Mobileye Under the Hood

mobileye®
An Intel Company

Prof. Amnon Shashua
President & CEO

CES 2022

2021 in Numbers

41

New design wins with 30+ OEMs
Record figure

50M

Pipeline volume of new design wins (compared to 37M in 2020)

188

Vehicle models launched in 2021 with Mobileye inside

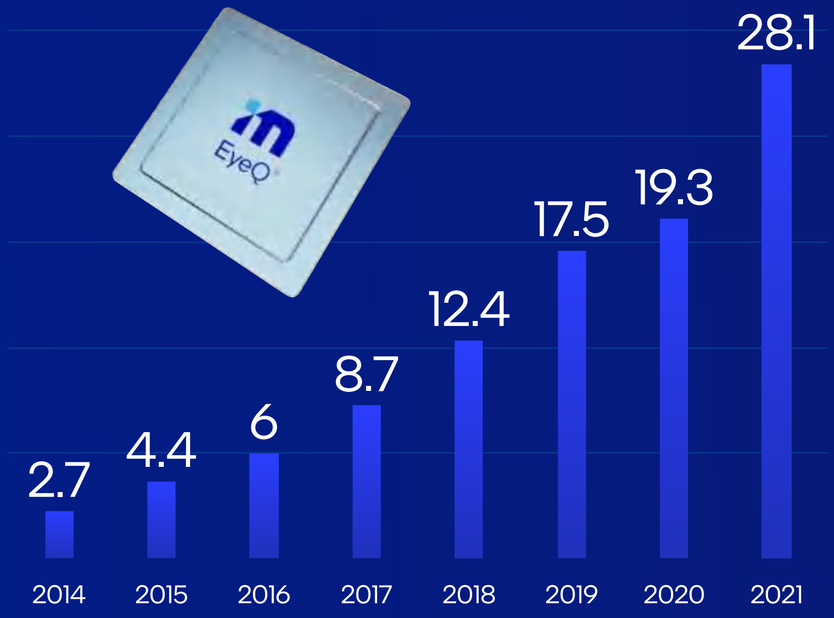
1.4B

Revenue in 2021
40% YoY

2021 → 2022

- Industry-first L3 (as CV provider) **Honda**
- 120° 8MP highest resolution ADAS **BMW**
- First cloud-enhanced ADAS using REM maps **Volkswagen**
- Industry-first 8MP surround system (11 cameras) **Zeekr**

EyeQ Shipped



100M EYEQ SHIPPED TO DATE

The Mobileye Database

Believed to be the largest driving database in the industry

Data:

200 PB

premise-On + cloud (AWS)

Reference numbers: Intel (238), Israeli governmental services (5), Israel's biggest insurance company (2)

16M CLIPS

25 years of driving

Compute:

500K PEAK CPU CORES (parallel)

All based on spot instance
10x more than SkyScanner

50M MONTHLY RUNS

100PB being processed every month on 500K hours of driving

Mobileye Strategy

2017 2021 2025

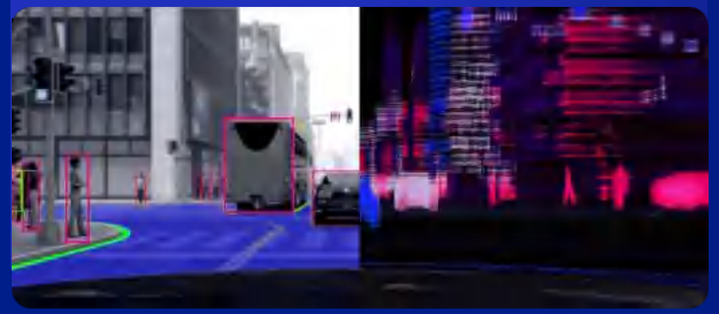
The fundamentals of Mobileye's strategy, as we outlined back in 2017:

REM™ MAPPING

+ Crowdsourced AV-maps
+ Cloud-based enhancements for ADAS

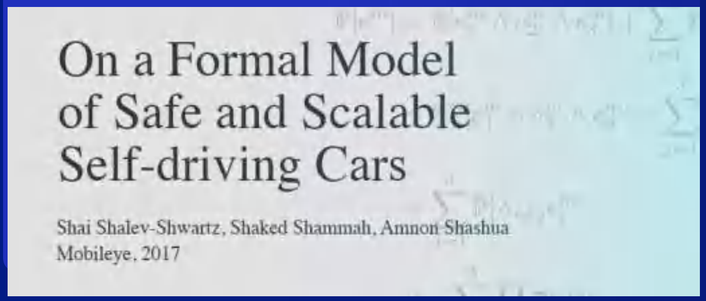
TRUE REDUNDANCY™

+ **Computer vision** that powers the Sense-Plan-Act cycle end-to-end
+ **Radar/ Lidar** sensing for redundancy



RSS SAFETY MODEL

+ Formal safety guarantees
+ Very lean compute for Driving Policy


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

Shai Shalev-Shwartz, Shaked Shammah, Amnon Shashua
Mobileye, 2017

Mobileye Strategy

True Redundancy, REM, and RSS are the building blocks for:

LEVEL 2+

Premium ADAS

- Driven by camera-only subsystem- **full ODD** at low cost
- REM- cloud enhancements for Pilot functions and **geographic scalability**
- RSS-based driving policy allows for **lean compute**

LEVEL 3 / 4

Conditional autonomy / full self-driving

- True Redundancy paves the way for **high MTBF**
- REM enables scale
- RSS provides formal safety guarantees and a regulatory framework
- Radars/ Lidars assets depend on the desired ODD

Achievements

Where we are today:

REM™ MAPPING

+ We built the largest crowdsourcing fleet for mapping- **25M km collected daily**
+ Fully functional for L2+: “Drive everywhere”
+ AV test vehicles deployed in many cities based on REM maps
(NYC, Detroit, Tokyo, Paris, Munich, Israel)

TRUE REDUNDANCY™

+ **SuperVision**™- productizing CV subsystem for hands-free L2+
+ **Radar/ Lidar** subsystem is complete
+ Unveiled our Robotaxi with the unified configuration at IAA, on the road 2022

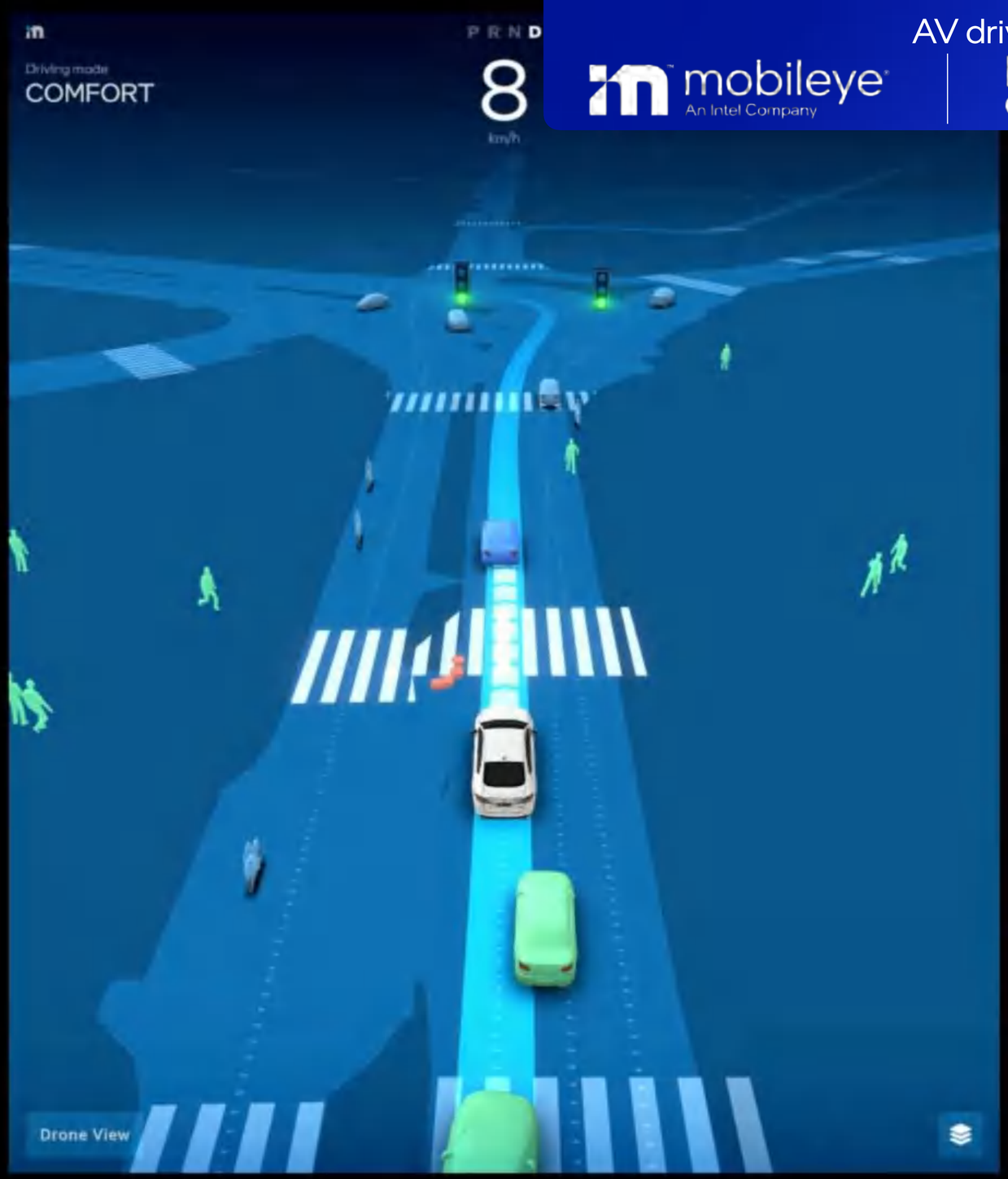
RSS SAFETY MODEL

+ **IEEE 2846** working group
  + Chaired by Intel-Mobileye with 30+ leading industry players
  + The final version of the standard is to be published by the end of Q1
+ Very lean Driving Policy enables L2+ at scale

The Largest Global Footprint in the AV Industry

AV driving in Paris

mobileye An Intel Company | RATP GROUP | moovit



AV driving in Tokyo

Achievements

2017 2021 2025

Where we are today:

CLOUD-ENHANCED L2

Volkswagen Travel Assist™ 2.5 (powered by **REM maps**)

Next-generation Ford Blue Cruise™ (powered by **REM maps**)

SuperVision™- productizing CV subsystem for hands-free L2+

LEVEL 3

Honda Legend, Japan only (computer vision)

BMW 7 Series, coming this year (computer vision)

Future program with higher ODD

LEVEL 4

+ Unveiled Robotaxi at IAA, on the road 2022
+ Signed Robotaxi/ AV shuttle/ goods delivery deals
+ First design win for consumer L4 with Geely-Zeekr (SoP 2024)

First Design Win

Consumer L4 Platform

Powered by 6 EyeQ®5 High

SoP early 2024

mobileye®
An Intel Company

ZEEKR

Where Does This Lead Us?

2017 2021 2025

New category emerging:

L2+ Premium ADAS

+ Surround sensing
+ Cloud-based enhancements- REM and OTA
+ Full Sense-Plan-Act cycle on a wide ODD range

Emerging 2022/2023:

L4 Robotaxi

+ Geo-fenced
+ Cost- $X0,000

Emerging 2024/2025:

L4 Consumer AV

+ Drives everywhere
+ Cost- <$5K

Where Does This Lead Us?

The autonomous mobility market may unfold in two forms

Robotaxi
(people and goods) → mobileye — Waymo, Argo, Cruise, Aurora, etc.

Consumer AV → mobileye — Tesla, Apple?

Consumer AV → **Robotaxi**

PTO/TNCs buy AVs and just add the service layer on top

Robotaxi ↛ **Consumer AV**

Geo scalability and consumer-level cost (<$5K BoM at scale) are **“weak spots”** for the Robotaxi companies

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Doing both is not just about hedging

There are strong synergies between Robotaxi and Consumer AV

Maximizing the learnings from Robotaxi operation can serve as a stepping stone for Consumer AV.

The Criteria for a Good Solution

	Capabilties	Robustness	Efficiency
Definition	Wide self-driving ODD Human-like driving policy	High MTBF	Cost (compute and sensors <$5K) Scale (drive everywhere)
Mobileye's approach	+ Full ODD from L2+ to L4 + What differentiates L2+ from L4 is MTBF, not ODD	+ RSS (formal safety) + True Redundancy Two separate sensing subsystems (CV, R/L)	+ Purpose-built SoC + SW-defined imaging radar + Lean Compute + REM crowdsource mapping

Strong synergies between the building blocks in Mobileye's approach

+ Purpose-built SoC
+ SW-defined imaging radar
+ Lean Compute
+ REM crowdsource mapping

The New Generation of EyeQ®

A Family of SoCs That Covers the Entire ADAS/ AV Spectrum

The New Generation of EyeQ®

EyeQ®6 Light

L1-L2

ADAS

EyeQ®6 High

L2+ / L3

Premium ADAS

EyeQ®ULTRA

L4

Full Self-Driving

The EyeQ® ULTRA

AV-on-Chip: A single SoC to power autonomous driving end-to-end

+ Controlling the entire AV stack allows us to know precisely what is required from the AV's onboard compute
+ We first built an AV and only then designed an application-specific SoC for the AV
+ EyeQ® ULTRA utilizes an array of four classes of Mobileye's proprietary accelerators (64 in total), each built for a specific task:

XNN
Dedicated AI engine for DL neural network

PMA
Programable CGRA.

VMP
An SIMD VLIW machine

MPC
Multiple barrel-threaded CPU cores

+ Full support for co-hosting third-party applications by offering a complete SDK package and OpenCL environment

5 nm **176** TOPS (INT8) **4.2** TFLOPS

Additional Vitals

CPU:	12 RISC-V cores (12C24T)
GPU GFLOPS:	256
ISP :	2.4GPxl/s
Video Enc:	2x H264/5 Enc 4K60, MJPEG
Power(SDP):	< 100W

ES: Q4/2023 | Volume production: 2025

EyeQ® 6 High

The ultimate compute platform for Premium ADAS

+ 3x more TOPS than an EyeQ5H with just 25% more power
+ Advanced visualization capabilities for parking and UX applications supported by dedicated GPU, ISP, and a video enc.
+ Will carry all premium ADAS tasks (next-gen SuperVision™)

7 nm **34** TOPS (INT8) **14** ACC. CORES

Additional Vitals

CPU:	MIPS64 (8C32T)
GPU (ARM) GFLOPS:	64
GFLOPS (OCL)	1000
ISP (ARM):	1.2GPxl/s
Video Enc:	MJPEG, Disp Out 4K60

ES: Q4/2022 | Volume production: 2024

EyeQ® 6 Light

The new work horse for all ADAS functions

- **The most power/performance/cost-efficient SoC we have ever built**
- Compared to EyeQ4M:
  - **45% smaller package**
  - **450% more TOPS**
  - **Similar power consumption**
- One-box, behind windshield solution that can support CV+ localization to power L2+ functionalities
- Committed deals for over 9M units

7 nm	5 TOPS (INT8)	5 ACC. CORES

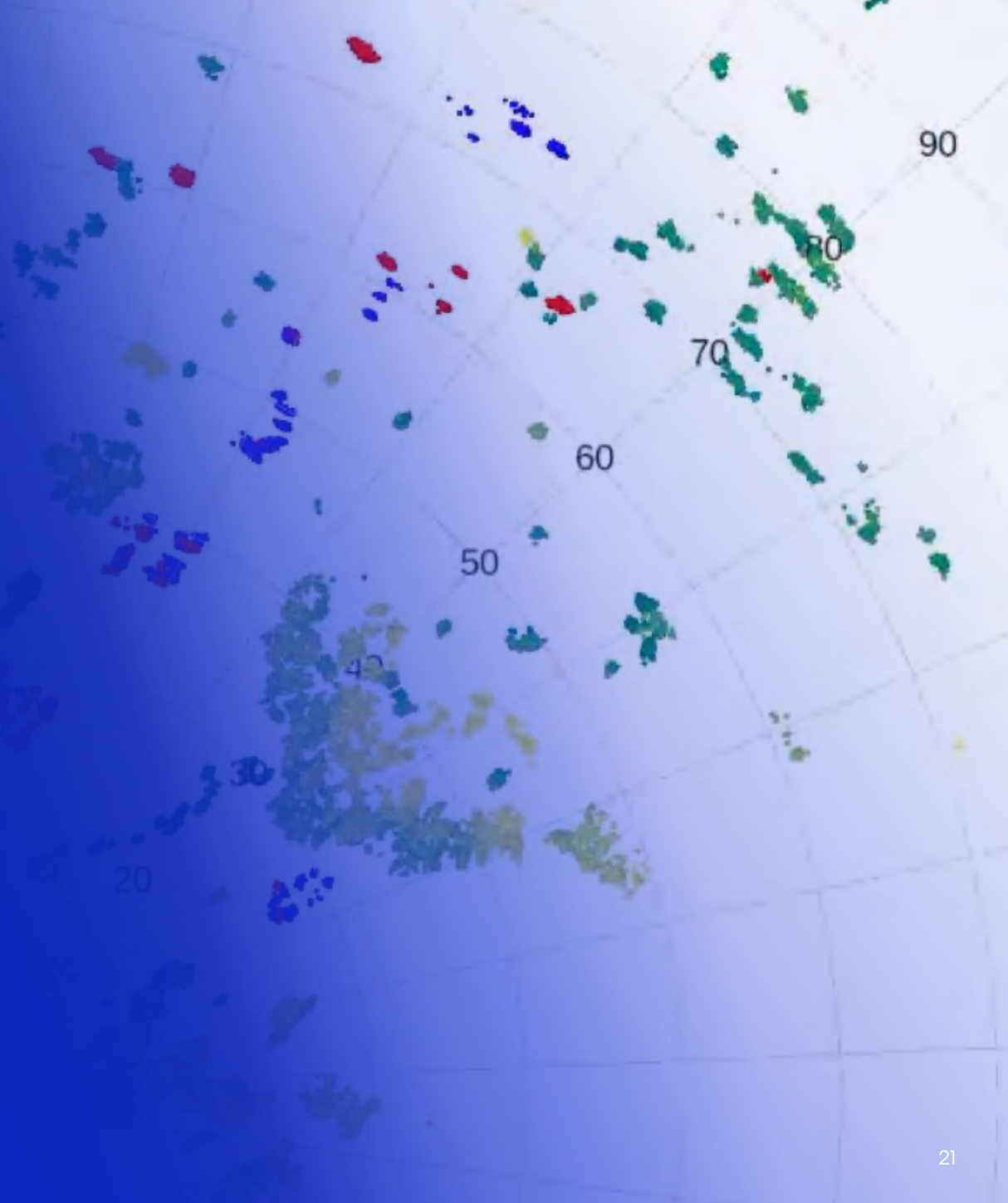
Additional Vitals

CPU:	MIPS64 (2C8T)
GFLOPS (OCL):	**720**

ES: Q2/2021 | SOP: Q2/2023

Redefining Radars and LiDARs

- Purpose-built SoC
- SW-defined imaging radar
- Lean Compute
- REM crowdsource mapping



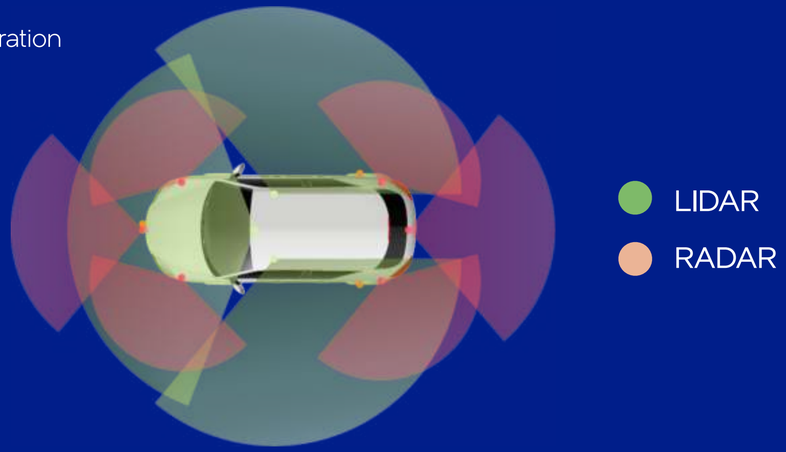
The Motivation Behind LiDAR and Radar Development

2022 LiDAR/radar subsystem

- ToF LiDAR - 360° coverage
- Advanced stock radars- 360° coverage

Need both to build a sensing state

Current radar-lidar subsystem configuration



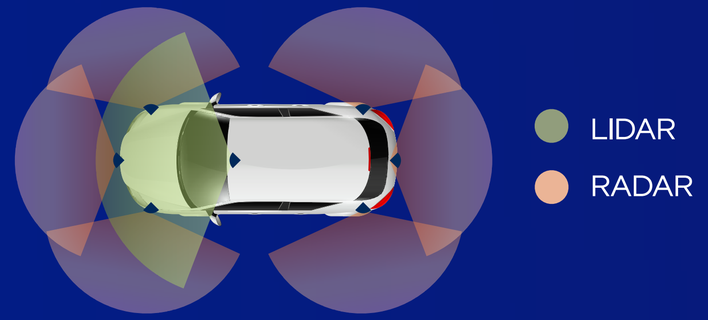
2025 LiDAR/radar subsystem

- Front sector- 3-way redundancy
- Remaining FoV- 2-way redundancy of cameras + radars
- Massive cost reduction that will unlock consumer L4 at scale

The enabler: **“Drive by” radar capabilities**

- Solving angular res., dynamic range, and side lobes effect

Next gen radar-lidar subsystem:
360° radar cocoon
+ 1 front facing LiDAR



SW-Defined Imaging Radar - Game-Changing Capabilities

Main attributes

- Massive MIMO radar with **2,304 virtual channels** (48x48)
- High angular and vertical res.- **0.5°x2°**
- **100dB** dynamic range
- **40dBc** azimuth sidelobe levels (SLL)
- **20 FPS**, Multi-mode scanning (SRR, MRR, steerable LRR)
- Digital signal processing for up to **500K PPS**

LOCAL OSCILLATOR

Ultra low Phase Noise

Assuring the system is not bounded by its internal noise

4 TX CHANNELS

High TX power

Can implement any waveform

6 Tx chips controlling 2 antennas= 48 Tx channels

6 RX CHANNELS

High bit rate sampling (1 GHz/ 11 bits)

