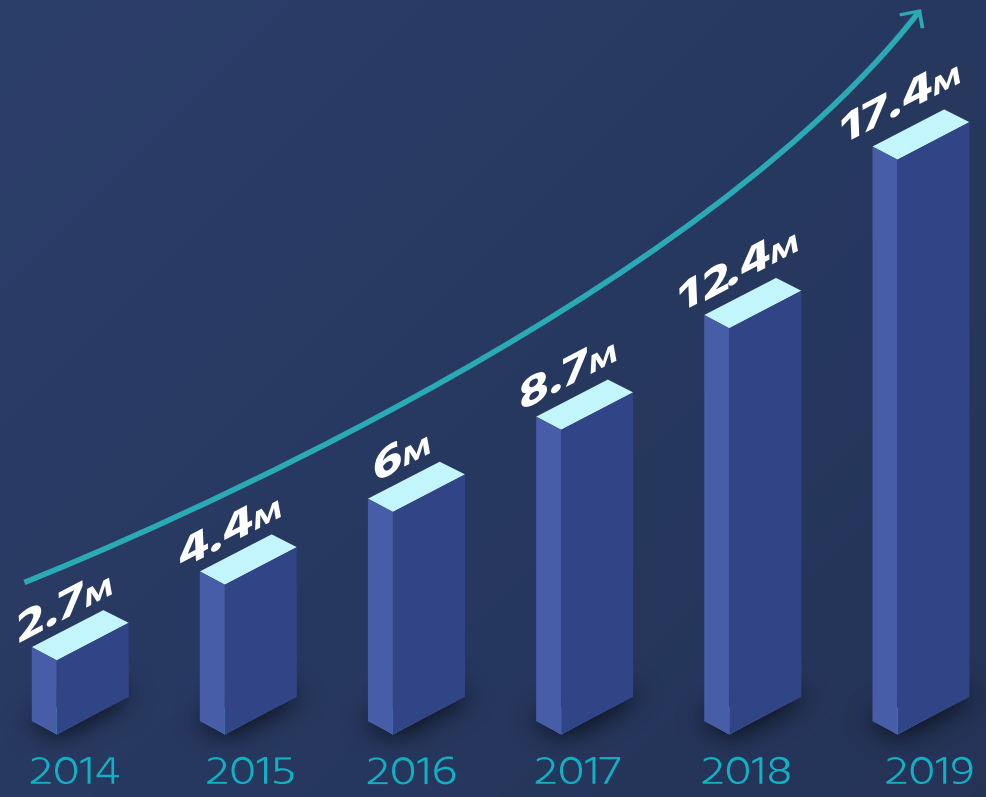
CES 2020

Engines Powering L2+ to L4

Mobileye in Numbers

EyeQ Shipped



Over

54M

EyeQs shipped to date

46% CAGR

- In EyeQ shipping since 2014

47 Running Programs

- Globally across 26 OEMs

In 2019:

33 Design Wins

- 28M units over life
- 4 high-end L2+ wins with 4 major EU and Chinese OEMs

16 Product Launches

- Industry first 100° camera with Honda
- VW high-volume launch (Golf, Passat)

Mobileye Solution Portfolio

Covering the Entire Value Chain

Today

L1-L2 ADAS

Driver assistance

Front camera SoC & SW:

- AEB, LKA, ACC, and more

Today

L2+/ L2++

Conditional Autonomy

Scalable proposition for

- Front vision sensing
- REM HD map

May also include:

- Driver monitoring, surround vision, redundancy

"Vision Zero"- RSS for ADAS

2022

L4/ L5 Mobility-as-a-Service

Full Autonomy

Full-Service provider-owning the entire MaaS stack

SDS to MaaS operators

SDS as a Product

2025

L3/4/5 Passenger cars

Consumers Autonomy

SDS to OEMs

Chauffeur mode

- Scalable robotaxi SDS design for a better position in the privately owned cars segment

REM® Data and Mapping

Crowdsourcing data from ADAS for

- HD mapping for AV and ADAS
- Providing smart city eco system with Safety/Flow Insights and foresights

The ADAS Segment Evolution

Visual perception

MOBILEYE®
An Intel Company

L2+ - The Next Leap in ADAS

L2+ common attributes

Multi-camera sensing

Multi-camera front sensing to full surround

HD maps

L2+ functionalities range from

Everywhere, all-speed lane centring

to

Everywhere, all-speed conditional hands-free driving

The opportunity

L2+ global volume expectation (M)

Source: Wolfe research, 2019

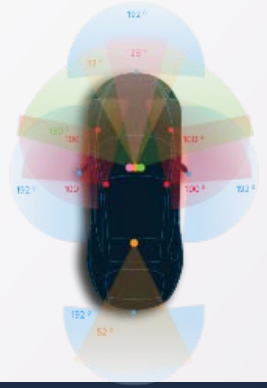
- L2+ - significant added value in comfort, not only safety
- Higher customer adoption and willingness to pay
- Significantly higher ASP- 3-15x more than legacy L1-L2
- System complexity leads to high technological barrier

Mobileye Scalable Solution for L2+

Camera-based 360° sensing is the enabler for the next leap in ADAS

360° cameras sensor suite

- Affordability allows mass adoption in ADAS
- Full 3D environmental model
- Algorithmic redundancy



REM™ HD Maps

- First in the industry to offer:
- “HD Maps Everywhere”
- High refresh rate

Lean compute platform

- Entire system running on 2x EyeQ® 5H
- 3rd party programmability
- 46 TOPS, 54W

Driving Policy layer

- RSS-based
- Formal safety guarantees
- Prevention driven system for ADAS

L2+ Business Status

More than 70% of the L2+ systems running today are powered by Mobileye's technology

For example:

Nissan ProPilot ™ 2.0

VW Travel Assist ™

Cadillac Supercruise ™

BMW KaFAS 4

Additional 12 active programs with L2+ variants and 13 open RFQs

Next Generation ADAS

Unlocking “Vision Zero” with RSS for Humans Drivers

ADAS Today

AEB, LKA | Emergency driven

ESC/ ESP | Prevention driven

Application of brakes longitudinally & laterally

ADAS Future Potential

AEB, LKA, ESC | All in one

Prevention driven system

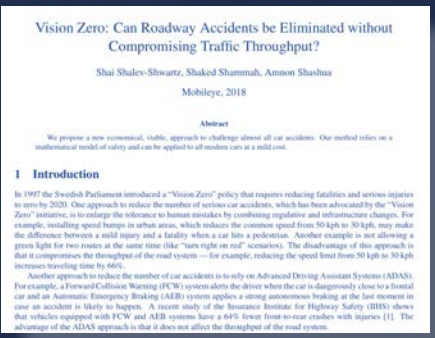
Formal Guarantees

Scalable surround CV system

RSS Jerk-bounded braking profile
longitudinal & lateral

Standard fitment/ Rating

Vision Zero



Vision Zero: Can Roadway Accidents be Eliminated without Compromising Traffic Throughput?

Shai Shalev-Shwartz, Shaked Shammah, Amnon Shashua

Mobileye, 2018

Abstract

We propose a new economical, viable, approach to challenge almost all car accidents. Our method relies on a mathematical model of safety and can be applied to all modern cars at a mild cost.

1 Introduction

In 1997 the Swedish Parliament introduced a “Vision Zero” policy that requires reducing fatalities and serious injuries to zero by 2020. One approach to reduce the number of serious car accidents, which has been advocated by the “Vision Zero” initiative, is to enlarge the tolerance to human mistakes by combining regulative and infrastructure changes. For example, installing speed bumps in urban areas, which reduces the common speed from 50 kph to 30 kph, may make the difference between a mild injury and a fatality when a car hits a pedestrian. Another example is not allowing a green light for two routes at the same time (like “turn right on red” scenarios). The disadvantage of this approach is that it compromises the throughput of the road system — for example, reducing the speed limit from 50 kph to 30 kph increases traveling time by 66%.

Another approach to reduce the number of car accidents is to rely on Advanced Driving Assistant Systems (ADAS). For example, a Forward Collision Warning (FCW) system alerts the driver when the car is dangerously close to a frontal car and an Automatic Emergency Braking (AEB) system applies a strong autonomous braking at the last moment in case an accident is likely to happen. A recent study of the Insurance Institute for Highway Safety (IIHS) shows that vehicles equipped with FCW and AEB systems have a 64% fewer front-to-rear crashes with injuries [1]. The advantage of the ADAS approach is that it does not affect the throughput of the road system.

Under the Hood of Mobileye's Computer Vision

The Motivation Behind Surround CV

The goal

- **Full stack camera only AV**
- 10^{-4} **MTBF for sensing mistake leading to RSS violation**
  (per hour of driving)

Why

- $\sim 10^{-4}$ Humans probability of injury per hour of driving
- $\sim 10^{-6}$ Humans probability of fatality per hour of driving

$\sim 10^{-7}$ **The sensing system desired MTBF** (with safety margins)
Driving 10M hours without a safety critical error

To meet the 10^{-7} MTBF, we break it down into two independent sub-systems:

$$\text{MTBF } 10^7 \approx \text{MTBF}_1 10^{3.5} \cdot \text{MTBF}_2 10^{3.5}$$

Critical MTBF of $10^4 \approx 10{,}000$ (with safety margins) hours is plausible.

The challenge

- 10^{-4} **MTBF still requires an extremely powerful surround vision**

Equivalent to driving 2 hours a day for 10 years without a safety critical sensing mistake

Mobileye's Sensing has Three Demanding Customers

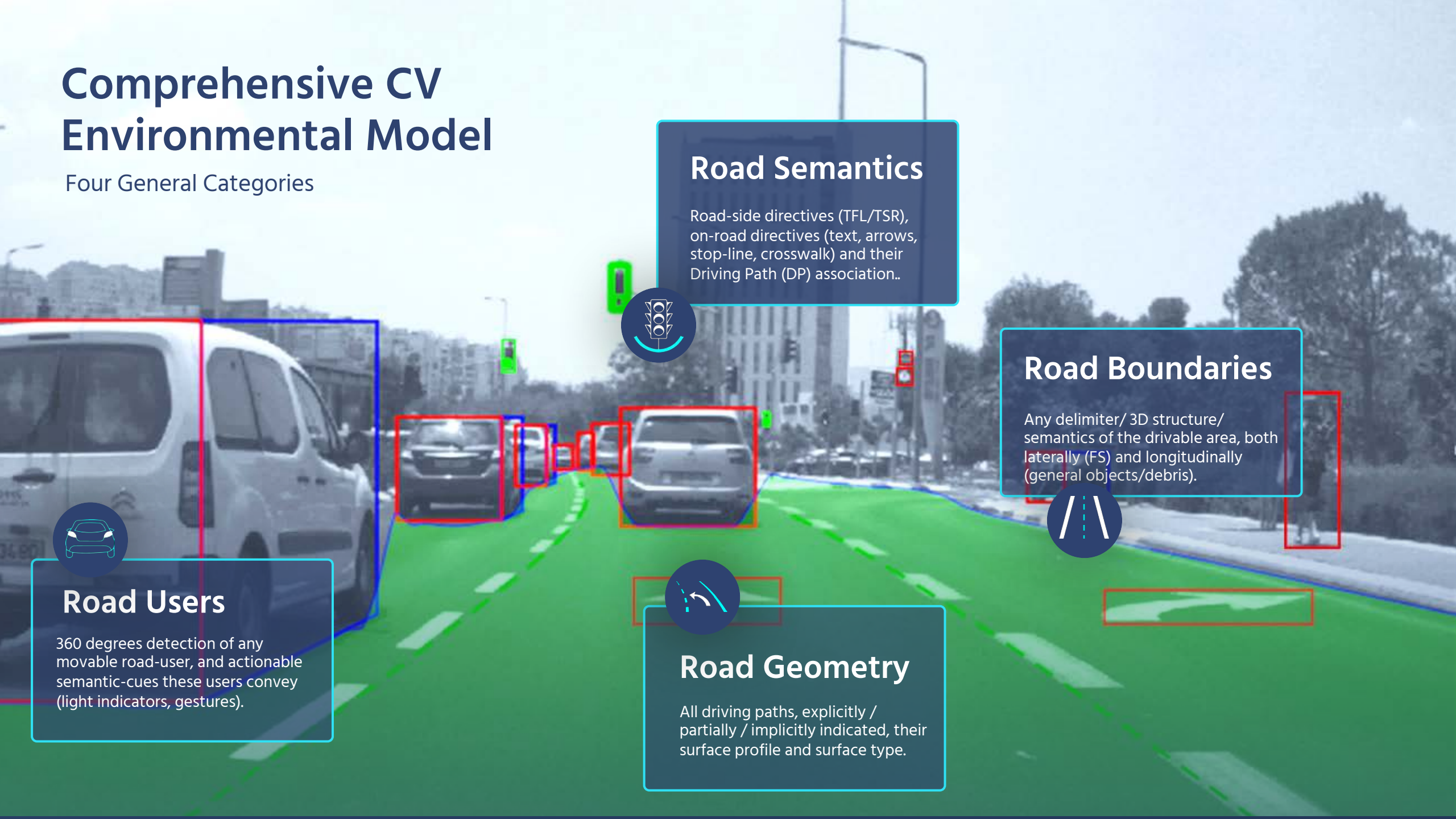
Sensing state for Driving Policy under the strict role of independency and redundancy.

Smart agent for harvesting, localization and dynamic information for REM based map

ADAS products working everywhere and at all conditions on millions of vehicles

Comprehensive CV Environmental Model

Four General Categories



Road Semantics

Road-side directives (TFL/TSR), on-road directives (text, arrows, stop-line, crosswalk) and their Driving Path (DP) association..

Road Boundaries

Any delimiter/ 3D structure/ semantics of the drivable area, both laterally (FS) and longitudinally (general objects/debris).

Road Users

360 degrees detection of any movable road-user, and actionable semantic-cues these users convey (light indicators, gestures).

