From Technologies to Markets

Sensor fusion for autonomous vehicles

December 15th , 2020

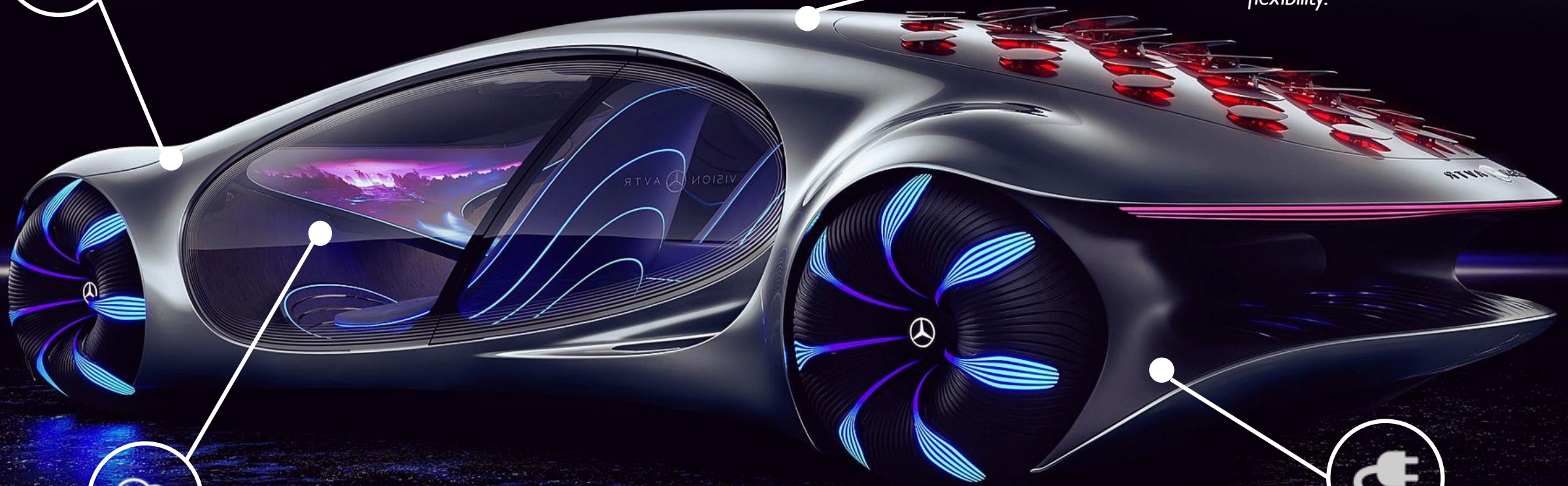
YOLE Développement

AGENDA

1. Introduction
2. Radar
3. The proliferation of camera modules
4. The emergence of LiDAR
5. The transformation of E/E architecture
6. Market forecasts for ADAS vehicles sensors
7. LiDAR for robotic and industrial applications
8. Sensor fusion

CONTEXT

C.A.S.E., the acronym taking over the auto industry



Autonomous

Sensor suite and computing developments for safer roads.

Shared

Owning, sharing, or renting, the mobility of the future offers greater flexibility.

Connectivity

Comfort, safety and entertainment in a new dimension.

Electric

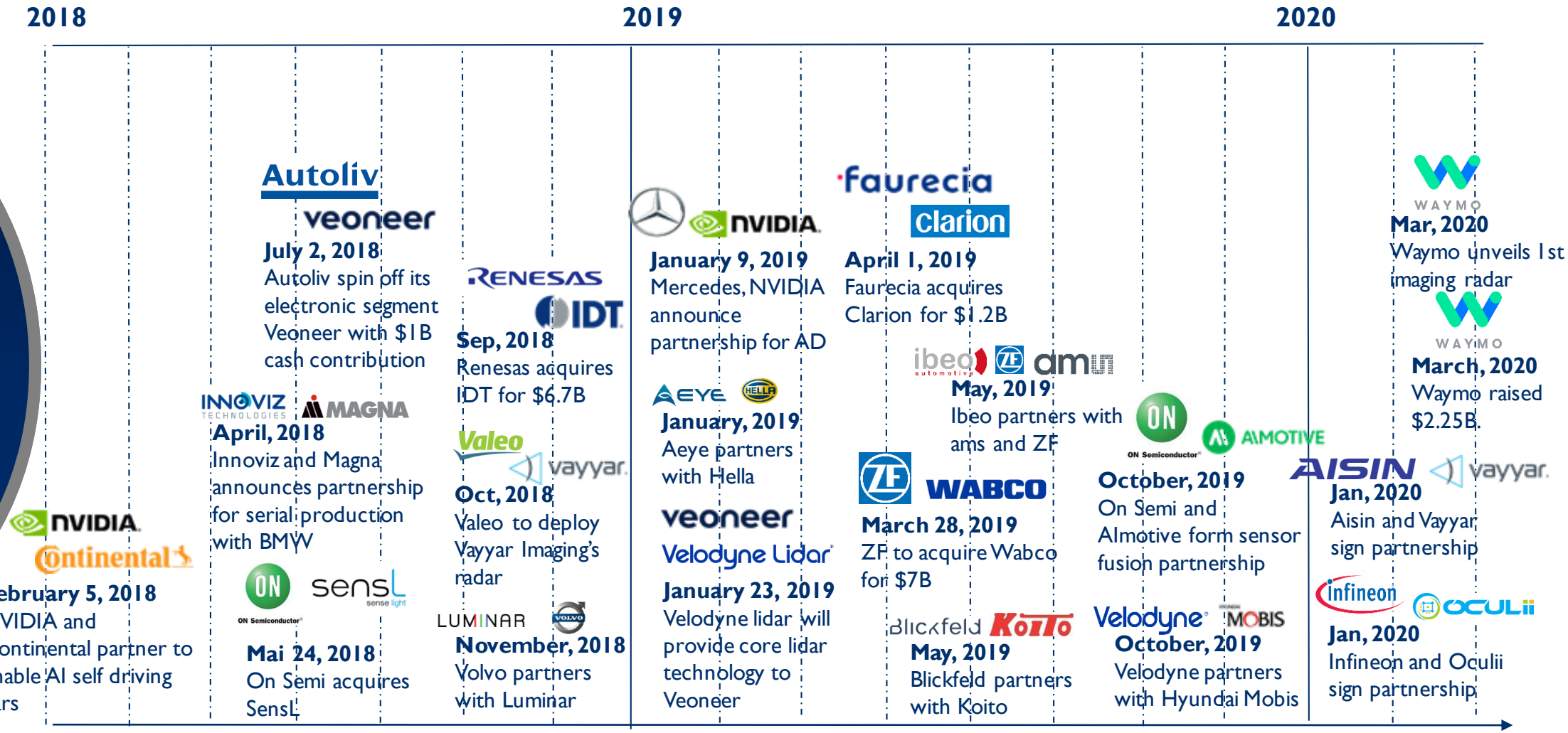
Alternative drive systems to reduce CO_2 emissions.

Source: Daimler

SENSORS IN ADAS VEHICLES

Noteworthy news

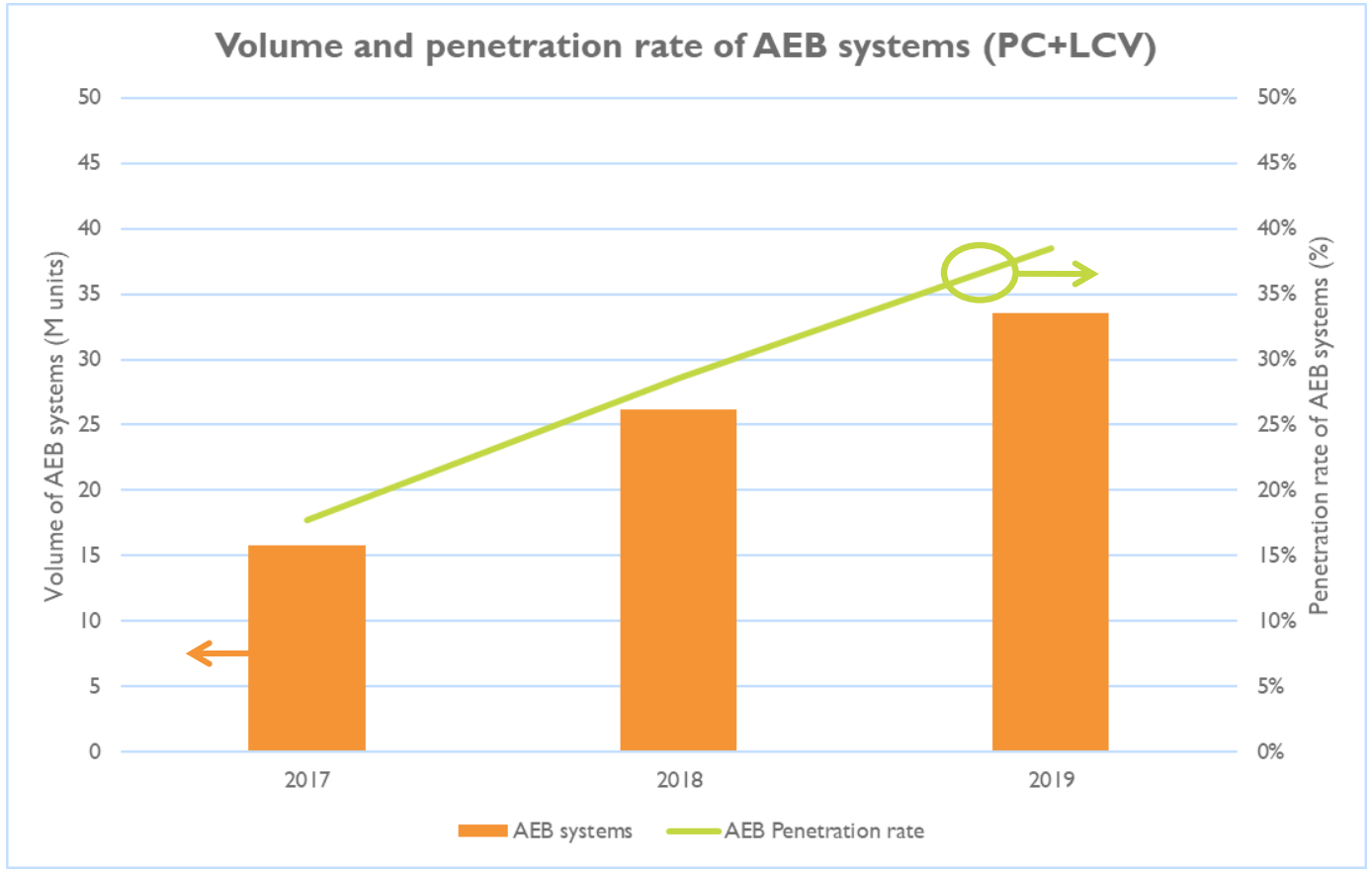
Since 2018, many acquisitions, partnerships or fundraising have been made regarding ADAS and AD activities.



SENSORS IN ADAS VEHICLES

Volume and penetration rate of AEB systems

Actual AEB systems are based on camera and radar. Its penetration rate keeps increasing from 18% in 2017 to 38% in 2019.



AEB systems based on:

Forward camera

+

Long Range Radar

SENSORS IN ADAS VEHICLES

AEB is still perfectible

Cars with high-tech safety systems are still really bad at not running people over.

- In October 2019, the American Automobile Association (AAA) conducted a series of tests using vehicles with AEB and pedestrian detection alerts on a closed course with dummy pedestrians.
- Several tests have been made at different speeds, mixing adult and children 'pedestrians' during daylight and night conditions.
- Tests were performed on: Chevy Malibu, Honda Accord, Tesla Model 3 and Toyota Camry.

A dummy pedestrian struck by a vehicle during the test.
Source: AAA

60% of the time, the vehicle struck the **adult** crossing the road during daylight at 20 mph.

89% of the time, the vehicle struck the **child** crossing the road during daylight at 20 mph.

100% of the time, the vehicle struck the **adult** after a right turn at 15 mph.

