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AUTOMOTIVE

Use of Machine Learning and Laser Scanner Technologies in Vehicles

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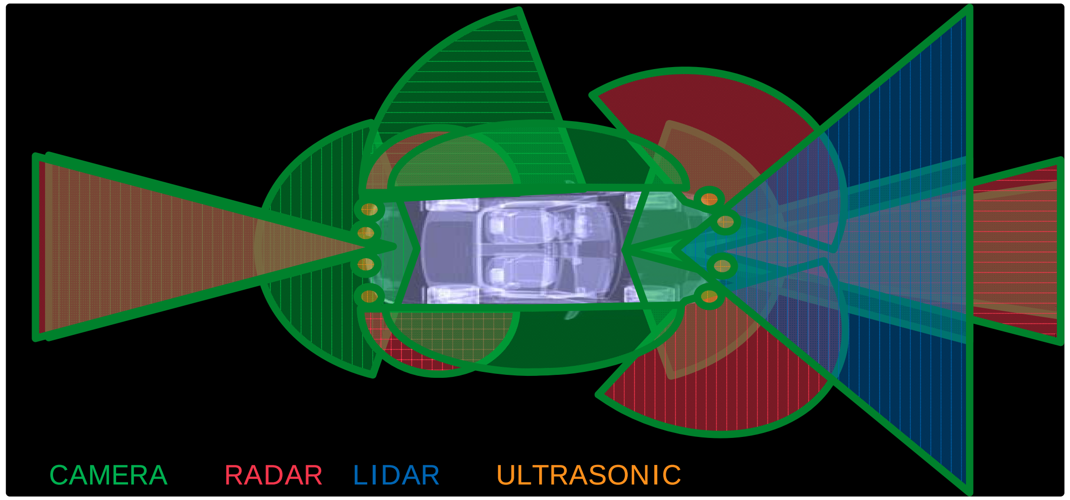
Why 2D/3D Lidar?

Omnidirectional Sensing for Driving Assistance, Active Safety, and Self-driving

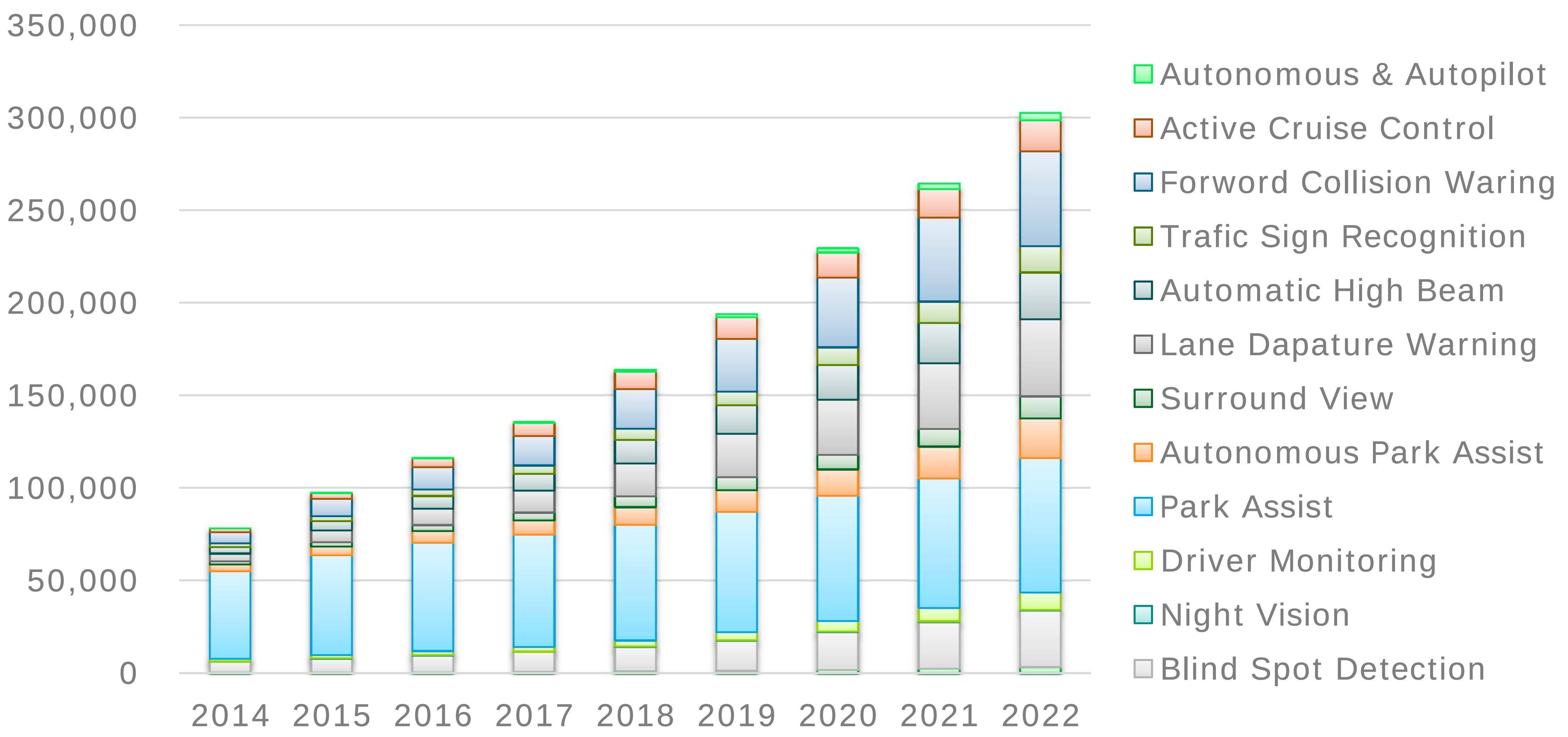
Automotive sensor	Advantages	Disadvantages
Forward-view camera	Capable of identifying objects ・Vehicles, pedestrians, bicycles, obstacles etc.	Difficult to detect under rapid environmental changes, against the sun, in heavy fog, heavy rain, or heavy snow
RADAR	Capable of measuring the distance from the object independent from the environment including weather	Difficult to identify objects due to resolution. Difficult to detect objects reflecting no radio waves
3D Lidar (Laser scanner)	Capable of identifying objects and measuring the distance under any environment	Expensive
Ultrasonic sensor	Capable of detecting presence/absence of objects or the distance over a wide range at low cost	Short detecting distance Low accuracy