Road Geometry

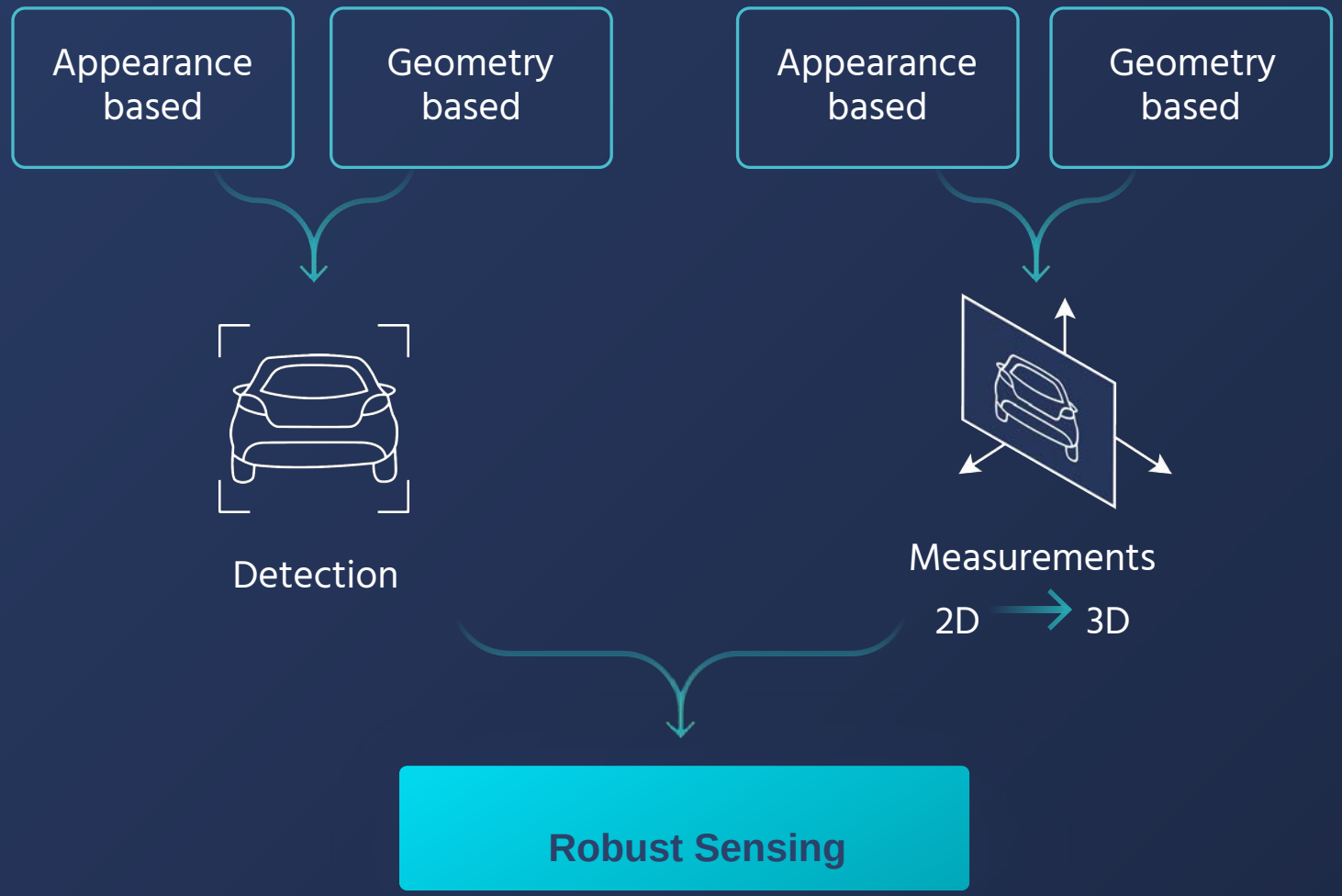
All driving paths, explicitly / partially / implicitly indicated, their surface profile and surface type.

Redundancy in the CV Subsystem

In order to satisfy an MTBF of 10^{-4} hours of driving of the CV-Sub-system:

Multiple independent CV engines overlap in their coverage of the four categories

This creates internal redundancy layers for both detection and measurements:



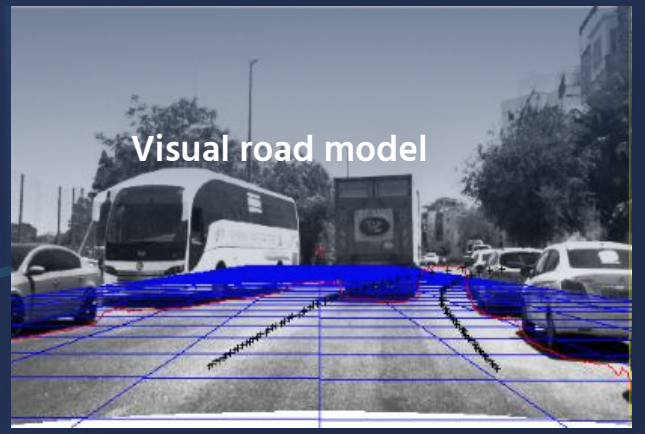
Object Detection

Generated and solidified using 6 different engines

Detection

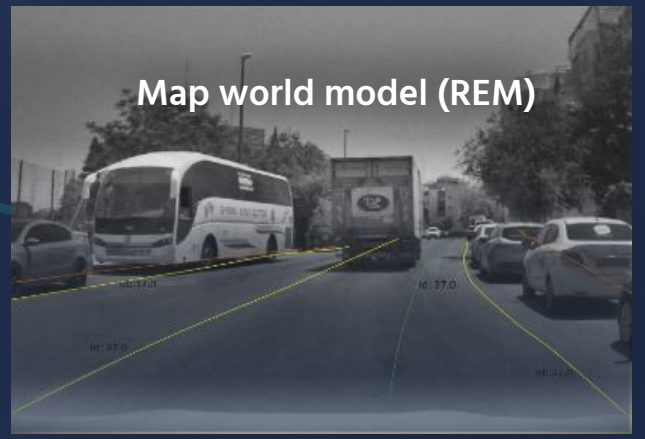
2D to 3D Process

Generated and solidified using 4 different engines



Measurements

2D → 3D



Full Image Detection

Two dedicated 360-stitching engines for completeness and coherency of the unified objects map:

- Vehicle signature
- Very close (part-of) vehicle in field of view: face & limits

Front right cam

Rear right cam

Front right cam

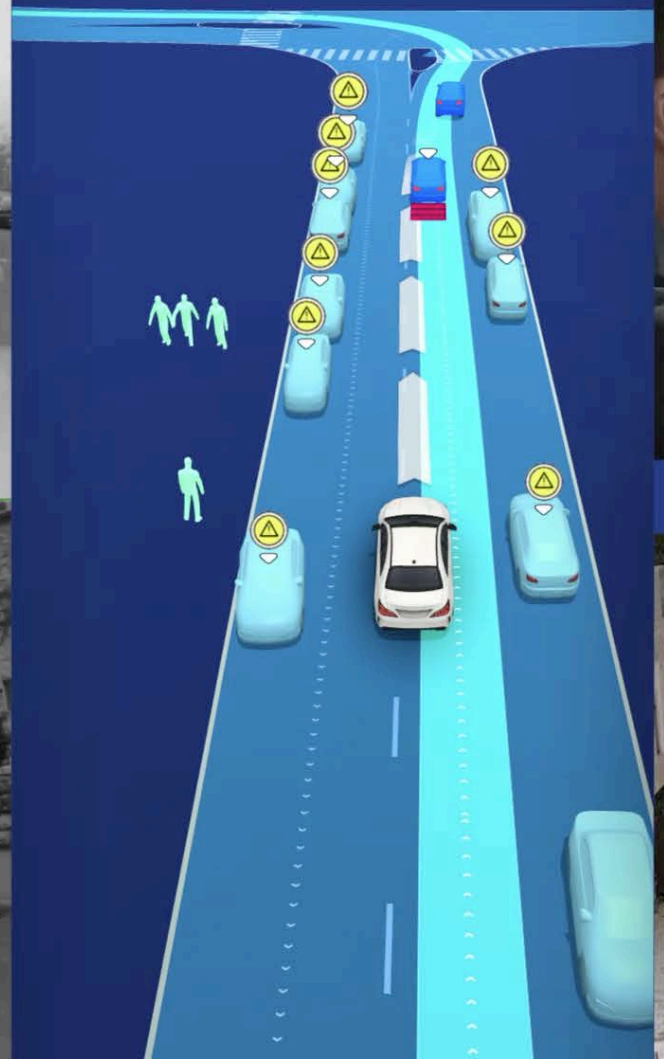
Rear right cam

Autonomous
ACTIVE

25
35
km/h

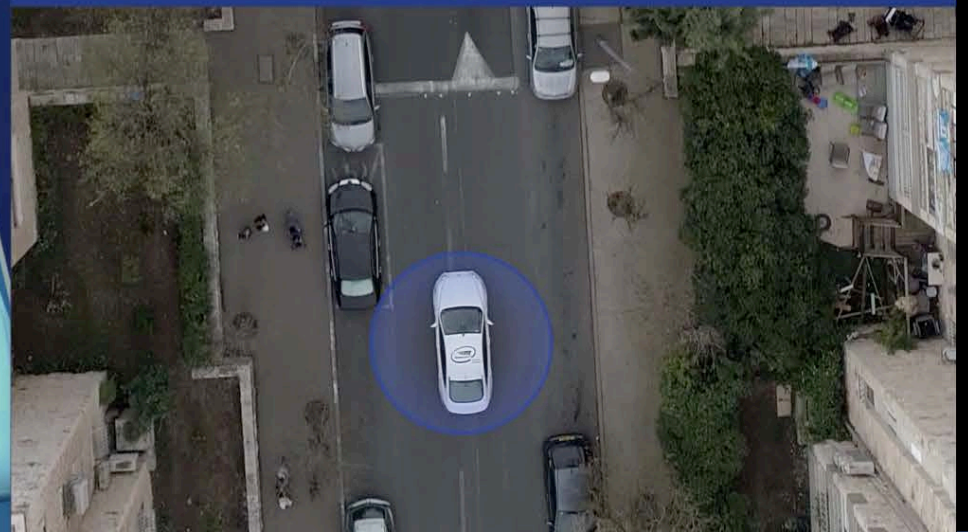
-4°

Left sector - FID in action



Interior View

Drone View



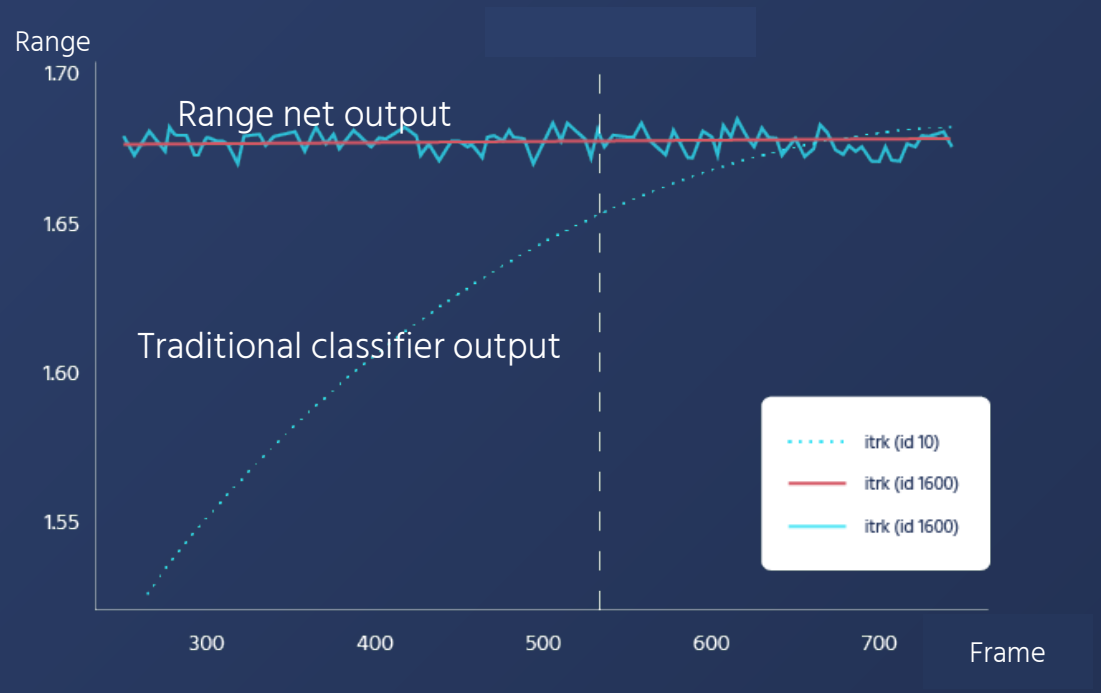
Inter-cameras tracking

Object signature network

Range Net

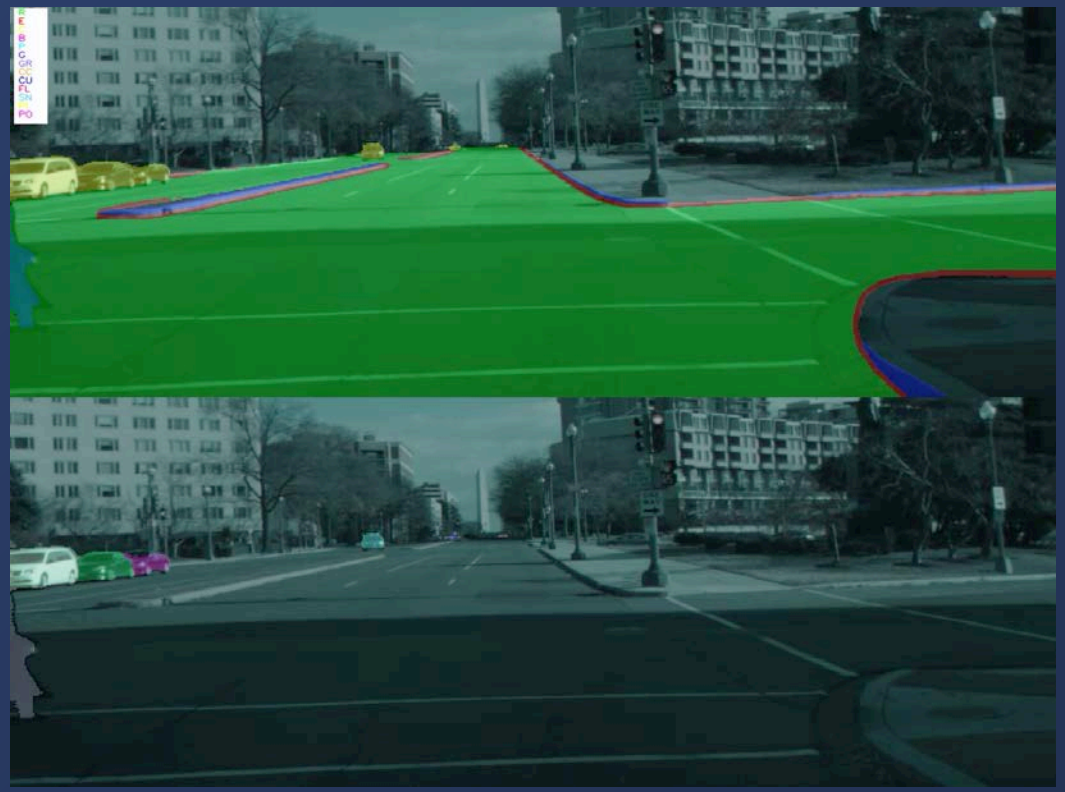
Metric Physical Range estimation

dramatically improve measurement quality using novel methods

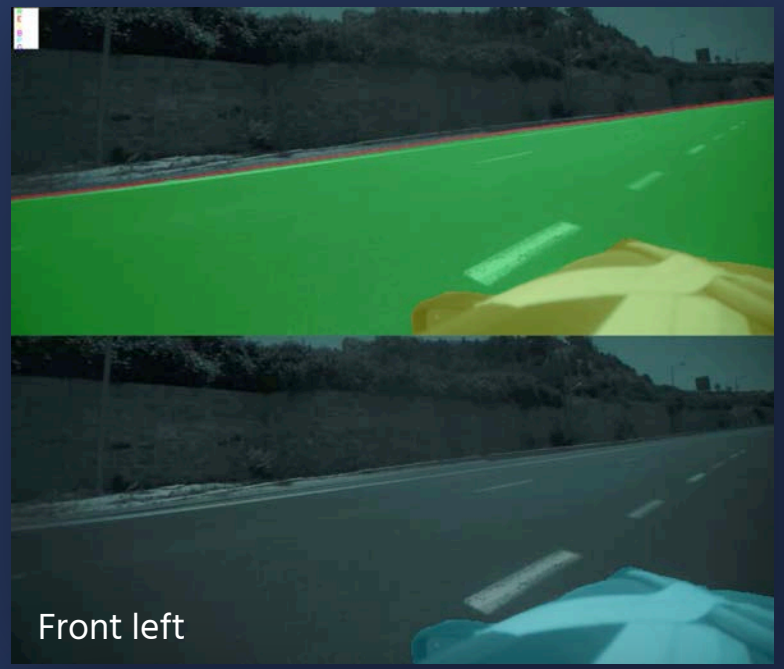


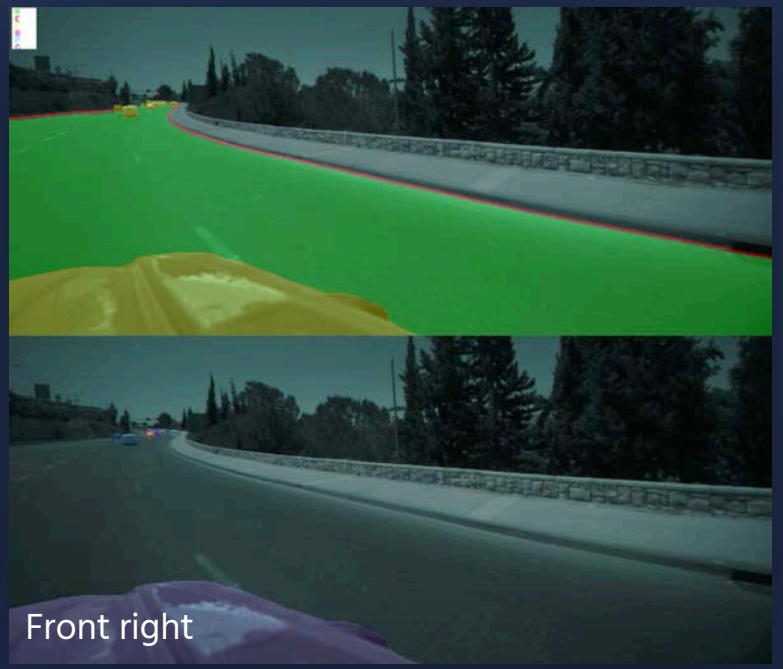
Pixel-level Scene Segmentation

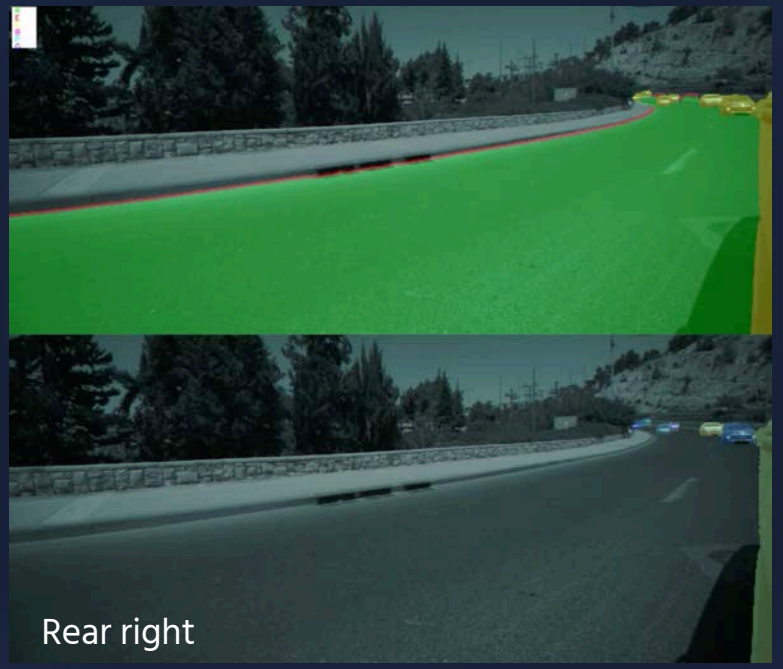
- Redundant to the object-dedicated networks
- Catches extremely-small visible fragments of road users;
- Used also for detecting “general objects”.



Surround Scene Segmentation with Instance

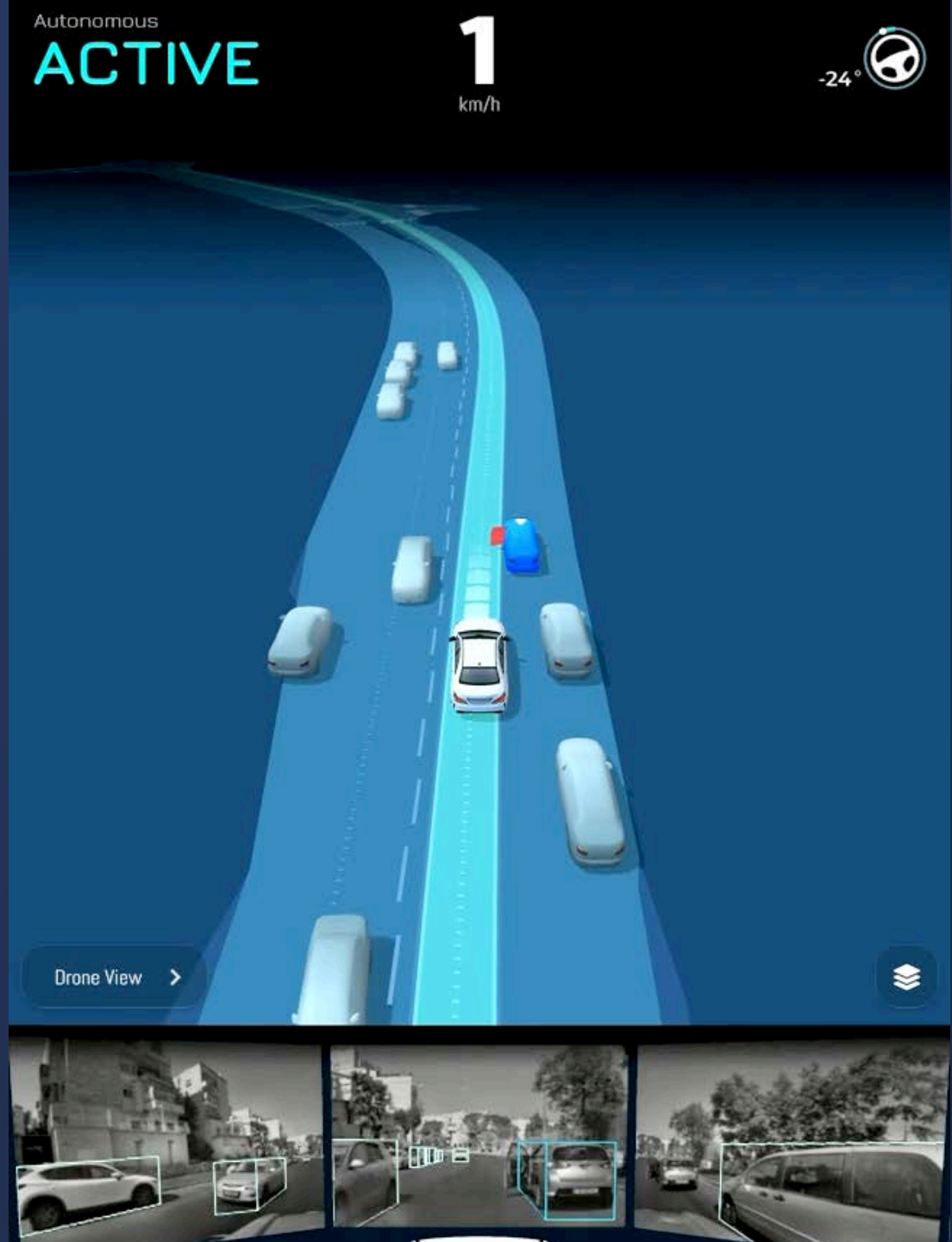






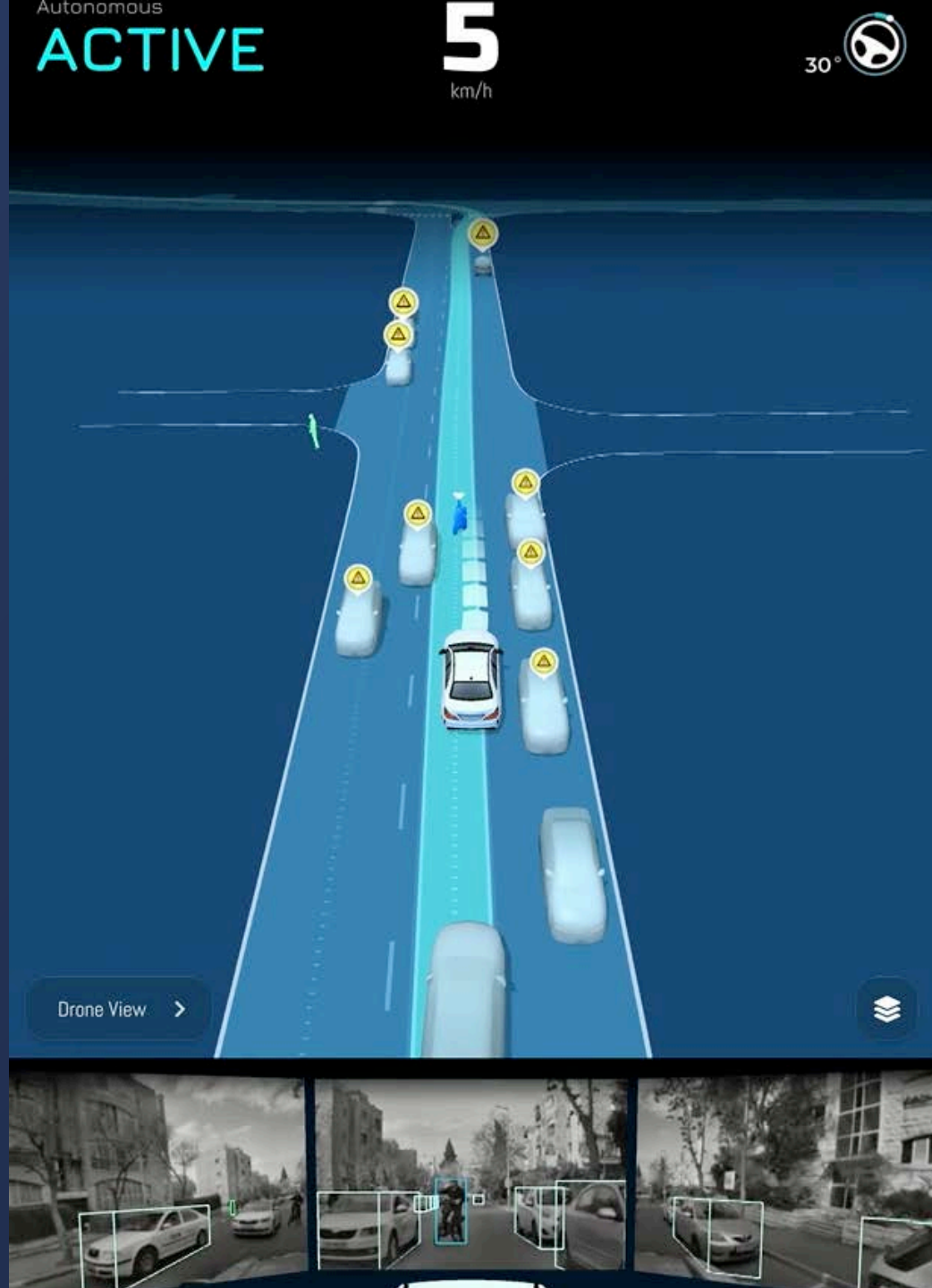
Road Users – open door

Uniquely classified , as it is both extremely common, critical, and of no ground intersection



