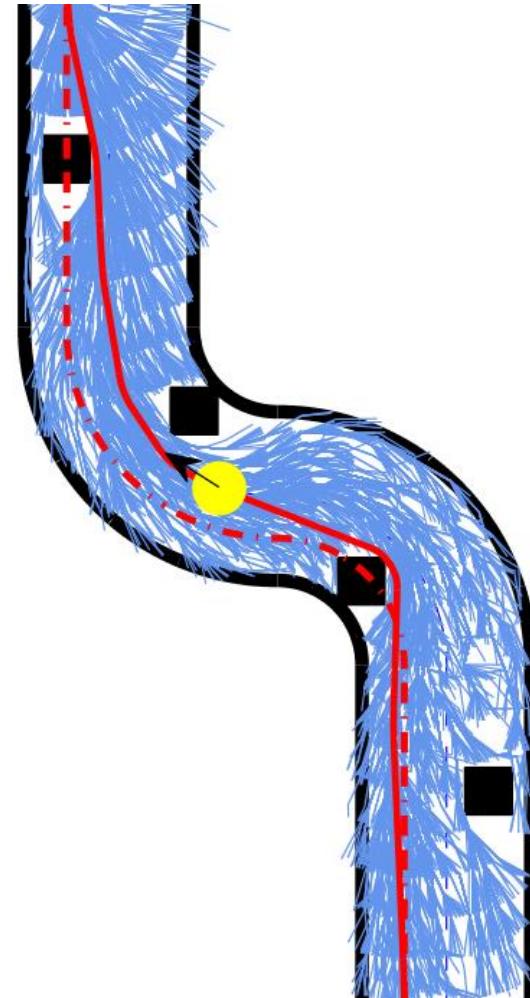


Road Texture and Condition from Audio (with Recurrent Neural Networks)