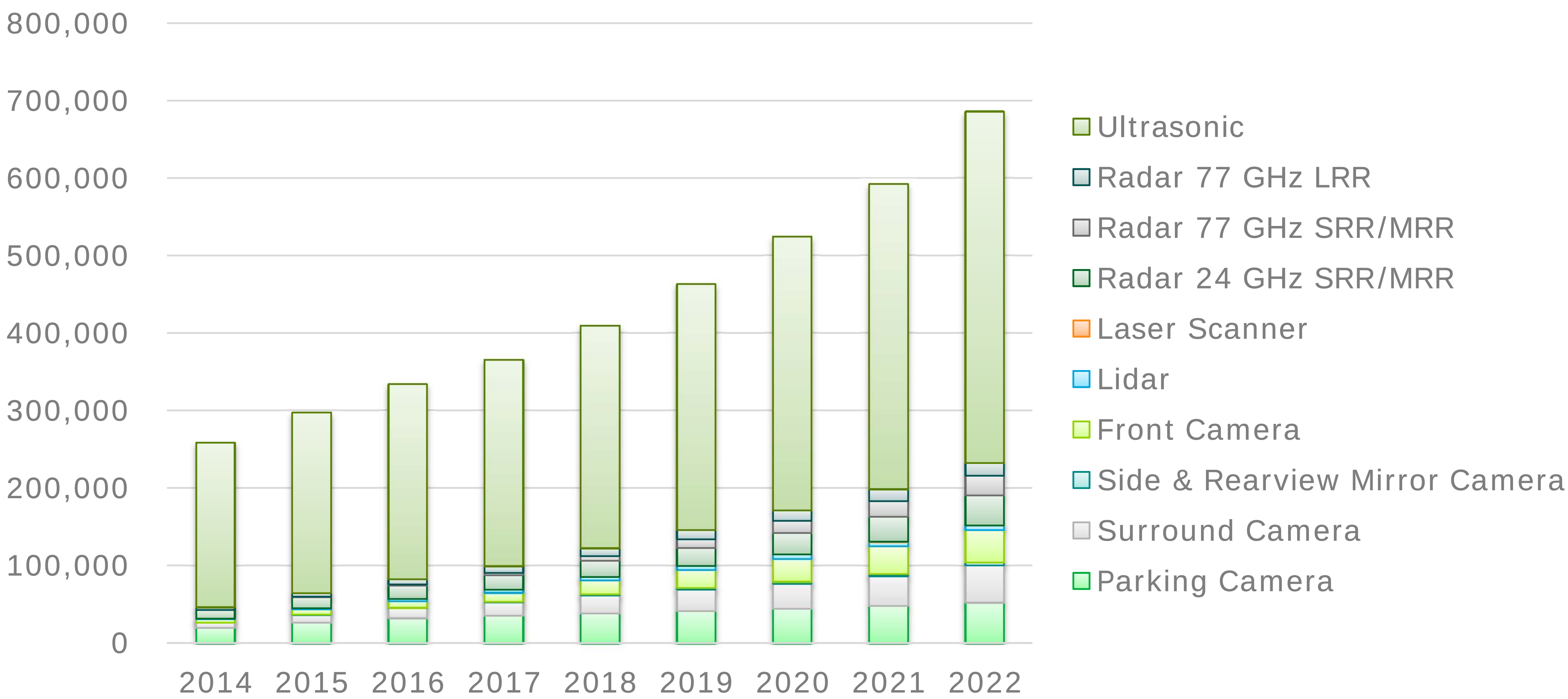
Automotive Sensor Market Summary

- Background of expanding automotive ADAS sensor market
  - Regulations (Rearview camera Monitor System etc.), voluntary consensus in the industry (e.g. AEB)
  - Omnidirectional sensing
  - Double or triple redundancy
- Further technological innovation is needed for downsizing or lowering prices
  - RF CMOS
  - Integration of multifocal camera and sensor technologies
  - LIDAR (2D/3D laser scanner) is a necessary sensor for development of self-driving cars. The challenge is how to reduce costs
- Others
  - Security measures against false recognition, interference, or hacking
  - Machine learning (artificial intelligence), sensor fusion computer (Automotive Super Computer)

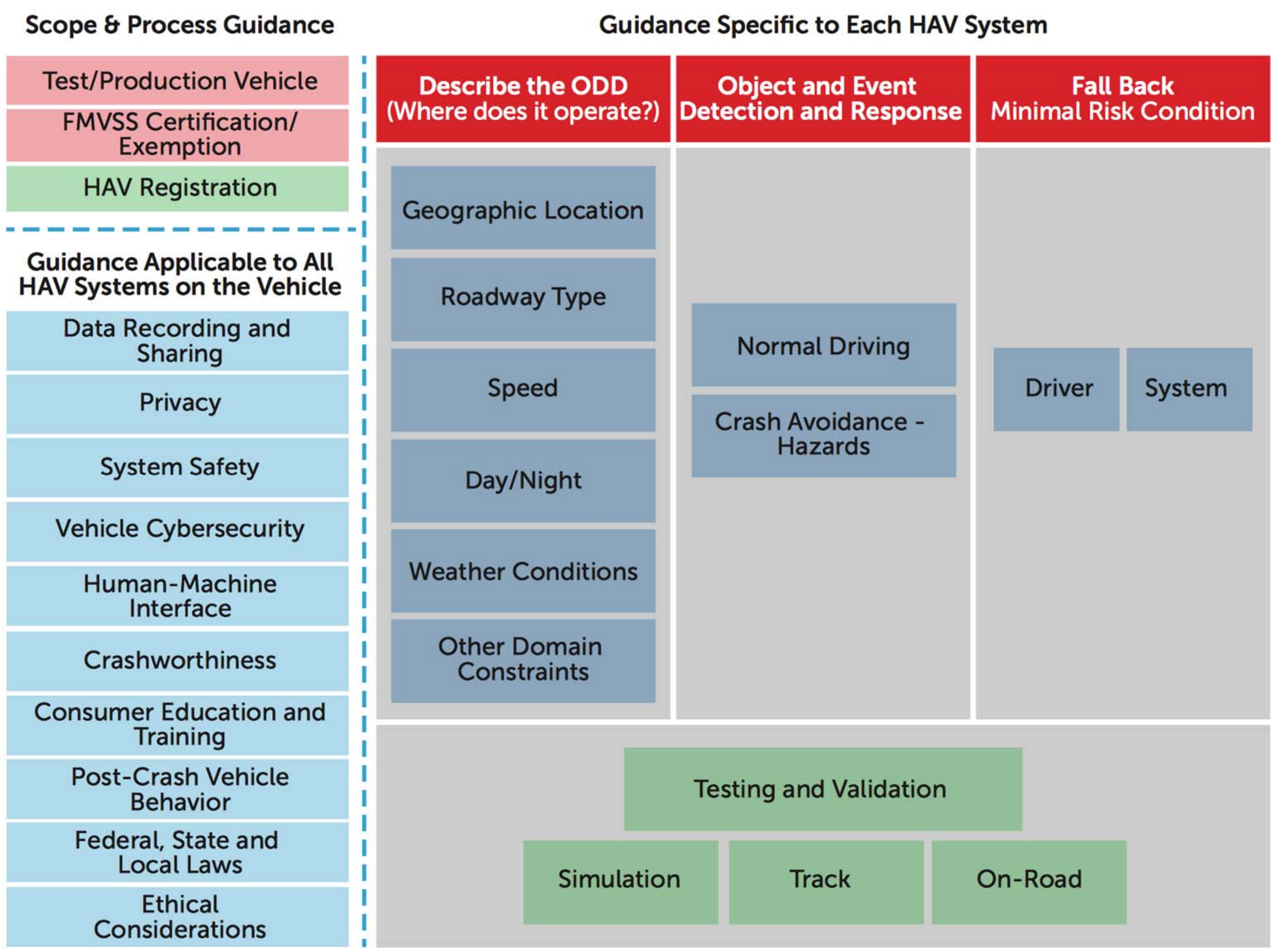
Global ADAS Market by Function (K unit)



Global Market by Sensor (K unit)



US Department of Transportation Guidelines for Self-driving Cars – Sept. 2016 Framework



New Vehicle Assessment / Active Safety

JNCAP	NCAP (NHTSA)	IIHS	Euro-NCAP	C-NCAP
Under testing • AEB ✓ vehicle ✓ pedestrian • LDW • LKS (plans to test in latter half of FY2017) • Rearview monitor • ACN(plans to test in FY2017)	Recommended safety technology • AEB ✓ Anti-vehicle • LDW • Rearview monitor • FCW	Under testing • AEB • Headlight evaluation • With or without ESC equipment	Under testing • AEB ✓ vehicle ✓ pedestrian ✓ Low speed ✓ High speed • LDW or LKS • ESC • Speed Assistance System	Under testing • ESC
Under basic research • Night pedestrian AEB • Variable light distribution headlight • Heads-up for night pedestrians in front Considering introduction after technology study based on actual traffic accident situations • Front obstacle collision damage reducing braking control unit (anti-car), (crossing collision) • Unsteady driving notification device • Preventing device of Stepping on the accelerator or brake by mistake	Performance assessment specifications are not established. Technologies to be considered at examining purchase are: • LKS • Anti-pedestrian AEB • CAN		* Since 2013, it has been changed to the method which adds more points on cars with in-vehicle cameras. The key to a high evaluation is functions such as emergency automatic braking or lane departure warning derived from in-vehicle camera technologies.	Test method under consideration • AEB ✓ Anti-vehicle ✓ Anti-pedestrian • FCW Under feasibility study • BSD • SCC • DBS • LDW • ISA

Major Developments in 2D / 3D Lidar Market

Valeo

- The first-generation SCALA adopted it for 2017 mass-production models.
- On February 10, Valeo agreed with LeddarTech, a manufacturer of advanced detectors/distance measuring equipment with TOF-typed infrared LED, on joint development and licensing.
- Develops solid-state Lidar by utilizing the laser technology from Canadian LeddarTech.

TriLumina

- Denso International America offers "LiDAR," a radar method with the laser beam source, and light sources of interior lighting products. The company announced that it invested into TriLumina, an innovative semiconductor laser technology company.

Velodyne

- Velodyne HDL-64E is priced at $75,000 (VLP-16 with 16 channels is at $8000).
- In August 2016, Baidu invested into Velodyne LiDAR in the US, a Lidar (laser sensor) manufacturer, jointly with FORD, at $75 million each. Lidar is a necessary precision sensor to create high-precision 3D maps. Baidu uses Velodyne Lidar sensors for creating its street views.
- Partnering with EPC(Efficient Power Conversion) for developing Solid State Lidar (GaN IC).

Quanergy

- Quanergy Systems has a capital of $90 million for series B round. Sensata Technologies, Delphi Automotive, Samsung Ventures, Motus Ventures, and GP Capital participated in this investment round.
- Koito Manufacturing and Quanergy collaborate in concept designing of automotive headlight with embedded LiDAR sensor.

Waymo

- Google's self-driving cars once adopted Velodyne HDL-64E. In-house development reduced costs by almost 90%.
- Revealed the sensor kit for self-driving mini van.

TOYOTA

- Co-develops the next-generation laser scanner with Toyota Central R&D Labs.

2D / 3D Lidar Methods

- Motor-driven mechanical method
  - OEMs are currently experimenting on it. Only the mechanical method can be used for mass-production vehicles.
  - Difficult in downsizing. Costs high.
- Flash method
  - Photodetector dividing system, infrared radiation
  - 3D distance images are shot by infrared radiation just like by a camera.
  - High resolution 3D flash Lidar technology has a big feature of real-time image recognition and ambient surrounding recognition achieved at the same time.
- MEMS method
  - Scanner consists of small MEMS mirrors with electromagnetic driving.
  - Small-sized, costs low.
  - Uses multiple fixed lasers.
- Optical phased array method
  - With a large number of phase-converting elements aligned on a plane, irradiates radar waves with slightly different phase from each element and then superimposes reflected radar waves to measure positions or 3D forms of surrounding objects.
  - Capability of high-speed beam manipulation (high-speed scanning) is its greatest feature.
  - The challenge is its short light wavelengths at one per thousands. Therefore, it is required to manufacture array chips with the accuracy of 100 nanometers or less, or to eliminate environmental fluctuation during operation.
- VCSEL method
  - Surface emitting laser is capable of testing performance by wafer
  - Allows two-dimensional array
  - Low power consumption

2D / 3D Lidar Product Table

	Current (CY 2016)				
Supplier Name	Velodyne			Quanergy	Valeo
Procut Name	HDL-32e	HDL-64e	VLP-16	M8	SCALA
Sensor Type	• ToF • Motor drive mechanical • Scan • 32 lasers	• ToF • Motor drive mechanical • Scan • 64 lasers	• ToF • Motor drive mechanical • Scan • 16 lasers	• ToF • Motor drive mechanical • Scan • 8 lasers	• ToF • Motor drive mechanical • Scan • 4 Lasers
Sensing Range & field of view	• 100m • Horizontal: 360 degree • Vertical: 41.3 degree (+10.67 to -30.67)	• 120m • Horizontal: 360 degree • Vertical: 26.8 degree (+2 to -24.8)	• 100m • Horizontal: 360 degree • Vertical: 30 degree (+/- 15)	• 150m • Horizontal: 360 degree • Vertical: 20 degree (+3 to -17)	• 200m • Horizontal: 145 degree (Resolution:0.25degree) Vertical: 3.2 degree (4 layer)
Measurement Speed (Update Frequency)	5 to 20Hz	5 to 20Hz	5 to 20Hz	5 to 30Hz	12.5 to 25Hz
Measurement Points (points/sec)	700,000	>2,200,000	300,000	>400,000	
Measurement accuracy	+/- 2cm	< 2cm	+/- 3cm	< 5cm	4cm
Power Consumption	12W	60W	8W	15W	<7W
Weight	1.2kg	13.2kg	0.8Kg	0.8kg	0.5kg
Size	H:144.2mm D:85.3mm	H:279.4mm D:203.2mm	H:72mm D:103mm	H:87mm D:97mm	105 x 60 x 100mm
Price Range		$75,000US	$8,000 US	<$1,000 US	<$1,000 US

