Towards Autonomous Driving

World Leader in Advanced Driver Assistance Technology and Autonomous Driving

New Design Wins 2017

30 Design Wins

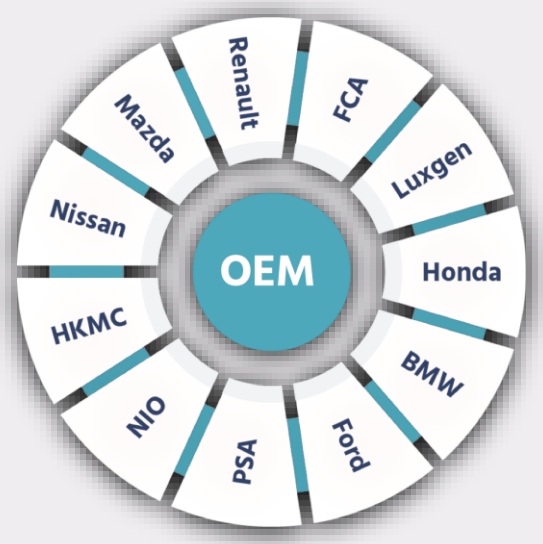
27 OEMs

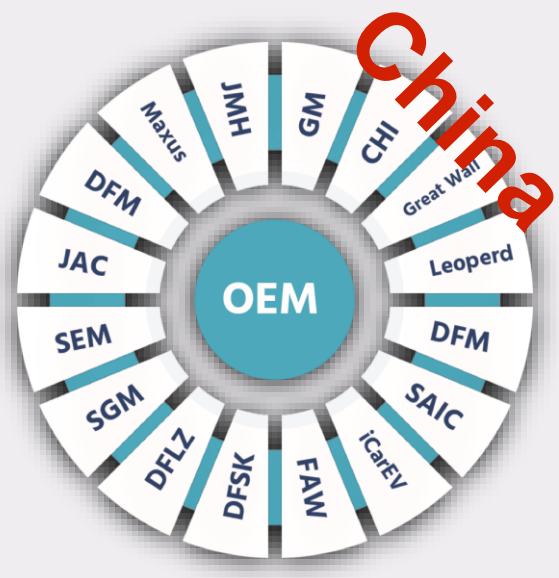
~70 car models

Nearly 70 vehicle models, 27 OEMs, 30 design wins
(in 2016 there were 12 design wins)

Main Features	Tier 1
AEB EUNCAP 2018, LDW	Valeo
AEB, ACC, LKA	ZF-TRW
AEB, VOACC, LKA	ZF-TRW
AEB EUNCAP 2020, Traffic Jam Assist, Road Profile	Aptiv
AEB, ACC, LKA, FreeSpce	ZF-TRW
AEB, LKA	Aptiv
AEB, ACC, HLB, FreeSpace	Mando
AEB, ACC, FreeSpace, Road Edge	KSS
AEB, ACC, LKA, TSR	Nidec
Base: L2/3 premium: L3/4	NIO
AEB, VOACC, Glare Free HB, 3D VD, REM	ZF-TRW
AEB, pedal confusion, Enhanced LKA	ZF-TRW
AEB EUNCAP 2020, Traffic Jam Assist, Road Profile	Valeo
AEB, LDW	Aptiv
AEB EUNCAP 2020 & NHTSA, Road	Magna

Main Features	Tier 1
AEB, LDW	Hirain
AEB, LDW, ACC	Hirain
AEB, LDW, ACC	Mando
AEB, ACC, LKA	Hirain
LDW, FCW	Hirain
AEB, ACC, LKA, TJA	Hirain
AEB, ACC, LKA, Lane Changes	DIAS
AEB, LDW, ACC	Hirain
AEB, LKA, ACC	Hirain
AEB, ACC, LKA, Lane Changes	KSS
AEB, LDW, ACC	Hirain
AEB, LDW, ACC	Hirain
Full EUNCAP2020 compliance, 3D VD, FreeSpce, Objects	Valeo
AEB, LKA, ACC	ZF-TRW
L3, surround, Road Profile, REM	Aptiv





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2017 Review

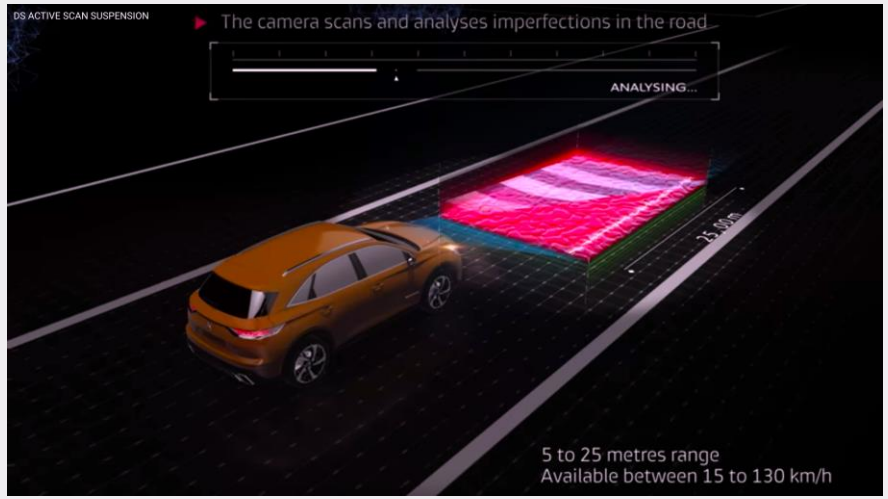
GM Super Cruise

Audi zFAS

Nissan ProPilot

Program Launches 2017

Installed by 2017 year end



OEM Launch	Special Features	Tier 1
GM CSAV2	AEB (fusion), LKA, HLB, TJA, Super Cruise™	**ZF-TRW**
Audi	AEB, LKA, HLB, RoadProfile, zFAS A8	**Aptiv**
Ford	AEB (fusion), LKA, HLB, TJA	**Aptiv**
HKMC	AEB (fusion), LKA, HLB	**Mando**
PSA wave 2	AEB (vision only), VOACC, LKA, RoadProfile	**ZF-TRW**
Nissan	Propilot (vision only) launch in the US	**ZF-TRW**