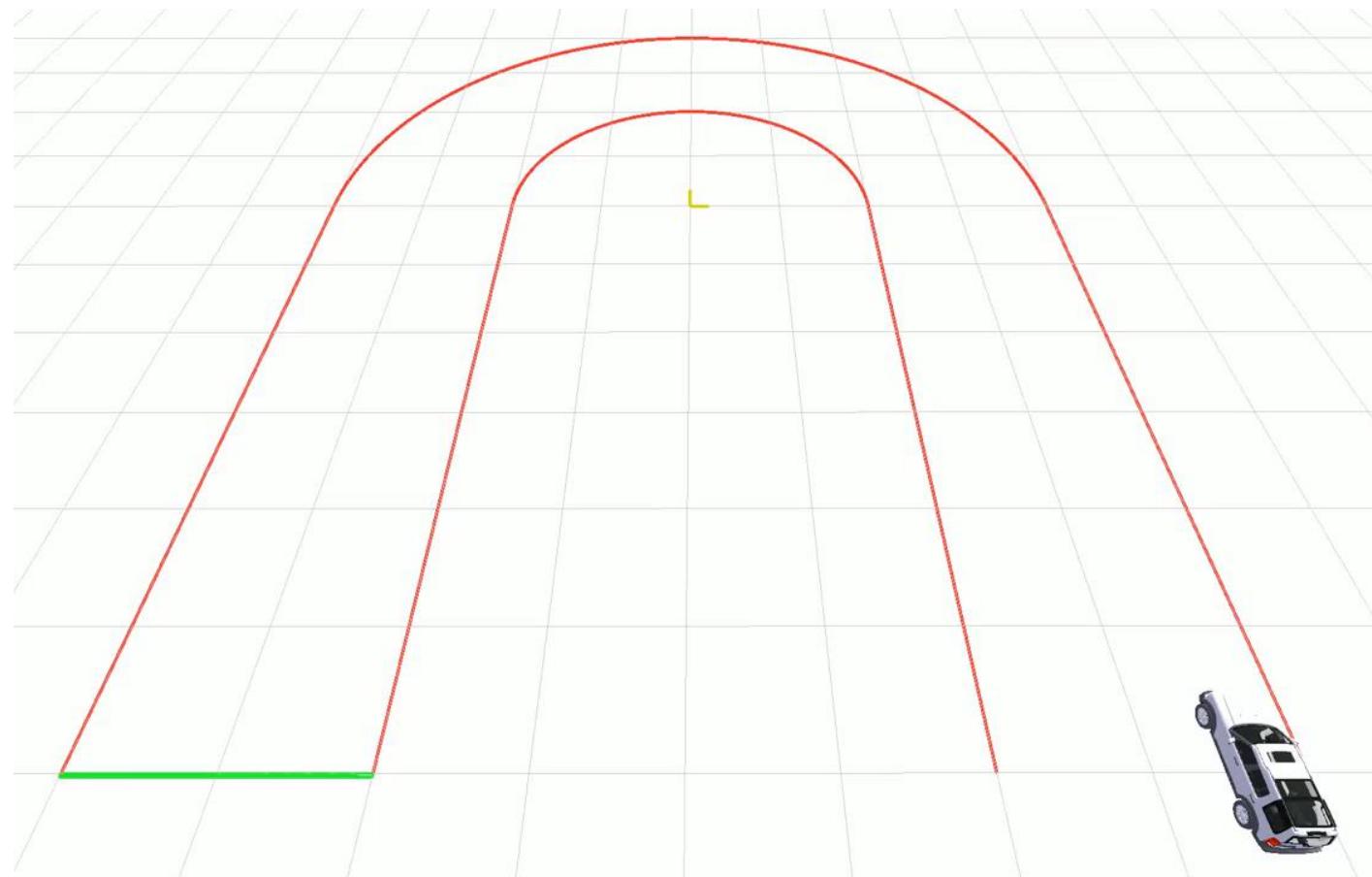


Self-Driving Car Tasks

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Where am I?
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Where is everyone else?
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How do I get from A to B?
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- Previous approaches: optimization-based control
- Deep reinforcement learning: give the ability to deal with under-actuated control, uncertainty, motion blur, lack of sensor calibration or prior map information.

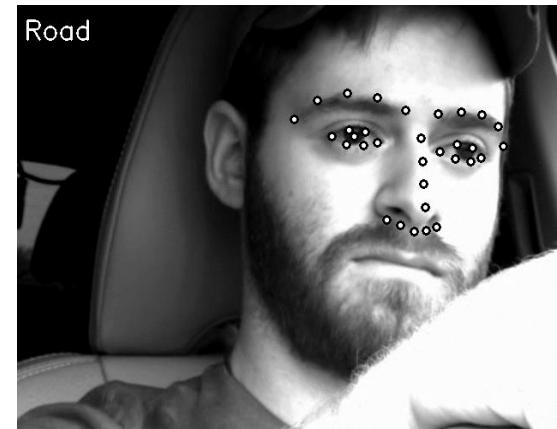


- **Previous approaches:** optimization-based control
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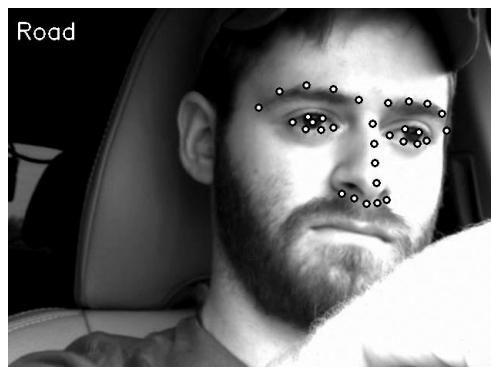
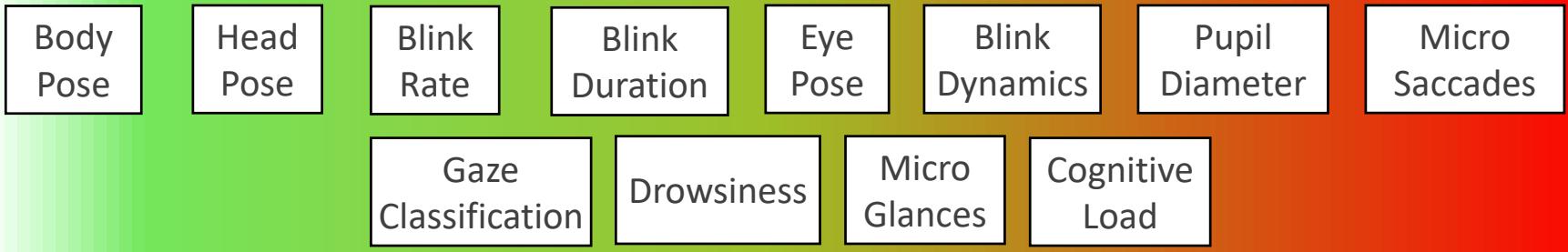
Self-Driving Car Tasks

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Where am I?
- **Object detection:**
Where is everyone else?
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What's the driver up to?