2D / 3D Lidar Product Table

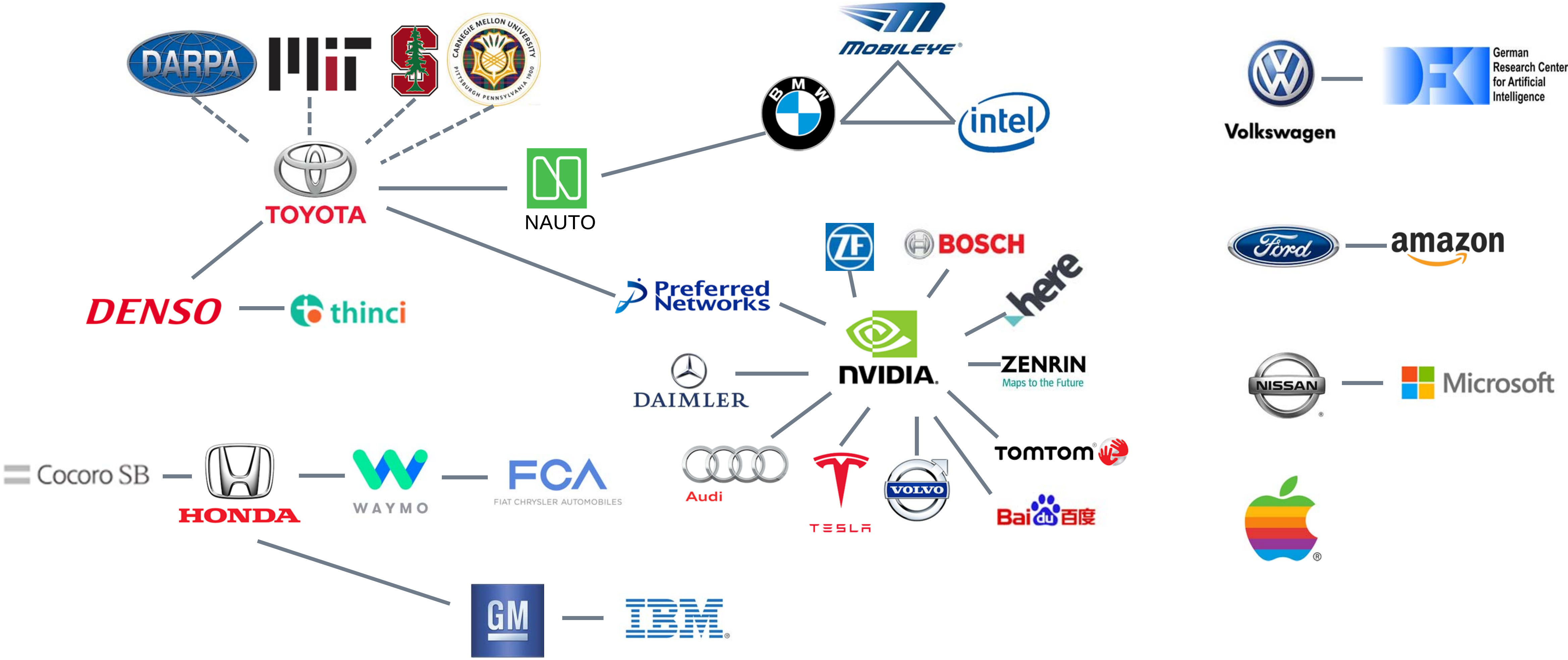
	Current to CY 2020				
Supplier Name	Velodyne	Quanergy		Valeo	Continental
Procut Name	Solid State Lidar	S3 MCM	S3 ASIC	Sold State Lidar (from LeddarTech)	From Advanced Scientific Concept
Sensor Type		• Optical phased array	• Optical phased array	• 3D Flash Lidar	• Optical phased array
Sensing Range & field of view		• 10m – 150m (Zoom in/ Zoom out) • Horizontal: 120 degree		• 100m • Horizontal: 60 degree	• 200m
Measurement Speed (Update Frequency)					
Measurement Points (points/sec)					
Measurement accuracy					
Power Consumption					
Weight					
Size		90x60x60mm			
Price Range	<$50US	<$250US	<$100US		

2D / 3D Lidar Product Table (Japan)

	Current to CY 2020						
Supplier Name	TOYOTA R&D	OMRON Automotive	Pioneer	Denso	KONICA MINOLTA	Nippon Signal	HOKURIKU
Procut Name	SPAD-LIDAR					FX10	YVT-X002
Sensor Type		• Flash	• MEMS • 1 laser	• VCEL	• Motor drive mechanical • 24 laser	• MEMS • 1 laser	• Motor drive mechanical • 1 laser
Sensing Range & field of view	• 60m • Horizontal: 55 degree	• 100 to 500m • Horizontal: 140 degree • Vertical: 20 degree	• 100 to 500m • Horizontal: 210 degree • Vertical: 20 degree		• 100m • Horizontal: 180 degree • Vertical: 9 to 12 degree	• 15m • Horizontal: 60 degree • Vertical: 50 degree	• 50m • Horizontal: 210 degree • Vertical: 40 degree
Measurement Speed (Update Frequency)							
Measurement Points (points/sec)							
Measurement accuracy							
Power Consumption							
Weight					1.4kg	0.35kg	
Size	67 x 73 x 177mm		60 x 70 x 50mm		180 x 132 x 150mm	50 x 77 x 96mm	
Price Range							