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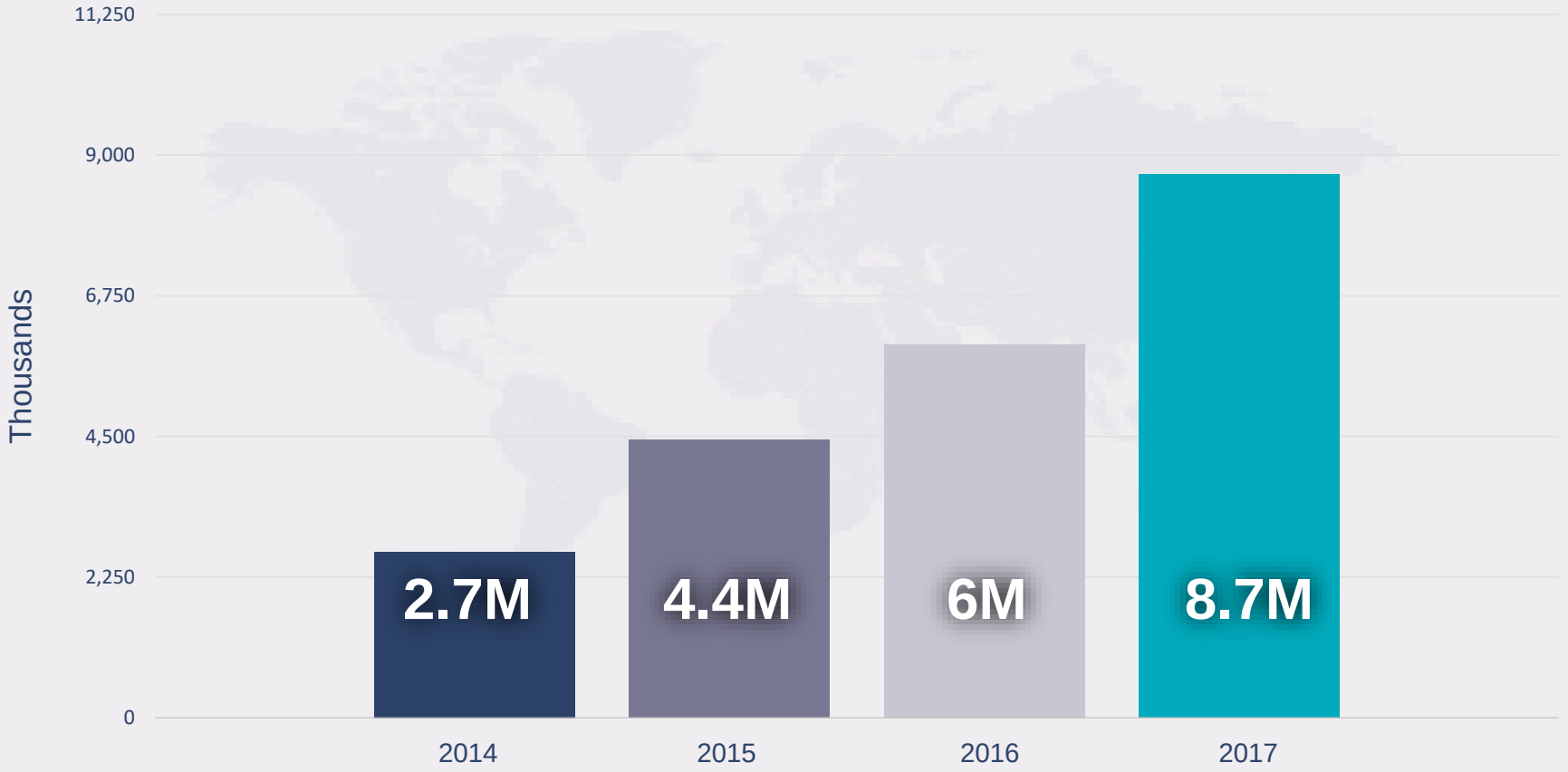
2017 Review

EyeQ® Shipped

24M EyeQs shipped to date

2017: ~9M EyeQs



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2018 Program Launches

15 programs to be launched during 2018

- 14 OEMs (4 of which are Chinese)
- 4 programs with EyeQ4 (12 additional launches starting from 2019)
- 2 programs with Trifocal camera configuration
- ALL programs have full-feature bundles (high-end)

New features launched in 2018:

- 3DVD
- Traffic Lights Detection and Recognition
- Advanced Road features: Semantic Free Space, Holistic Path Prediction
- REM

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Strategy

Philosophy: a single effort

Level-4/5 Automation → derivatives → L2, L2+, L3

Economical Scalability

- Automating HD-maps through a crowdsourcing approach
- Controlling the explosive computational demands of Driving Policy (Planning)
- Scalable, workload-diverse and low-power SoC together with powerful ATOM cpu

Model for Safety Guarantees

- Decouple Sensing from Planning mistakes that could lead to an accident
- RSS - a formal model of the human judgement of common-sense of Planning
- Using RSS to provide safety guarantees

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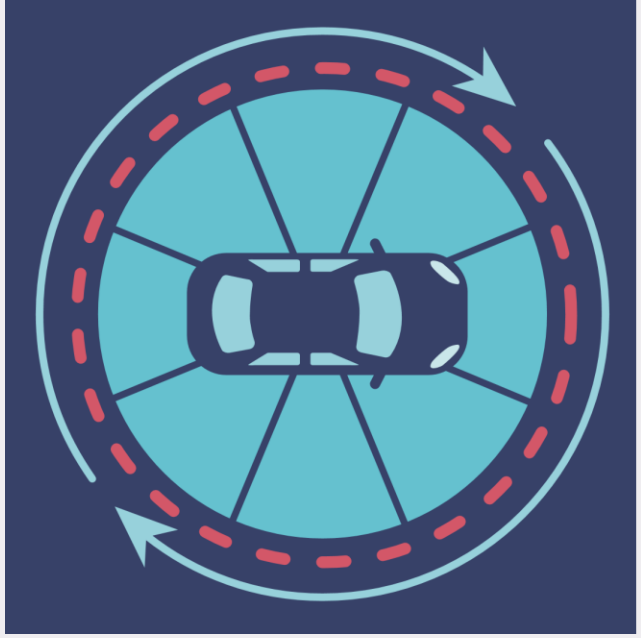
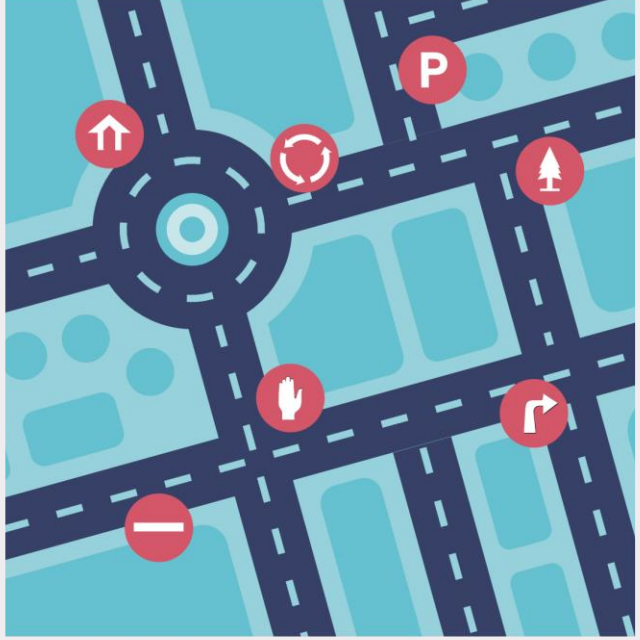
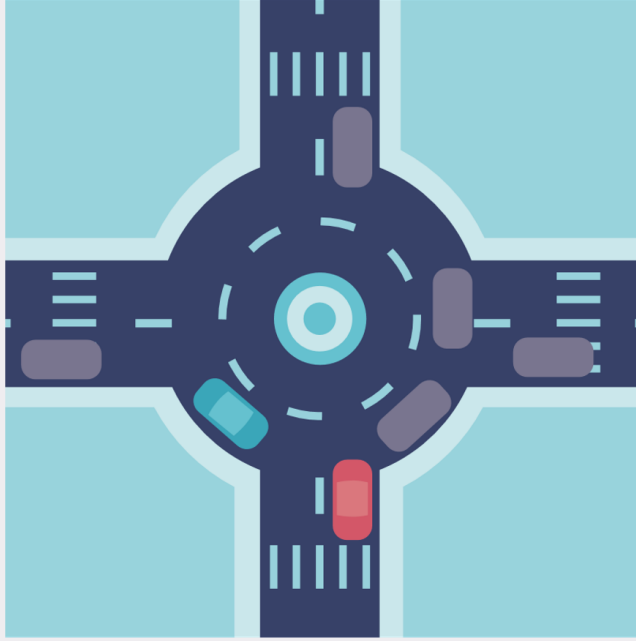
Autonomous Driving: Three Pillars