Drive State Detection: A Multi-Resolutonal View

Increasing level of detection resolution and difficulty

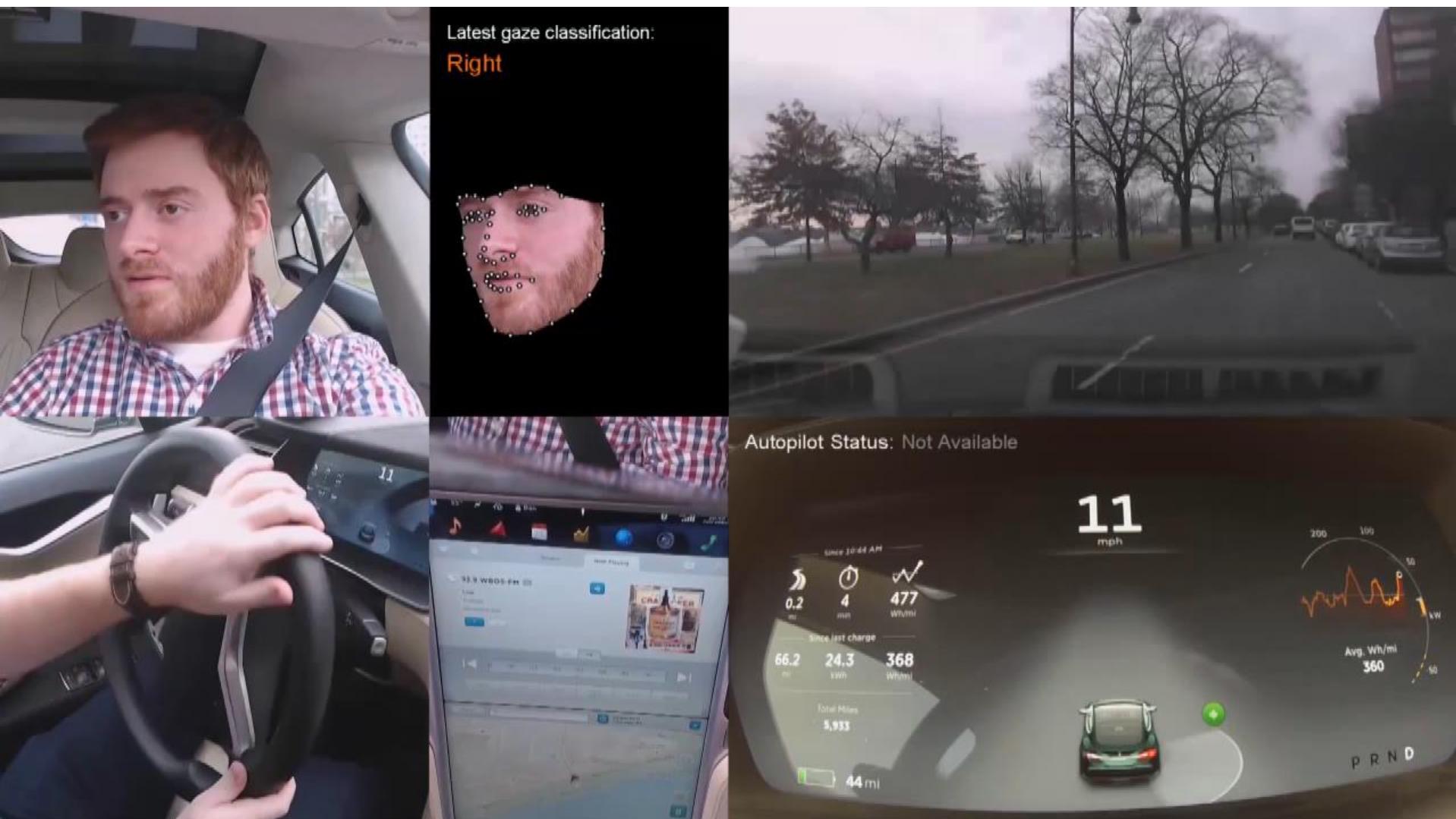


Frames: 1 Accuracy: **100%**
Time: 0.03 secs
Total Confident Decisions: 1
Correct Confident Decisions: 1
Wrong Confident Decisions: 0