Artificial Intelligence and Machine Learning @ Automotive

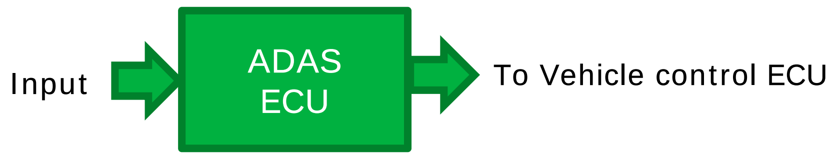
Team up: Automobile Industry + High-tech Industry + Universities/Research Institutions



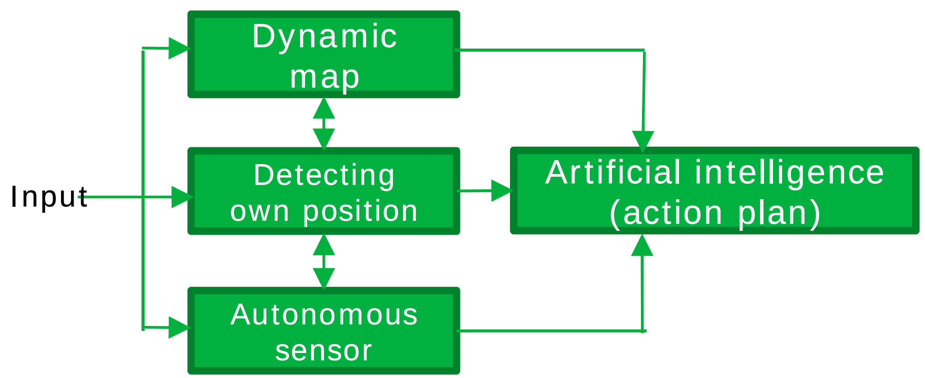
Deep Learning @ Automotive

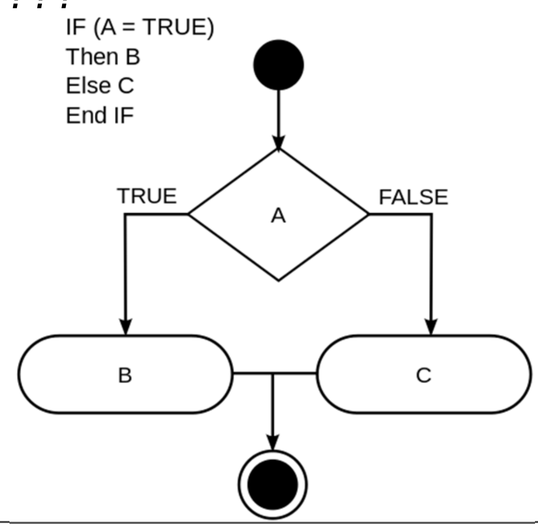
Utilizing deep learning:

- **Voice recognition, natural language processing, image recognition, prediction, object recognition:**
  Machine learning through deep neural network (Only "how to learn" is programmed into the machine. Afterward, the machine itself performs repetitive learning from repetition of successes and failures based on massive data to find out a smart judgement.)



- **Full self-driving car**: Can artificial intelligence alone be a "driver"???





Vehicle control (accelerator, steering, brake etc.)

Deep Learning Framework Table

	Chainer	Caffe	Torch7	theano	TensorFlow	CNTK Computation Network Toolkit
Summary	Python library for learning neural network through error propagation. GPU by Nvidia is required to support CUDA for execution.	Specializing in image recognition	Machine learning library for scientific computation, operating on LuaJIT	Python library for numerical calculation	Google's machine learning/deep learning/multi-layer neural network library. Using data flow graphs, the library is for easy description of complex networks.	Capable of parallel processing across multiple GPUs and servers. Achieves high processing speed in deep learning models such as voice recognition.
Major developer	ChainerはPreferred Networks	Berkeley Vision and Learning Center	Led by Ronan Collobert	Developed under Prof. Bengio at University of Montreal	Google	Microsoft
Major programming language	Python	C++	Lua	Python	C++/Python	
	Opened to the public in June 2015				Source opened to the public in November 2015	MIT's open source license was applied on January 25, 2016
Introduction case	Image recognition /natural language processing/robotic control etc.	Used in the Recruit Group for image analysis.	Facebook open-sourced extended Torch to the public.		Google's internal service	Microsoft's tool kit for deep learning