SENSING

Environmental model

360 awareness

REM (Roadbook)
Road Experience Management

Localization at high accuracy (10 cm)

Drivable Paths

DRIVING POLICY (Planning)

Negotiating in a multi agent game

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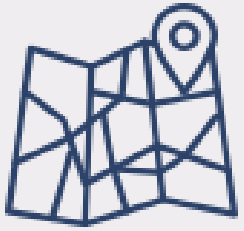
Sensing

Detecting Road-users and spatially-compact objects

Vehicles, Pedestrians, Cyclists, Traffic Signs, Traffic Lights

(mature technology in series production as part of ADAS evolution)



Parsing the Roadway

Lane marks, road edges, path delimiters, drivable paths

- Drivable path(s) by **redundancy** of (i) sensing, and (ii) HD-map
- Necessary building block for **automating** HD-map construction (REM)

Notes:

- Parsing Roadway to sufficient details for L4 is an **open problem**
- Conventional approaches **avoid** Road-parsing and use only HD-map

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Sensing

Path Delimiters in urban environments

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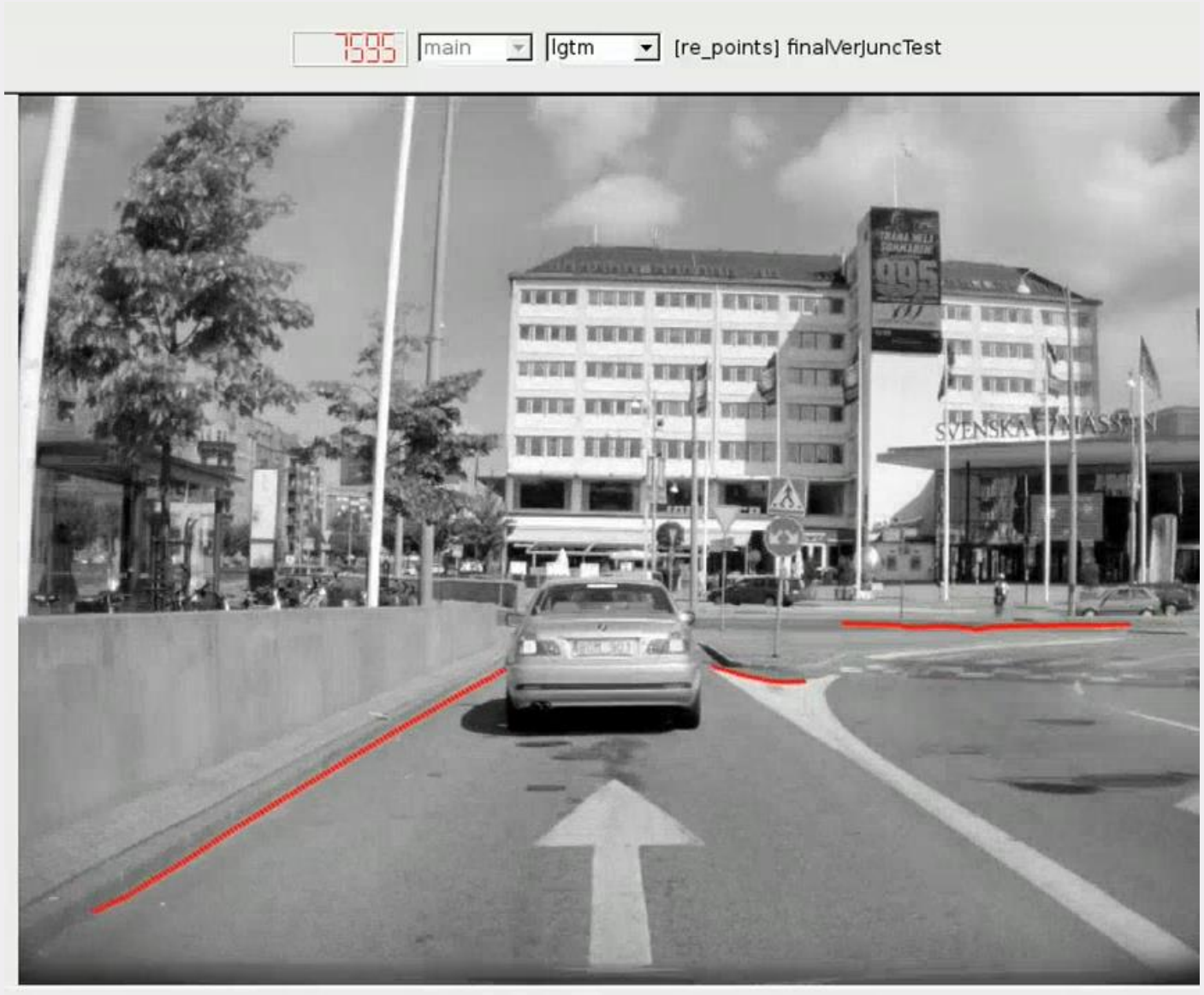
Sensing

Path Delimiters in urban environments



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Sensing

Road users and Path Delimiters

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Sensing

Holistic Lane Centering

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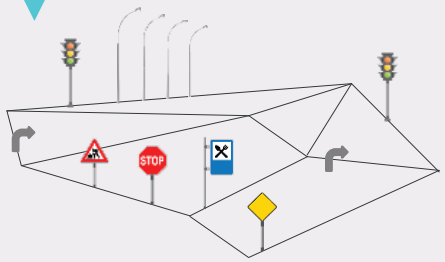
Road Experience Management (REM)

Visual Landmarks

Visual Landmarks on map



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Strategic Value of REM

Leveraging ADAS

- Introduce REM software on EyeQ for front-facing cameras (leverage existing real-estate in the car)

Leveraging Crowd-sourcing

- Bandwidth of data from car to cloud is very low **~10kb** per kilometer of driving

Automation

- The process for creating and updating maps is automatic.

Density of data sources

- Volume of ADAS-enabled vehicles enable very low "**time to reflect reality**" everywhere, rather than merely in "geo-fenced" neighborhoods.

REM introduces highly scalable "live" HD-map at low-cost

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Building Blocks of REM

Harvesting

collections of roadway data (lanes, etc.) and landmarks to create RSD at 10kb/km

Aggregation

fusing all the RSDs in the cloud into a RoadBook

Localization

using RB and realtime detection of landmarks localize the host car in the RB at an accuracy sufficient for Policy and vehicle control