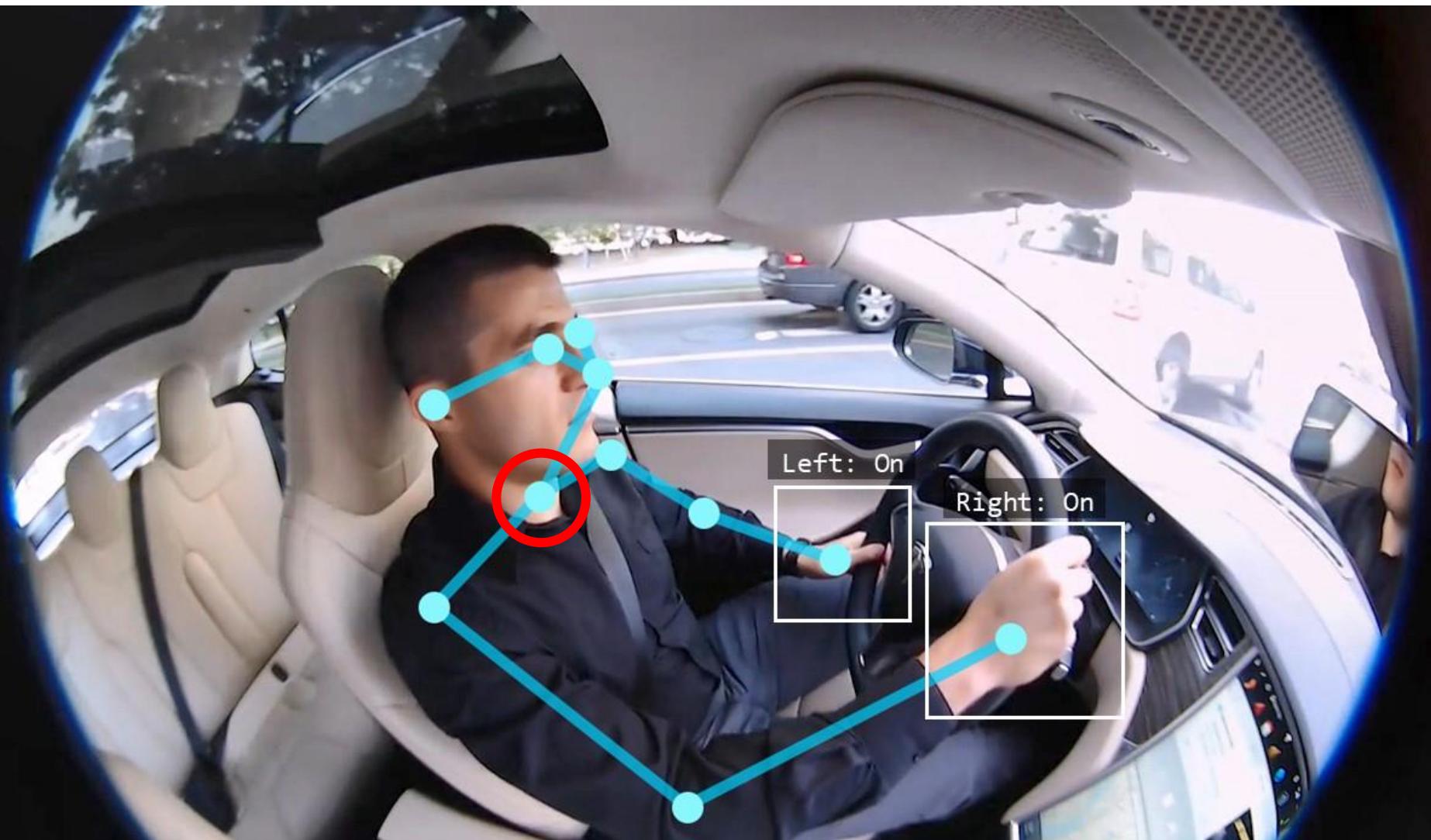


Frames: 1 Accuracy: **100%**
Time: 0.03 secs
Total Confident Decisions: 1
Correct Confident Decisions: 1
Wrong Confident Decisions: 0