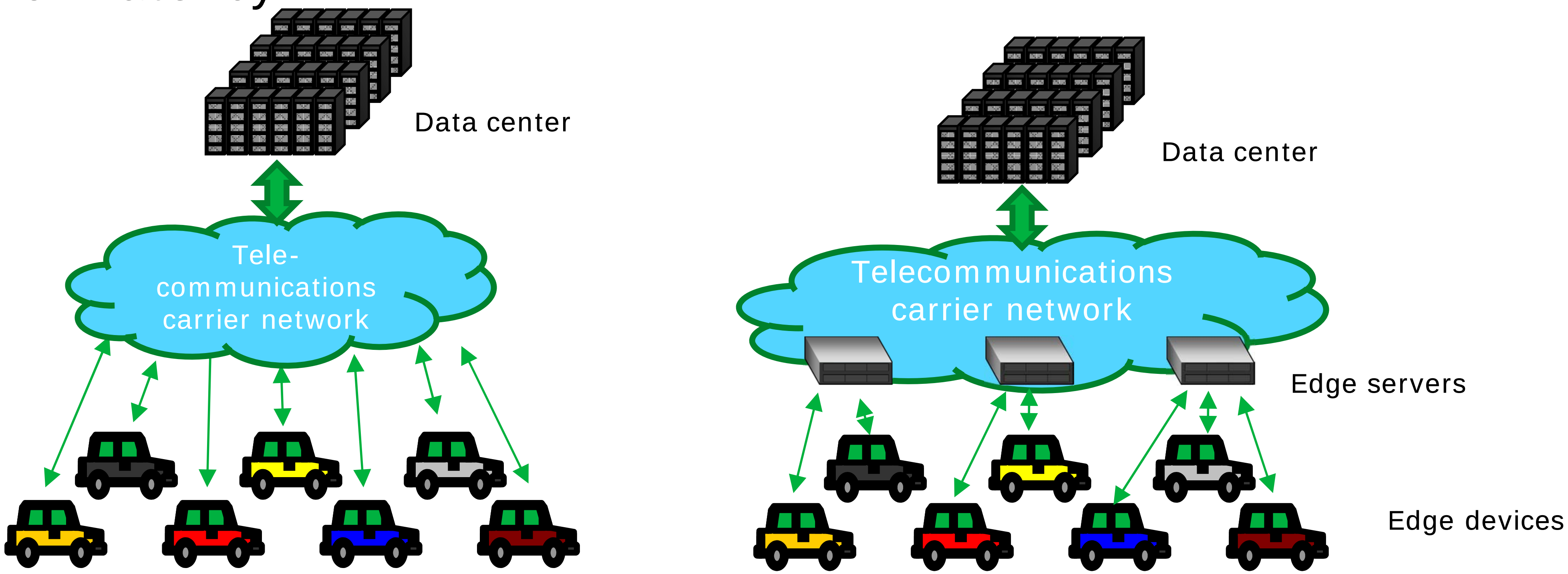
Automotive Super Computer

- **Requirements for automotive super computer for self-driving:**
  - **High computing power**
  - **High-speed processing / low latency, systems are required to respond within 70-80ms**
  - **Power consumption**
    - Automotive super computer or sensor fusion ECU: 15-20W or lower (target)

    * 4 W or lower for individual sensors
  - **Communication channel and data storage infrastructure:**
    - Connectivity (IoT)
      - To store and analyze learning data and vehicle parameters
      - OTA function (for updating/upgrading systems)
  - **Safety:**
    - How to deal with uncertainty of artificial intelligence to achieve self-driving
    - Cyber security measures

Cloud Computing and Edge Computing

- Exchanging massive data arising from vehicle services in real-time causes heavy load on telecommunications carrier networks.
- Cloud computing has a risk of tardiness for real-time processing which requires low latency



Key Takeaway Box

- 2D/3D Lidar
  - The 2D/3D Lidar market has not thrived as an industry yet. However, there are active movements including partnering for technologies and capital involvement in the market since it is considered as a necessary sensor to realize self-driving at L3 or higher.
- Artificial intelligence, machine learning
  - There is a strong feeling of hesitation toward for riding in a car driven by 100% artificial intelligence.
  - Artificial intelligence and machine learning are essential for self-driving and recognition technologies. However, for controlling vehicle actuators including accelerator, steering wheel, and brake, it is required to combine them with rule description based on state transition.

Thank you!

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