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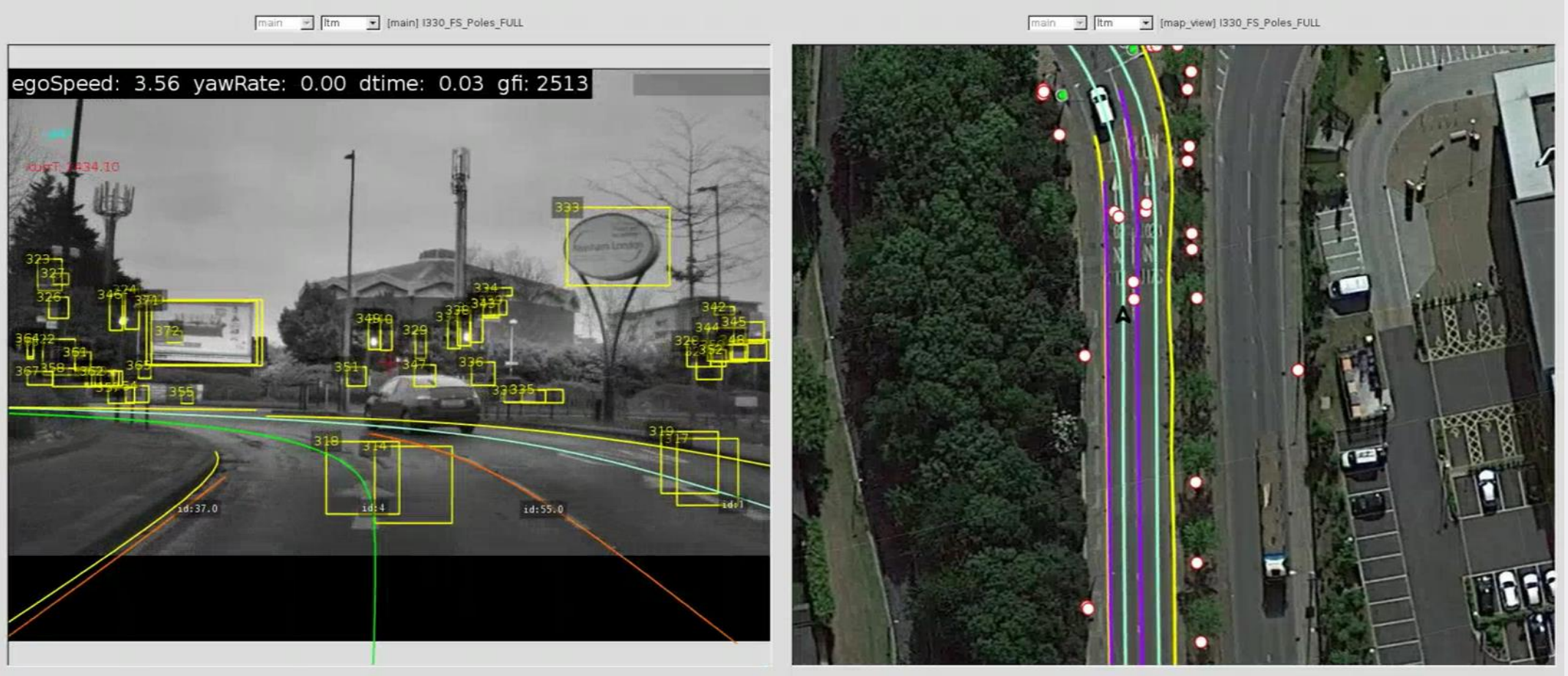
REM



RB data projected onto image space.
Road edge, lane marks, lane center, landmarks (in Yellow).

RB data projected onto Google Earth.

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REM 2017 Achievements

- Preparing harvesting for 2018 production programs (BMW, Nissan, VW)
- Preparing RB covering all Japan highways in cooperation with Zenrin and Nissan
- Cooperation with NavInfo and SAIC for bringing REM to China
- Deals ongoing with OEMs for Harvesting 2019 and beyond
- Deals ongoing with OEMs for RB usage for L2+ (new ADAS category)
- Aftermarket “Mobileye 8 Connect” REM supported and deals for 2018 deployment
- Mapping neighborhoods across the globe for supporting internal L4 development as a turn-key solution

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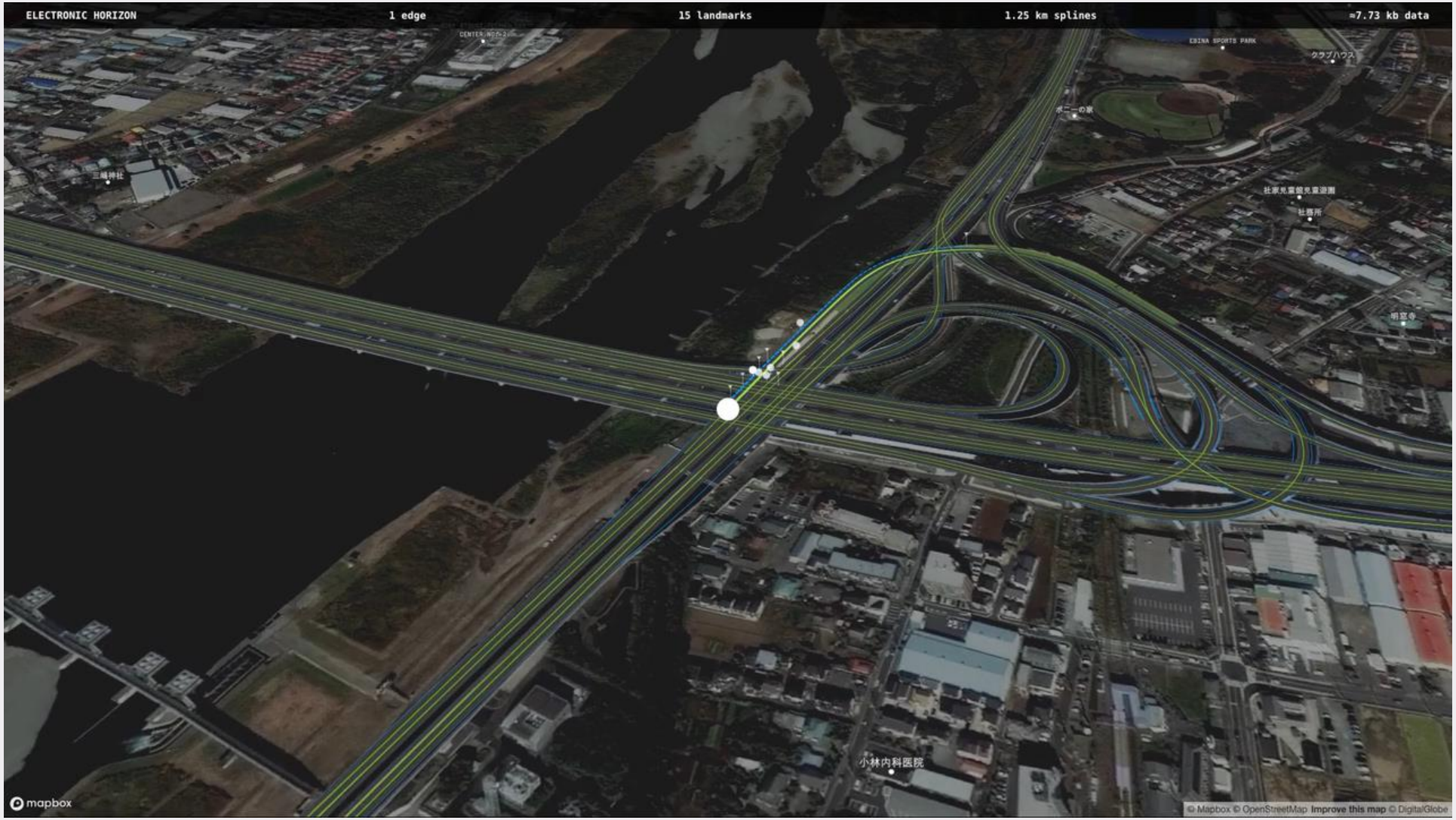
REM



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Mapping of Japan highways - with Zenrin/Mapbox/Nissan for L3 launch in 2019

REM

L2+

front-facing camera + Roadbook
A leap in ADAS L2 features (LKA/ACC).

Sensing alone (righthand image) cannot robustly detect the drivable path to enable safe hands-free control. The Roadbook data can bridge the gap as localization is based on a high degree of redundancy of landmarks and is therefore robust.

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REM

L2+

front-facing camera + Roadbook
A leap in ADAS L2 features (LKA/ACC).

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Mobileye 8 Connect™

REM in the Aftermarket

A big data potential for REM

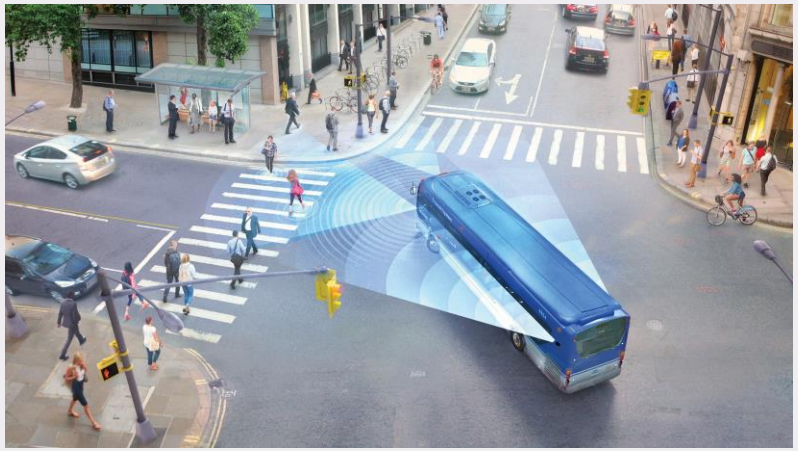
Volume of device shipment to fleets ~10% of OEM business (and growing), but each vehicle drives x10 the mileage of passenger cars

- Mobileye 5, 6, 7
- EyeQ2

- Shield+

Launch Q1/2018

- Mobileye 8 Connect™
- EyeQ4 + Modem



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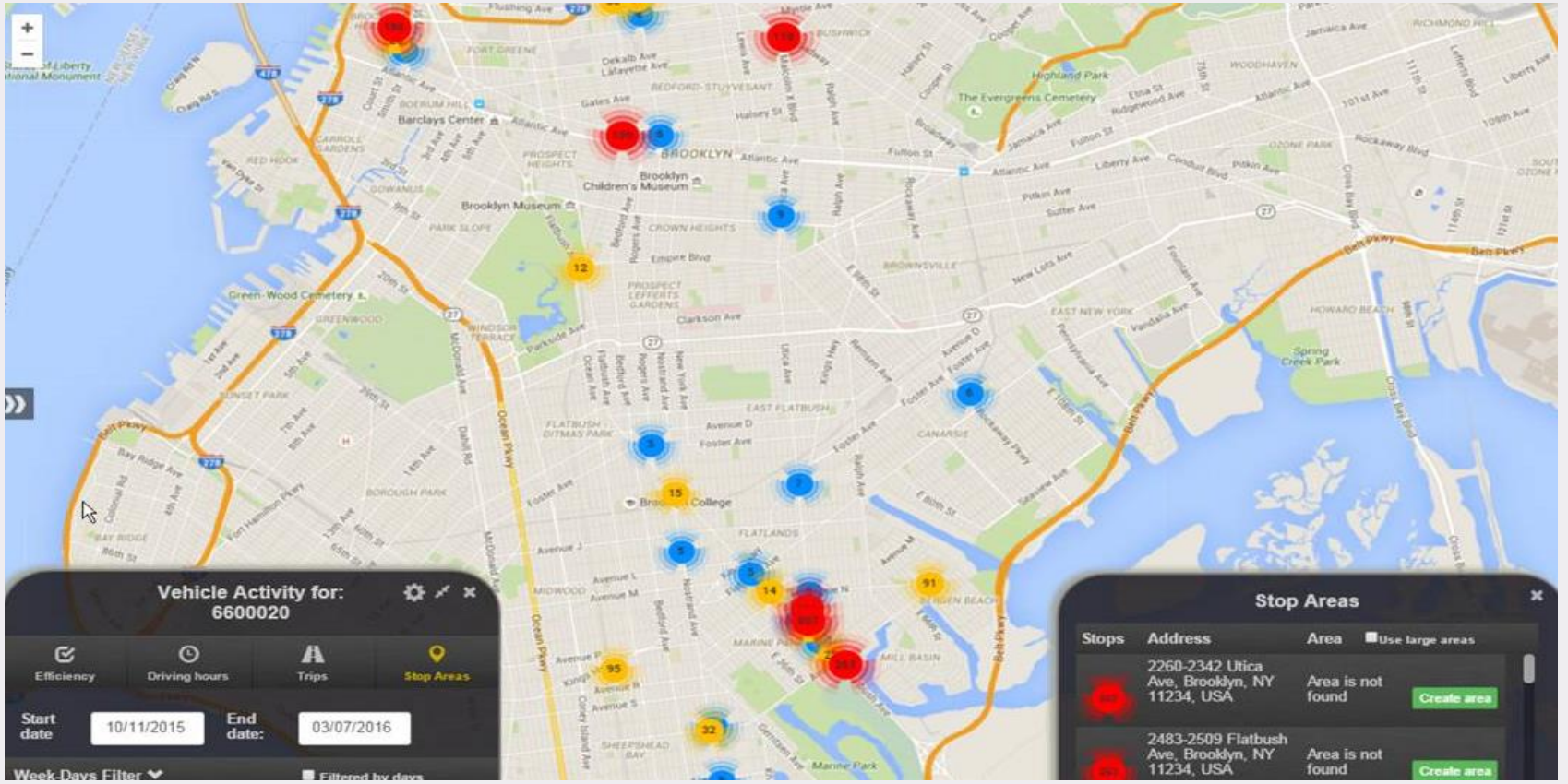
Mobileye 8 Connect™

REM in the Aftermarket

Hotspots highlight areas

where pedestrians are more vulnerable to accidents and together with REM can provide data about infrastructure (lanes, traffic signs) for decision makers



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Mobileye 8 Connect™

REM in the Aftermarket

Traffic light & Sign surveying

Accident Hot Spots

Infrastructure Deficiencies

Map Your City

Parking Spaces

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REM in the Aftermarket

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Esri Collaborates with Mobileye to Bring Real-Time Sensor Data to Public Transit

Mobileye Shield+ Offering Will Use Esri Analytics and Visualization to Improve Pedestrian Safety

Tweet 26 Share 117 Share 147

November 14, 2017

Redlands, California—Esri, the global leader in spatial analytics, today announced a collaboration with Mobileye, an Intel Company and a leading provider of advanced driver-assistance systems software, to integrate Esri mapping, analysis, and visualization with Mobileye's Shield+™ product. This collaboration will provide cities with the ability to visualize and analyze real-time location data from Shield+, improving safety for all road users in urban environments.

Real-Time Sensor Data

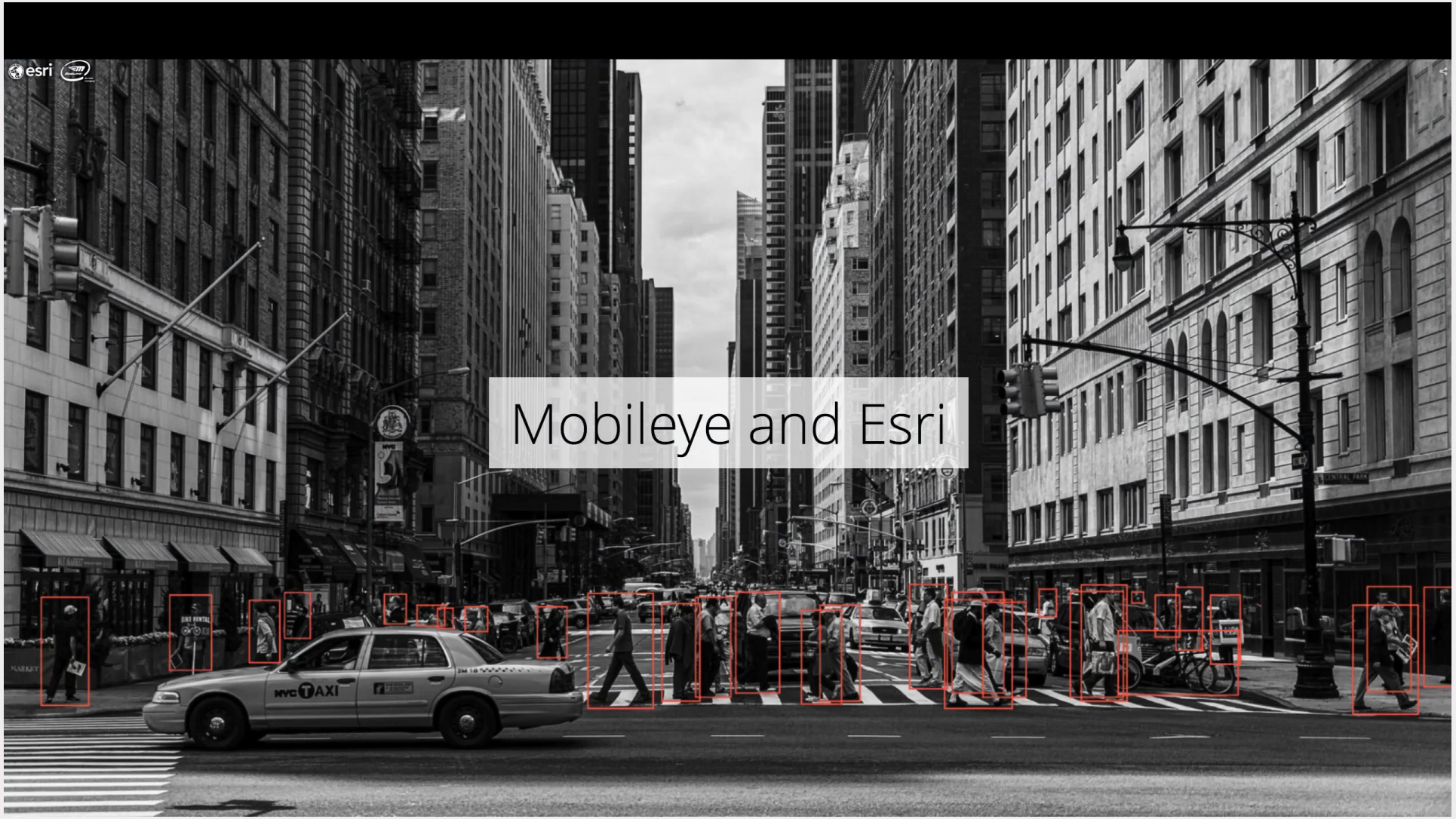
Mobileye's Shield+ will stream road safety data retrieved from city fleets into Esri's ArcGIS platform, where information such as pedestrian and cyclist detection in blindspots can be viewed on the Mobileye Smart Mobility Dashboard. Shield+ alerts will be updated to the dashboard in real time, providing a city-wide view of pedestrian and cyclist safety. Amongst other things, this will allow users such as municipal bus drivers to then receive alerts about imminent hazards seconds before a potential collision, and to have a better, safer awareness of the roads they travel.

"Esri is excited to collaborate with Mobileye for an offering that brings us so much closer to creating safer communities," said Jim Young, Esri head of business development. "Making spatial data available to governments to improve safety and overall quality of life is an important step."

As a part of this new collaboration, Mobileye will give municipalities entering into new contracts with it the option to incorporate the analytics-based capability powered by Esri's ArcGIS software.

Mobileye 8 Connect™

REM in the Aftermarket



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Mobileye 8 Connect™

REM in the Aftermarket

Deals that have been signed with REM deployment

During 2018

Partner	City	# of Vehicles	Goal	Timing
KoMoD Research Project (Germany Ministry of Transport)	Dusseldorf, Germany	750	Prepare the city for smarter & safer driving	Q1
Gett	London	500	Map City of London	Q2
Buggy	New York	2,000	Map City of New York	Q3
Road Safety Authority DGT (Directorate-General of Traffic) – Spain	Undisclosed, Spain	~5,000	Make Spain **Autonomous Ready™**	Q2/3
Guard Insurance	Across the US	1,000-2,000 tow trucks		Q3

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How to Guarantee Safety?

AV Safety: the “Elephant in the Room”

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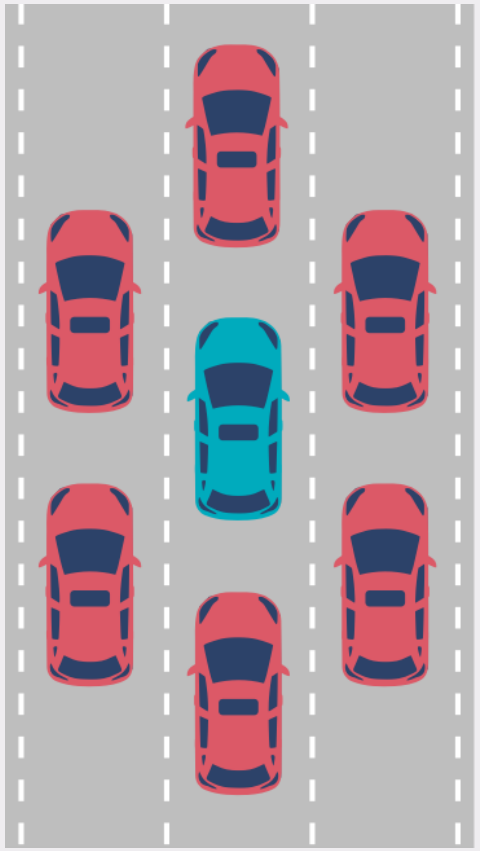
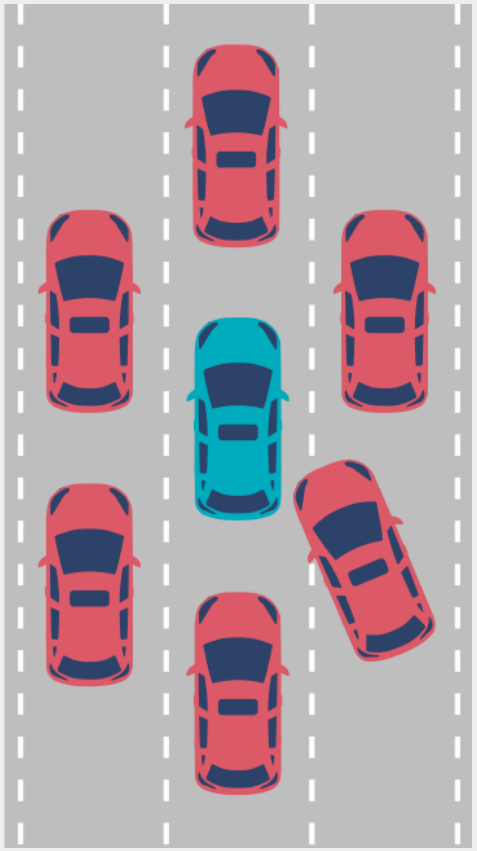
How to Guarantee Safety?

Absolute Safety is impossible – typical highway situation

Before



After



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How to Guarantee Safety?