Driver Glance Region Classification



Driver Body Pose Estimation



Driver Emotion

Class 1: **Satisfied** with Voice-Based Interaction



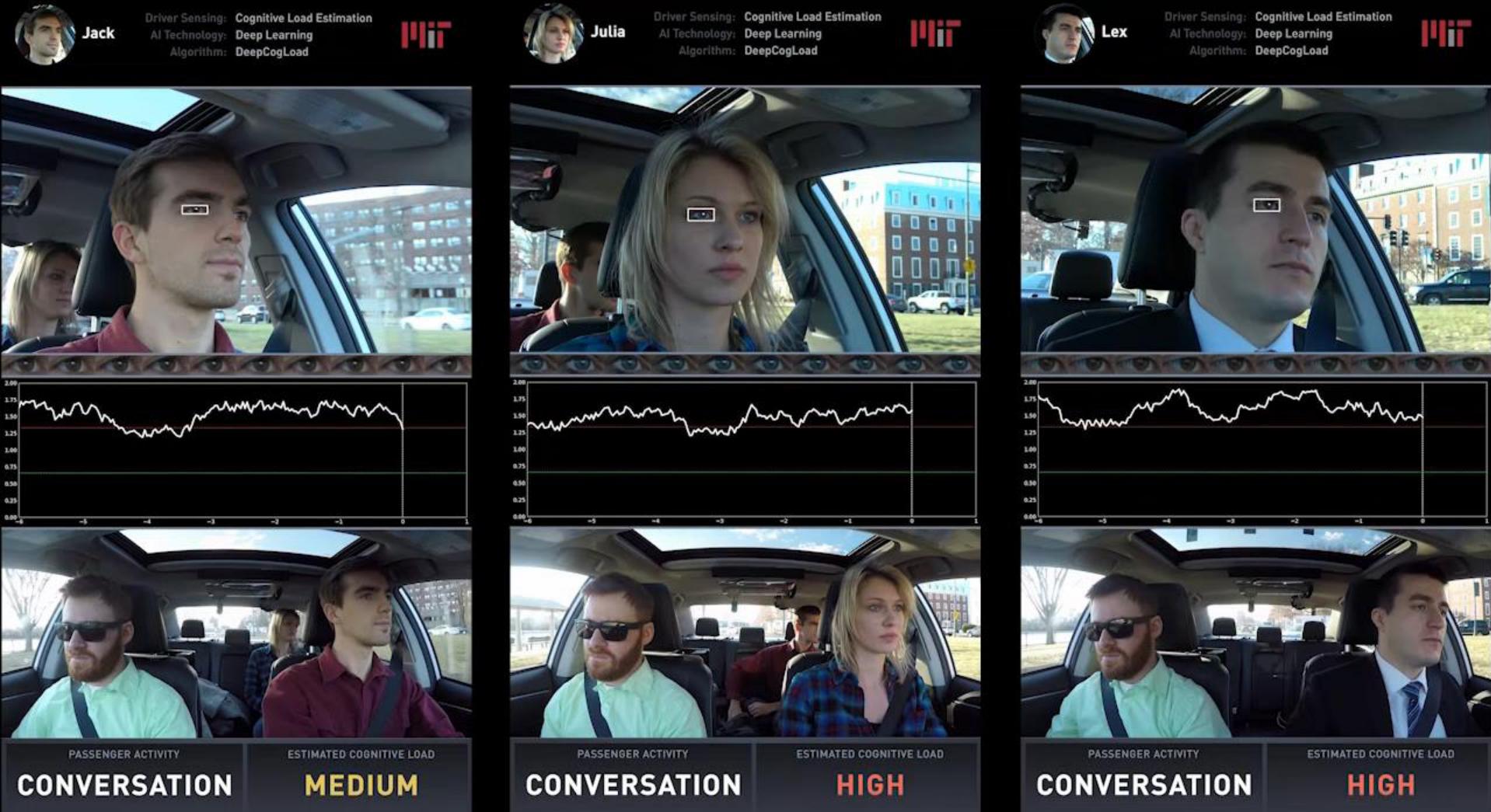
:brow furrow
:chin raiser
:disgust (image)
:eyes closed
:inner brow raise
:lip depressor
:lip press
:lip pucker
:lip raiser
:lip suck
:mouth open
:nose wrinkle
:outer brow raise
:smile
:smirk
:smirk (left)
:smirk (right)