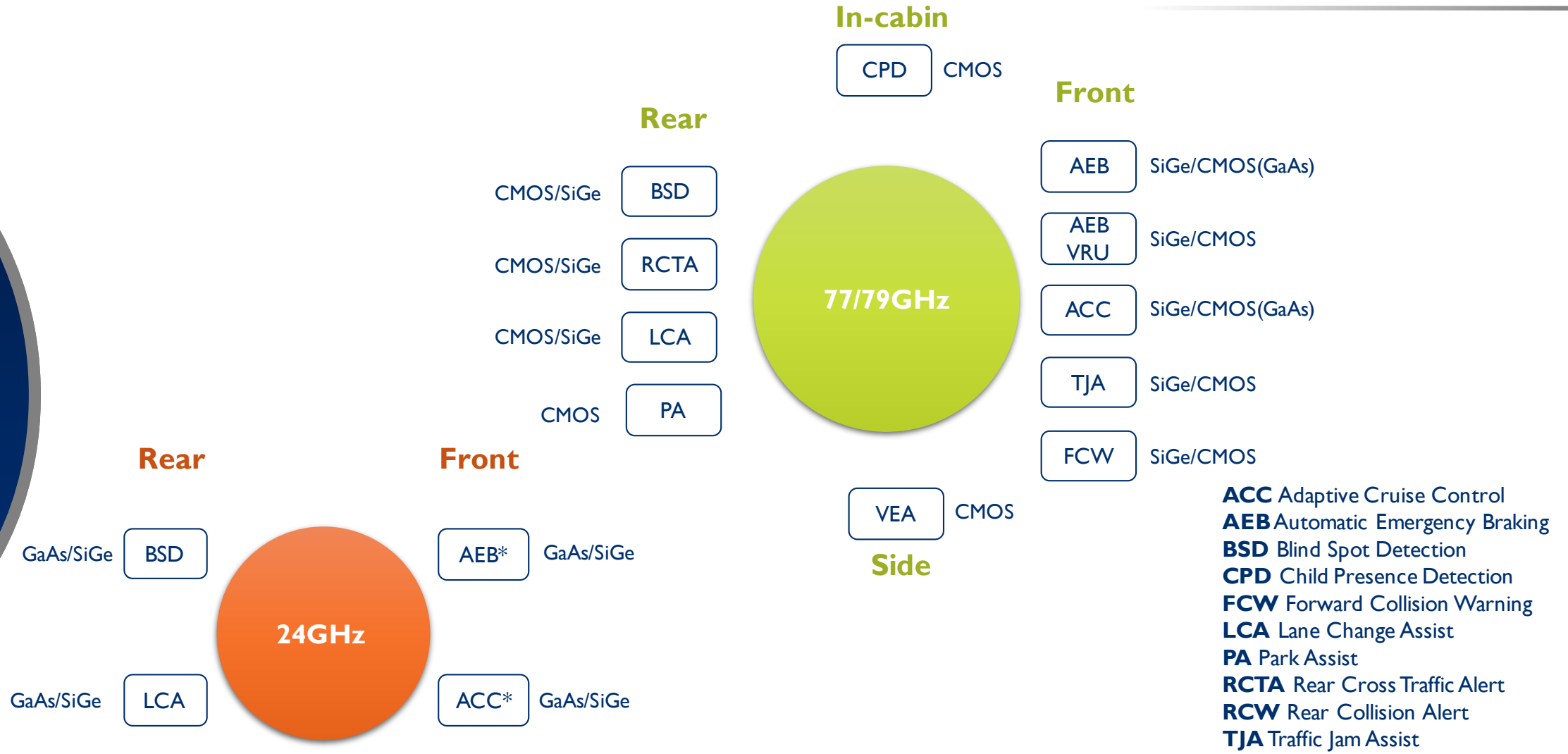
When encountering an adult pedestrian **at night**, these systems were **ineffective**.

New sensors like LiDAR or thermal cameras will need to be implemented

CURRENT RADAR TECHNOLOGIES AND USE CASES

Which technology for which application?

The 77/79GHz frequency is opening more use cases for monitoring car surroundings.



* Limited range – supported at low speed

ACC Adaptive Cruise Control
AEB Automatic Emergency Braking
BSD Blind Spot Detection
CPD Child Presence Detection
FCW Forward Collision Warning
LCA Lane Change Assist
PA Park Assist
RCTA Rear Cross Traffic Alert
RCW Rear Collision Alert
TJA Traffic Jam Assist
VEA Vehicle Exit Assist
VRU Vulnerable Road User

FUTURE RADAR TRENDS

Four steps towards super sensors

Future radar developments towards automated driving.

3D
Measure height

Elevation capability

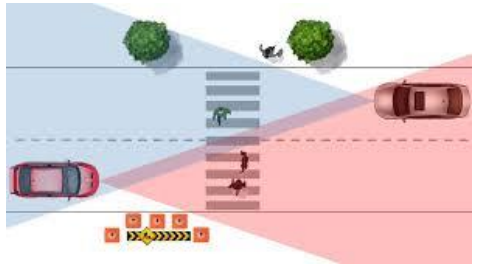
Started in 2019.

Imaging
Discriminate nearby objects

High resolution

Phase in from 2021.

Ensure no misses



Availability interference mitigation

Implementation from 2020.

Classification, labelling

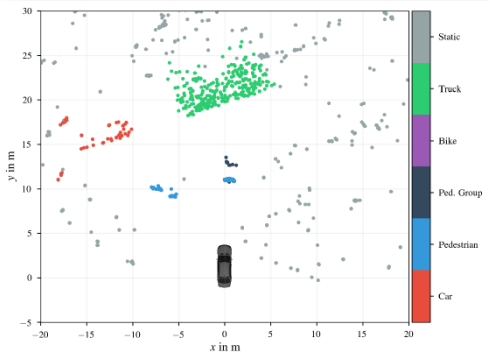


Image processing
AI/deep learning

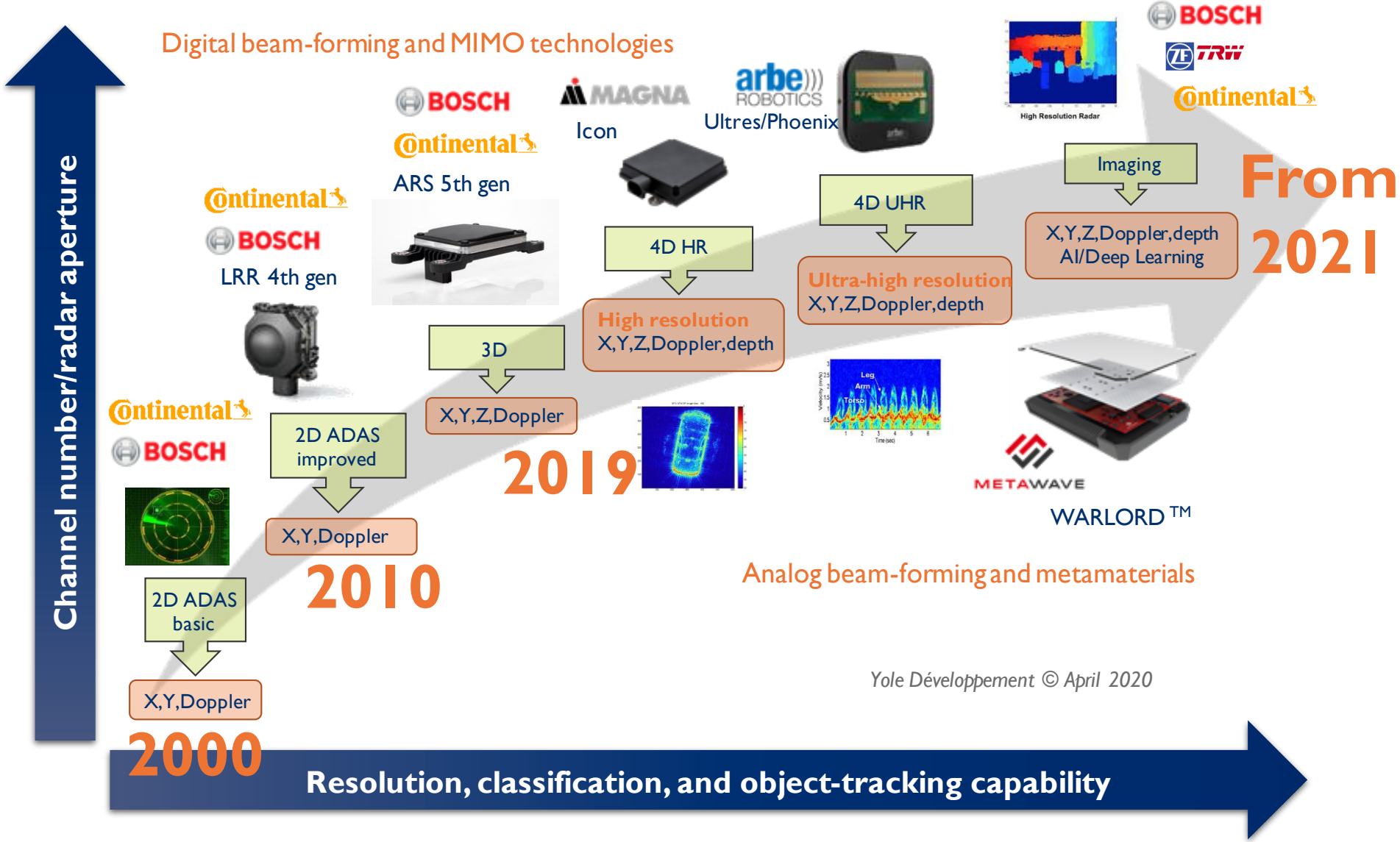
Ongoing on OEM side likely to follow imaging radar.

Yole Développement © April 2020

FUTURE RADAR TRENDS

The road to high resolution

Leveraging military and telecom technologies, advanced radar technology fully supports up to level-4 autonomy, with high resolution and radar imaging reaching the market with low C-SWAP.



C-SWAP: cost, size, weight, and power

RADAR MARKET SHARES

Automotive radar market shares

The top five companies capture 83% of the market. The merging players are progressing well. Waymo's market share has started to become visible.

Top five

Continental ↑
HELLA Mando ↑
BOSCH Invented for life ↑
DENSO TEN ↑
veoneer ↘

Emerging

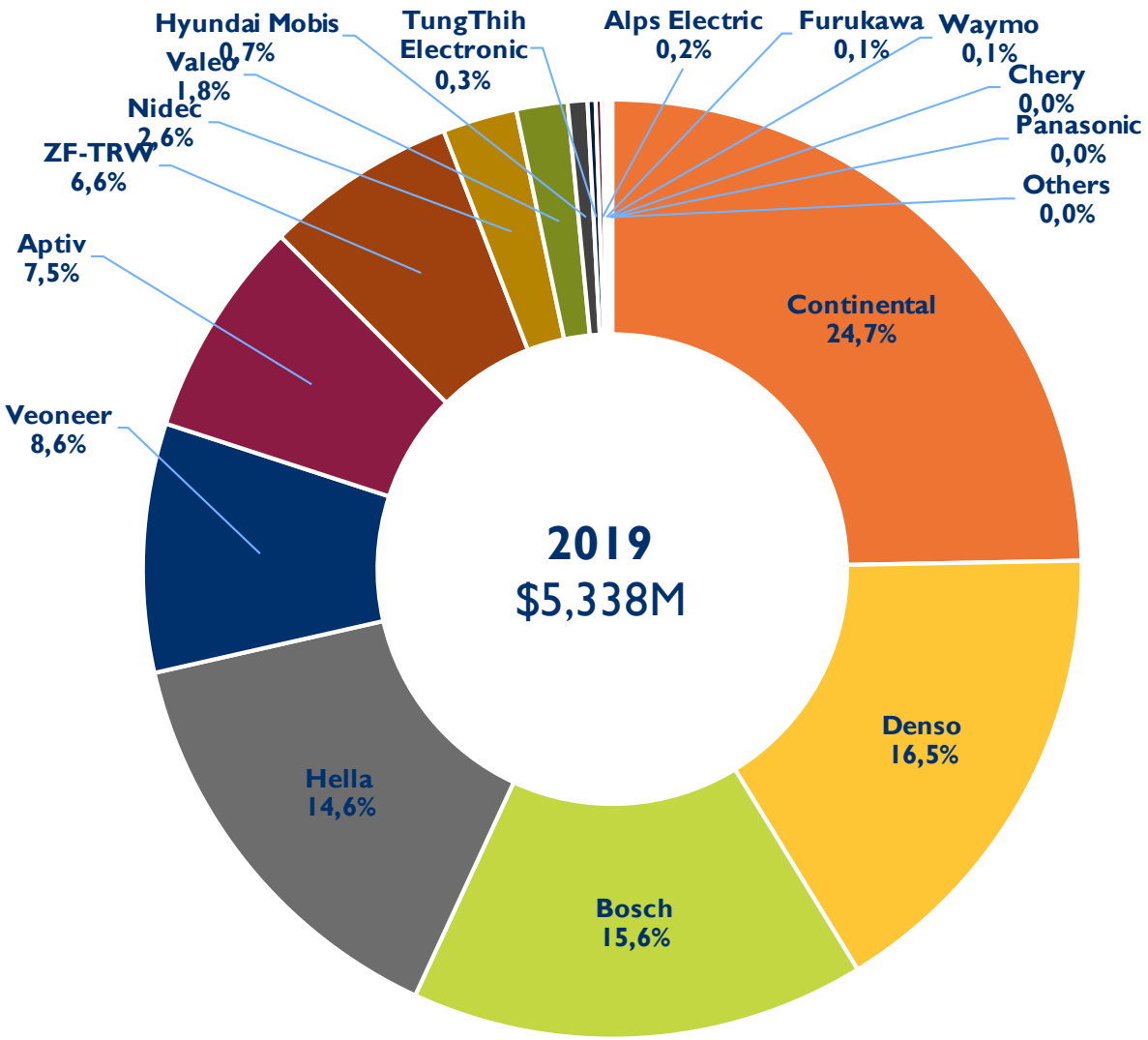
ZF TRW ↑
APTIV ↑
Nidec All for dreams ↑
ALPS ↑
HYUNDAI MOBIS ↑
Panasonic ↑

Others

Valeo =
TTE 同致電子企業股份有限公司 TungThih Electronic Co., Ltd. =
FURUKAWA ELECTRIC GROUP =
CHERY =

Special

WAYMO ↑

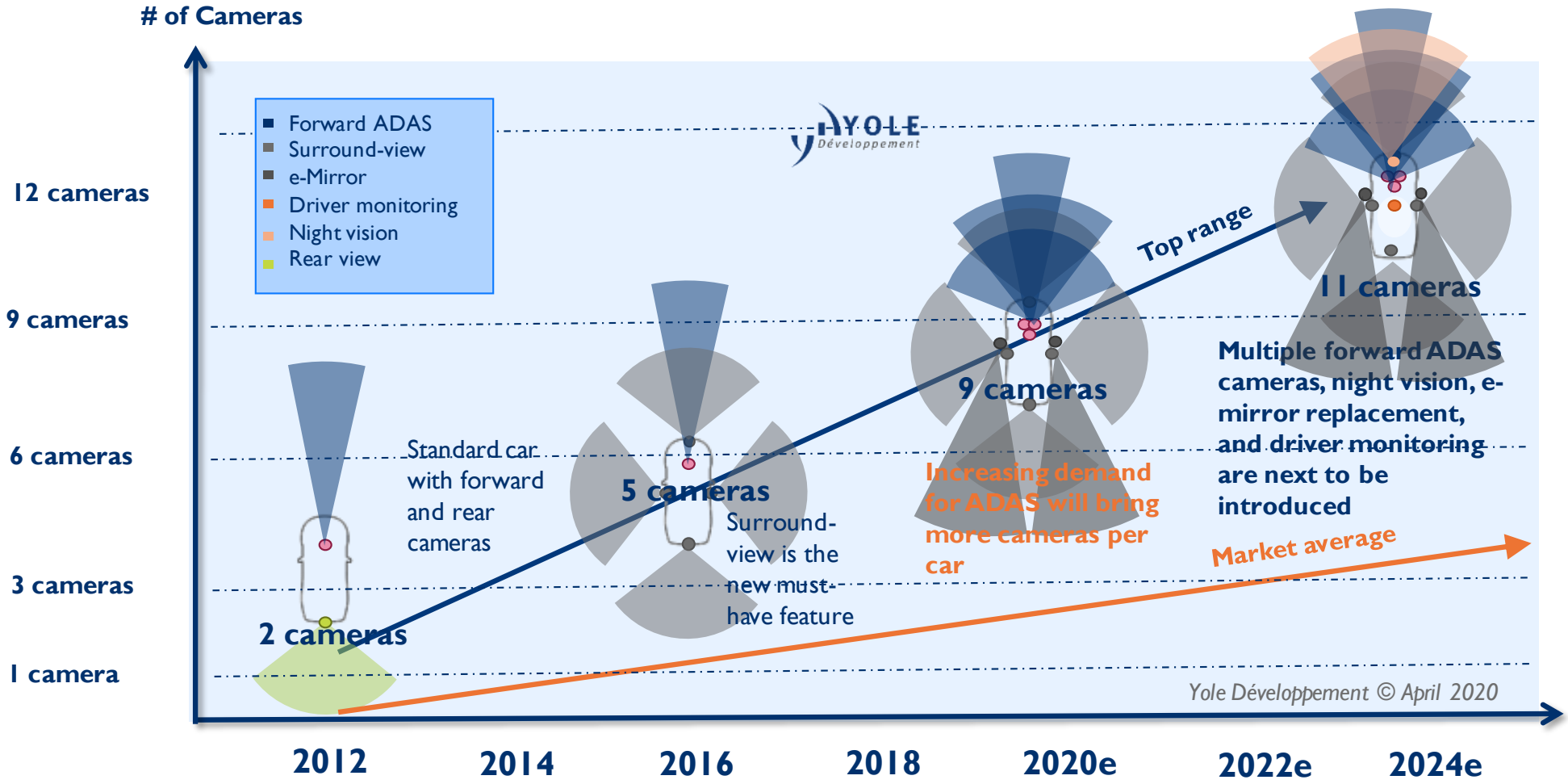


Non exhaustive list of companies – Others section

THE PROLIFERATION OF CAMERA MODULES

The 'Ten-plus cameras per car' roadmap

The market is driven by camera proliferation.



CAMERA MODULE MARKET SHARES

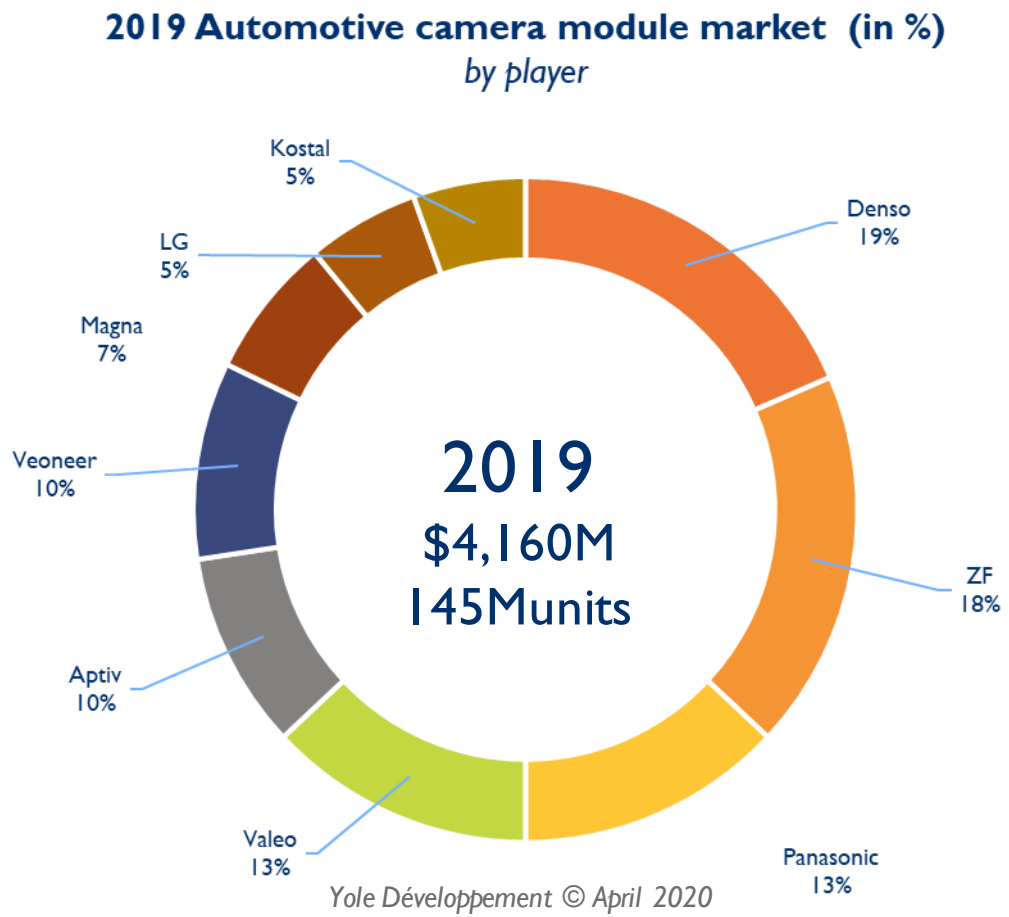
Automotive camera module - Market breakdown by manufacturer in %

The market is still highly competitive, and Tier-1s trust the first positions.

Tier-1s have entered the fray and trust the main positions.

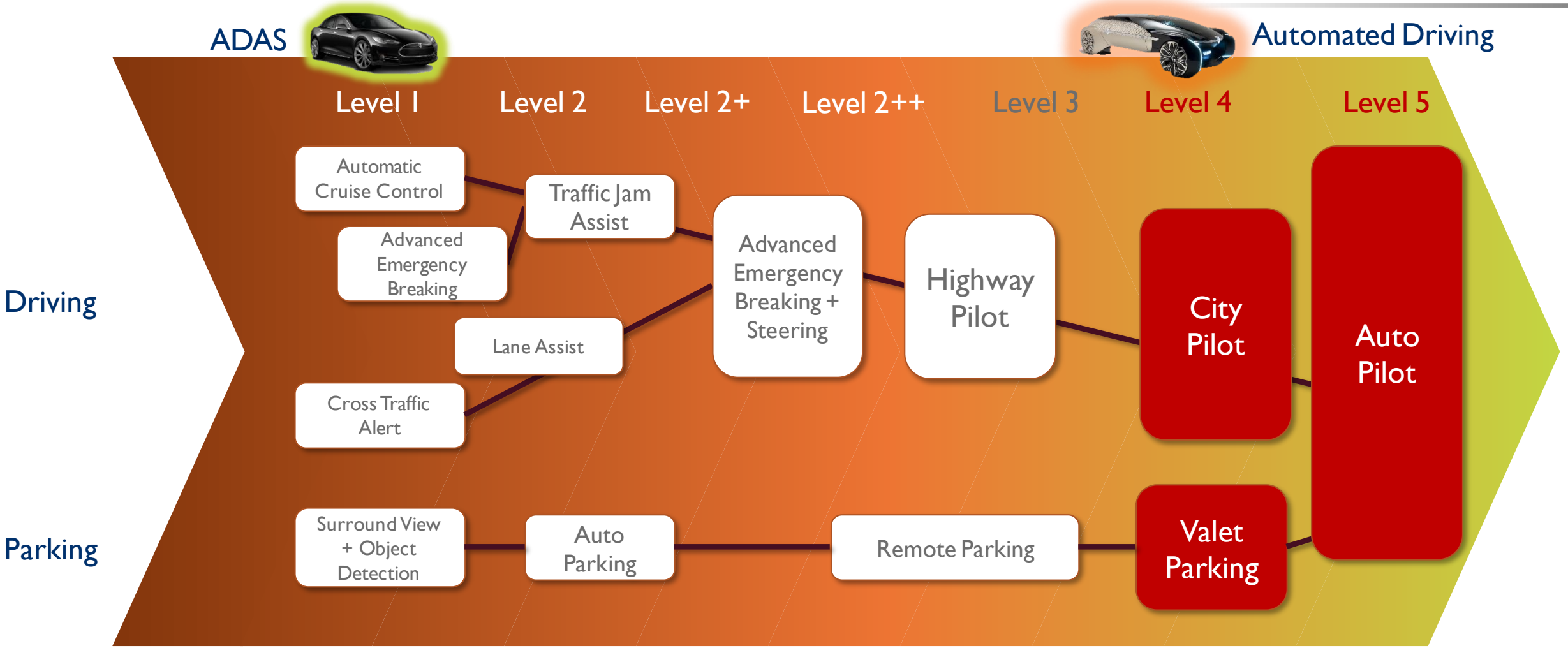
All other players are well-known camera manufacturers that have diversified from either mobile or digital photography.

Competition will probably toughen in the next few years as market growth attracts more players.



THE EVOLUTION OF DRIVING

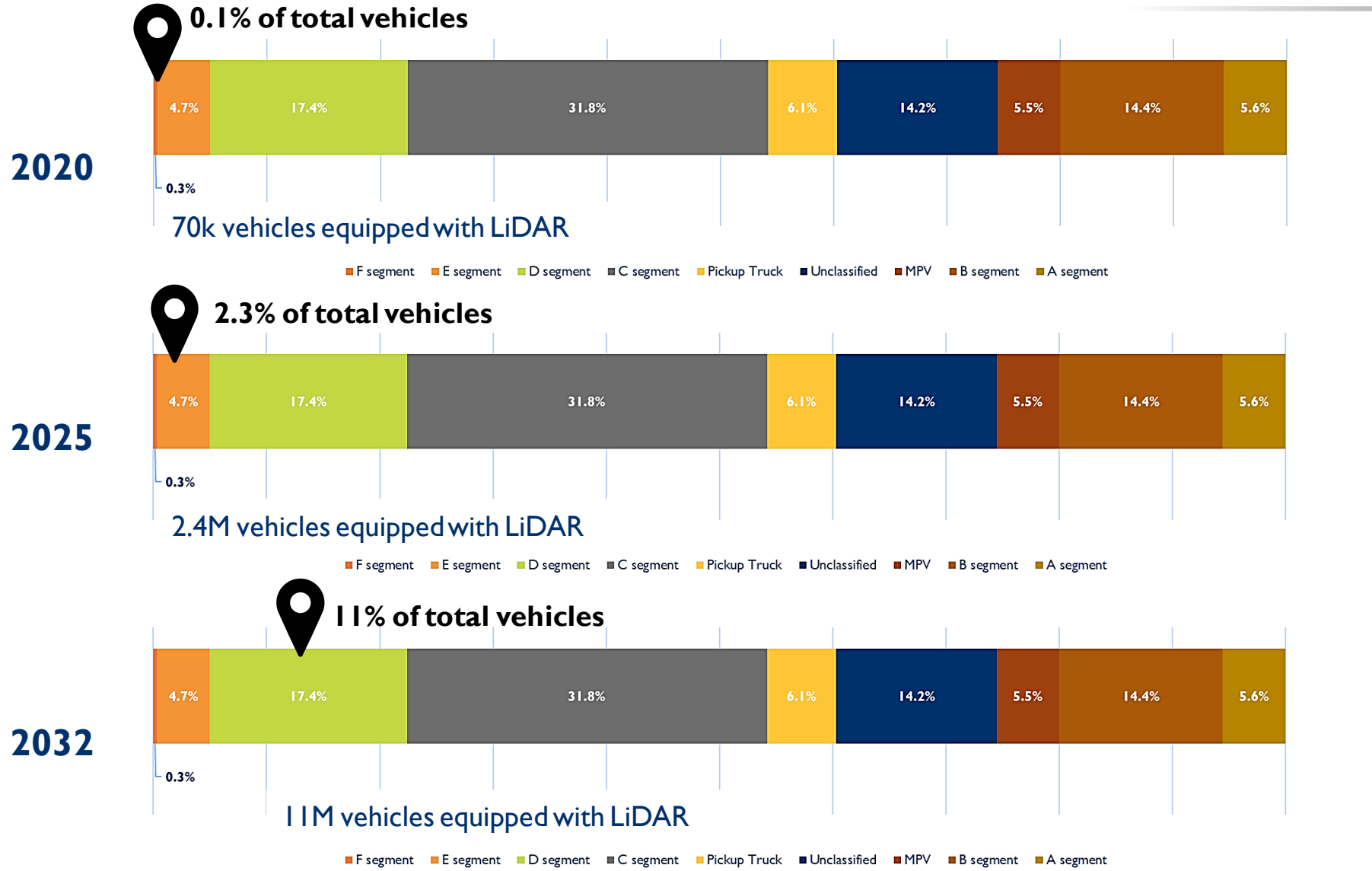
Evolution of functionalities towards full autonomy



THE EMERGENCE OF LIDAR

Adoption of LiDAR in ADAS vehicles

LiDAR is penetrating the ADAS market in the F-segment. As the price decreases, it will be implemented in lower segments.



LiDAR ASP

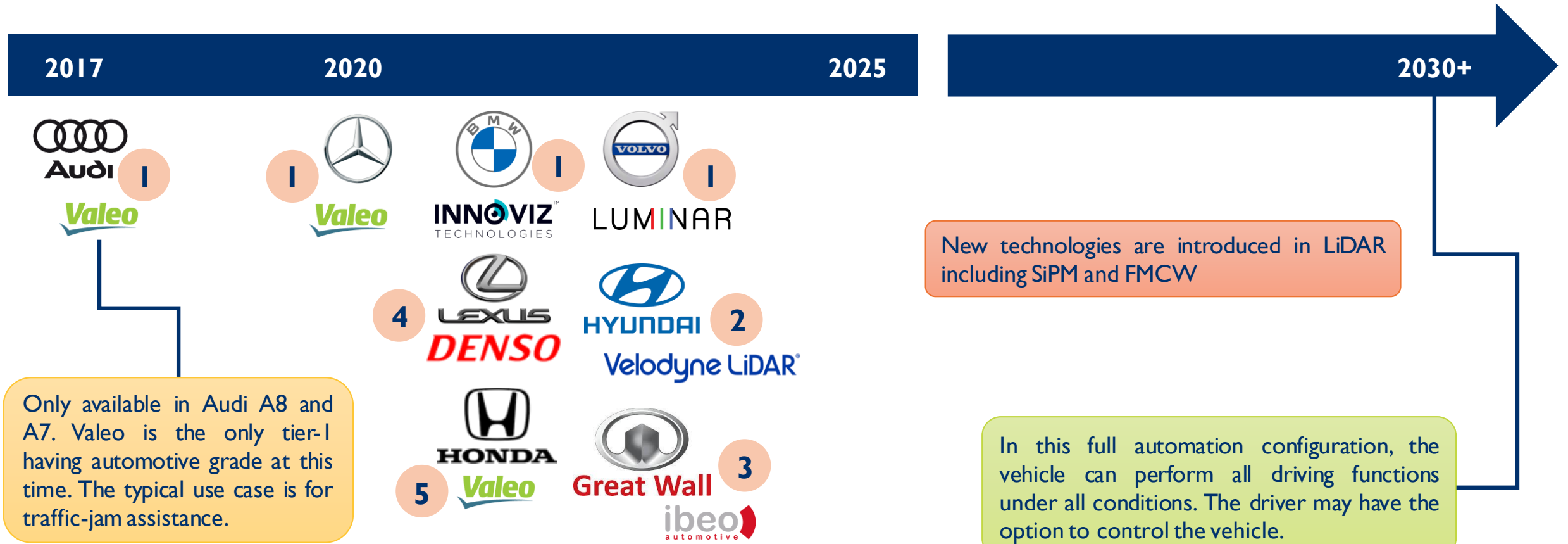
LR: $570
SR/MR: N/A

LR: $500
SR/MR: $122

LR: $380
SR/MR: $99

THE EMERGENCE OF LIDAR

ADAS LiDAR roadmap

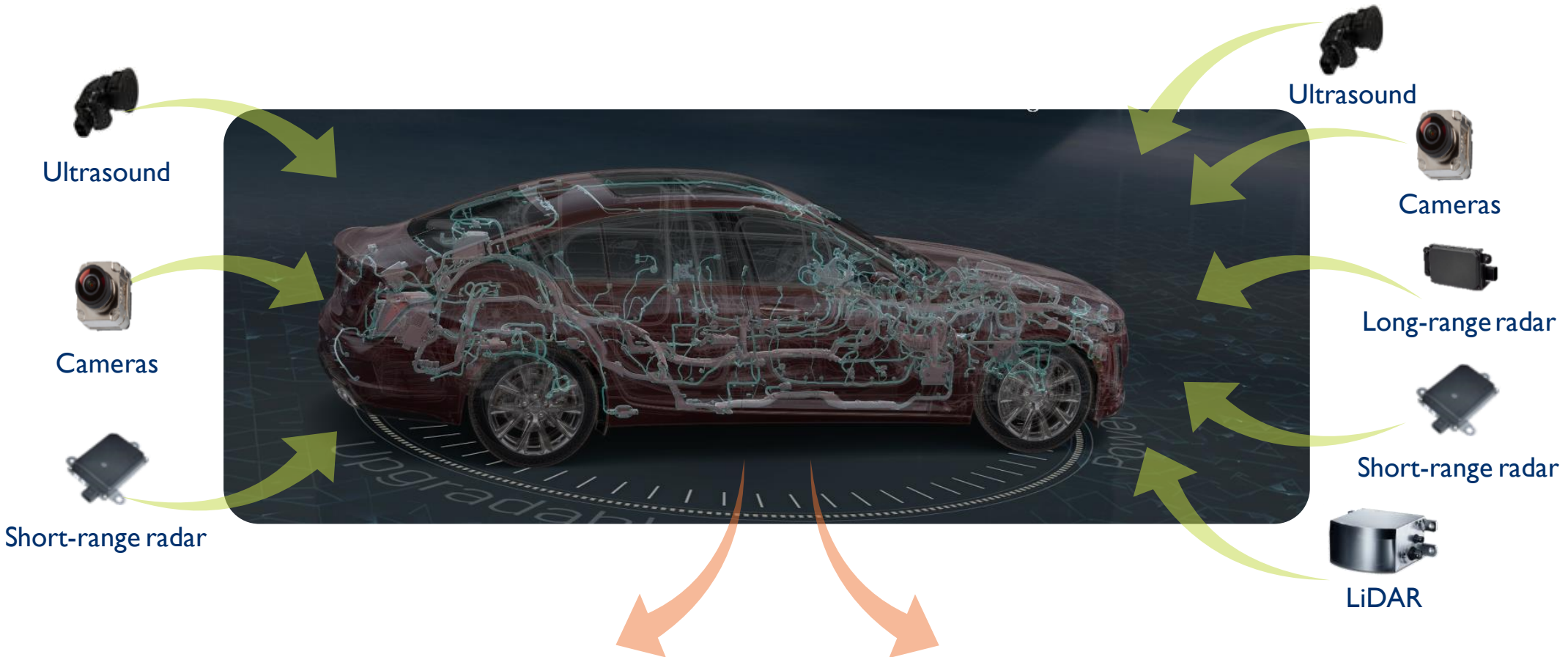


FMCW: Frequency-modulated continuous-wave
SiPM: Silicon photo multiplier
SPAD: Single photon avalanche diode

THE ADDITION OF SENSORS

Impact of adding sensors in ADAS vehicles

The multiplication of sensors in vehicles directly impacts the complexity of electronic architecture.



More ECUs requested

More computing power

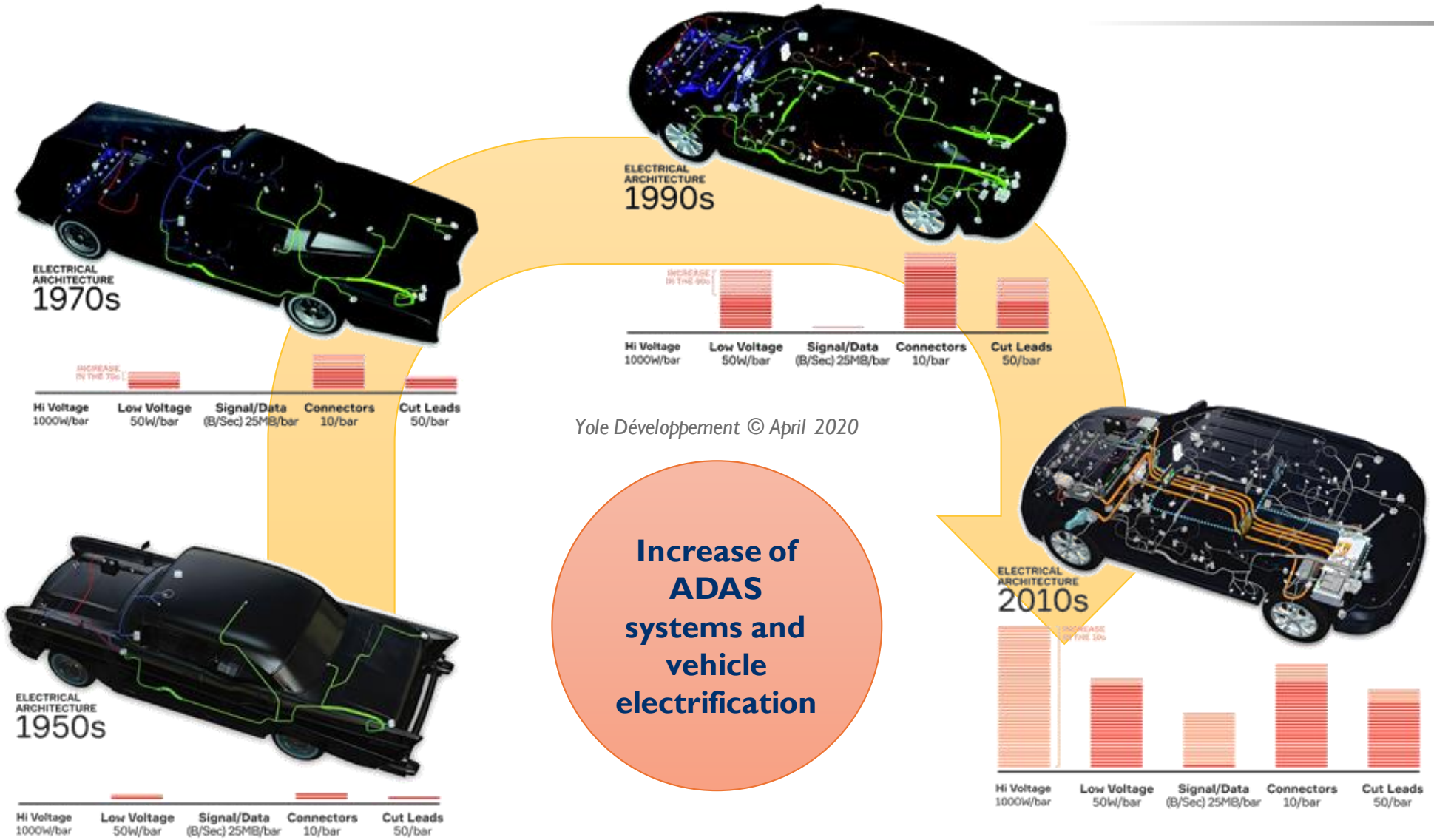
More software requested

More complex E/E architecture

E/E ARCHITECTURE AND COMPUTING

Evolution of E/E architecture

Consumer demand for safety and software-enabled features is increasing at an unprecedented rate.



Yole Développement © April 2020

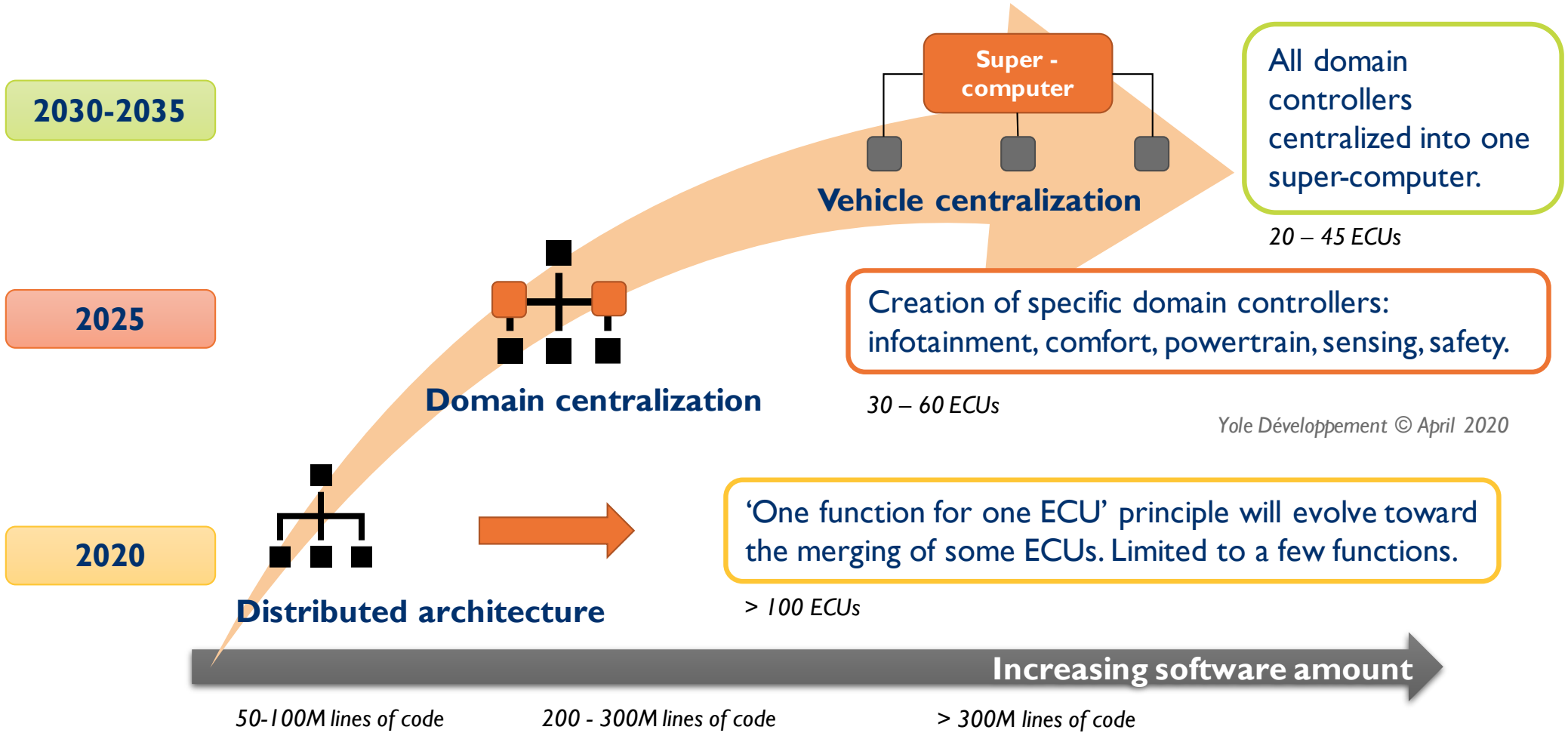
Increase of ADAS systems and vehicle electrification

Source: Aptiv/Modified by Yole

THE TRANSFORMATION OF E/E ARCHITECTURE

E/E architecture evolution - Roadmap

Development from a distributed architecture to a centralized architecture.

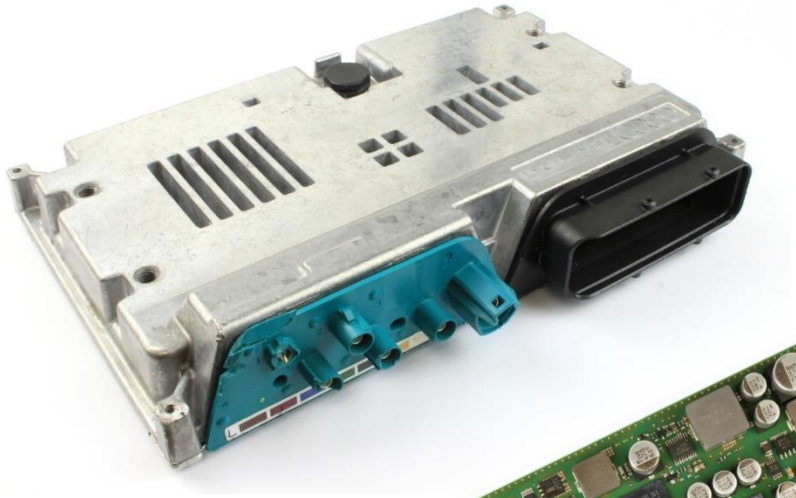


- Today, OEMs are still using a distributed E/E architecture with roughly one ECU per function.

THE TRANSFORMATION OF E/E ARCHITECTURE

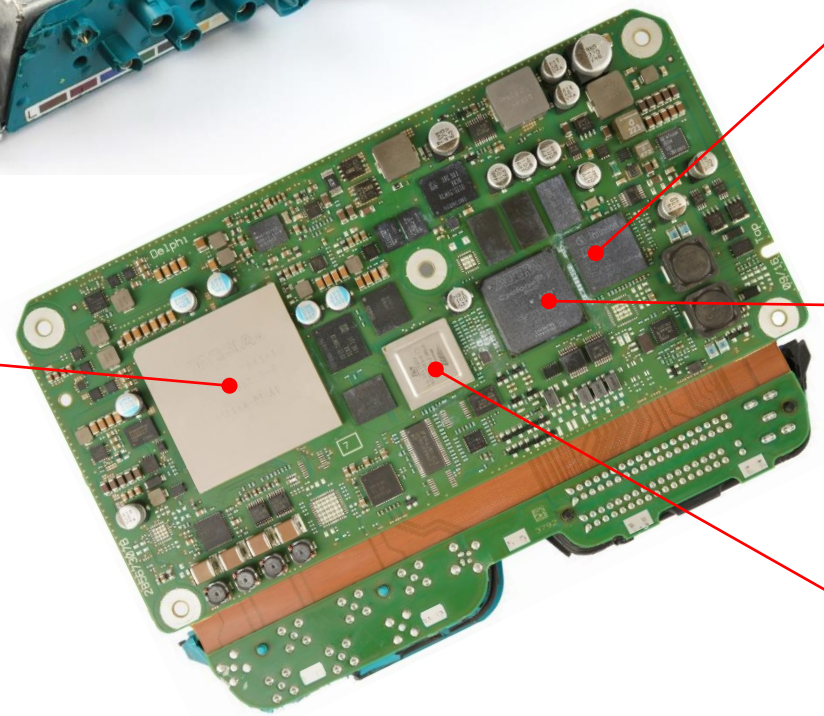
zFAS module from Audi – Teardown from S+C

This module has been developed to integrate data coming from radars, cameras, LiDARs and ultrasonic sensors.



APTIV

Aptiv is the supplier of this module.



MCU 32-bit Aurix
- Hosting different functions
- A-SIL D compliant
- Interface to the car architecture

Cyclone V SoC
- Responsible for sensor fusion
- Pre-processing ultrasonic sensors
- Internal gateway

Nvidia Tegra K1 SoC
- Image processing for parking
- Four cameras computed
- Driver monitoring

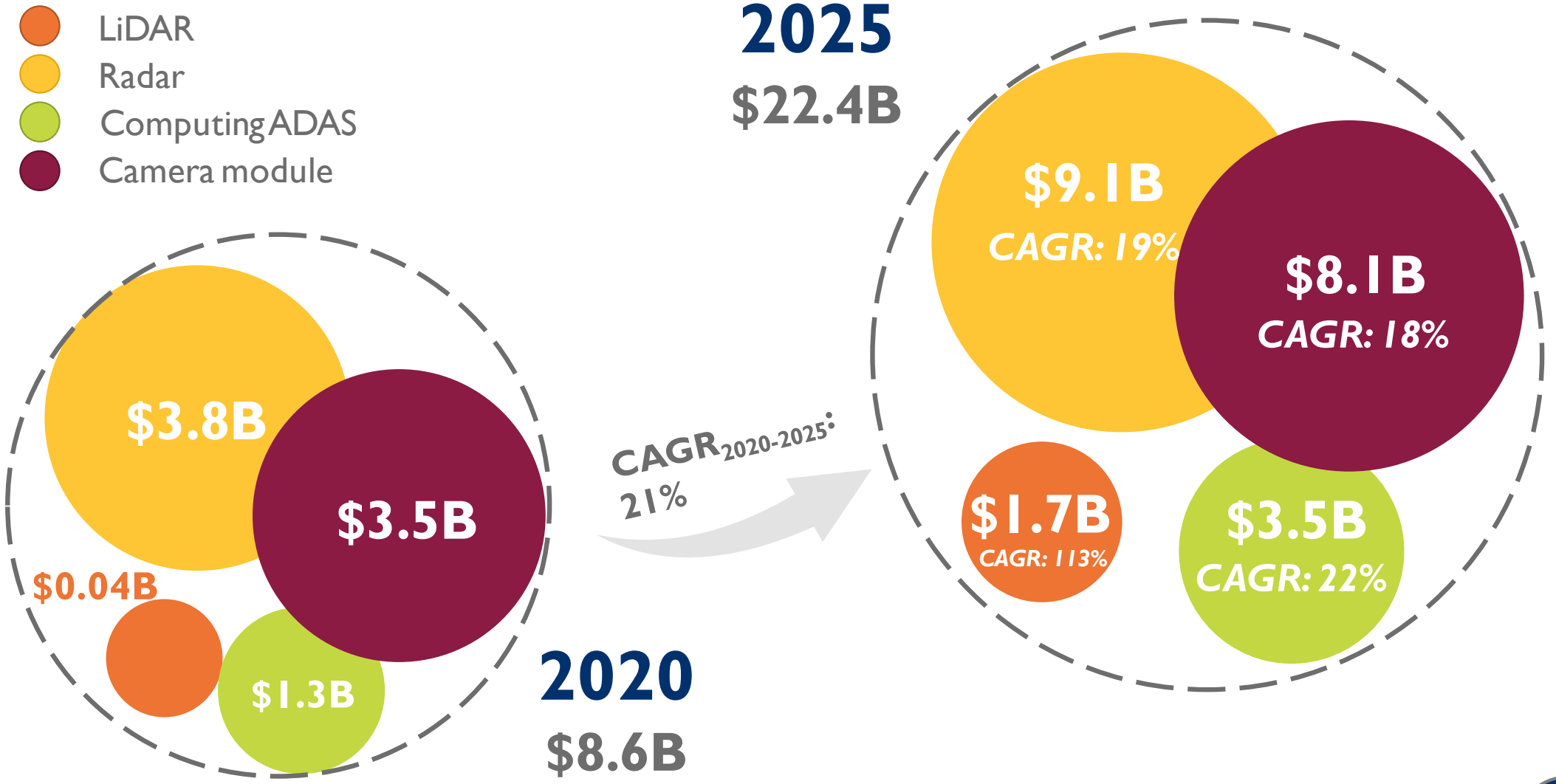
MobilEye EYEQ3
- Front camera image processing
- AEB for cars and pedestrians

Courtesy of System Plus Consulting

MARKET FORECASTS

Overview of sensors and computing market revenue

A fast-growing market at a $CAGR_{2020\text{-}2025}$ of 21%.



INDUSTRY OVERVIEW

Consolidation expected in the LiDAR industry

More than 80 LiDAR companies

There are too many LiDAR companies compared to the number of OEMs willing to implement LiDAR. LiDAR companies must find other markets to generate cash.

Limited number of OEMs

Oryx went bankrupt in 2019 and Aurora acquired Blackmore the same year. Aurora recently acquired Uber ATG.
Other LiDAR companies are expected to follow the same path.

ROBOTIC VEHICLE SENSING TECHNOLOGY TREND

5th generation Waymo sensor suite

Robotic vehicles will primarily use industrial grade technology.

Lidars

Short-/mid range	x4
Long range	x1

Radars

360° view	x6

Cameras :

360° view Cameras	x29

Courtesy of Waymo

SENSING FOR AUTONOMOUS DRIVING

Automation
Automotive /Aerospace

Robotics
Robo-cars/shuttles/UAM

Market Drivers

Serviceability

"Lidars have been instrumental in putting fully self-driving cars on public roads"

Performance & supportability

For ADAS equipment, cost is the primary driver and reliability the barrier to entry. « Good enough » performance has nevertheless to be achieved.