“Self-driving cars should be statistically better than a human driver”

Problems:

Infeasible:

Theorem: to make sure that the probability of an accident per hour is at most p, one must drive more than 1/p hours after every update of the software.

can be an acceptable target (x1000 than human…)

$$p = 10^{-9}$$

Not transparent:

What will happen when a self-driving car will be involved in an accident? Will society be satisfied with the statistical argument?

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RSS Principles

On a Formal Model of Safe and Scalable Self-driving Cars

Shai Shalev-Shwartz, Shaked Shammah, Amnon Shashua

Mobileye, 2017

Abstract

In recent years, car makers and tech companies have been racing towards self driving cars. It seems that the main parameter in this race is who will have the first car on the road. The goal of this paper is to add to the equation two additional crucial parameters. The first is standardization of safety assurance — what are the minimal requirements that every self-driving car must satisfy, and how can we verify these requirements. The second parameter is scalability — engineering solutions that lead to unleashed costs will not scale to millions of cars, which will push interest in this field into a niche academic corner, and drive the entire field into a "winter of autonomous driving". In the first part of the paper we propose a white-box, interpretable, mathematical model for safety assurance, which we call Responsibility-Sensitive Safety (RSS). In the second part we describe a design of a system that adheres to our safety assurance requirements and is scalable to millions of cars.

1 Introduction

The "Winter of AI" is commonly known as the decades long period of inactivity following the collapse of Artificial Intelligence research that over-reached its goals and hyped its promise until the inevitable fall during the early 80s. We believe that the development of Autonomous Vehicles (AV) is dangerously moving along a similar path that might end in great disappointment after which further progress will come to a halt for many years to come.

The challenges posed by most current approaches are centered around lack of safety guarantees, and lack of scalability. Consider the issue of guaranteeing a multi-agent safe driving ("Safety"). Given that society will unlikely tolerate road accident fatalities caused by machines, guarantee of Safety is paramount to the acceptance of AV. Ultimately, our desire is to guarantee zero accidents, but this is impossible since multiple agents are typically involved in an accident and one can easily envision situations where an accident occurs solely due to the blame of other agents (see Fig. 1 for illustration). In light of this, the typical response of practitioners of AV is to resort to a statistical data-driven approach where Safety validation becomes tighter as more mileage is collected.

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RSS Principles

Goal: Self-driving cars should never be responsible for accidents, meaning:

- Self-driving cars should never **cause** accidents
- Self-driving cars should **properly respond** to mistakes of other drivers

RSS is:

A mathematical, interpretable, model, formalizing the “common sense" or “human judgement" of “**who is responsible for an accident**"

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Requirements for a formal responsibility model

Soundness:

When the model says that the self-driving car is not responsible for an accident, it should clearly match “common sense“ of human judgement

Usefulness:

it is possible to efficiently create a driving policy that guarantees to never cause accidents, while still maintaining normal flow of traffic.

Covering all multi-agent scenarios in the **NHTSA** Pre-Crash Scenario Typology For Crash Avoidance Research

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Our approach: Responsibility Sensitive Safety

(RSS)

AV Safety

Define

Mathematically formalizing “human judgment” & common sense by defining:

- What is a safe distance in all situations
- What is a **Dangerous Situation**
- What is the **Proper Response** to it?

Guarantee / Prove

Execute

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Our approach: Responsibility Sensitive Safety

(RSS)

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Guarantee / Prove

This is how we can guarantee that:

- AV will never initiate a Dangerous Situation
- AV will always follow the Proper Response
- Namely - **AV will never cause an accident**

Execute

An Intel Company

Our approach: Responsibility Sensitive Safety

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AV Safety

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Guarantee / Prove

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Execute

Create a scalable and easy to validate platform

- Planning errors guaranteed by RSS
- Sensing validation is data-driven
- No "Butterfly" effect
- Separate "comfort" planning driven by Reinforcement Learning from "safety" driven by RSS.

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RSS Principles

RSS formalizes common sense rules of determining -

"who is responsible for an accident"

1

Rule One

A hit from behind is not the front car's fault

2

Rule Two

Unless the front car performed a reckless cut-in

3

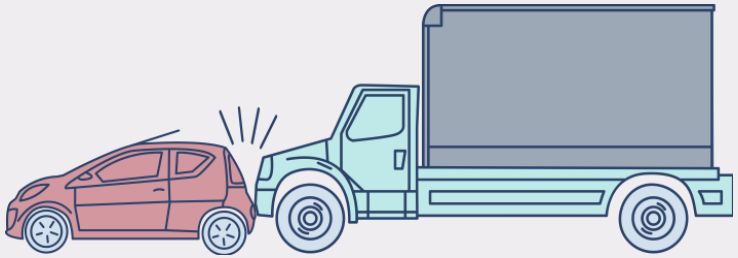
Rule Three

Right-of-way is given, not taken

4

Rule Four

Be careful of areas with limited visibility



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RSS Principles

Set the rules of “Blame” in advance.

Formalize the “common sense” of human judgement in negotiating traffic (safety, legal and culture).

Concept of “Safe State”: a state in which an AV cannot cause an accident of its blame **regardless** of what other agents do.

A method for verifying that the AV transitions only between Safe States (notion of “Proper Response”).

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Strategy

Philosophy: a single effort

Level-4/5 Automation → (derivatives) → L2, L2+, L3

Economical Scalability

- Automating HD-maps through a crowdsourcing approach
- Controlling the explosive computational demands of Driving Policy (Planning)
- Scalable, workload-diverse and low-power SoC together with powerful ATOM cpu

Model for Safety Guarantees

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- Using RSS to provide safety guarantees

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EyeQx Family: Terra OPs/W

- **EyeQ3**

  4 x VMP+ 4 x CPU,a 40nm, series prod since 11/2014

  0.25 TOPs @ 3W

- **EyeQ4H**

  6 x VMP + 2 x PMA + 2 x PMC + 4 x CPU, 28nm, series prod from 3/2018 launches by 4 OEMs in 2018, 12 OEMs in 2019 and onwards

  2.5 TOPs @ 6W

  ← Nvidia Parker: 1.5TOPs / 15W

- **EyeQ5H**

  7nm, 1st silicon 8/2018, series prod from 3/2020 design wins by 4 OEMs from 2020 and onwards.