Class 2: **Frustrated** with Voice-Based Interaction



:brow furrow
:chin raiser
:disgust (image)
:eyes closed
:inner brow raise
:lip depressor
:lip press
:lip pucker
:lip raiser
:lip suck
:mouth open
:nose wrinkle
:outer brow raise
:smile
:smirk
:smirk (left)
:smirk (right)

Cognitive Load



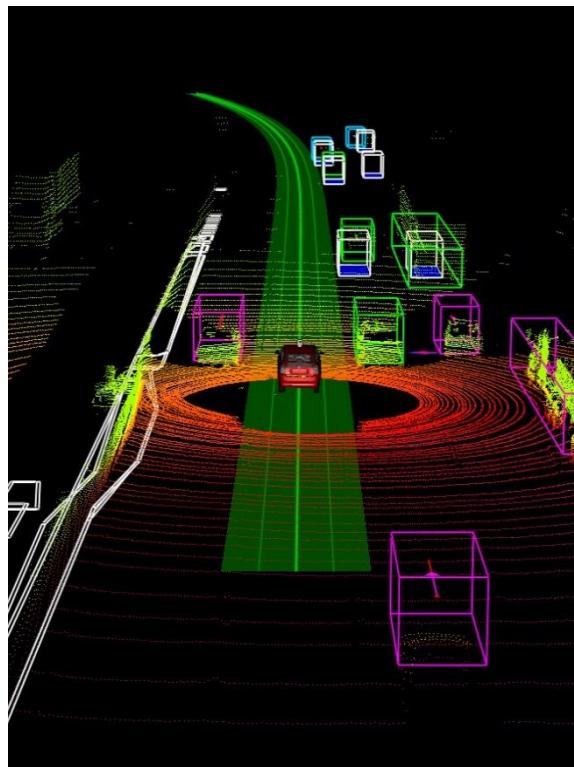
Two Paths to an Autonomous Future

A1:

Human-Centered Autonomy

- **Localization and Mapping:** Where am I?
- **Scene Understanding:** Where/who/what/why of everyone else?
- **Movement Planning:** How do I get from A to B?
- **Human-Robot Interaction:** What is the physical and mental state of the driver?
- **Communicate:** How to I convey intent to the driver and to the world?

Blue Text: Easier
Red Text: Harder



A2:

Full Autonomy

- **Localization and Mapping:** Where am I?
- **Scene Understanding:** Where/who/what/why of everyone else?
- **Movement Planning:** How do I get from A to B?
- **Human-Robot Interaction:** What is the physical and mental state of the driver?
- **Communicate:** How to I convey intent to the driver and to the world?

Full Autonomy (A2) Requires Solving This



Full Autonomy (A2) Requires Solving This



Full Autonomy (A2) Requires Solving This



Full Autonomy (A2) Requires Solving This



Full Autonomy (A2) Requires a Good Reward Function (that balances driving safety and enjoyment)



Thank You



Next lecture: Deep Reinforcement Learning

DeepTraffic

Main Page - Leaderboard - About DeepTraffic
Americans spend 8 billion hours stuck in traffic every year.
Deep neural networks can help!

```
5 lanesSide = 3;
6 patchesAhead = 30;
7 patchesBehind = 10;
8 trainIterations = 100000;
9
10 // the number of other autonomous vehicles controlled by your network
11 otherAgents = 8; // max of 9
12
13 var num_inputs = (lanesSide * 2 + 1) * (patchesAhead + patchesBehind);
```

Speed:
72 mph
Cars Passed:
195

Road Overlay:
None

Simulation Speed:
Fast

LOAD CUSTOM IMAGE
red
REQUEST VISUALIZATION
vehicle skins

Apply Code/Reset Net Save Code/Net to File Load Code/Net from File

Submit Model to Competition

New Training Start Evaluation Run

Value Function Approximating Neural Network:

