A Holistic View of Perception in Intel. Vehicles

Part I: Perception and Autonomy

IEEE IV 2023
IEEE INTELLIGENT VEHICLES SYMPOSIUM

OLIVES @GeorgiaTech

Georgia Tech

Objectives

Objectives in Part I

- Summarize the progress of AVs over the years
- Discuss the role of perception in AVs and where it fits within the AV workflow
- Review well-known failures of AVs in providing safety to drivers and to others
- Discuss major technical challenges currently facing AV
- Motivate deep learning as a holistic solution to perception challenges

Perception
What is Perception?

ME!!!!

What is perception?

See, process, understand.

https://www.animalcognition.org/2015/04/15/list-of-animals-that-have-passed-the-mirror-test/

Perception

Perception in AVs

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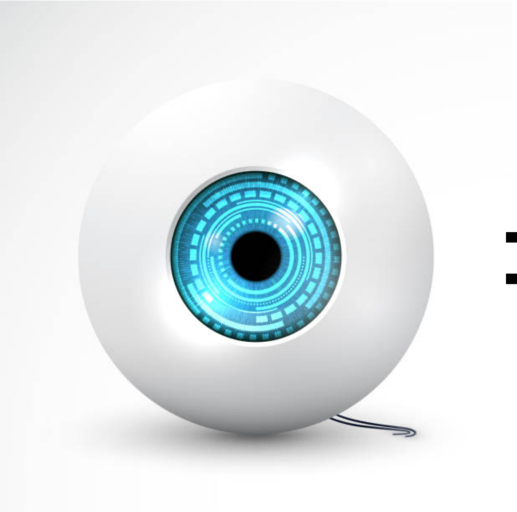

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Perception in AVs

Tsubaka Mechanical Engineering Laboratory (1977)

First standalone “autonomous” vehicle

Automatically Operated Car

Technology demonstrated:

Two video cameras and an analog computer onboard for image processing, Detect street markings

Tsubaka: Srinivas Rao, P., Gudla, R., Telidevulapalli, V. S., Kota, J. S., & Mandha, G. (2022). Review on self-driving cars using neural network architectures.

Perception in AVs
Eureka PROMETHEUS Project (1987 - 1995)

New technologies demonstrated:

Vision enhancement, Lane keeping support, visibility range monitoring, Driver status monitoring, Collision avoidance, Cooperative driving, Autonomous intelligent cruise control

PROMETHEUS: https://en.wikipedia.org/wiki/Eureka_Prometheus_Project

Perception in AVs

DARPA Grand Challenge (2004 - 2005)

New technologies demonstrated:

Wide sensor suite including stereo vision, LIDAR, radar, and ultrasound sensors, sensor fusion, obstacle detection, off-road path following, path finding

Urmson, Chris, Charlie Ragusa, David Ray, Joshua Anhalt, Daniel Bartz, Tugrul Galatali, Alexander Gutierrez et al. "A robust approach to high-speed navigation for unrehearsed desert terrain." *Journal of Field Robotics* 23, no. 8 (2006): 467-508.

Georgia Tech in DARPA Challenge

Need for Failsafe in AVs

Video/News Articles

Remote Repositioning

A driver in the Cloud Remotely Drives a Completely Equipped Vehicle

New technologies demonstrated:

Low latency failsafe mechanisms in connected cars

AV statistics in California (Dec 2019 – Nov 2020)

Company	Country	Miles	Miles per disengagement
Waymo (Alphabet)	USA	628,839	29,945
Cruise (GM)	USA	770,049	28,520
AutoX	China	40,734	20,367
Pony.AI	China	225,496	10,738
Argo.AI (Ford, VW)	USA	21,037	10,519
WeRide	China	13,014	6,507
DiDi Chuxing	China	10,401	5,201
Nuro	USA	55,370	5,034

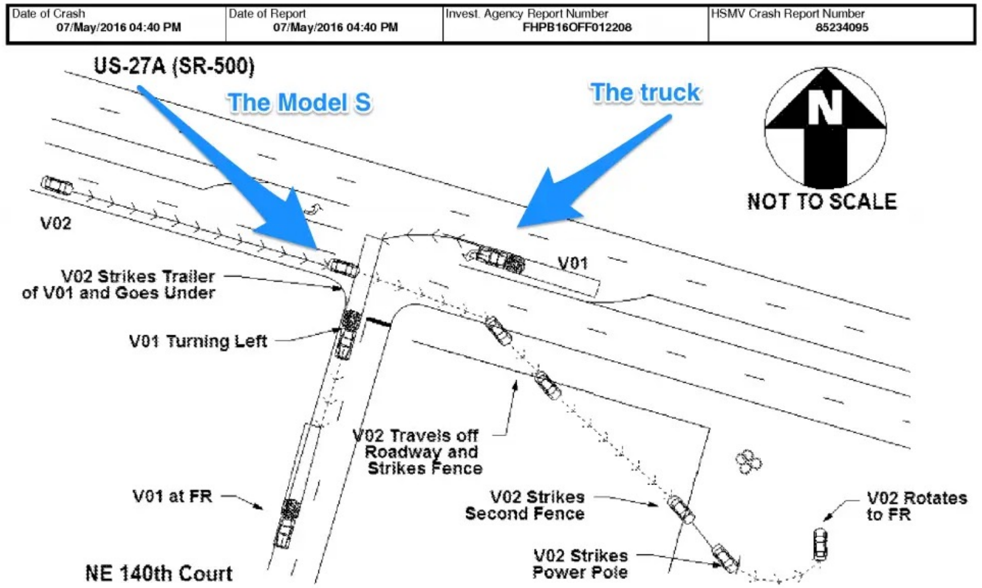
Disengagement: Cases where the car's software detects a failure or the driver perceived a failure, resulting in control being seized by the driver.

[Tutorial] | [Ghassan AlRegib and Mohit Prabhushankar] | [June 4, 2023]

Source: https://www.statista.com/chart/17144/test-miles-and-reportable-miles-per-disengagement/

Tesla driver dies in first fatal crash while using autopilot mode

The autopilot sensors on the Model S failed to distinguish a white tractor-trailer crossing the highway against a bright sky



Autopilot didn't detect the trailer as an obstacle (NHTSA investigation and Tesla statements)

1. The National Highway Traffic Safety Administration (NHTSA) determined that a "lack of safeguards" contributed to the death
2. "Neither Autopilot nor the driver noticed the white side of the tractor trailer against a brightly lit sky, so the brake was not applied," Tesla said.