Industrial cameras

Industrial lidars

High-end automotive radars

Cost

Performance

SS lidars

4D radars

FMCW lidars

Automotive cameras

Automotive radars

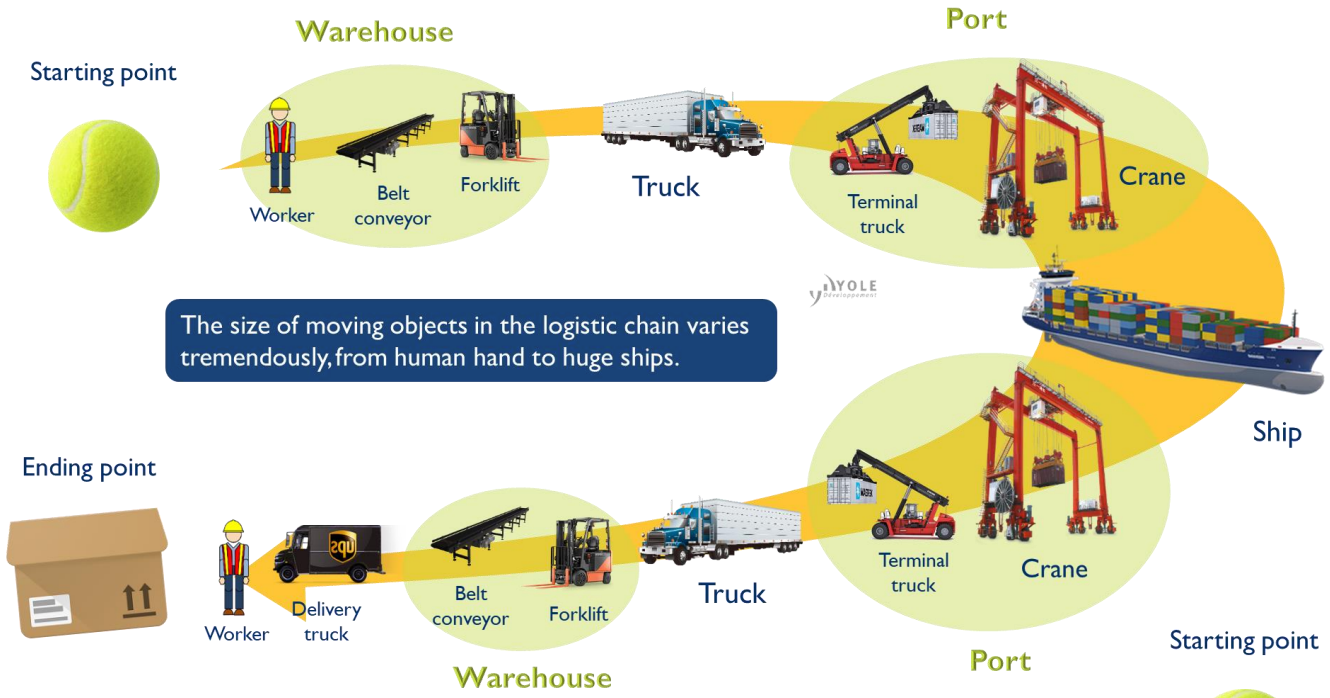
US transducers

Cost & reliability

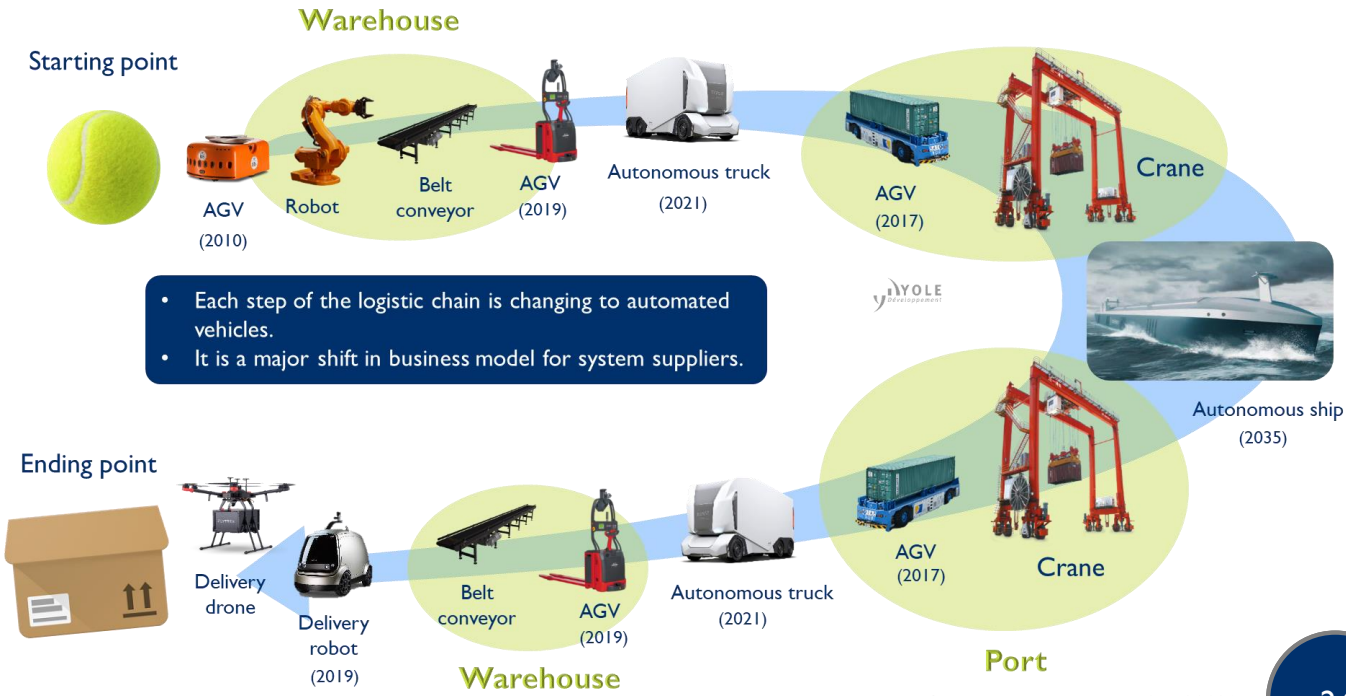
Robotic vehicles are using high-end industrial sensors. The retrofit approach and the serviceability/low volume of MaaS means there is no stringent reliability nor cost issue. The key driver here is performance.

Reliability

LOGISTICS: THE FLOW OF THINGS



Need of sensors: cameras, radars, LiDARs



Logistics: Toward full automation

LOGISTICS: MANY PLAYERS ALREADY INVOLVED

Industry

Large AGV

AGV

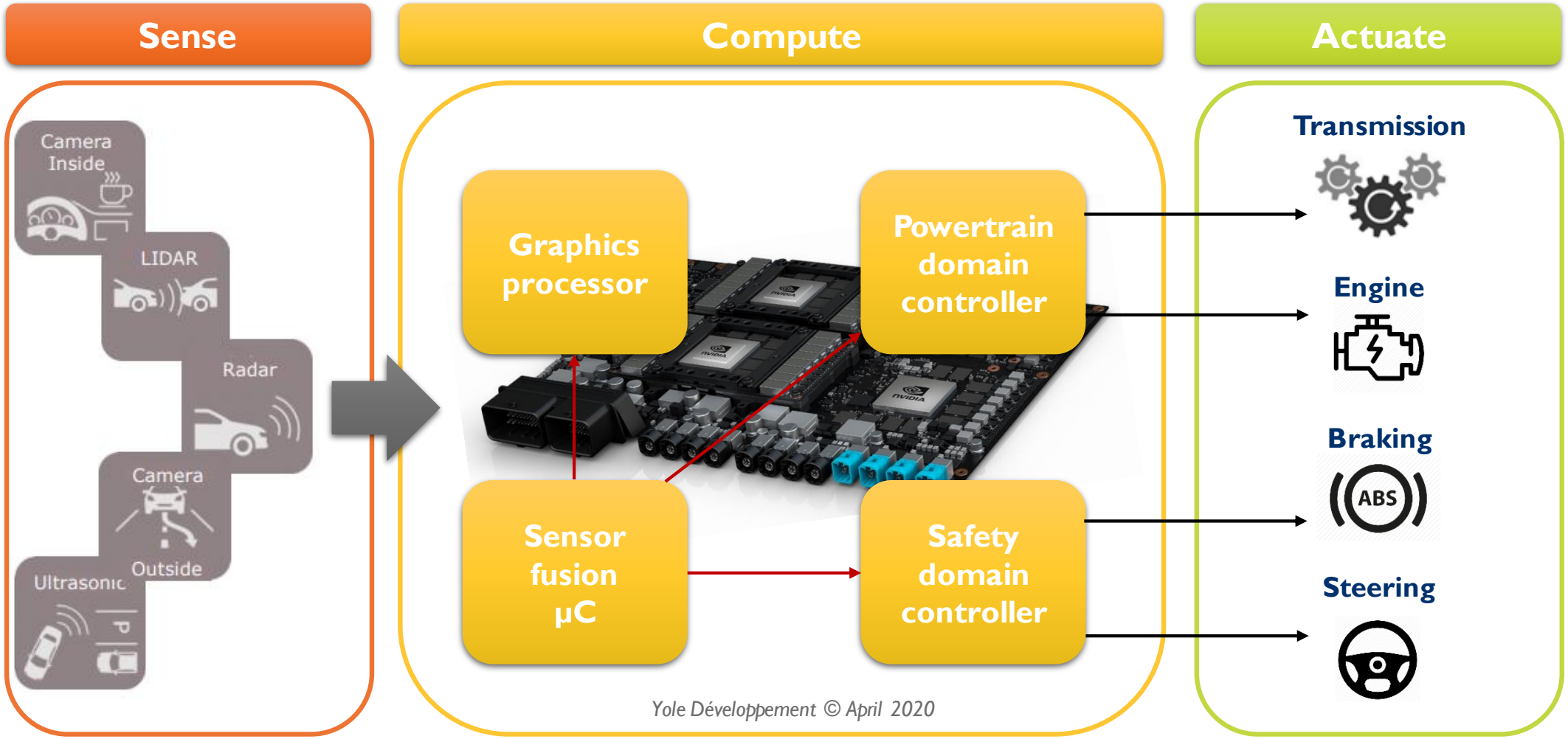
Trucks

Last mile delivery

SENSOR FUSION

Computing unit – ADAS system overview

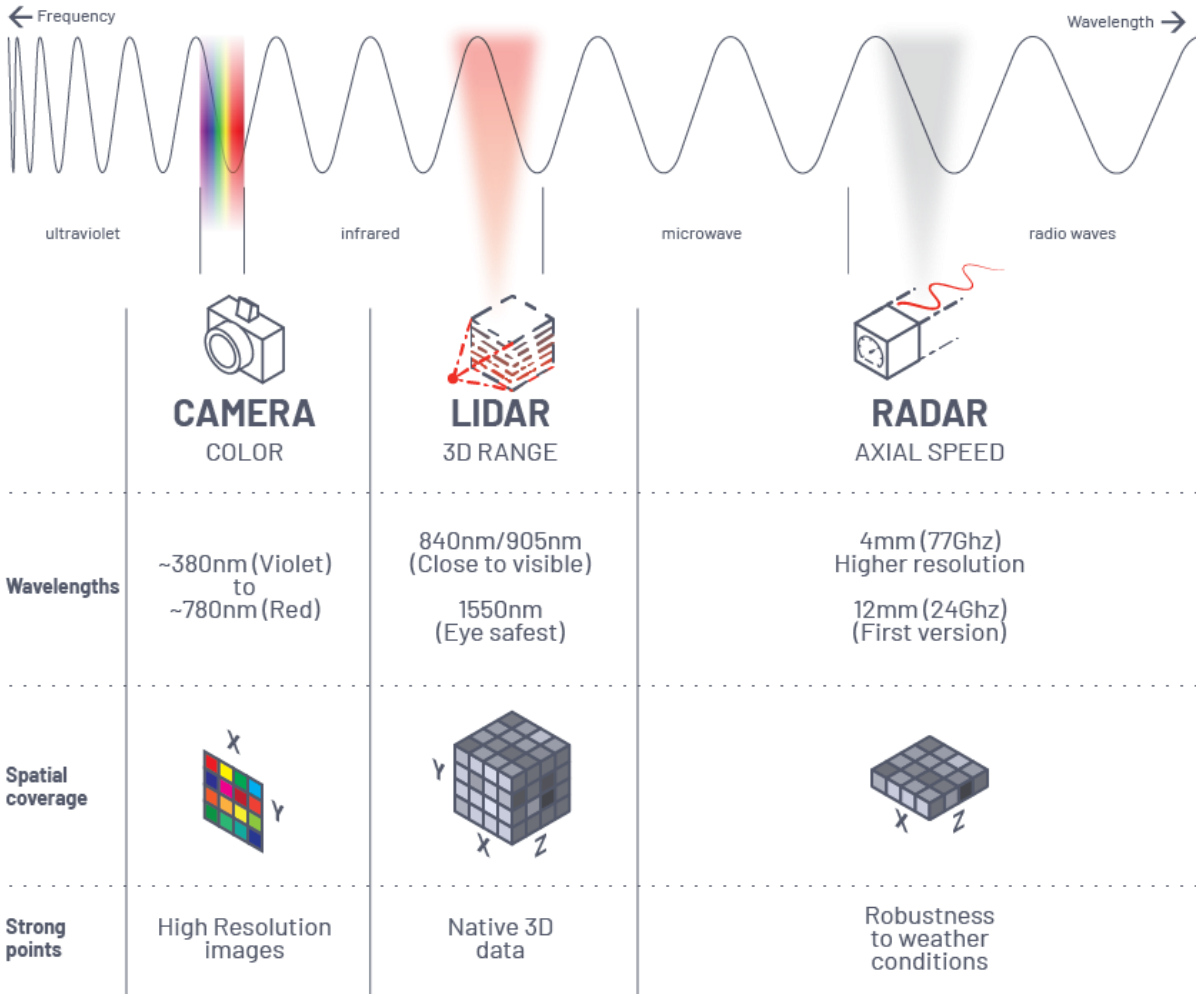
As more and more sensors are used for ADAS, computing will become critical. Data processing and computing power will become differentiating parameters.



SENSOR FUSION

Different sensor capabilities for sensor fusion

There is no perfect 3D sensing technology.



Courtesy of Outsight

Camera: provide high resolution images but lack of native depth information and depend on light conditions.

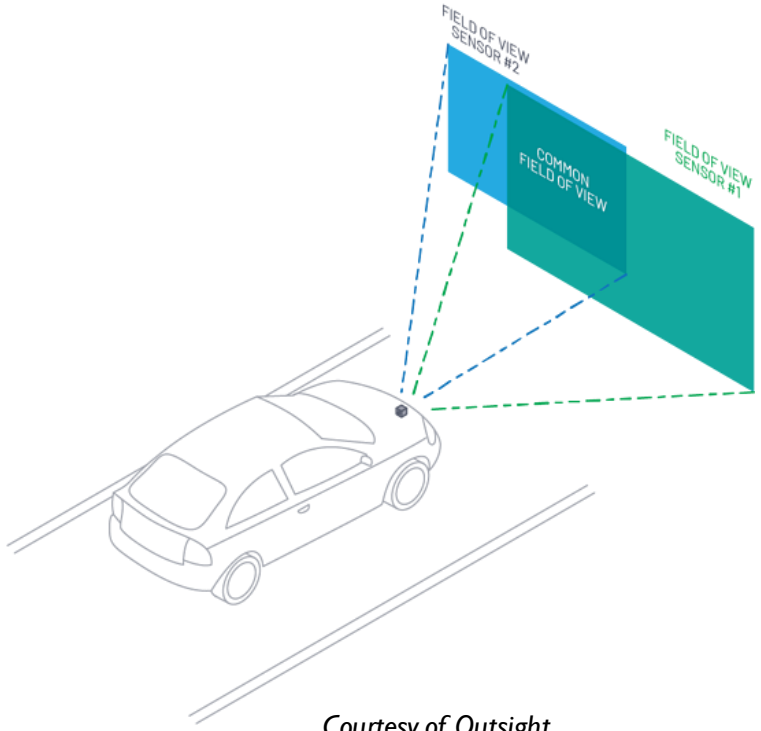
Radar: measure velocity with great precision but have trouble to detect static objects and to measure the position of objects due to low resolution.

LiDAR: only sensor to provide native 3D data but high performances LiDAR are very expensive.

SENSOR FUSION

The parallax issue

Calibration will be crucial to combine different perspectives.



Courtesy of Outsight

When sensors are positioned apart from each other, they will have a different perspective on the vehicle's environment (parallax) which may lead to a situation in which one sensor can perceive an object, while it is occluded for the other sensor

SENSOR FUSION

Dream vs reality

Gathering all the sensors in one place is not possible in ADAS vehicles.