  24 TOPs @ 10W

  ← Nvidia Xavier: 30TOPs / 30W

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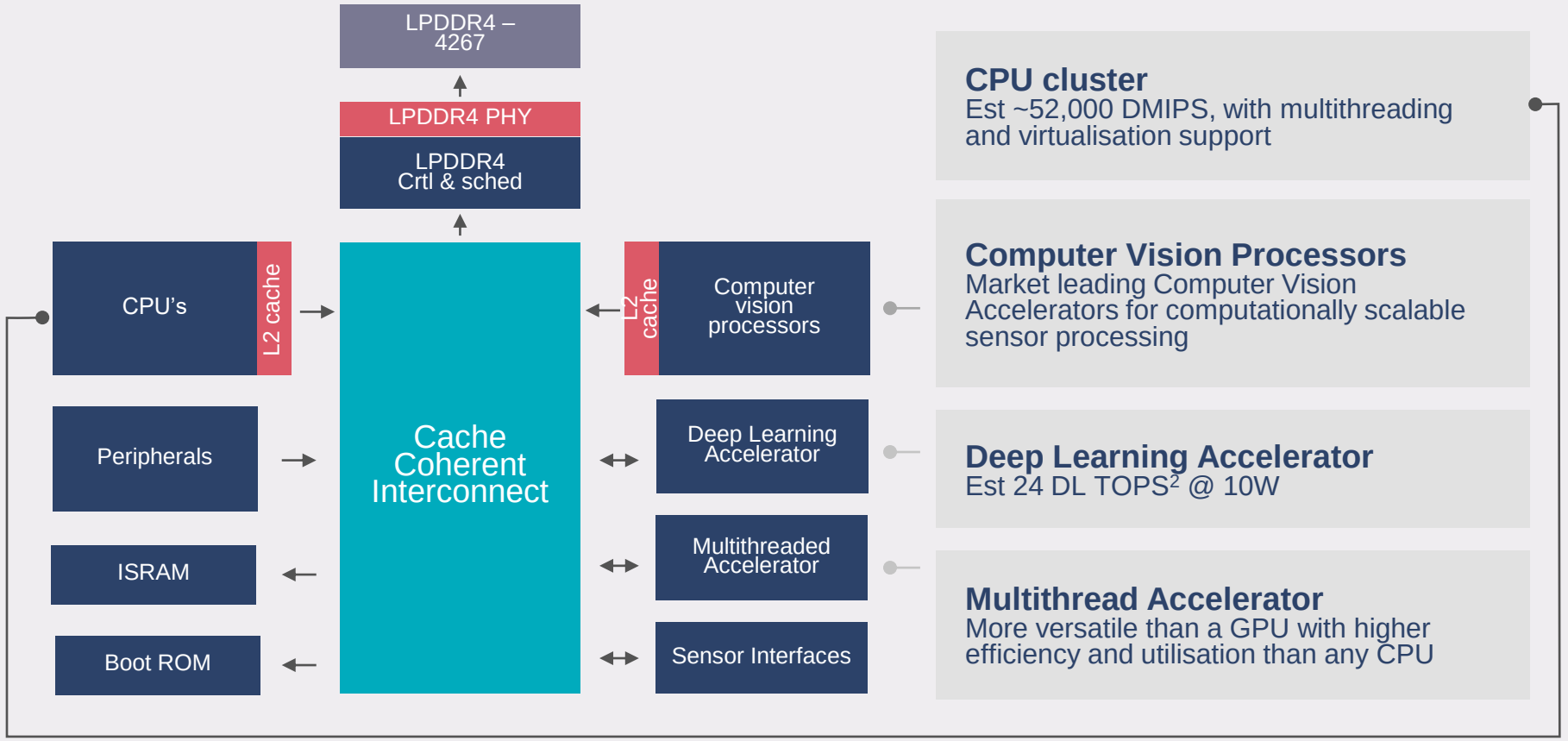
EyeQ5

Introducing:
EyeQ5® technology



CPU cluster
Est ~52,000 DMIPS, with multithreading and virtualisation support

Computer Vision Processors
Market leading Computer Vision Accelerators for computationally scalable sensor processing

Deep Learning Accelerator
Est 24 DL TOPS[2] @ 10W

Multithread Accelerator
More versatile than a GPU with higher efficiency and utilisation than any CPU

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Harnessing The Power of Intel

Intel

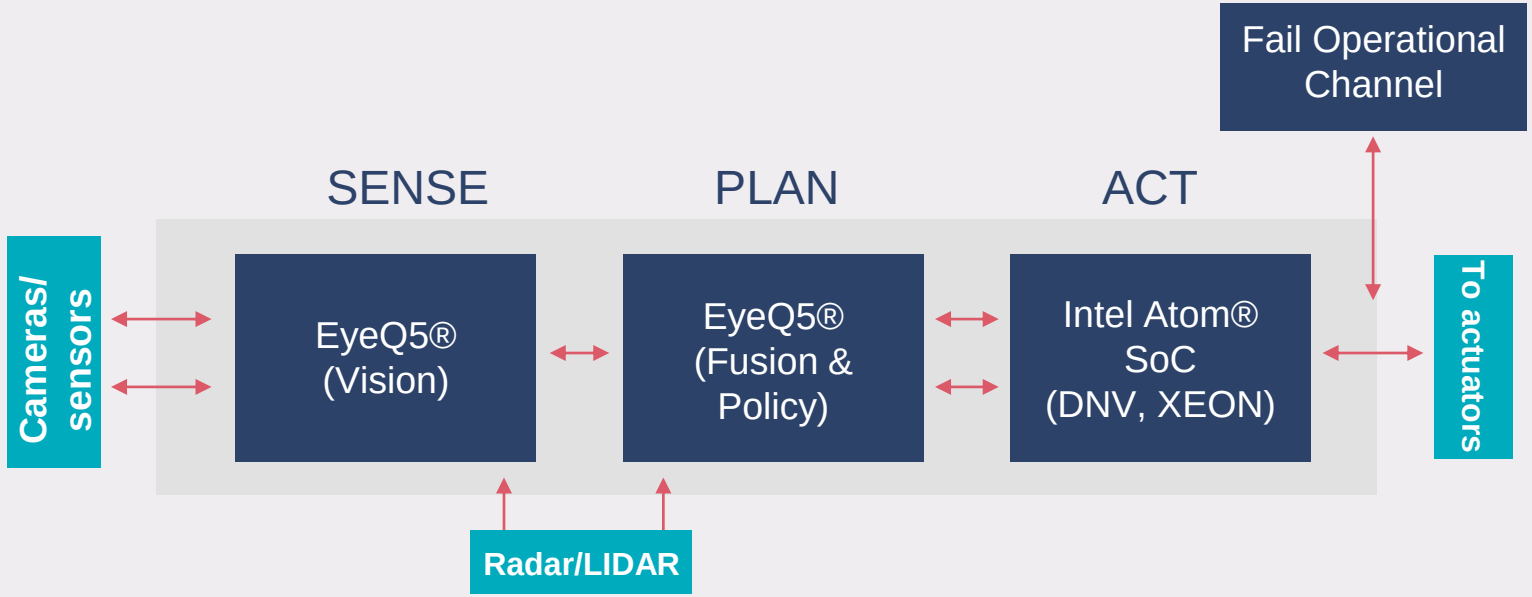
EyeQ5 → **EyeQ6 w/Atom**

Intel

↓

open to 3rd parties as an “open compute” platform with SDK and Libraries

Solution Architecture



Fleet: Intel → 100 vehicles for testing, data collection, validation and customer support

Data Center: Intel → 250Pb for supporting Fleet, validation and customer support

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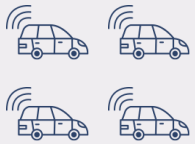
Partnerships

L3 Production (series development) 2019+

- Audi, BMW, Fiat-Chrysler, Honda, NIO, Nissan, SAIC

L4 Production (strategic partnerships) 2020+

- BMW, Fiat-Chrysler, SAIC, NIO
- **3 x OEMs** ongoing sourcing decisions



L4 Turnkey solution

- CSLP platform with Delphi (Aptiv)
- Intel/Mobileye internal fleet of 100 vehicles ramping up throughout 2018

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Master Plan 2018

L4 partnerships

- Turnkey solution: perception, driving policy, safety, MDC prototype (2 x EQ5+Atom) - platform derived from the 100-car fleet.
- Perception turnkey (EQ5) whereas Fusion, Driving Policy on open-EQ5 (software as joint collaboration or solely by partner OEM/Tier-1).
- Open-compute + libraries: open-EQ5, Denverton, Xeon, Altera.

Intel →

L2+ programs:

Front-Facing sensing + Roadbook (“ADAS 2.0”)

Intel → **REM** as a “data strategy”

Intel → **RSS** with industry and regulatory bodies

MOBILEYE® An Intel Company

THANK YOU

Drive Safe!