Uber's self-driving SUV saw the pedestrian in fatal accident but didn't brake, officials say

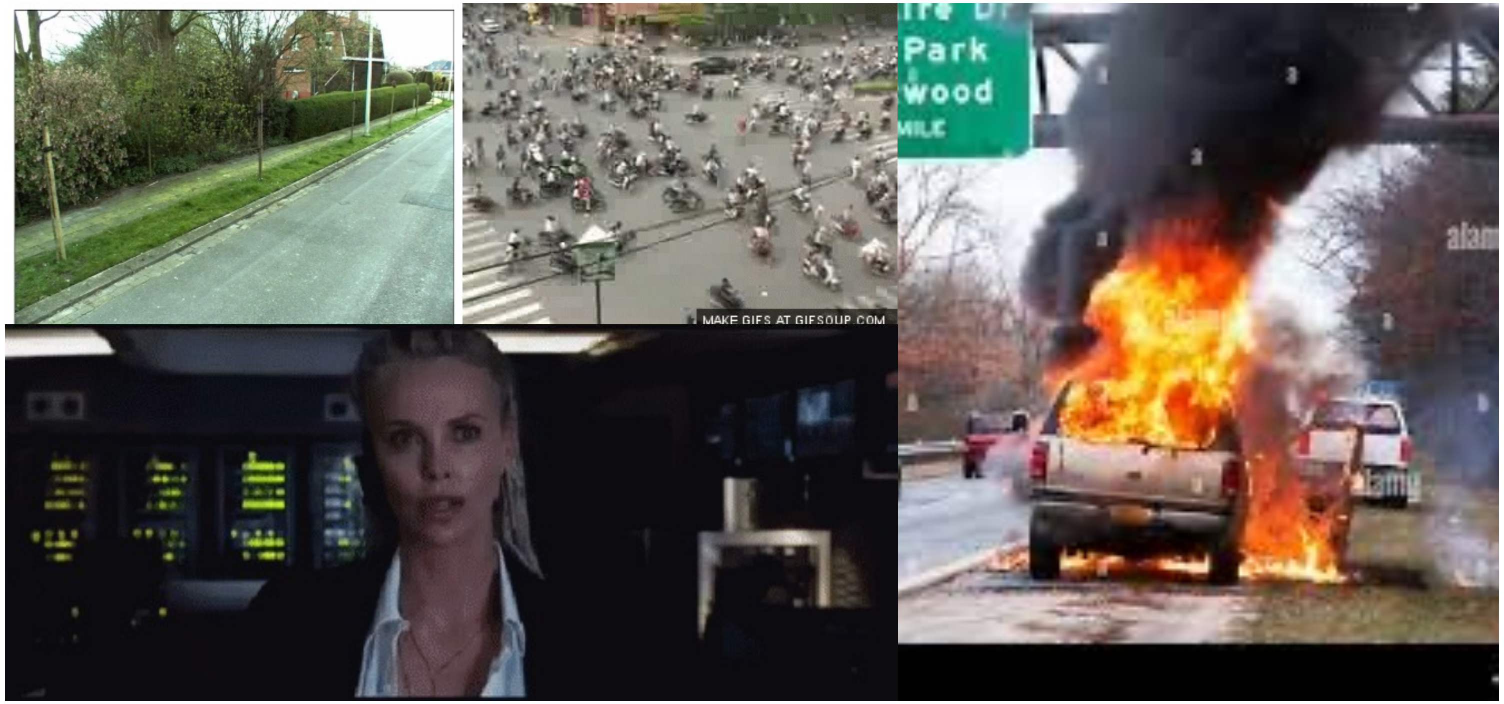
PUBLISHED THU, MAY 24 2018•9:52 AM EDT | UPDATED THU, MAY 24 2018•10:43 AM EDT

Sensors on the fully autonomous Volvo XC-90 SUV spotted [redacted] while the car was traveling 43 miles per hour and determined that braking was needed 1.3 seconds before impact, according to the report.

1. https://www.telegraph.co.uk/technology/2018/03/20/ubers-fatal-accident-end-driverless-cars/
2. https://www.cnbc.com/2018/05/24/ubers-self-driving-suv-saw-the-pedestrian-in-fatal-accident-but-didnt-brake-officials-say.html

Perception in AVs
Technical Challenges

- Challenging weather
- Challenging sensing
- Challenging environments
- Context awareness
- Embedded perception
- V2X perception



Technical Challenges in Perception for AVs
Challenging Sensing and Weather

- Challenging weather
- Challenging sensing
- Challenging environments
- Context awareness
- Embedded perception
- V2X perception

Temel, Dogancan, et al. "Cure-tsd: Challenging unreal and real environments for traffic sign detection." *IEEE Transactions on Intelligent Transportation Systems* (2017).

Technical Challenges in Perception for AVs

Challenging Environments

- Challenging weather
- Challenging sensing
- Challenging environments
- Context awareness
- Embedded perception
- V2X perception

Dokania, S., Hafez, A. H., Subramanian, A., Chandraker, M., & Jawahar, C. V. (2023). IDD-3D: Indian Driving Dataset for 3D Unstructured Road Scenes. In *Proceedings of the IEEE/CVF Winter Conference on Applications of Computer Vision* (pp. 4482-4491).