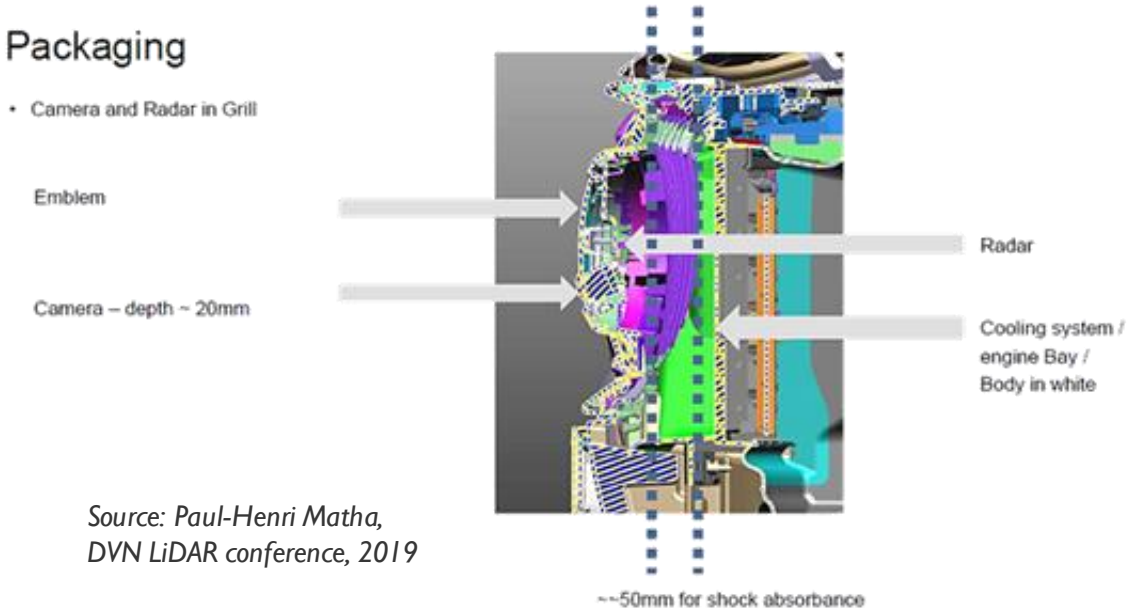
The ideal case

Courtesy of System Plus Consulting

All the sensors are aligned and closed one to the others. The parallax issue is limited, and fusion of data is easier.

The reality: not enough space

VOLVO



Source: Paul-Henri Matha, DVN LiDAR conference, 2019

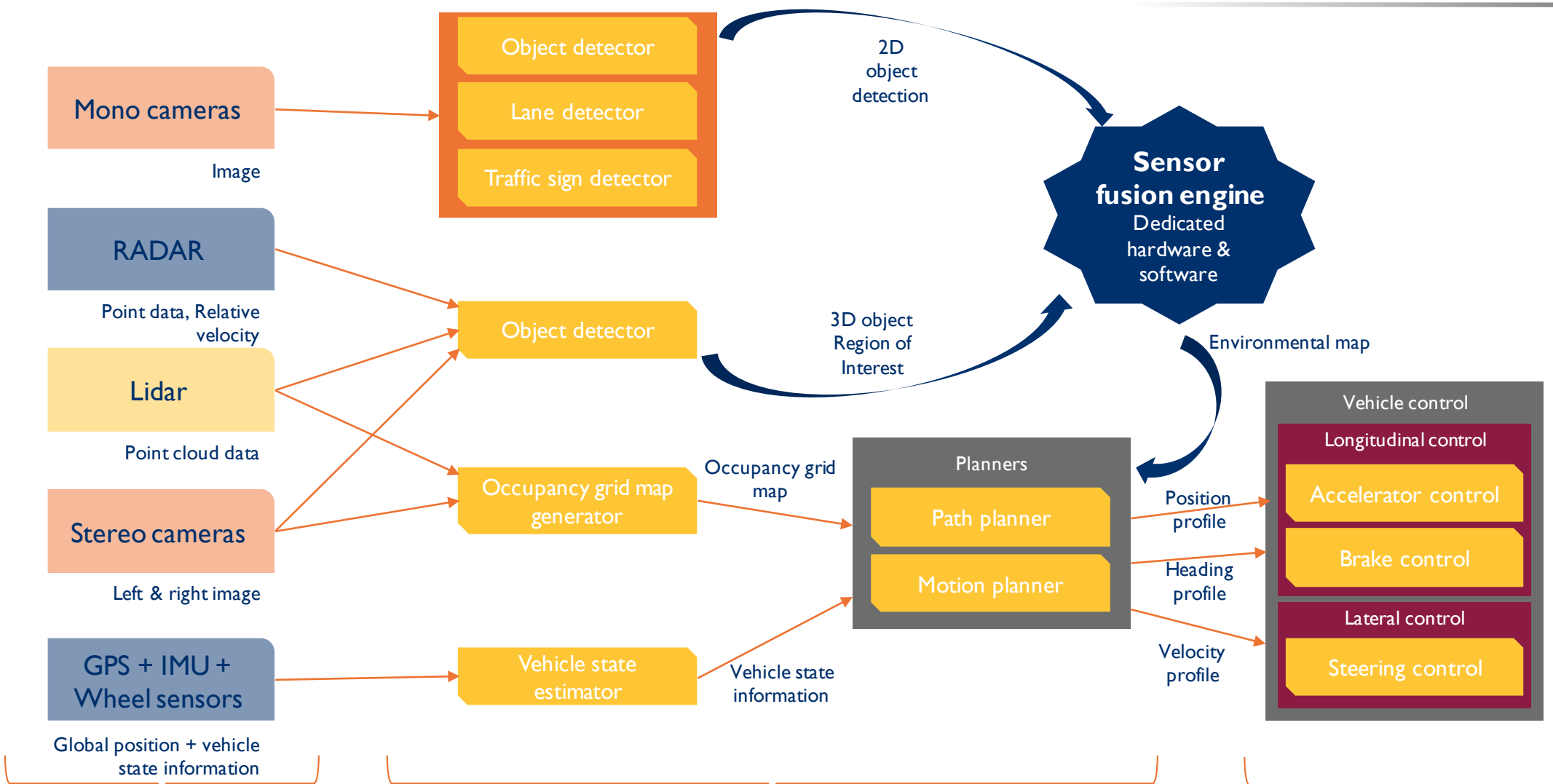
In most of the times, it is difficult to integrate more than two sensors in a place due to several constraints.

SENSOR FUSION

The place of the sensor fusion engine in the control decision map

Sensor fusion uses sophisticated computer vision and deep-learning-based algorithms

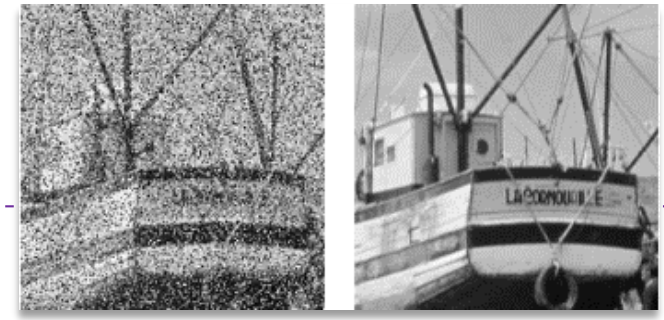
Complex use-case scenarios expected of driverless cars can be understood.