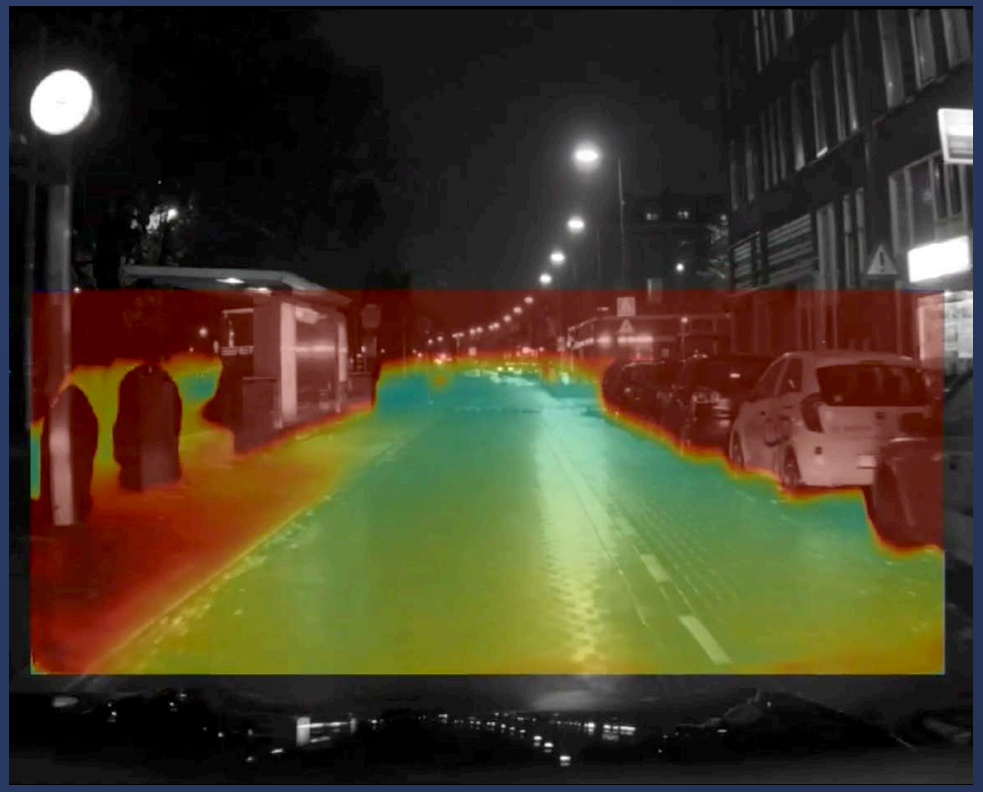
Road Users - VRU

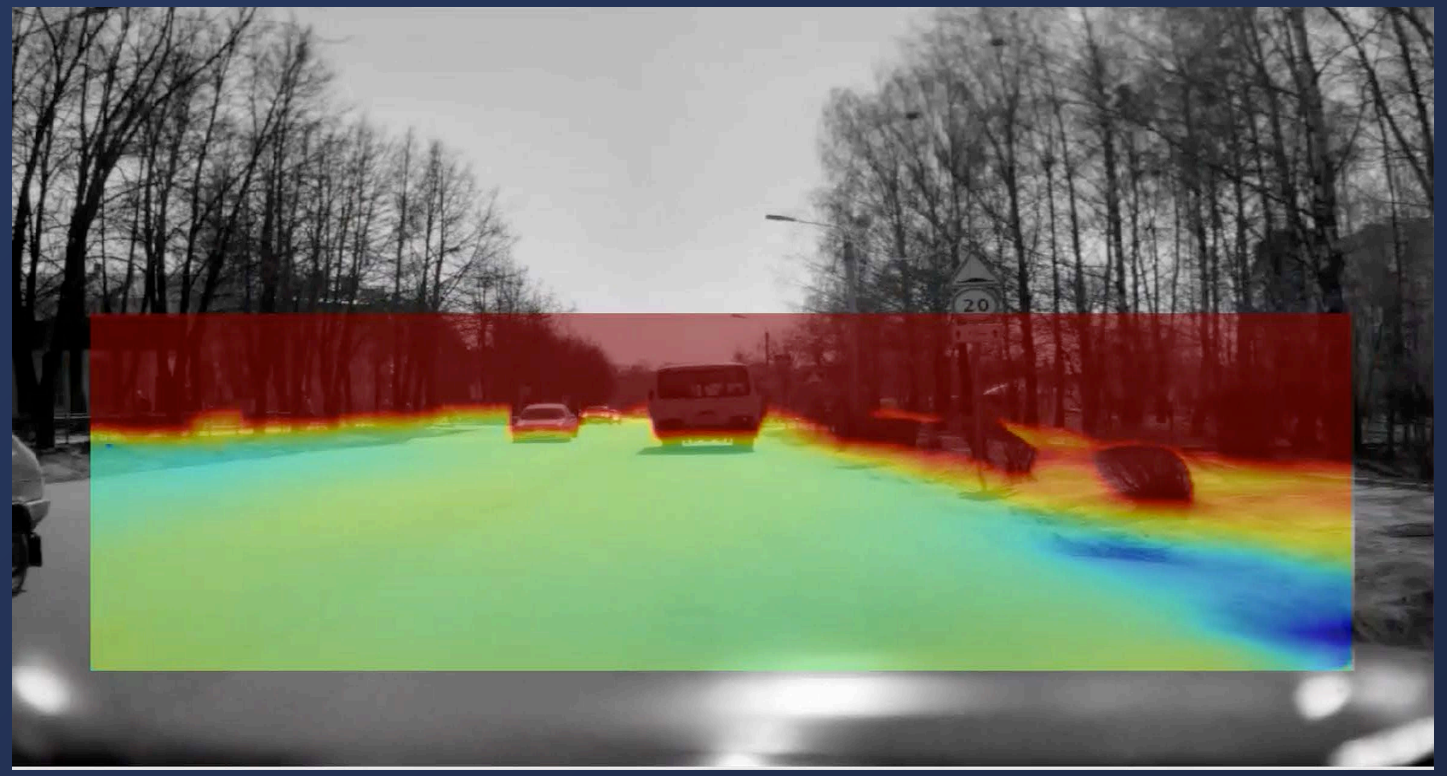
Baby strollers and wheel chairs are detected through a dedicated engine on top of the pedestrians detection system



Parallax Net

Parallax Net engine provides accurate structure understanding by assessing residual elevation (flow) from the locally governing road surface (homography).

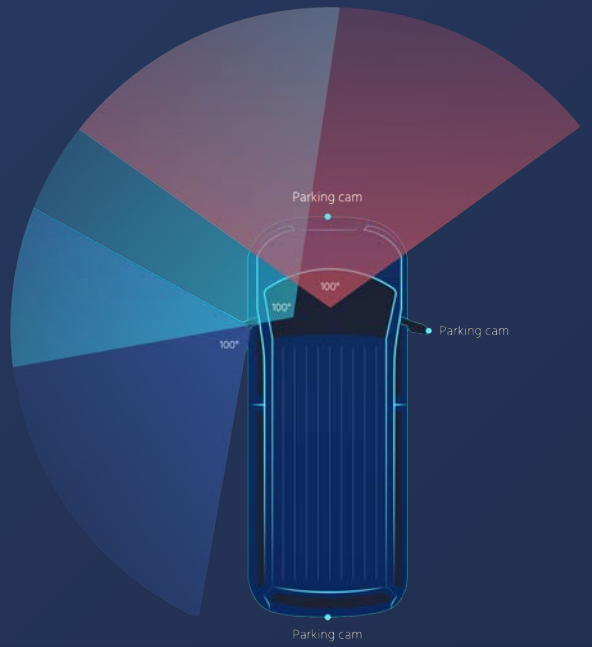


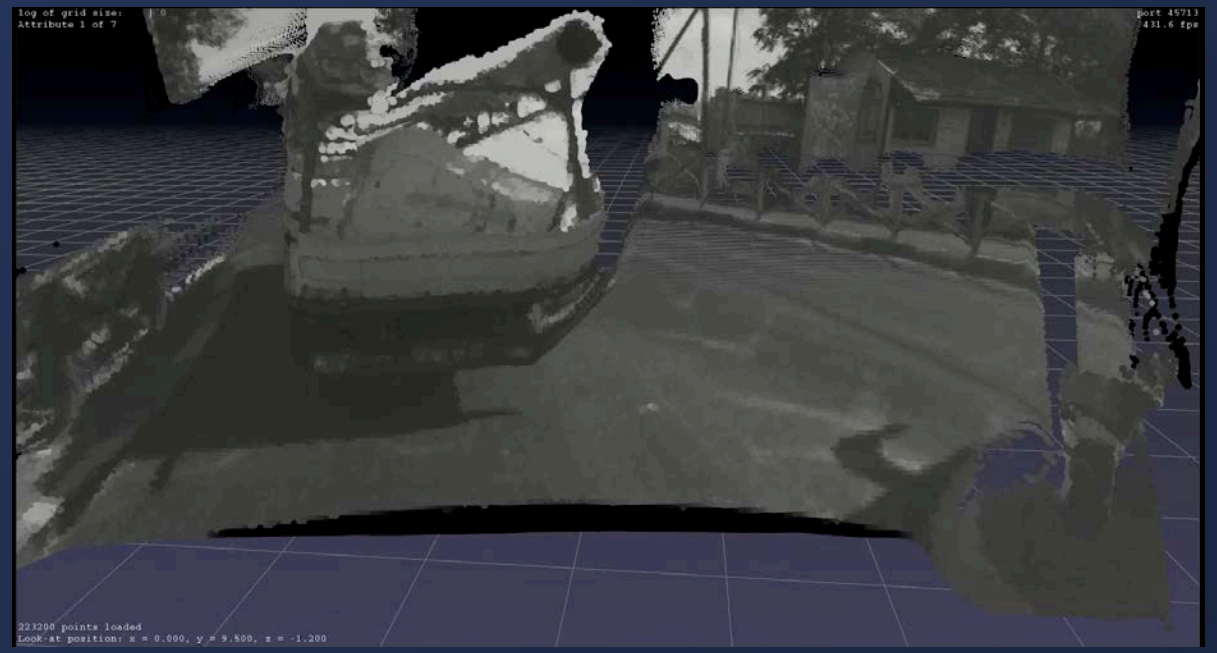


VIDAR

“Visual Lidar”: DNN-based Multi-view Stereo

- Redundant to the appearance and measurement engines
- handling “rear protruding” objects – which hover above the object’s ground plane.





VIDAR Input

Front left

Main

Front right

Rear left

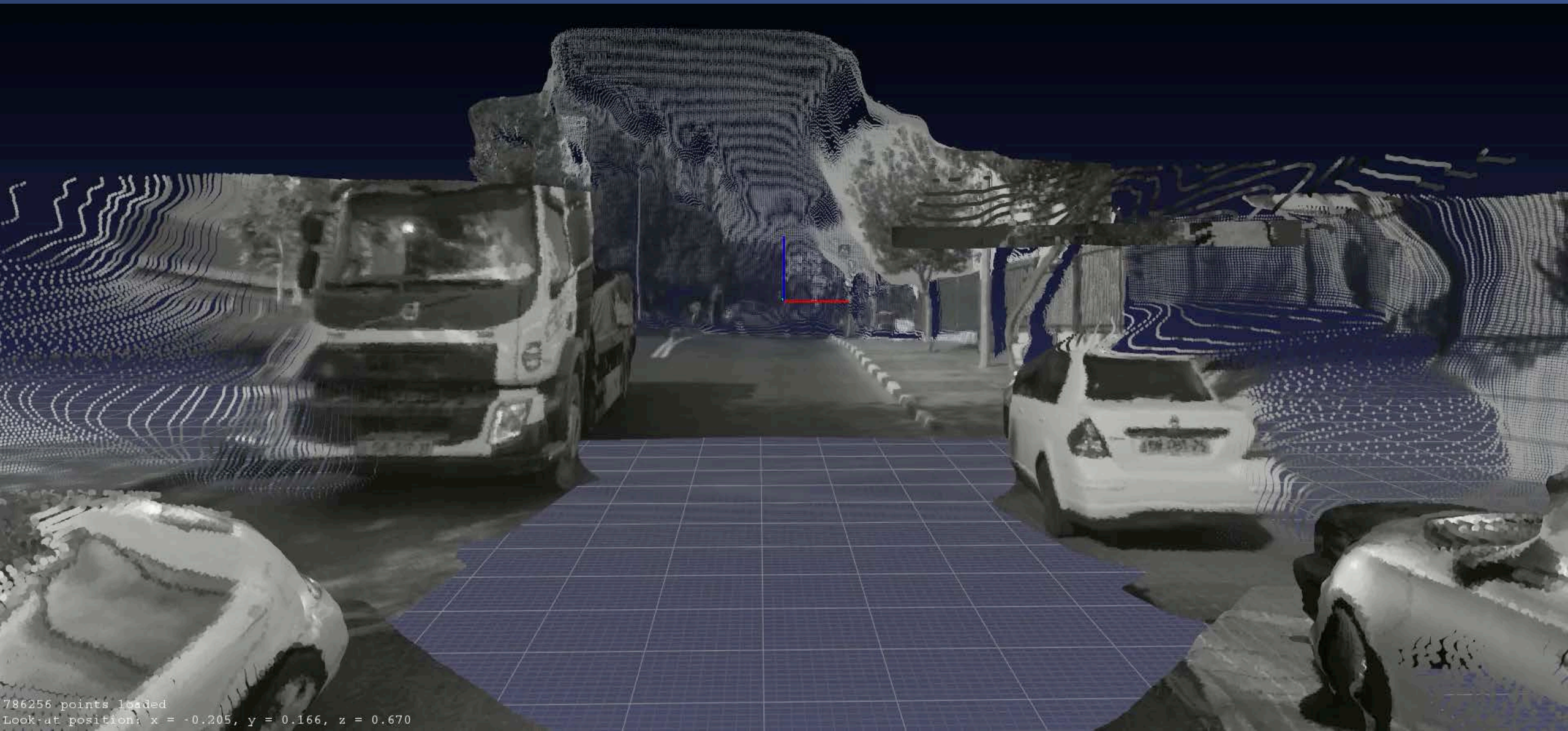
Parking left

Parking right

Rear right

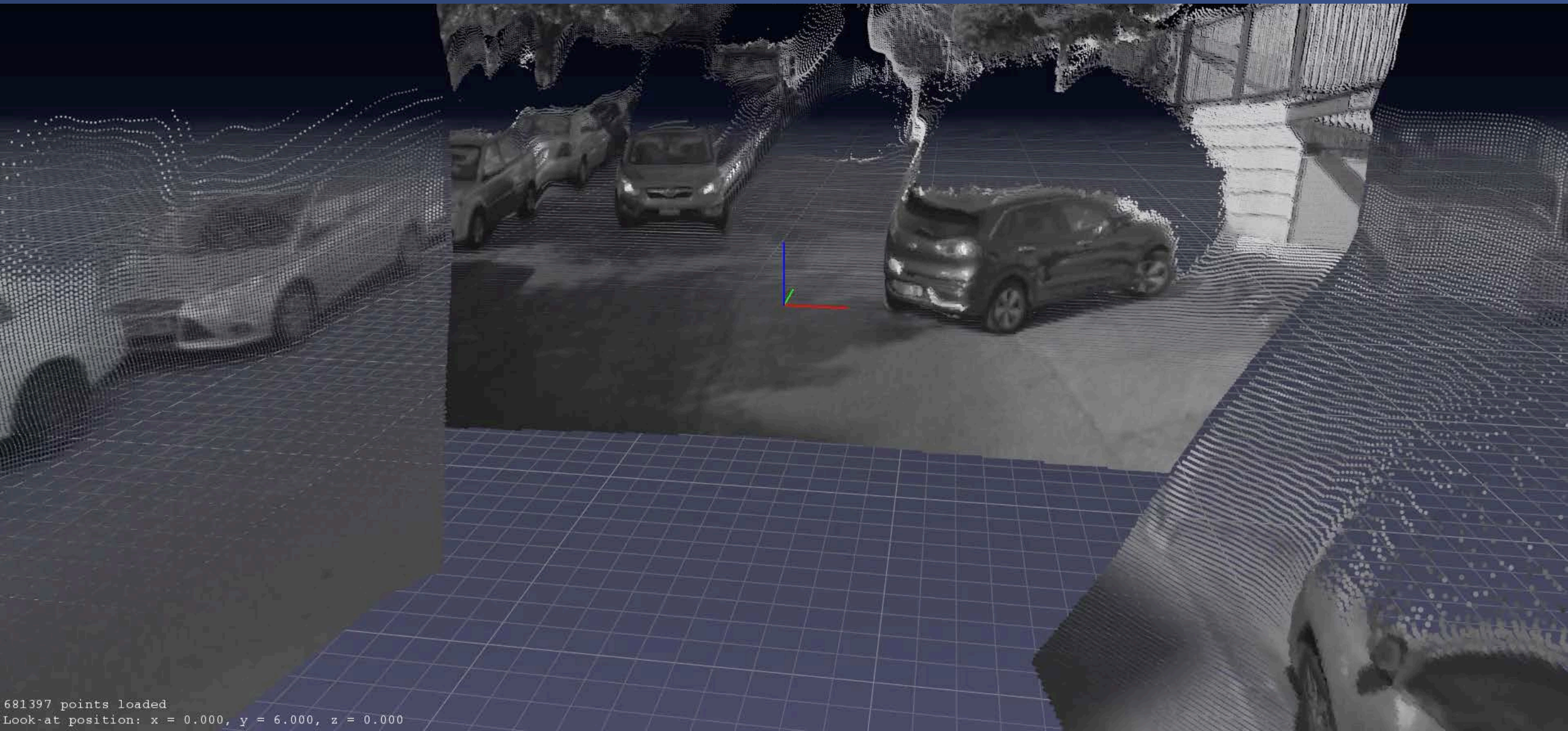
VIDAR Output

DNN based multi-view stereo



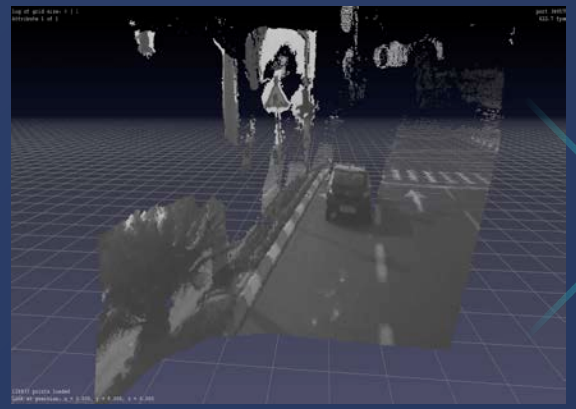
VIDAR Output

DNN based multi-view stereo

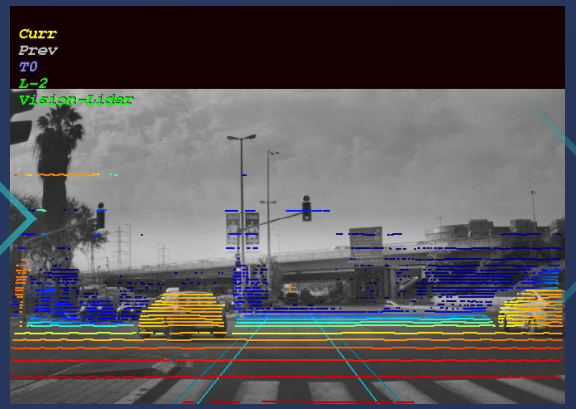


Road Users from VIDAR

Leveraging Lidar Processing Module for Stereo Camera Sensing – “VIDAR”

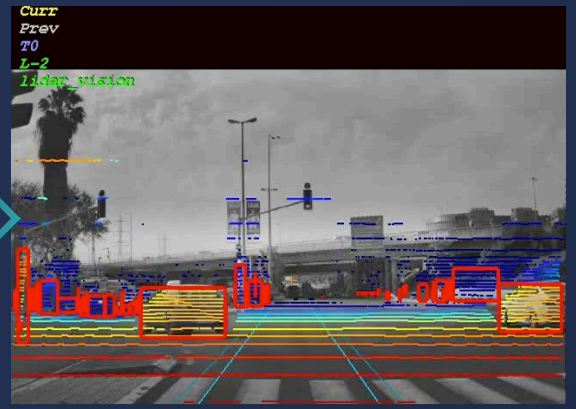


Dense depth image from VIDAR



High-res Pseudo-Lidar

Upright obstacle ‘stick’ extraction



Object detection

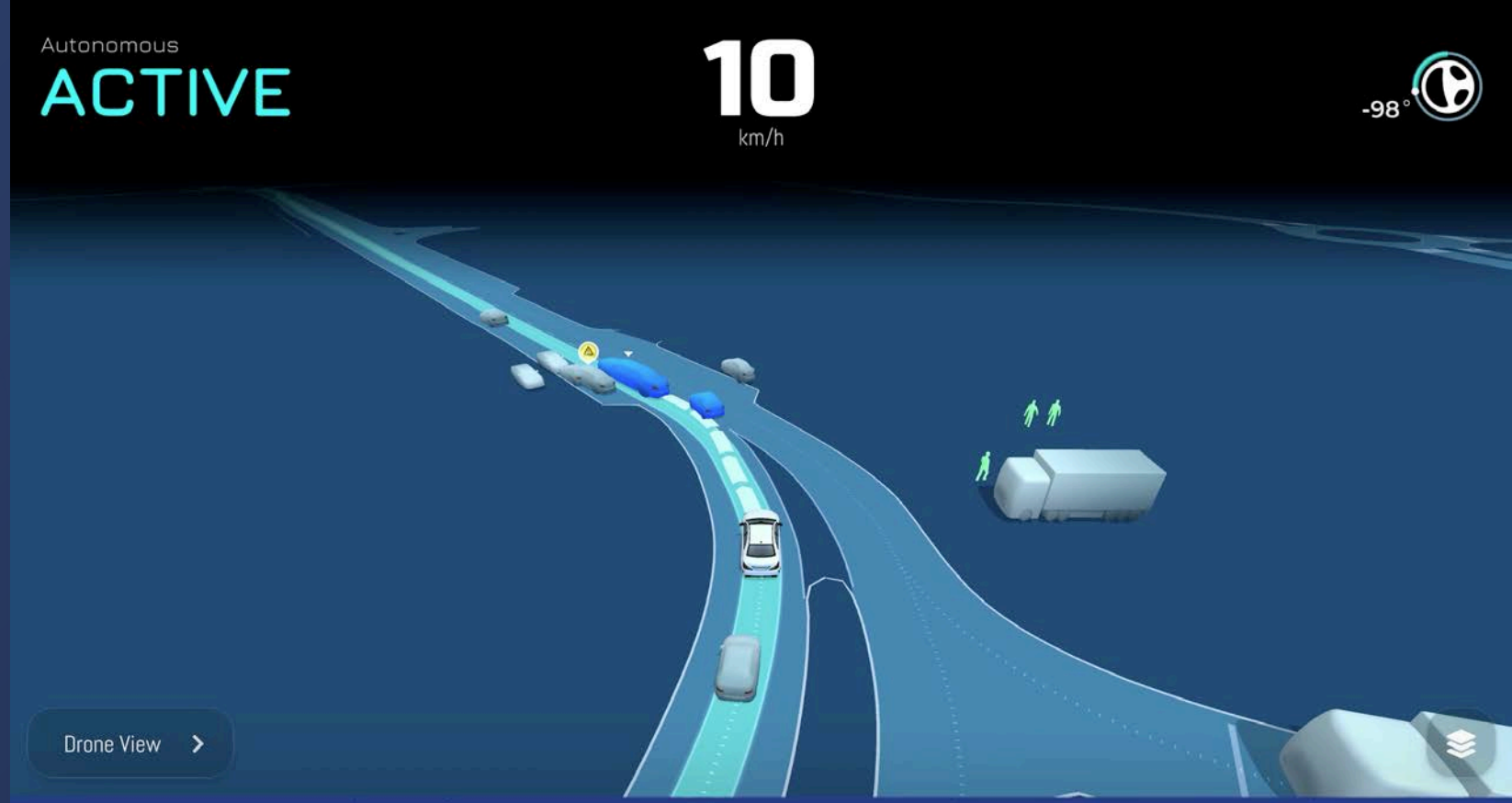
Obstacle Classification

Obstacle classification

e.g., how to differentiate a double parked car from a traffic jam

Using cues from the environment

- Behavior of other road users
- What's in front of the object
- Object location
- Opened door
- Emergency lights



Interior View

Main Front Camera View

Road Users Semantics

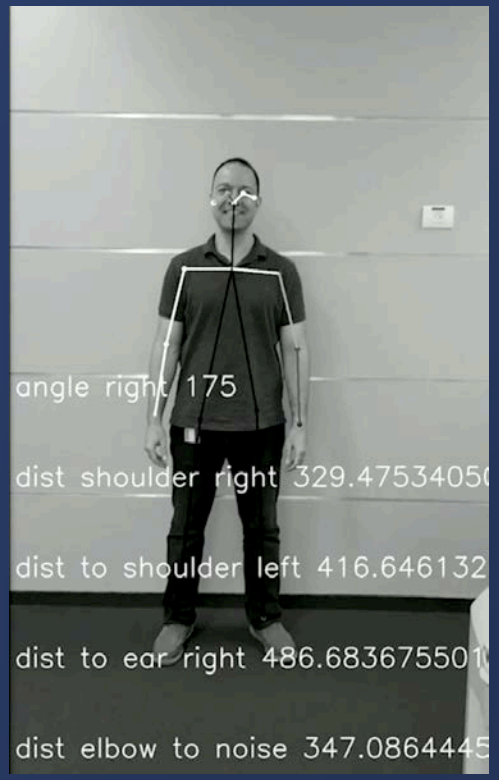
- Head/pose orientation
- Pedestrians posture/gesture.
- Vehicle light indicators
- Emergency vehicle/Personnel classification.

Emergency vehicle , light indicators

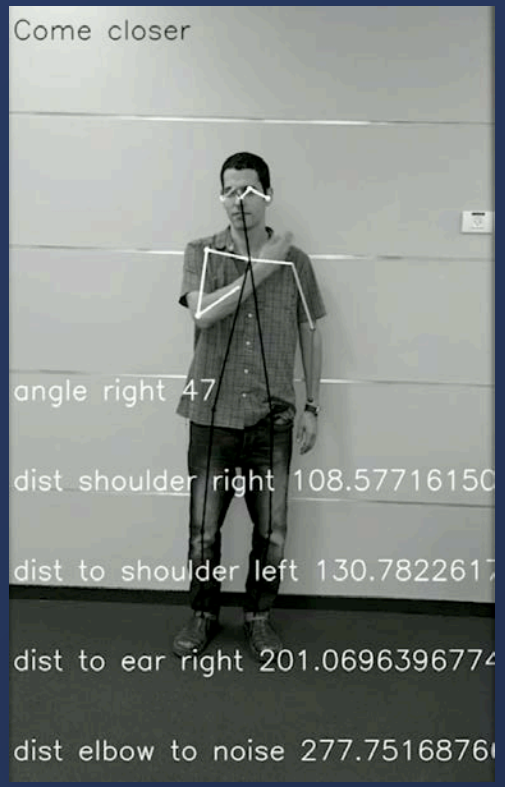
Pedestrian understanding

Road Users Semantics

Pedestrian Gesture Understanding

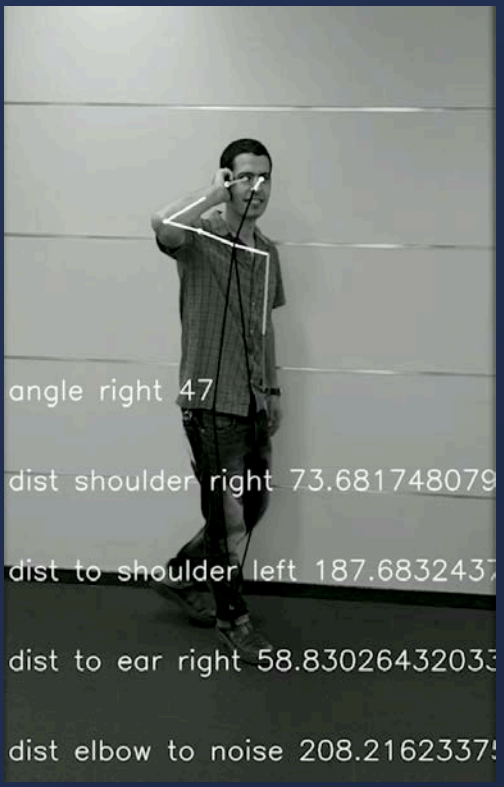


Come closer

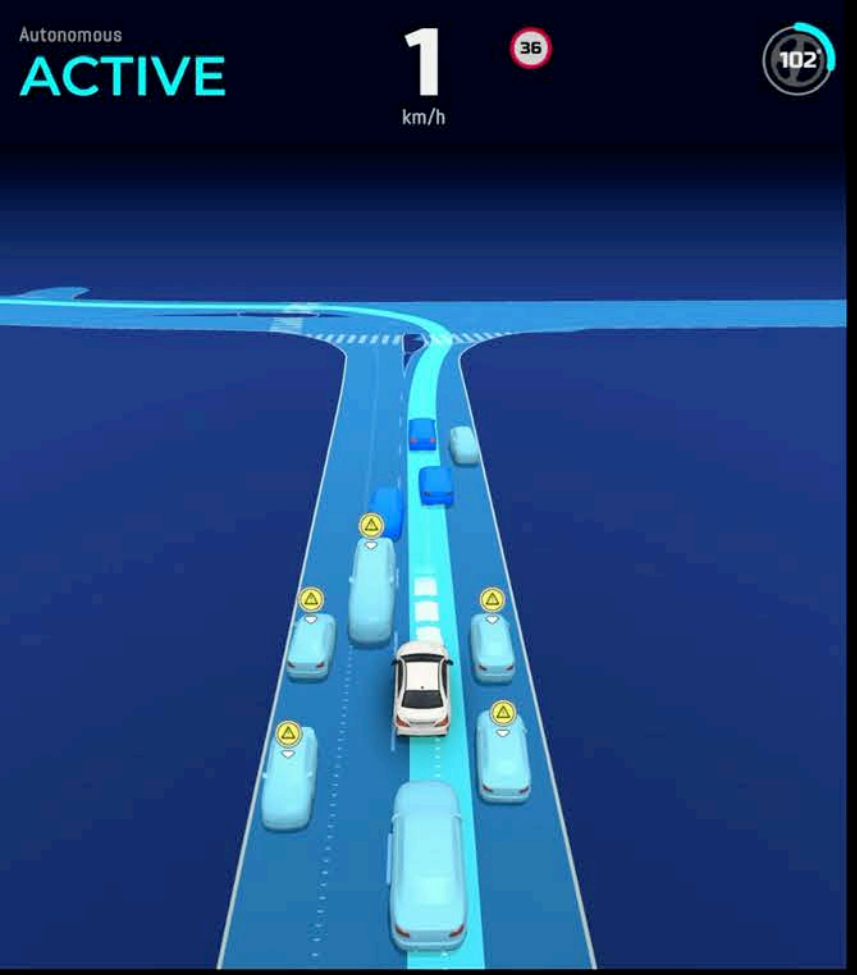


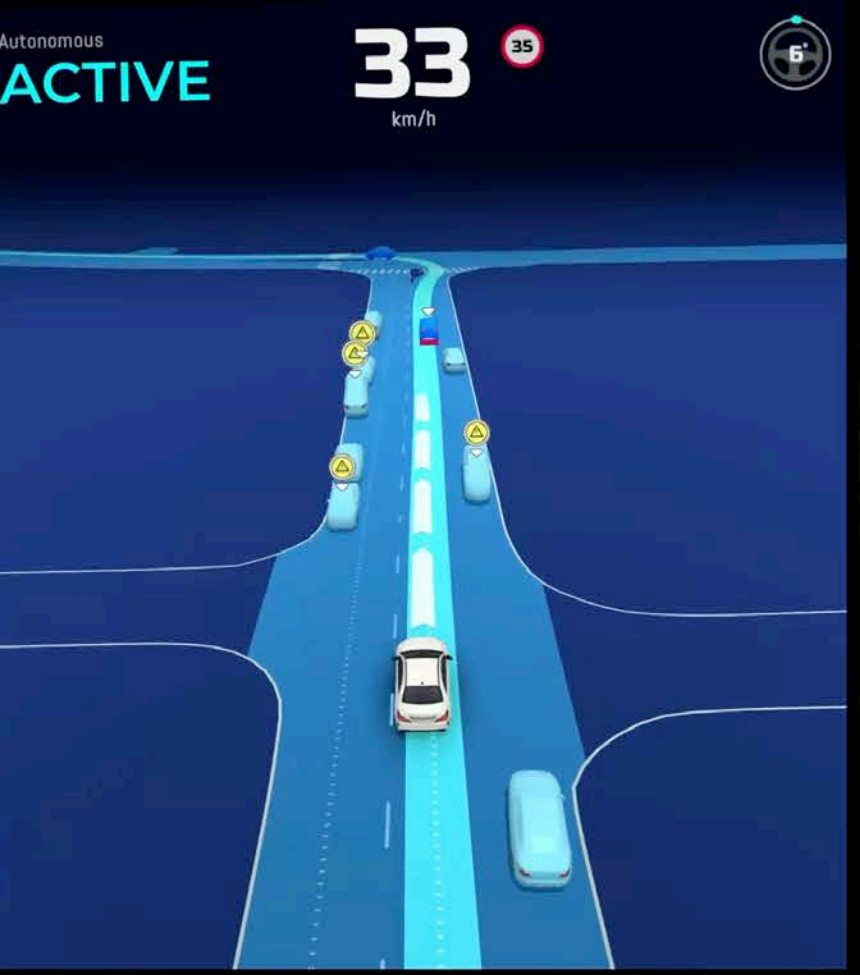
You can pass

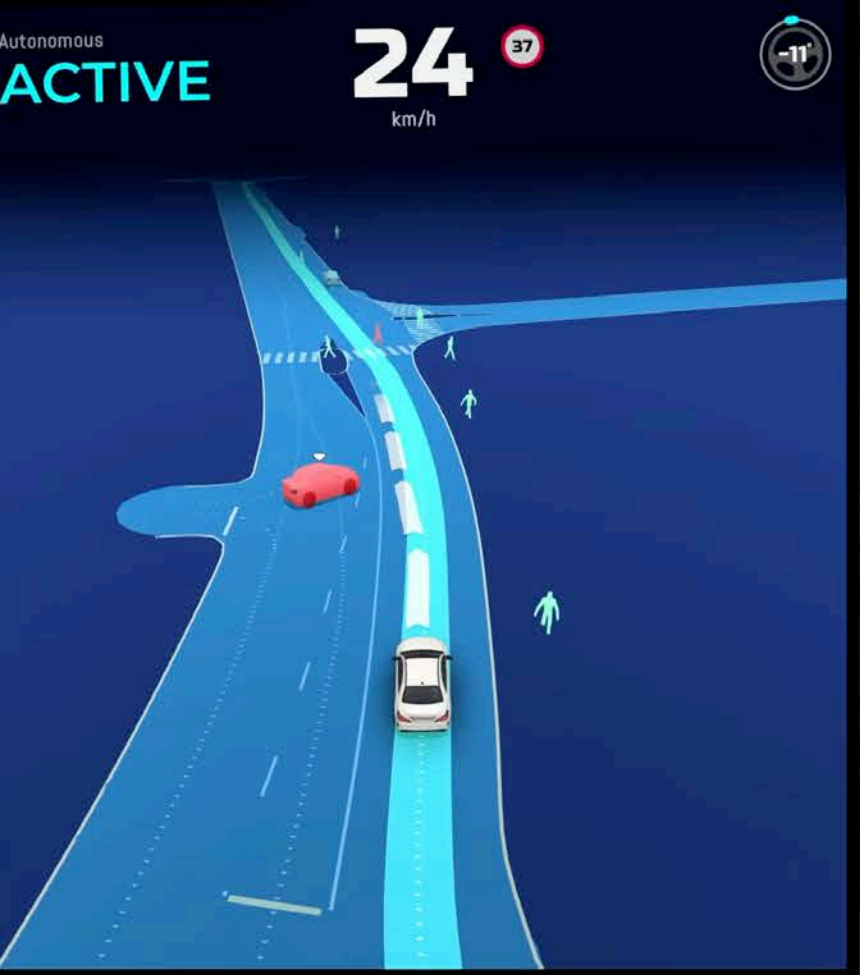
Stop!



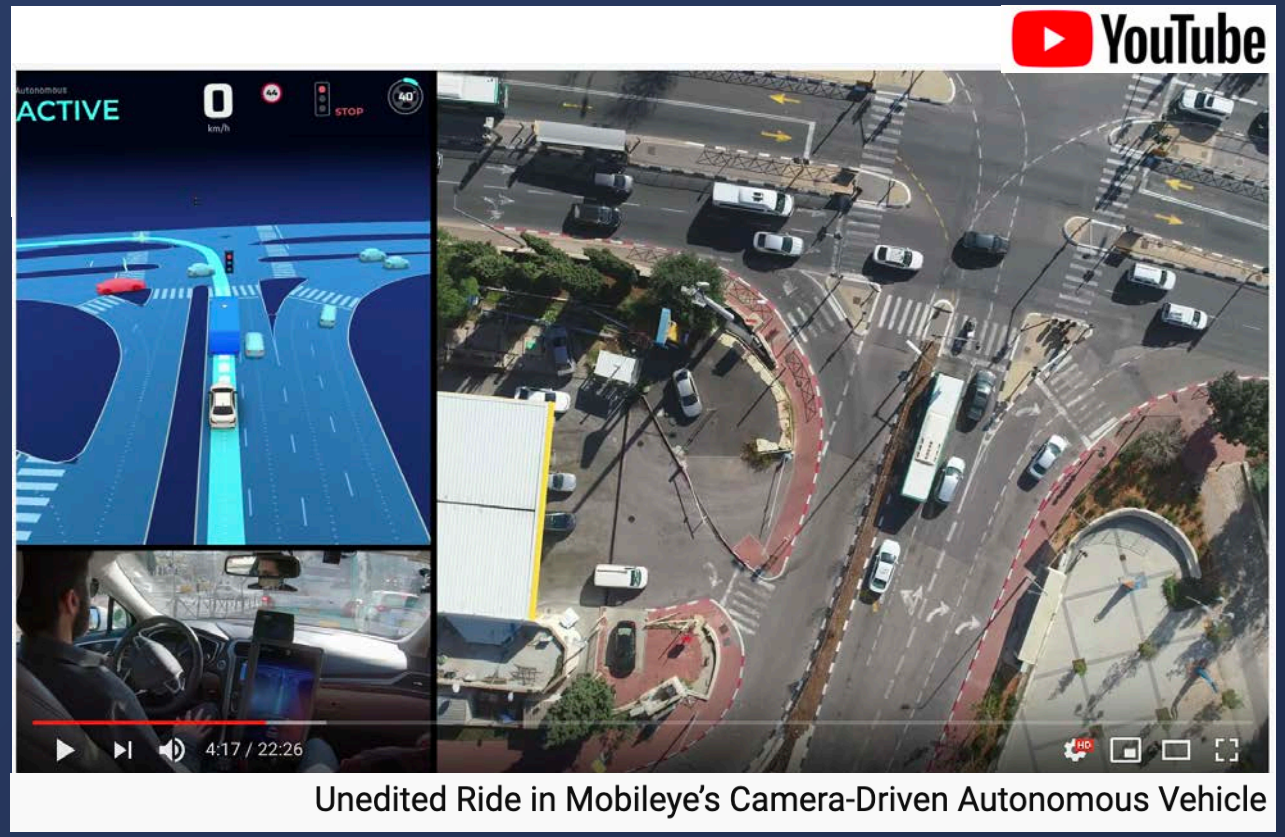
On the phone


Autonomous
ACTIVE
1
km/h
36
102


Autonomous
ACTIVE
33
km/h
35
6°


Autonomous
ACTIVE
24
km/h
37
-11°

The full unedited 25min ride is available at Mobileye's YouTube Channel



Unedited Ride in Mobileye's Camera-Driven Autonomous Vehicle

https://www.youtube.com/watch?v=hCWL0XF_f8Y&t=15s

REM Mapping and Data

REM Process

1. Harvesting

Collecting road and landmarks through EyeQ-equipped vehicles

2

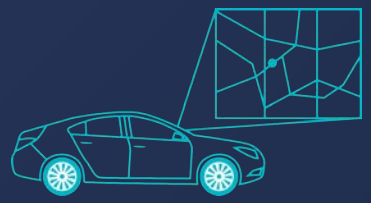
Anonymizing and encrypting REM data

3. Aggregation

Generating HD crowdsourced RoadBook for autonomous driving

4

Map tile distributed to the car



5. Localizing

Localizing the car within 10cm accuracy in the road book.

Also available via retrofit solutions

REM Volumes

Harvesting agreements with 6 major car makers

Harvesting:

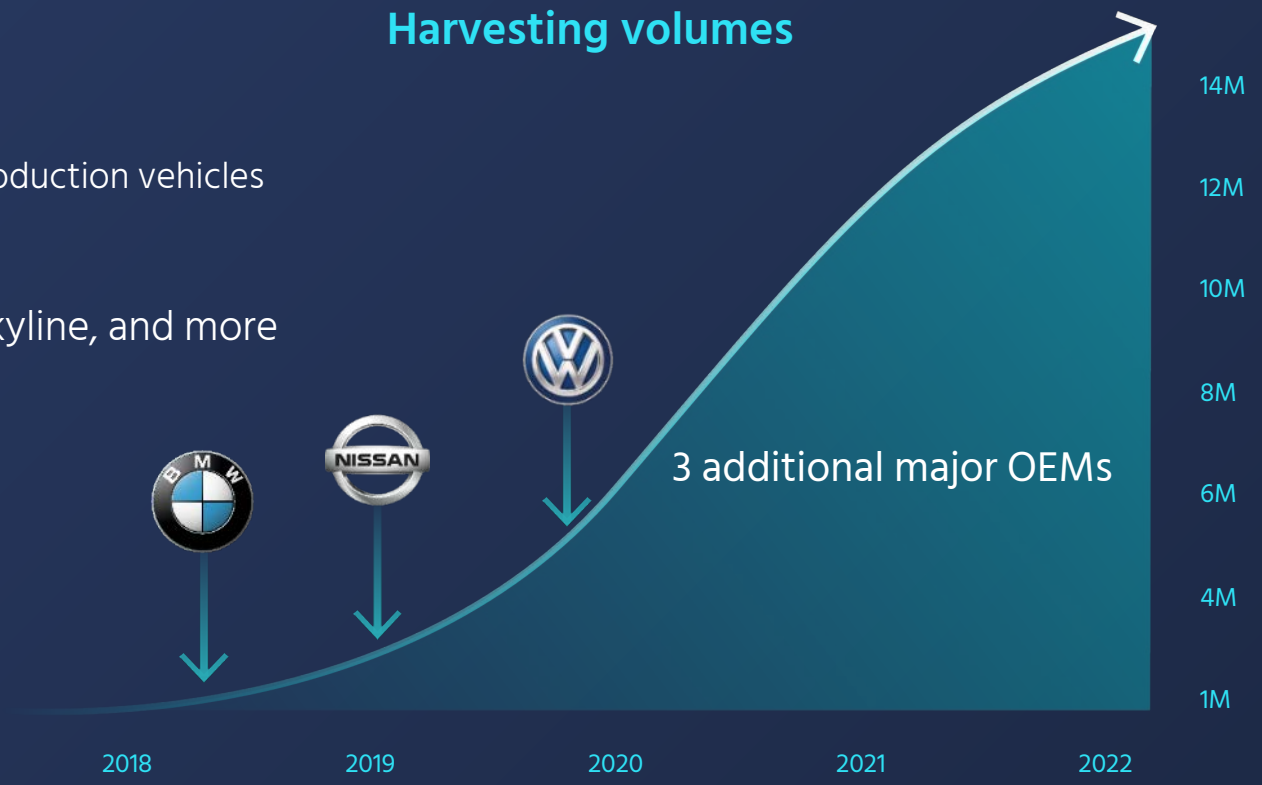
- Over 1M Harvesting vehicles in EU by 2020
- Over 1M Harvesting vehicles in US by 2021
- **Collecting 6 million km per day** from serial production vehicles such as:

Volkswagen Golf, Passat, BMW 5 series, 3 series, Nissan Skyline, and more

Localization:

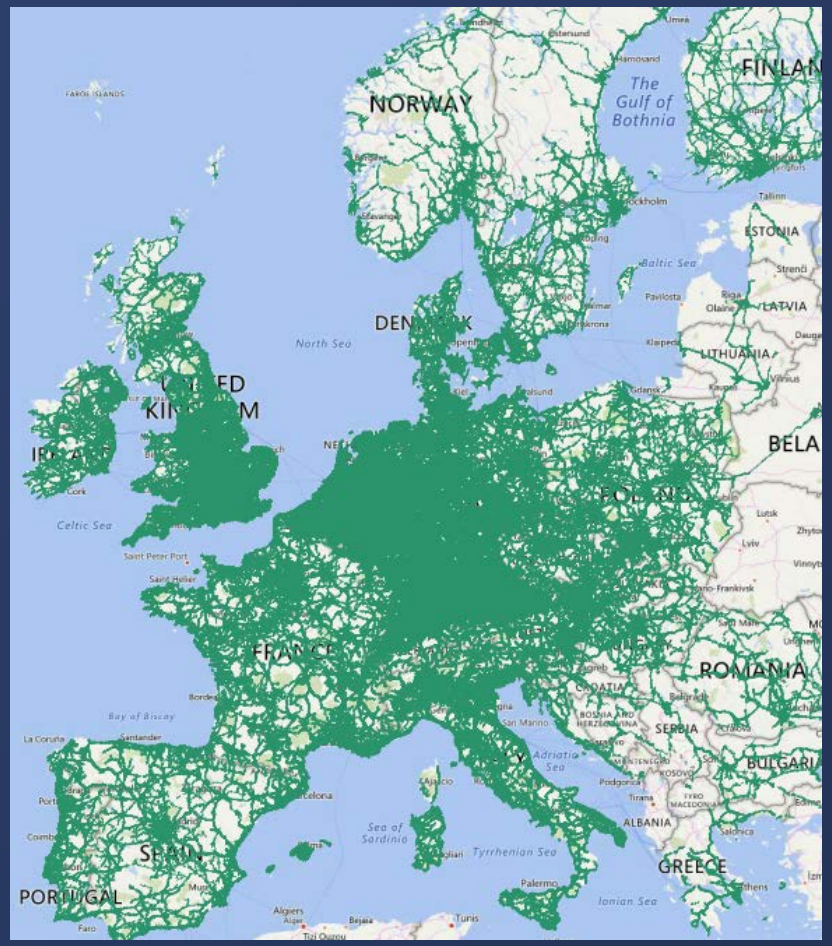
- Programs for using Roadbook™ for L2+:

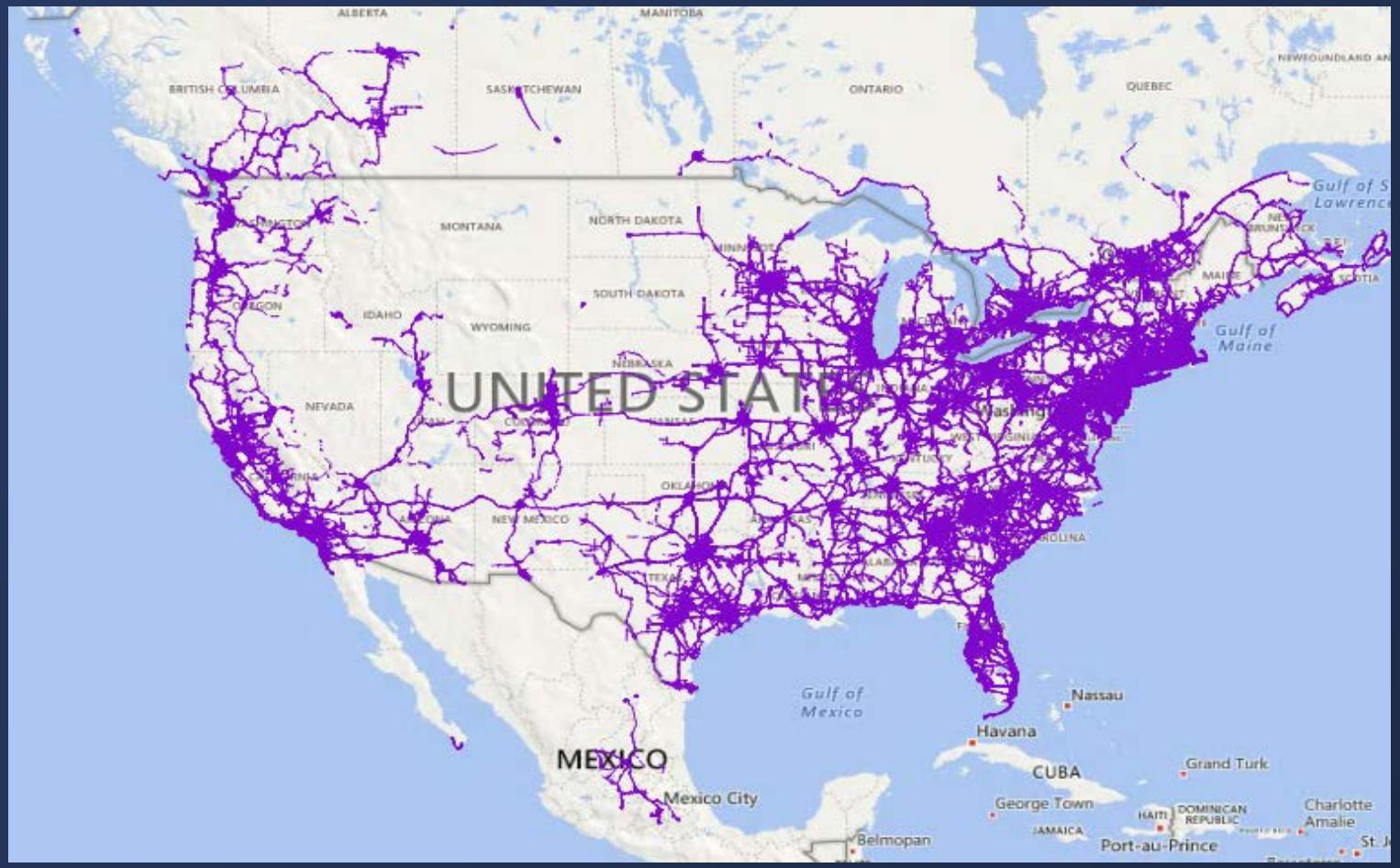
2 OEMs | 2 OEMs | 2 OEMs



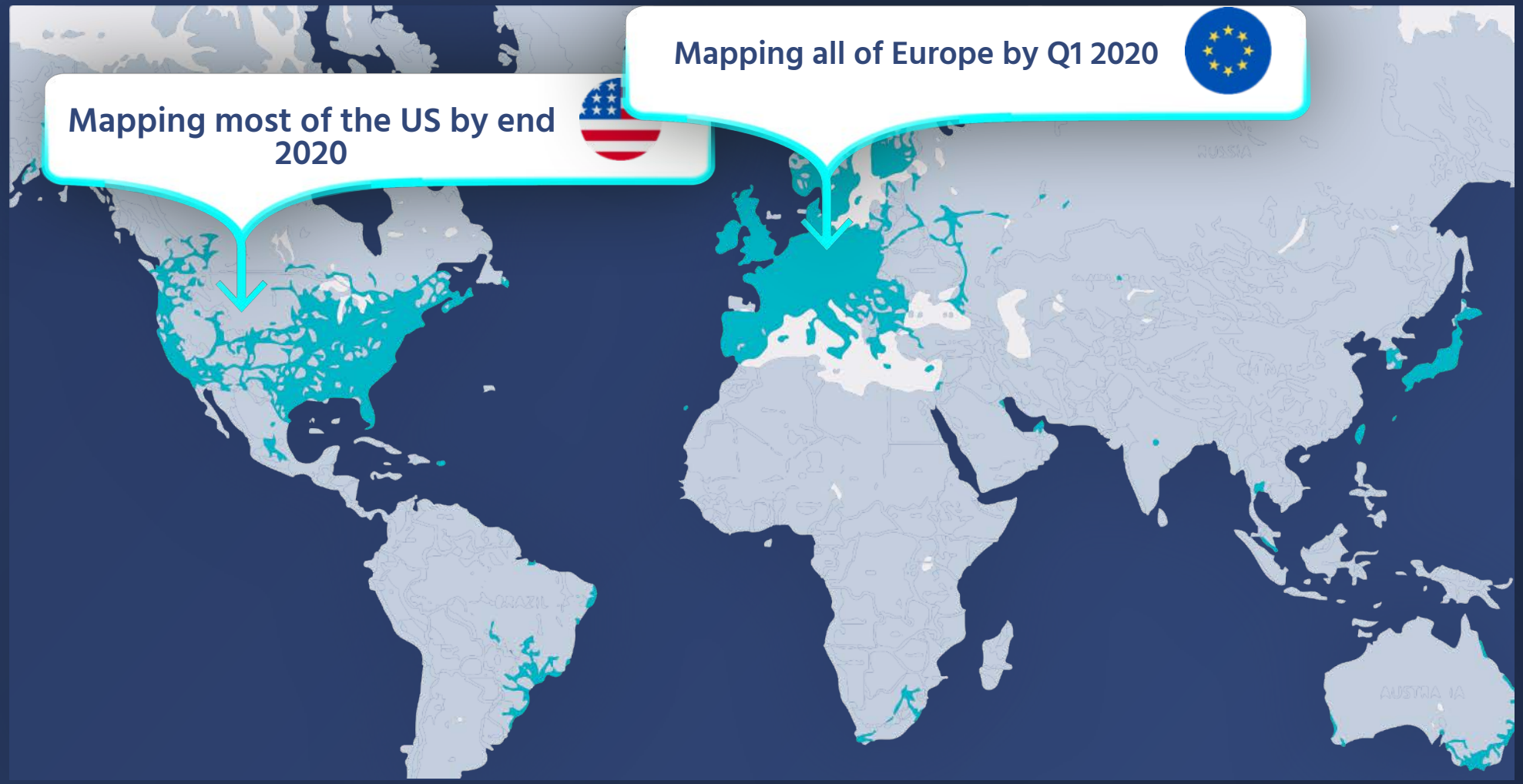
REM-data Aggregation

RSD Coverage Global Snapshot





REM Milestones



REM for Autonomous Driving

Already operational and is proving to be a true segment game changer

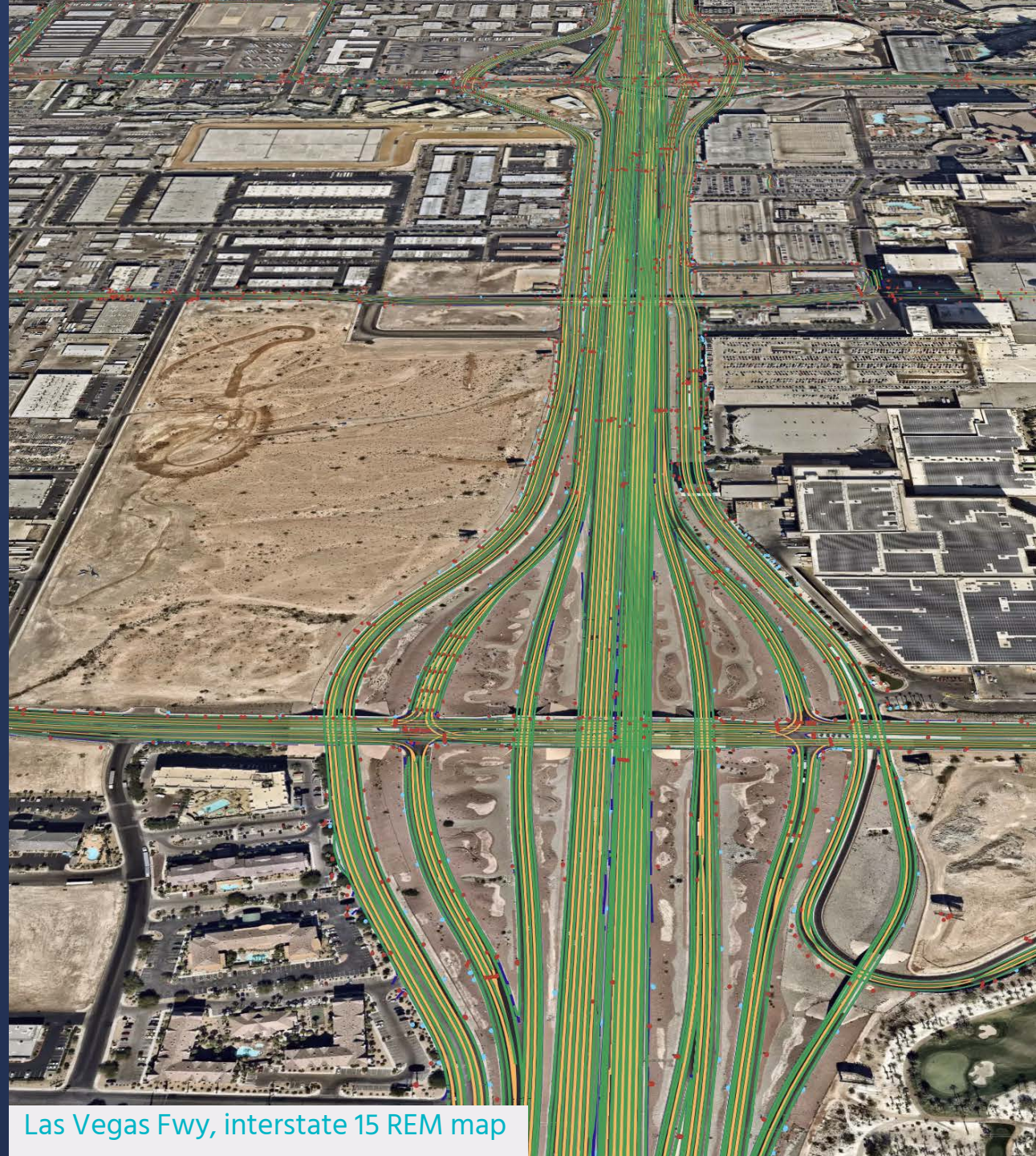
For roads above 45 Mph

- Maps created in a fully automated process TODAY
- Contains all static, dynamic, and semantic layers to allows fully autonomous drive

45 Mph

For roads below 45 Mph

- Semi-automated process
- Full automation in 2021



Las Vegas Fwy, interstate 15 REM map

REM in China

Data harvesting agreements in China complying with regulatory constraints

Mobileye An Intel Company | SAIC

Strategic collaboration with SAIC Motor for REM data harvesting
Accelerate the AV development for passenger vehicles in China

Mobileye An Intel Company | NIO

Harvesting data in China as part of a collaboration with NIO on L4 synergy for Robotaxi and consumer AV

Mobileye An Intel Company | 紫光集团 TSINGHUA UNIGROUP

JV agreement with Unigroup to enable the collection, processing, and monetization of data in China