Technical Challenges in Perception for AVs
Context Awareness

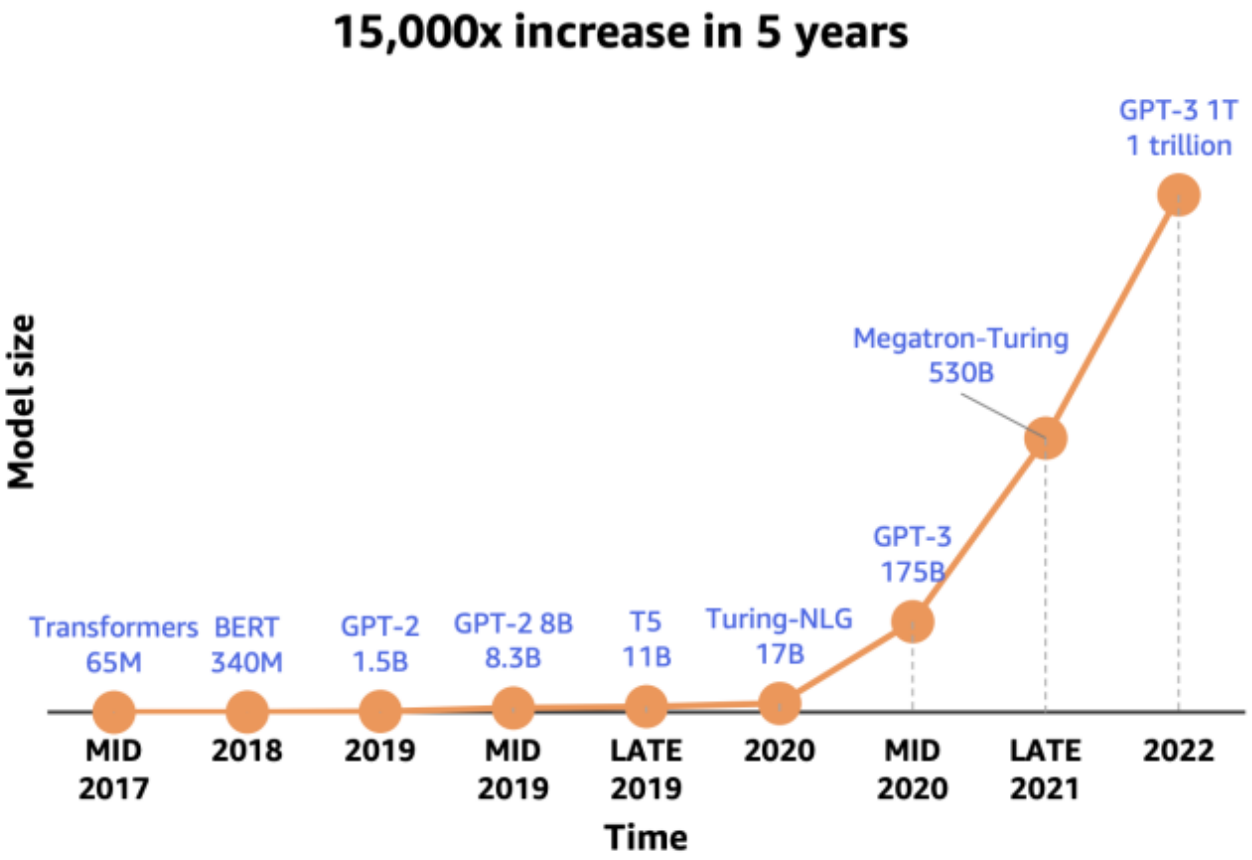
Does the fire impede mobility?

- Challenging weather
- Challenging sensing
- Challenging environments
- Context awareness
- Embedded perception
- V2X perception

Technical Challenges in Perception for AVs
Embedded Perception

On-board computational capabilities of modern deep learning algorithms is a challenge

- Challenging weather
- Challenging sensing
- Challenging environments
- Context awareness
- Embedded perception
- V2X perception



Technical Challenges in Perception for AVs

V2X Perception

Source: Fast and Furious 8!

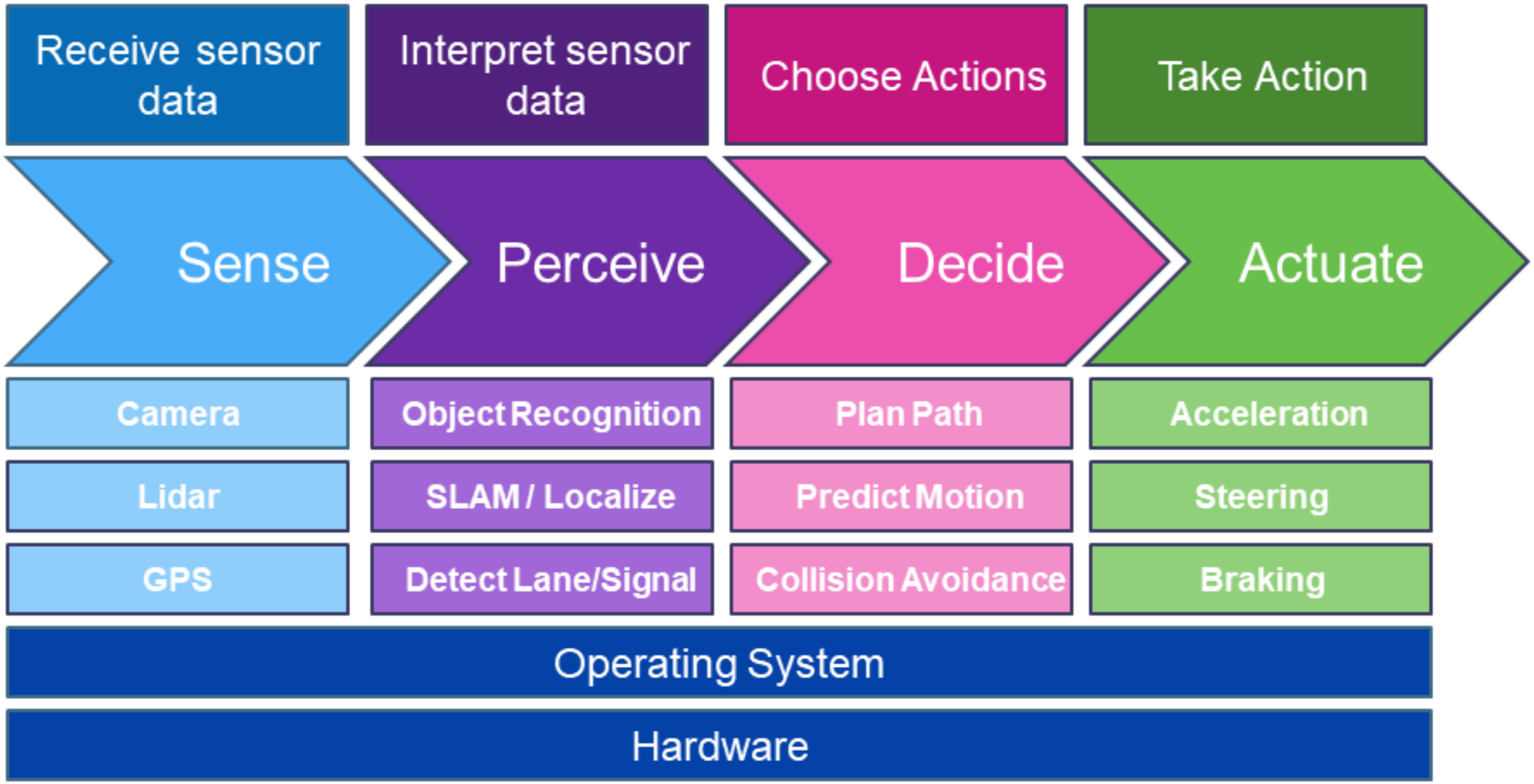
- Challenging weather
- Challenging sensing
- Challenging environments
- Context awareness
- Embedded perception
- V2X perception