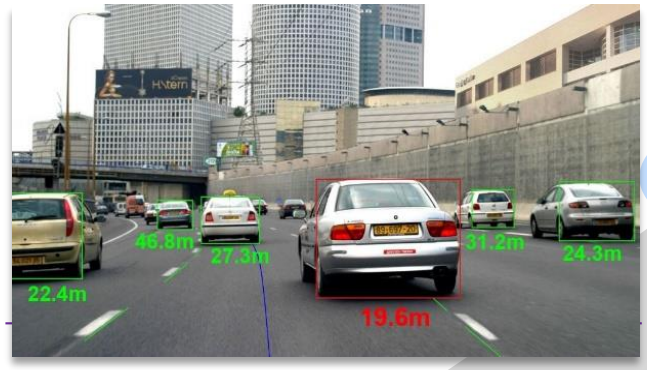


SENSOR FUSION

From image processing to fusion platform

- Amount of data processed
- Performance
- Consumption





Fusion platform from NVIDIA

Frame processing + other sensors
Fusion platform

Price per unit

> $1000

Centralization

$100

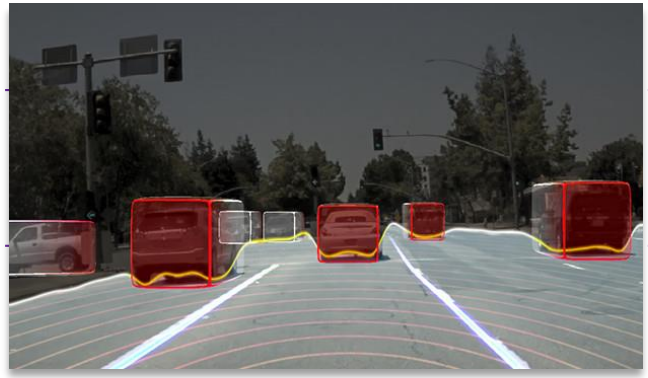
Frame processing
Vision processor

Vision processor from MobilEye

Sensing Processing Unit – ISP stacked with CIS

$10

Acceleration



Set of pixels processing
Image Signal Processor

Standalone ISP from Altek

< $1

Image processing

Computer vision

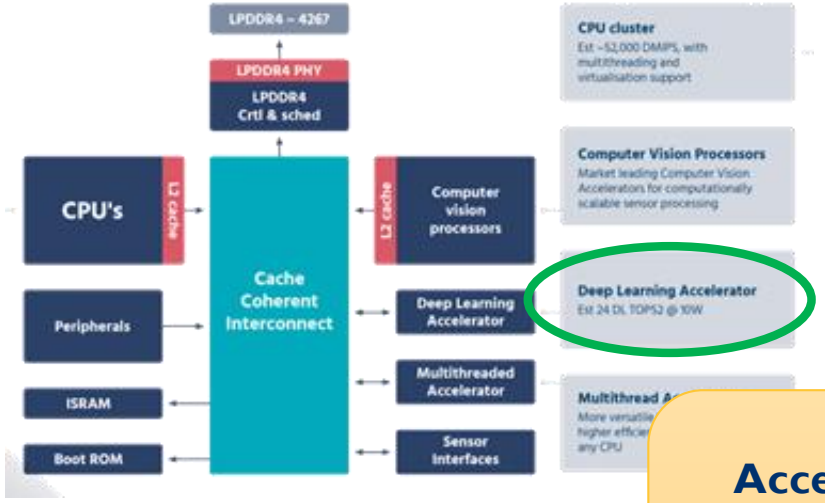
AI algorithms

Algorithm complexity

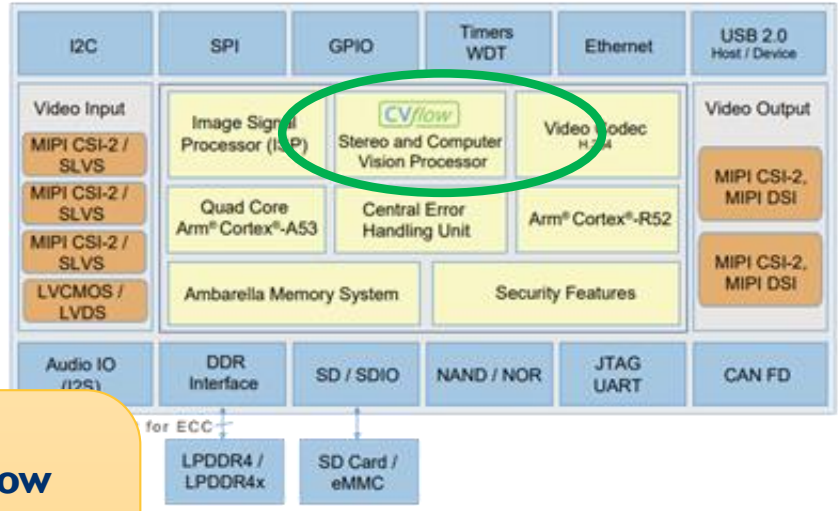
SENSOR FUSION

Toward accelerators in automotive

In production for 2021



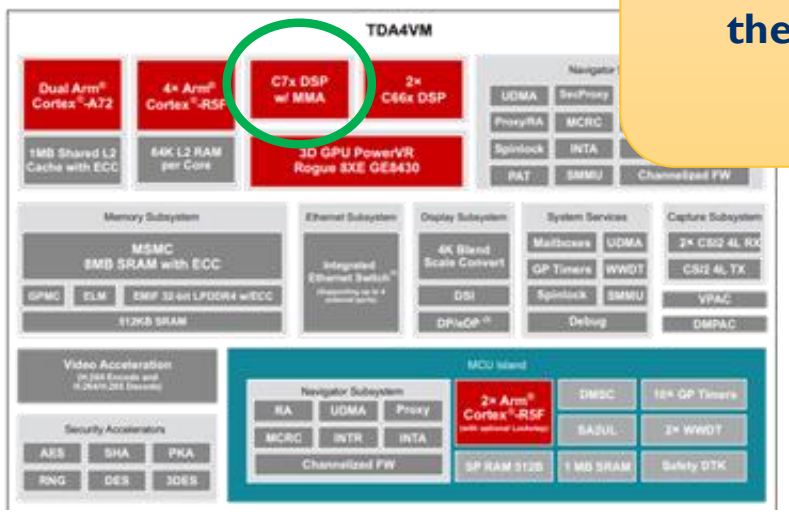
MOBILEYE
An Intel Company



Ambarella CV2 series
In production for 2021

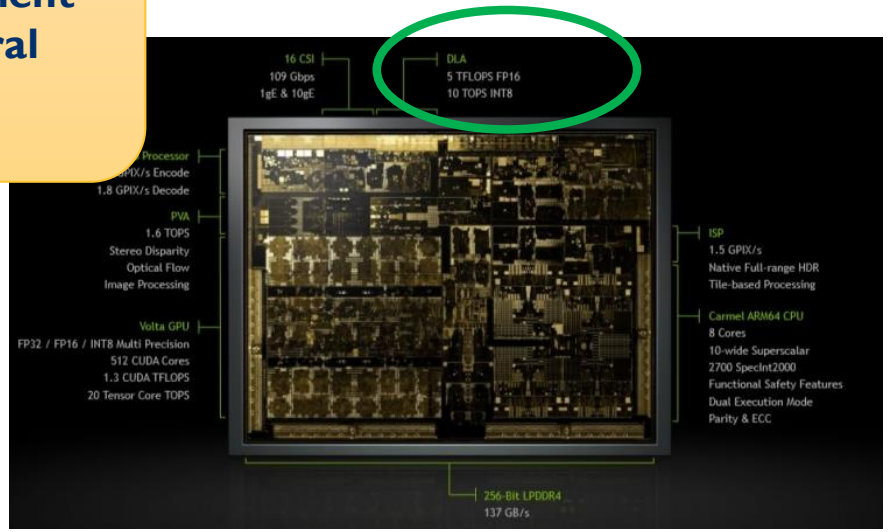
Ambarella™

Accelerators allow OEMs to implement their own neural networks



In production for 2021

Texas Instruments



Accelerator embedded in SoC

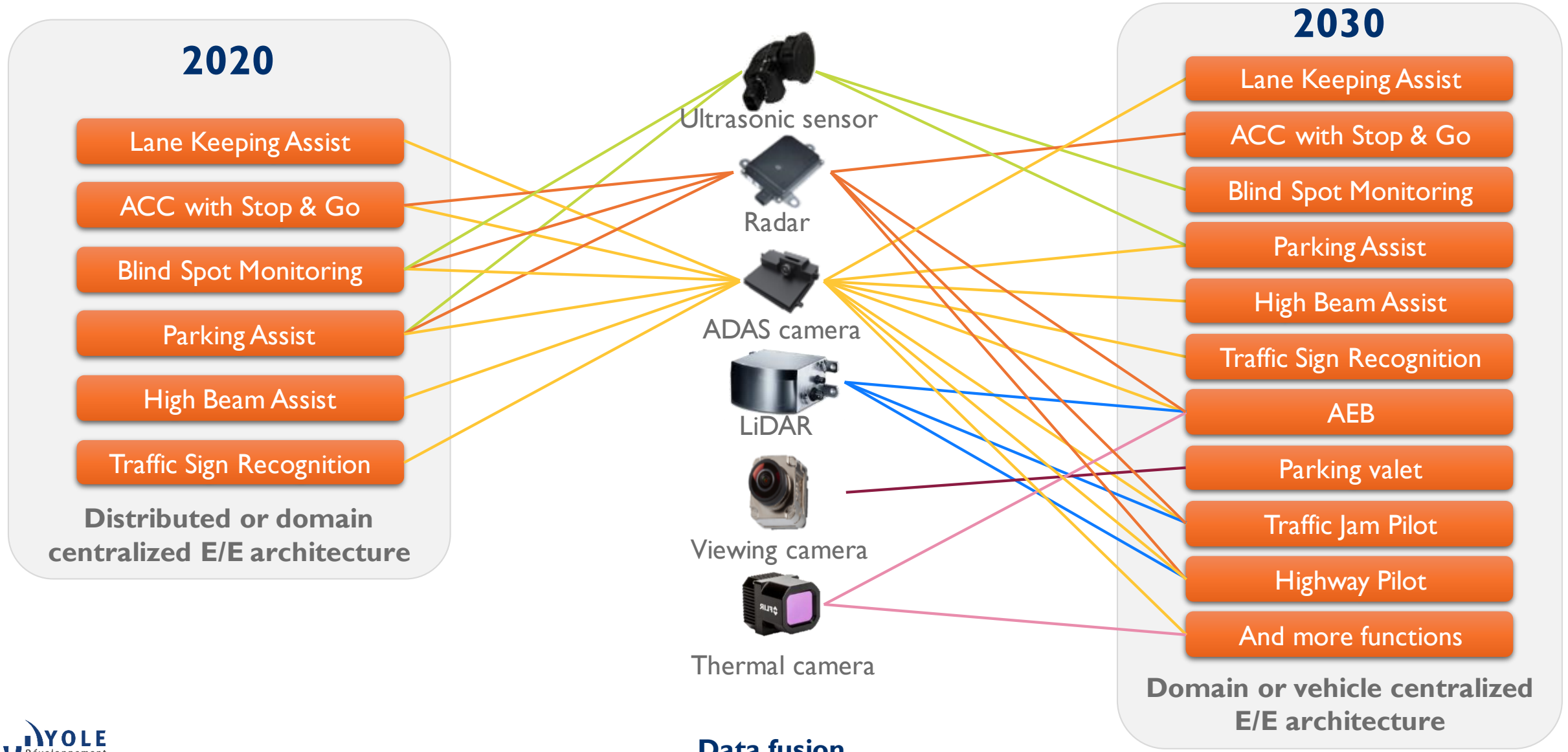
In production for 2021

NVIDIA

YOLE Développement

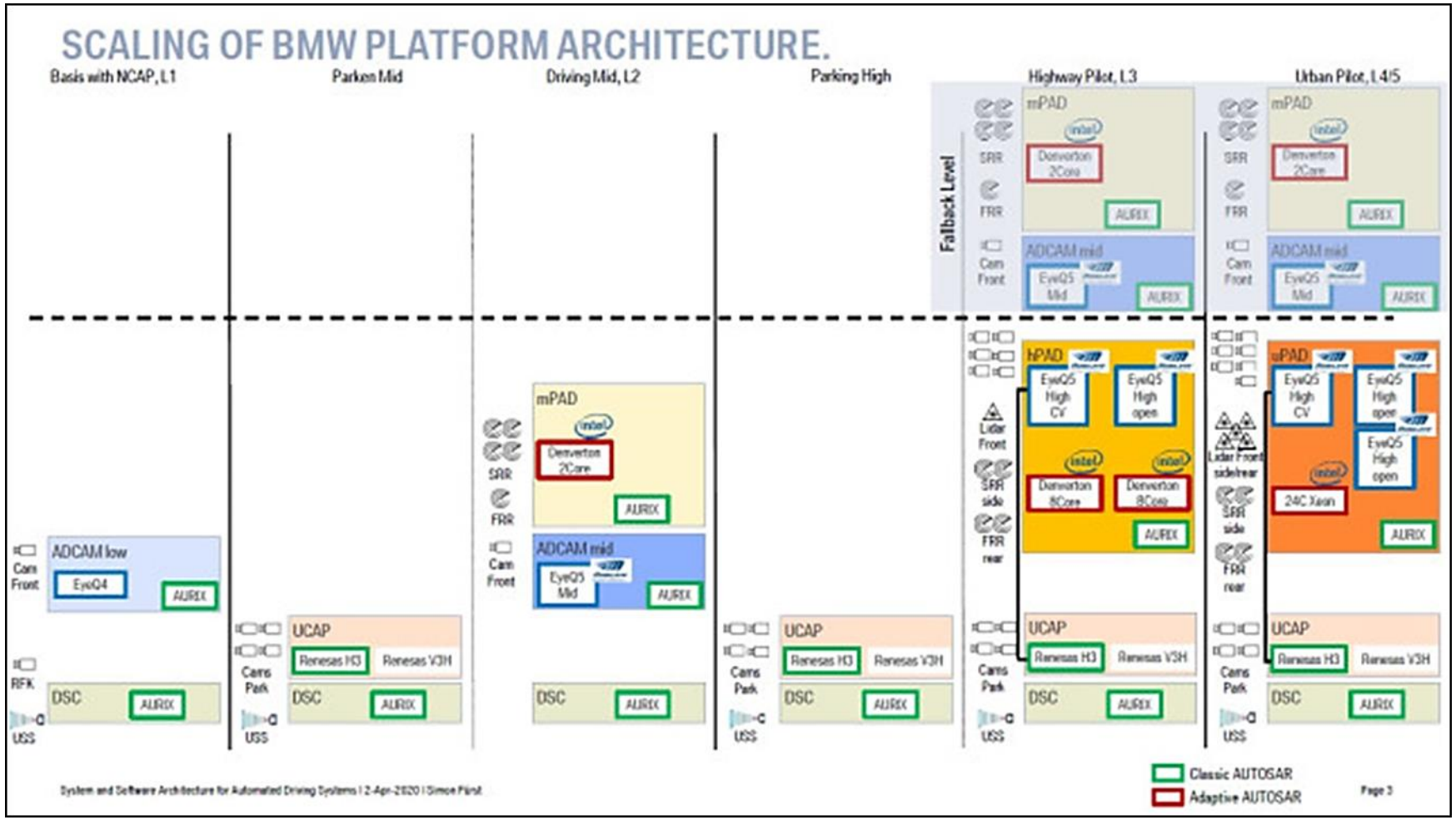
SENSOR FUSION

Data fusion for automated driving enables more functionalities



SENSOR FUSION

Add chips to add functionalities



Source: BMW

Level 1
1 chip
2.5 TOPS
6W

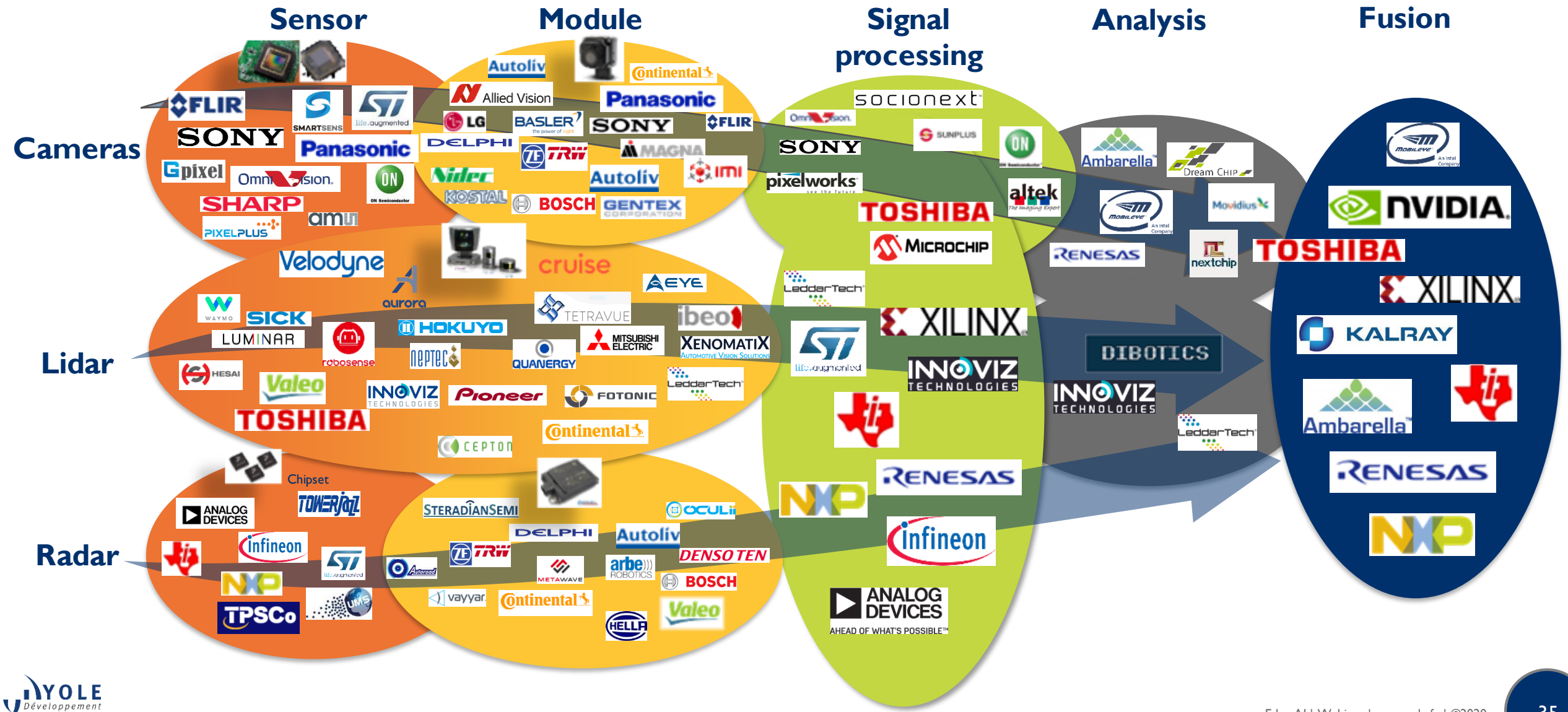
Level 2
1 chip
24 TOPS
10W

Level 3
2 + 1 chips
72TOPS
30W

Level 4/5
3 + 1 chips
96TOPS
40W

SENSOR FUSION

From sensors to fusion in automotive – Overview of players



Thank you for your attention

Contact: pierrick.boulay@yole.fr

Courtesy of Peugeot

Empowering Product Creators to Harness Edge AI and Vision

The Edge AI and Vision Alliance (www.edge-ai-vision.com) is a partnership of ~100 leading edge AI and vision technology and services suppliers, and solutions providers

Mission: To inspire and empower engineers to design products that perceive and understand.

The Alliance provides low-cost, high-quality technical educational resources for product developers

Register for updates at www.edge-ai-vision.com

The Alliance enables edge AI and vision technology providers to grow their businesses through leads, partnerships, and insights

For membership, email us: membership@edge-ai-vision.com

Join us at the Embedded Vision Summit

May 25-27, 2021—Online

The only industry event focused on practical techniques and technologies for system and application creators

- *"Awesome! I was very inspired!"*
- *"Fantastic. Learned a lot and met great people."*
- *"Wonderful speakers and informative exhibits!"*

2021 embedded VISION summit®
VIRTUAL | MAY 25-27

Embedded Vision Summit 2021 highlights:

- **Inspiring keynotes** by leading innovators
- High-quality, practical **technical, business and product talks**
- Exciting **demos**, **tutorials** and **expert bars** of the latest applications and technologies

Visit www.EmbeddedVisionSummit.com to sign up for updates