The Smart Cities Opportunity

Mobileye Data Services

Product Portfolio

Infrastructure Asset Inventory

- Automated, AI-powered road asset surveying
- Efficient asset management, precise GIS data and change detection
- Strategic collaboration with Ordnance Survey (UK)

Pavement Condition Assessment

- Automated surveying & assessment of road conditions
- Efficient road maintenance with precise GIS data of surface distress

Dynamic Mobility Mapping

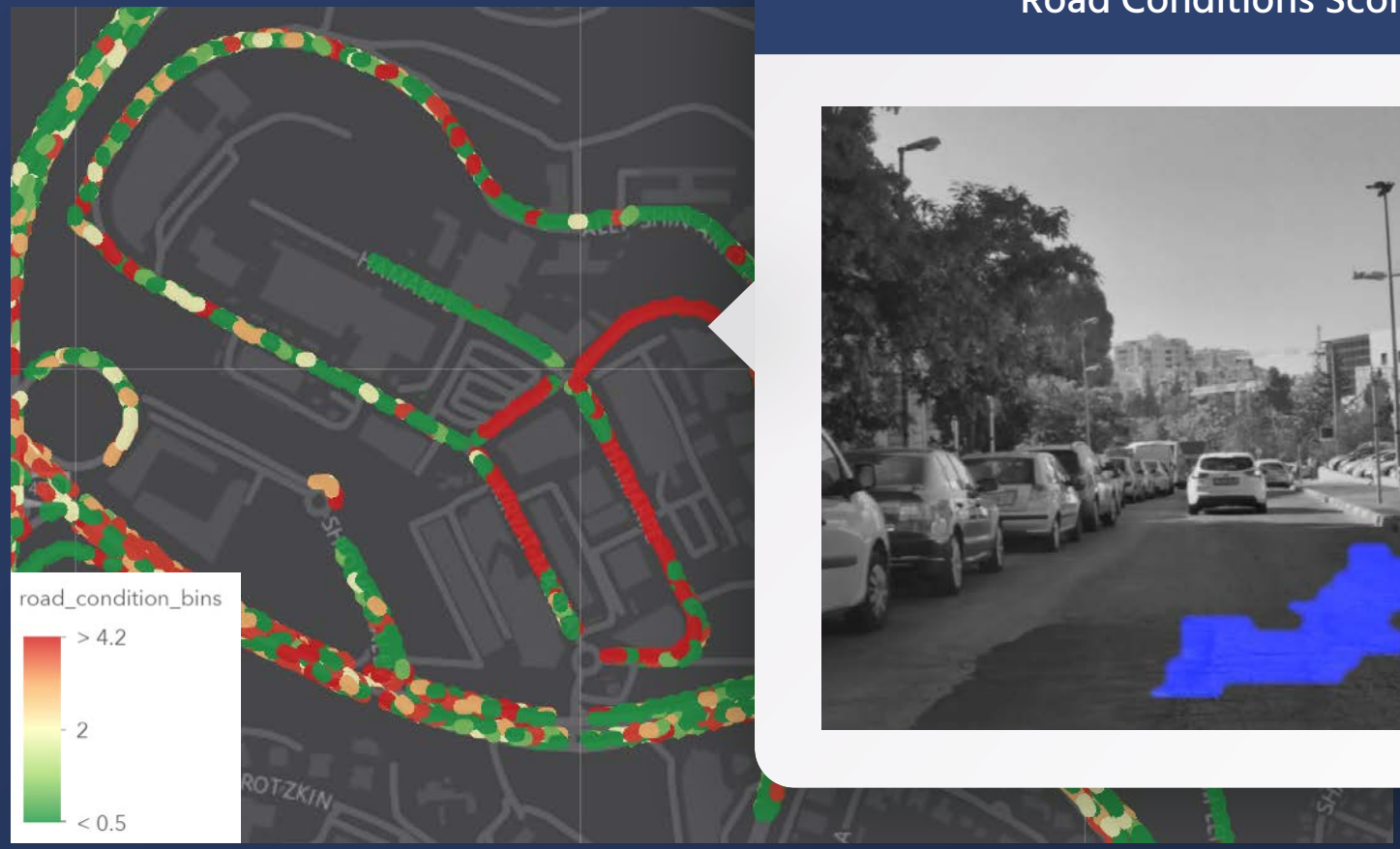
- Near real-time & historical data on movement in the city; dynamic mobility GIS datasets
- Evidence-based urban planning improvements

Infrastructure Asset Inventory

Pavement Conditions Assessment

5 levels score

- 0 – Excellent conditions - requires no repair



Road Conditions Score – Poor (5)

Pavement Conditions Assessment

- Cracks and potholes harvester in action

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RSS Driving Policy and Driving Experience

The Driving Policy Challenge

- Do we allow an accident due to a “lapse of judgement” of Driving Policy?
- Should the occurrence of “lapse of judgement” be measured statistically?

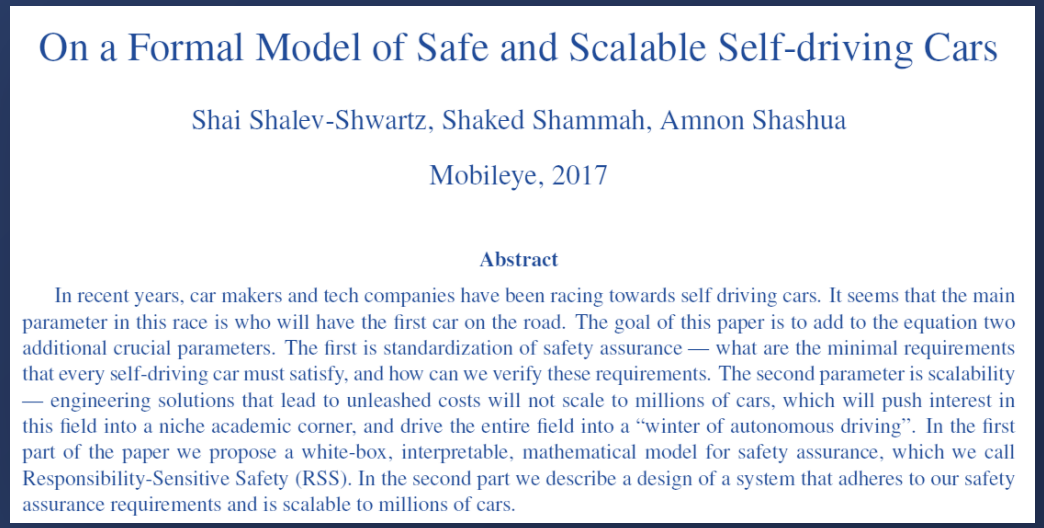
→ Safety is a technological layer living outside of Machine Learning. It is like “Ethics” in AI - a set of rules.

- It all boils down to a formal definition of “what it means to be careful”

→ There is a need for “regulatory science and innovation”. Technological innovation is not sufficient.

What is RSS?

A formal model for safety, that provides mathematical guarantees for the AV to never cause an accident



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.

http://arxiv.org/abs/1708.06374

The Method

01 Defining reasonable boundaries on the behavior of other road users

02 Within the boundaries specified by RSS, one must always assume the worst-case behavior of other agents

03 The boundaries capture the common sense of reasonable assumptions that human drivers make

04 Any action beyond the defined boundaries is not reasonable to assume

For Example Ego car A is following car B on a single-lane straight road

The Goal Efficient policy for A that guarantees not to hit B in the worst-case

The Implementation Safe distance for A to not hit B in the worst-case – under a reasonable assumption on $V_{b\ max\ brake}$

The Policy

- Define **Dangerous Situation-** a time is dangerous if the distance is non-safe
- Define **Proper Response-** as long as the time is dangerous, brake until stop

The Guarantees

- Proof by induction
- More complex situations (n agents) need to prove “no conflicts” (efficiently verifiable)

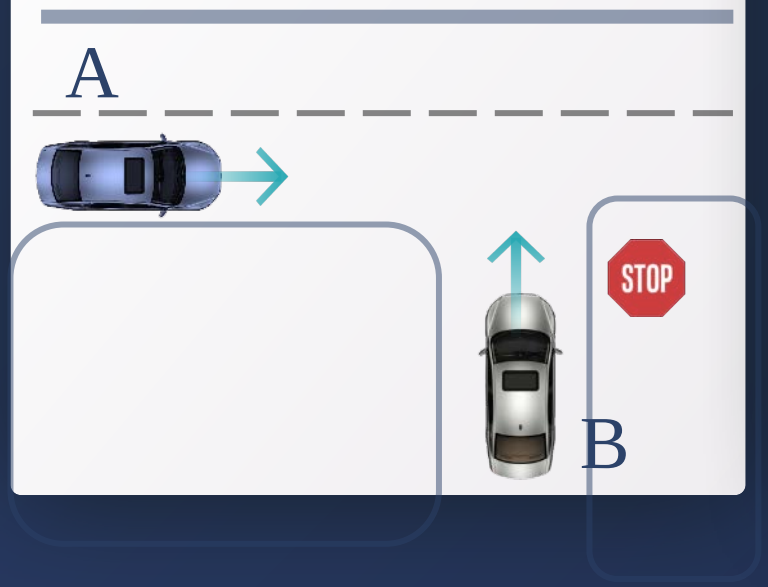
More Complex Situations

RSS sets the boundaries of reasonable assumptions for all driving scenarios

What is reasonable to assume on B in the scenarios below

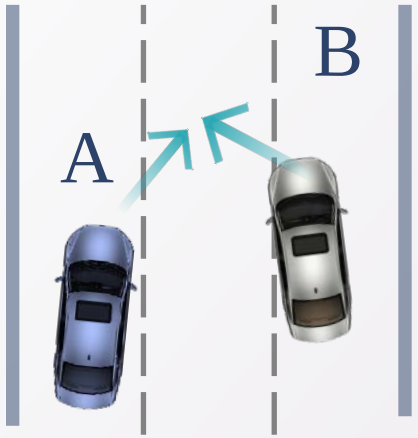
Multiple Geometry

If B can brake at B_{min_brake} without violating right-of-way, B will brake, otherwise A must stop



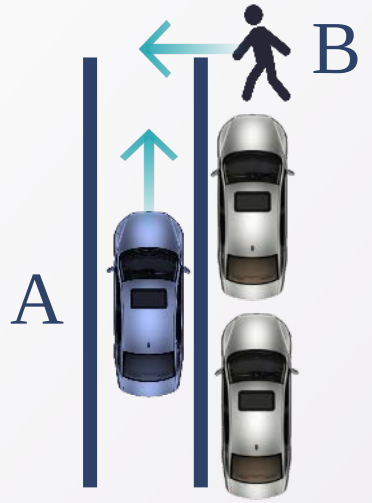
Lateral Maneuvers

If B can brake at B lat min brake , B will brake laterally, otherwise A must brake laterally



Occlusions

Assuming the max velocity of B - dictates the max speed for A



In Summary

Assuming **cooperative behavior on the roadway** is the key for drivability and “human-like” driving

Formal definition of the “reasonable assumptions” provides **mathematical guarantees for safety**

The parameters dictates the **cautiousness and utility tradeoff** and allow transparent and concise regulatory framework

The RSS adheres to 5 principles:

01 **Soundness**- full compliance with common sense of human driving

02 **Completeness**- covering all driving scenarios by always assuming the worst case under the reasonable assumptions

03 **Usefulness**- Policy for efficient and not overly-conservative driving

04 **Transparency**- The model should be a white-box

05 **Efficiently Verifiable**- proof of guarantee by induction, insuring no butterfly effect

Industry Acceptance

The RSS is gaining global acceptance as an Automated Vehicle Safety Standard

Previously announced adoptions of RSS:

Baidu 百度 | apollo

Valeo

C-ITS CHINA ITS INDUSTRY ALLIANCE

Safety First for Automated Driving (SaFAD)

Companies involved are:

BMW, Daimler, Audi, VW, FCA, Aptiv, Continental, here, Baidu, Infineon

Together with 11 industry leaders, we established an industry-wide definition of safety with the SaFAD white paper, based on RSS definitions

IEEE to define a formal model for AV safety with Intel-Mobileye leading the workgroup

MOBILEYE An Intel Company | IEEE Advancing Technology for Humanity

The new standard will establish a formal mathematical model for safety inspired by RSS principles

Industry Acceptance

The RSS is gaining global acceptance as an Automated Vehicle Safety Standard

China ITS Industry Alliance (C-ITS) to formally approve an RSS-based standard

The standard, **"Technical Requirement of Safety Assurance of AV Decision Making"**, has been released to public and will take effect on March, 2020

- The world's first standard, based on RSS
- Proof point that RSS can handle one of the world's most challenging driving environments: China
- The world's first proposed parameter set that defines the balance between safety and usefulness

The Path to Becoming an End-to-End Mobility-as-a-Service Provider

MaaS Business Status

Mobileye is forging driverless MaaS as a near term revenue-generating channel

- The JV to bring robotaxi MaaS to Tel-Aviv is officially signed
- Deploying and testing in Tel-Aviv during this year
- Establishing the regulatory framework in Israel

- RATP and Mobileye partnered with the City of Paris to deploy a driverless mobility solution
- The first EU city where testing with Mobileye's AV will start this year

- This year Mobileye will start using Nio ES8 for AV testing and validation
- In 2022 launching a next-gen platform with Mobileye's L4 tech offered to consumers in China
- Robotaxi variant will be launched exclusively for our robotaxi fleets

- Daegu City and Mobileye announce today a partnership to start testing robotaxi MaaS in South Korea this year
- Deployment during 2022

Our Self-Driving-System HW Generations

EPM 52

- In deployment
- Up to 2x EQ5H
- Up to 7x8MP + 4x1.3MP
  Up to 48 TOPs

EPM 59

- Deployment in Q2 2020
- Up to 6x EQ5H
- Additional 2-3 for FOP
- E2E support in all aspects- fusion, policy, control
  Up to 216 TOPs

EPM 6

- Deployment in 2023
- Single EQ6H to support E2E functionality
- Additional EQ6H FOP
  Up to 220 TOPs

Main Takeaways

01 L2+ a growing new category for ADAS where Surround-CV unlocks considerable value at volume production cost.

02 Realization of (safe) L4 and unlocking the full potential of L2+ requires Surround-CV at a standalone (end-to-end) quality

03 L2+ required HD-map-everywhere at growing use-case (types of roads) → L4 requires HD-maps → Consumer-AV requires HD-maps-everywhere → Automation at scale is enabled by crowd-sourced data (REM)

04 Crowd-sourced data from ADAS-enabled vehicles (REM) unlocks great value for Smart Cities

05 To unlock the value of automation there is a need for “regulatory science” (RSS)

06 The road to Consumer-AV goes through Robotaxi MaaS

Thank You!