Role of Perception
Role of Perception within AVs

Role of Perception:

- Filter,
- process, and
- understand

sensor data



Wards Intelligence, **Smarter Than Humans? AI for AVs: Sensing, Perception, Prediction and Planning**

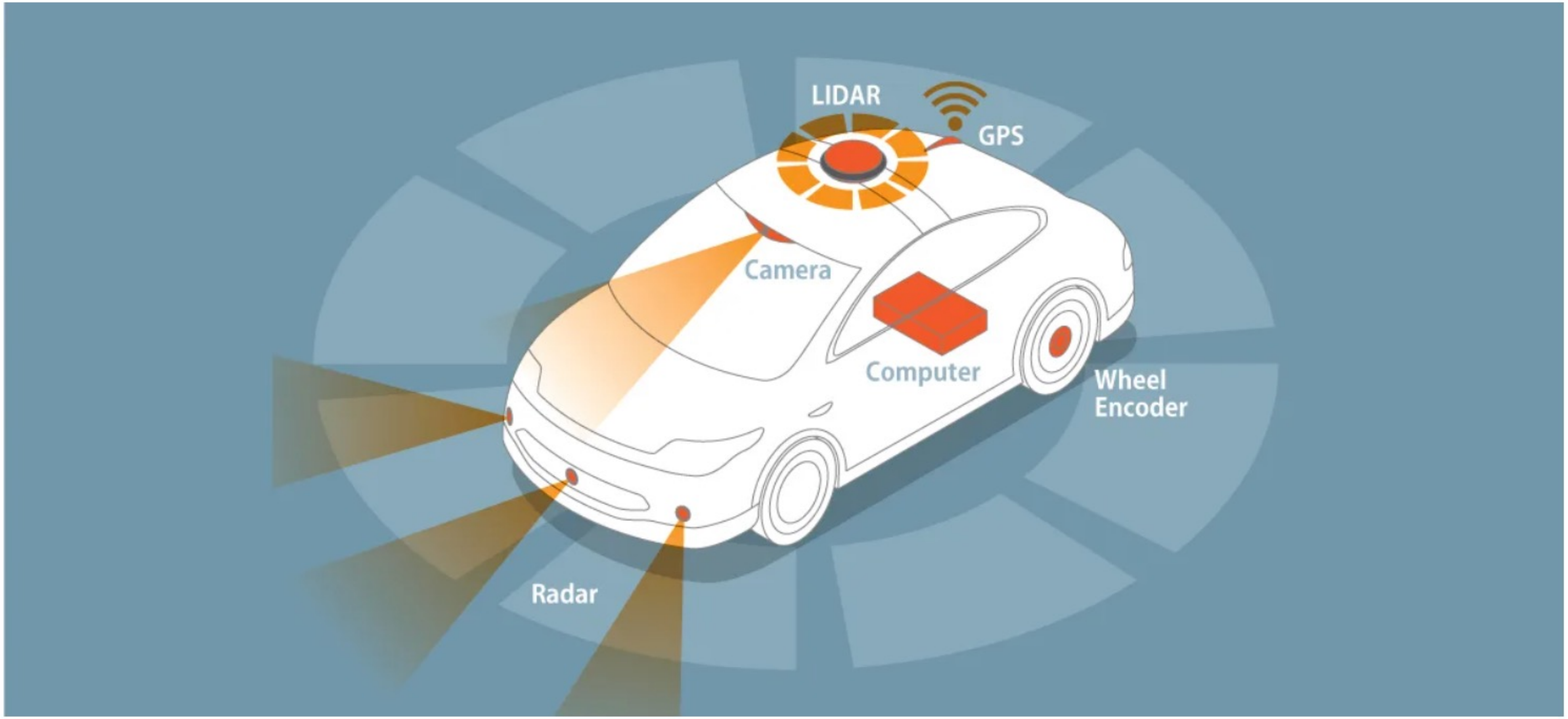
Sensors
Role of Sensors for Perception

Tsubaka Mechanical Engineering Laboratory (1977) → Eureka PROMETHEUS Project (1987 - 1995) → DARPA Grand Challenge (2004 - 2005)

More sensors and better fusion strategies!

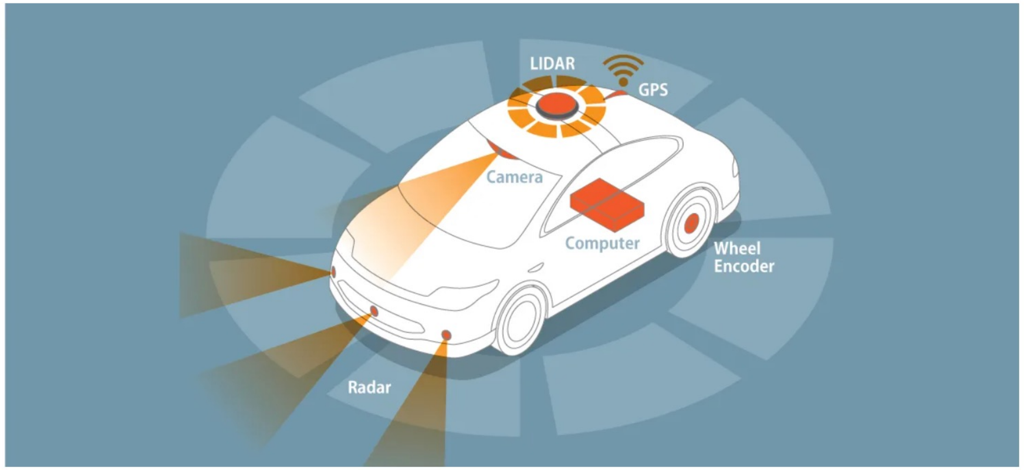
Sensors

How can we choose the "appropriate" Sensors?



Sensors
Choosing the Appropriate Sensors

- Sensors need to work under **challenging weather conditions**
- Sensors need to have sensing capacity and resolution in meeting **challenging sensing environments**
- Sensors must be **cost** effective
- Sensor fusion and sensor registration must be **computationally effective**
- Sensors must output minimum **noise** or their working ranges must be known in advance
- Sensor data must be resistant to **cyber and adversarial attacks**



Sensors
Choosing the Appropriate Sensors

Factors	Camera	LiDAR	Radar	Fusion
Range	~	~	✓	✓
Resolution	✓	~	×	✓
Distance Accuracy	~	✓	✓	✓
Velocity	~	×	✓	✓
Color Perception, e.g., traffic lights	✓	×	×	✓
Object Detection	~	✓	✓	✓
Object Classification	✓	~	×	✓
Lane Detection	✓	×	×	✓
Obstacle Edge Detection	✓	✓	×	✓
Illumination Conditions	×	✓	✓	✓
Weather Conditions	×	~	✓	✓

Yeong, D. J., Velasco-Hernandez, G., Barry, J., & Walsh, J. (2021). Sensor and sensor fusion technology in autonomous vehicles: A review. *Sensors*, *21*(6), 2140.

Sensors
Choosing the Appropriate Sensors

TABLE I
DIFFERENT SENSORS USED IN AV DEVELOPMENT

Vehicle	A#	B	C	D	E	F
Audi's Research Vehicle [48]	Y	Y	Y	Y	Y	Y
Ford: Hybrid Fusion [49]	Y			Y	Y	Y
Google: Toyota Prius [50]	Y	Y		Y	Y	
Nagoya and Nagasaki University's Open ZMP Robocar HV (Toyota Prius) [51]	Y			Y		
Volvo: (Stoklosa, Cars) [52]	Y		Y	Y	Y	Y
Apple: Lexus RX450h SUVs [53]	Y		Y	Y	Y	Y
DIDI's research vehicle [54]	Y		Y	Y	Y	Y
Infiniti Q50S [55]	Y				Y	Y
Lexus RX [56]	Y				Y	Y
Volvo XC90 [57]	Y				Y	Y
BMW750i xDrive [58]	Y	Y	Y		Y	Y
Mercedes-Benz E & S-Class [55]	Y	Y	Y		Y	Y
Otto Semi-Trucks [59]	Y			Y	Y	
Renault GT Nav [60]	Y				Y	Y
Tesla Model S [61]	Y				Y	Y
Baidu Apollo [62]	Y				Y	Y

#Note: A:Vision; B:Stereovision; C:IR Camera; D:LIDAR; E:Radar; and F:Sonar.

Ma, Y., Wang, Z., Yang, H., & Yang, L. (2020). Artificial intelligence applications in the development of autonomous vehicles: A survey. *IEEE/CAA Journal of Automatica Sinica*, *7*(2), 315-329.

Levels of Autonomy
Taxonomy

Current technology:

- Levels 1 and 2 are in the market
- Extensive testing on Level 3

SAE INTERNATIONAL

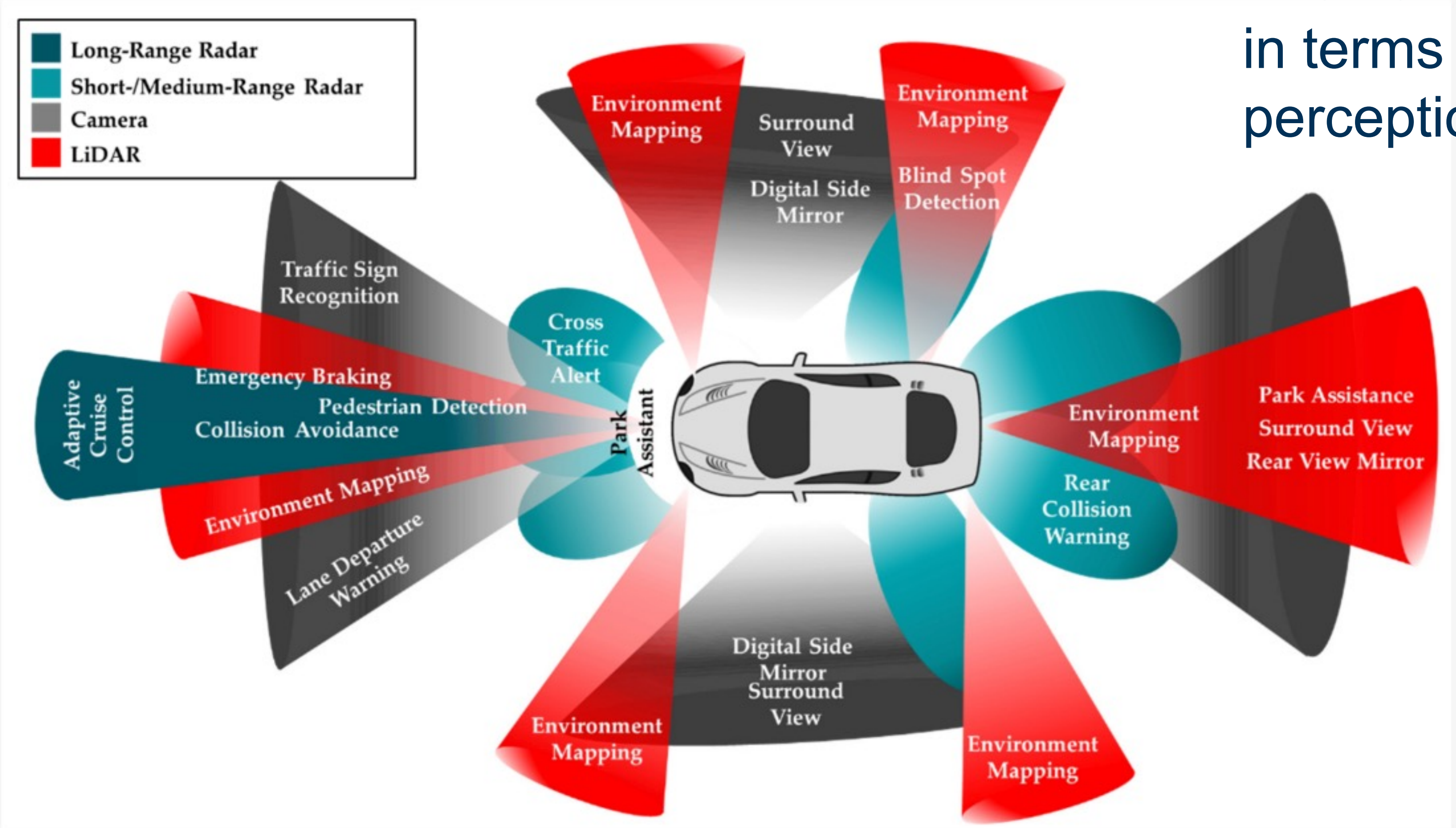
SAE J3016™ LEVELS OF DRIVING AUTOMATION™

Learn more here: sae.org/standards/content/j3016_202104

	SAE LEVEL 0™	SAE LEVEL 1™	SAE LEVEL 2™	SAE LEVEL 3™	SAE LEVEL 4™	SAE LEVEL 5™
What does the human in the driver's seat have to do?	**You are driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			**You are not driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			**These are automated driving features**		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering **OR** brake/ acceleration support to the driver	These features provide steering **AND** brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering **OR** • adaptive cruise control	• lane centering **AND** • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

https://www.sae.org/blog/sae-j3016-update

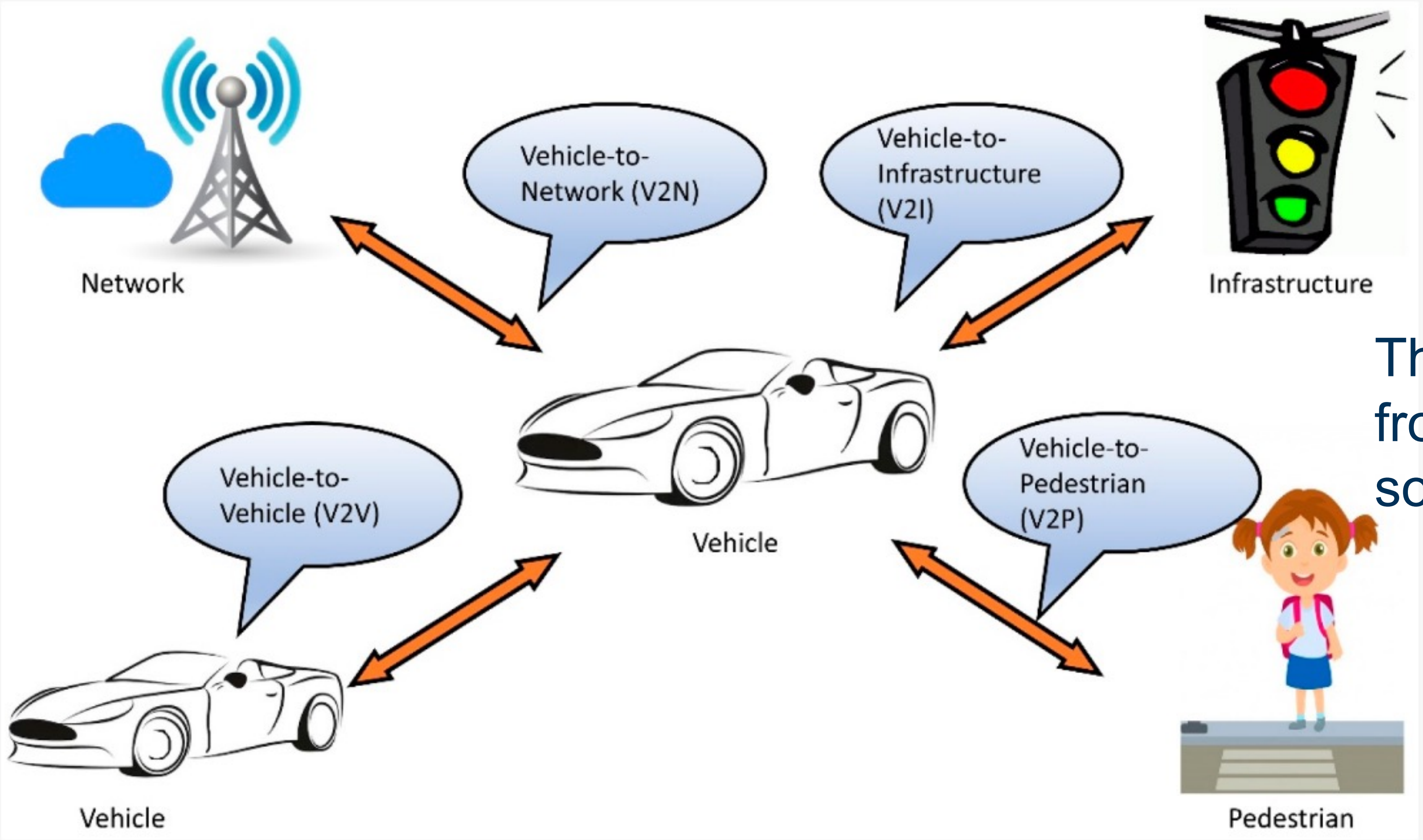
Levels of Autonomy
Levels 1 and 2 Autonomy



The vehicle is self-sufficient in terms of onboard sensors and perception!

Yeong, De Jong, Gustavo Velasco-Hernandez, John Barry, and Joseph Walsh. "Sensor and sensor fusion technology in autonomous vehicles: A review." *Sensors* 21, no. 6 (2021): 2140.

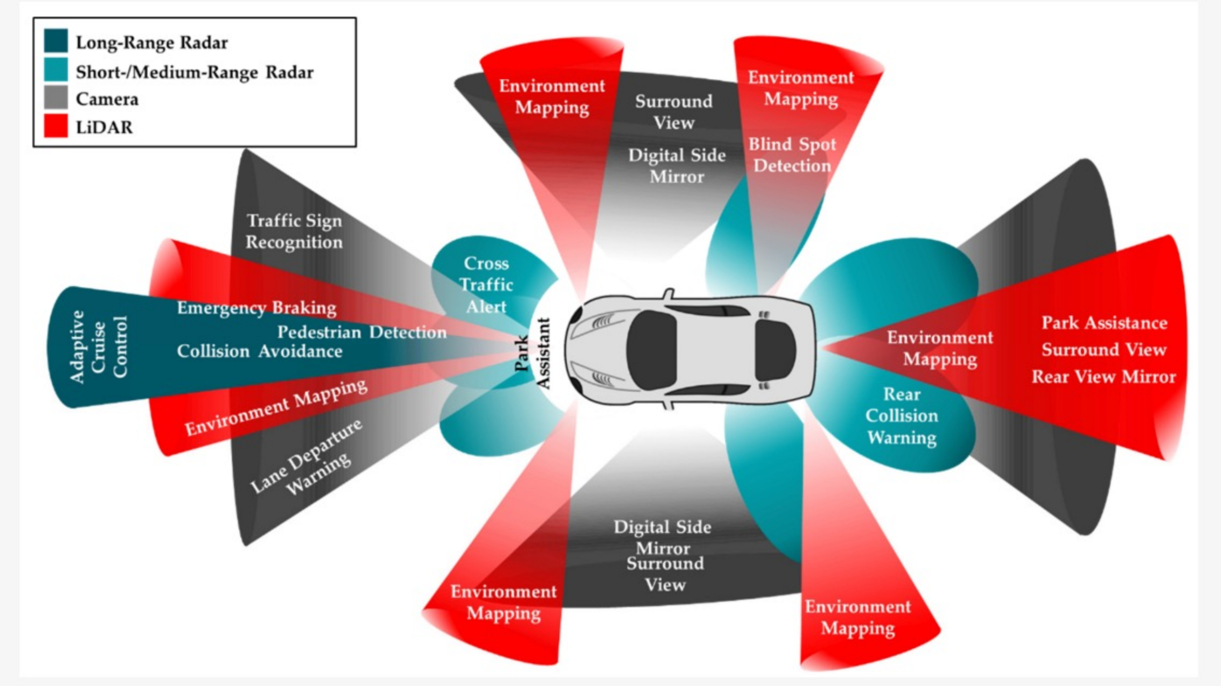
Levels of Autonomy
Levels 3 and Beyond

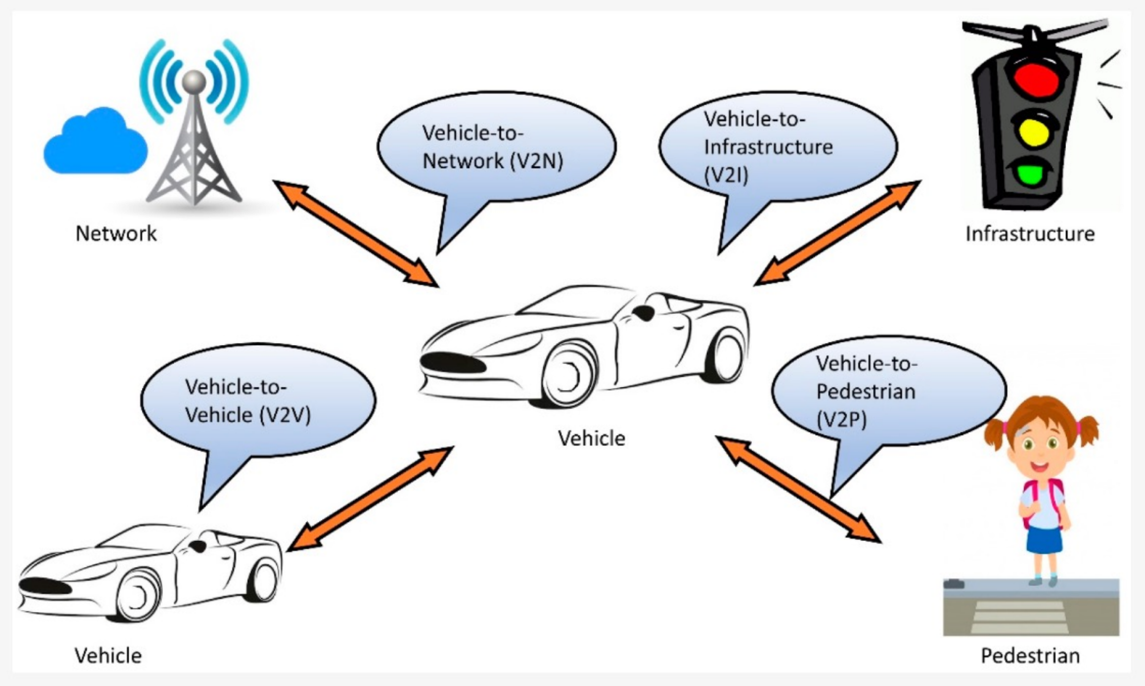


The vehicle needs help from other sensors, sources, and processors!

Haque, K. F., Abdelgawad, A., Yanambaka, V. P., & Yelamarthi, K. (2020). Lora architecture for v2x communication: An experimental evaluation with vehicles on the move. *Sensors*, *20*(23), 6876.

Levels of Autonomy
Achieving Perception



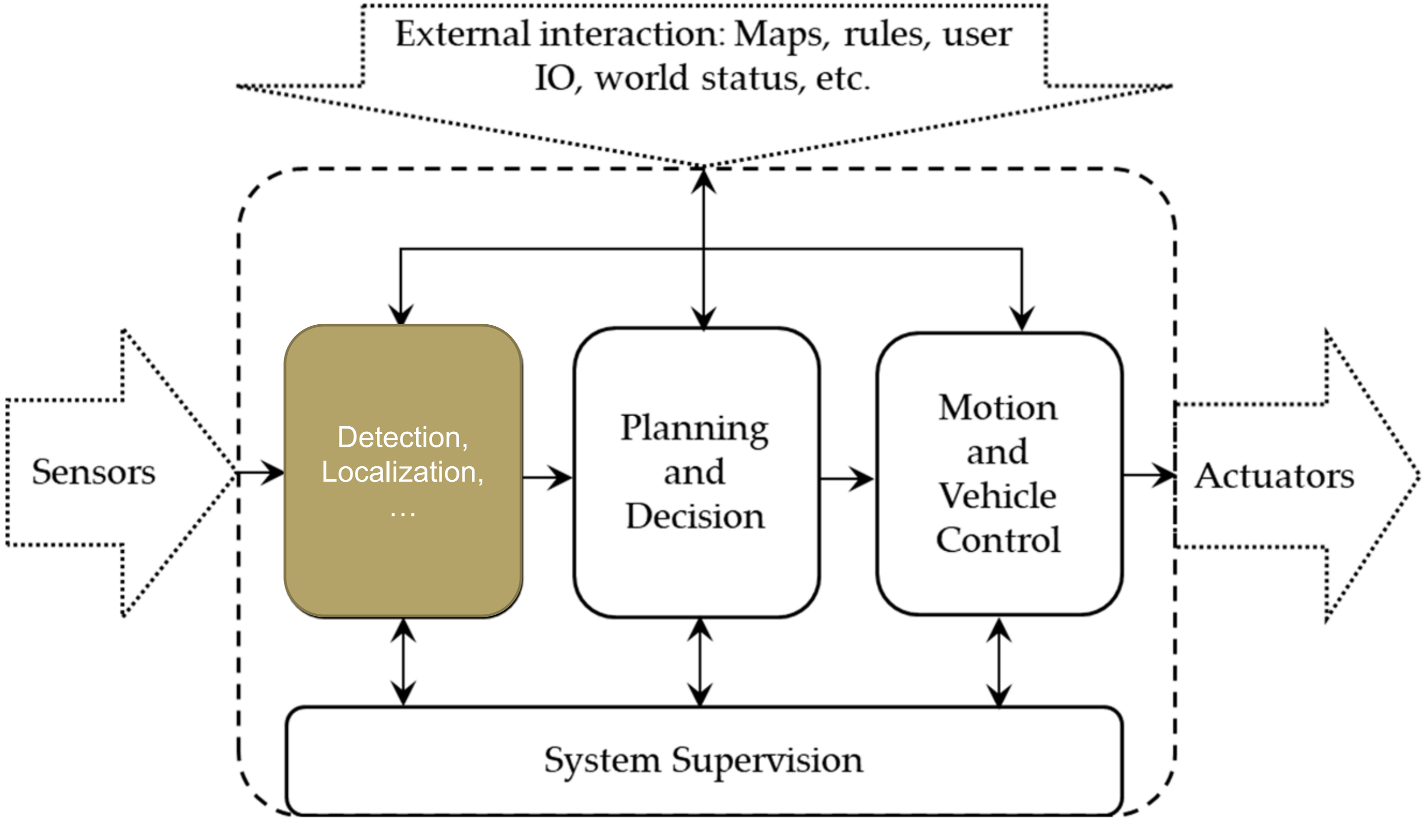


How to filter, process, and understand sensor data?

Yeong, De Jong, Gustavo Velasco-Hernandez, John Barry, and Joseph Walsh. "Sensor and sensor fusion technology in autonomous vehicles: A review." *Sensors* 21, no. 6 (2021): 2140.

Levels of Autonomy
Achieving Perception

Before: Perception is decomposed into a number of manageable applications



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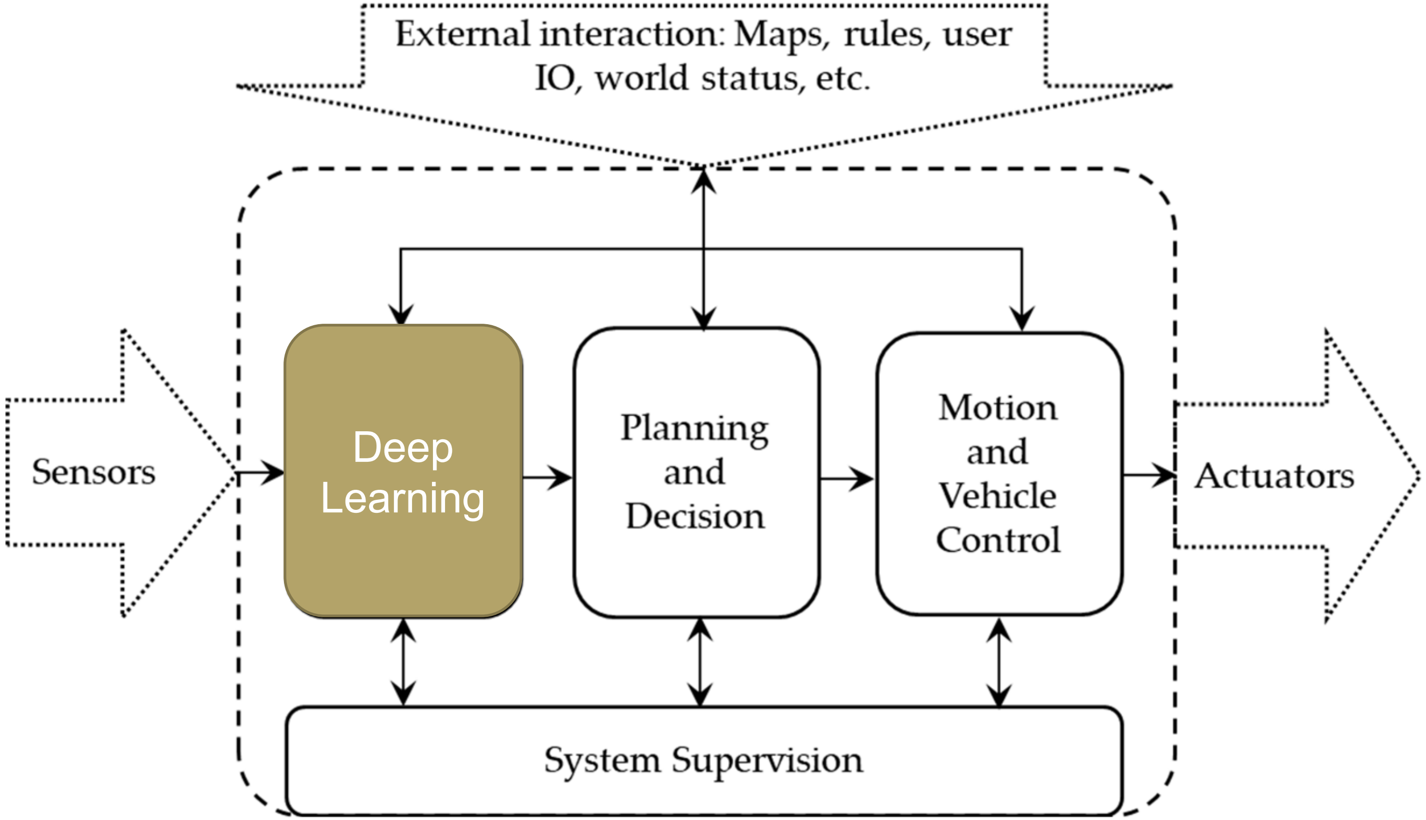
Levels of Autonomy
Goal of the Tutorial

Deep Learning: Provides a holistic solution to perception



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Objectives
Takeaways from Part I

- **Part I: Challenges in Perception and Autonomy**
  - Robustness under challenging conditions, environments, context and surroundings-awareness are challenges in AV perception
  - Deep Learning promises a holistic solution to a number of the above challenges
- Part II: Deep Learning for Perception
- Part III: Existing Deep Learning solutions to Challenges in Perception
- Part IV: Remaining Challenges and Future Directions