Low noise figure

8 Rx chips = 48 Rx channels

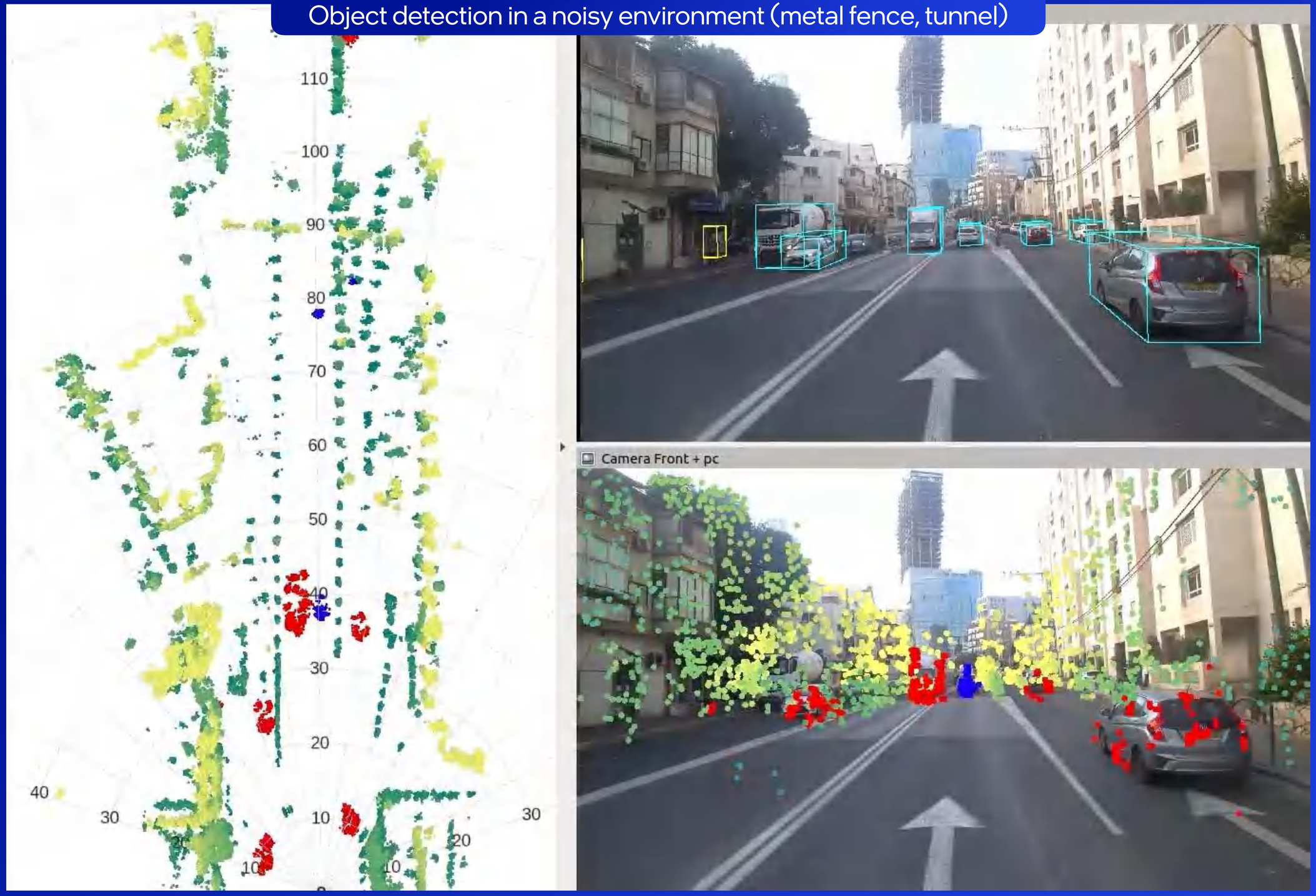
MAIN RADAR PROCESSING UNIT

11 TOPS SoC

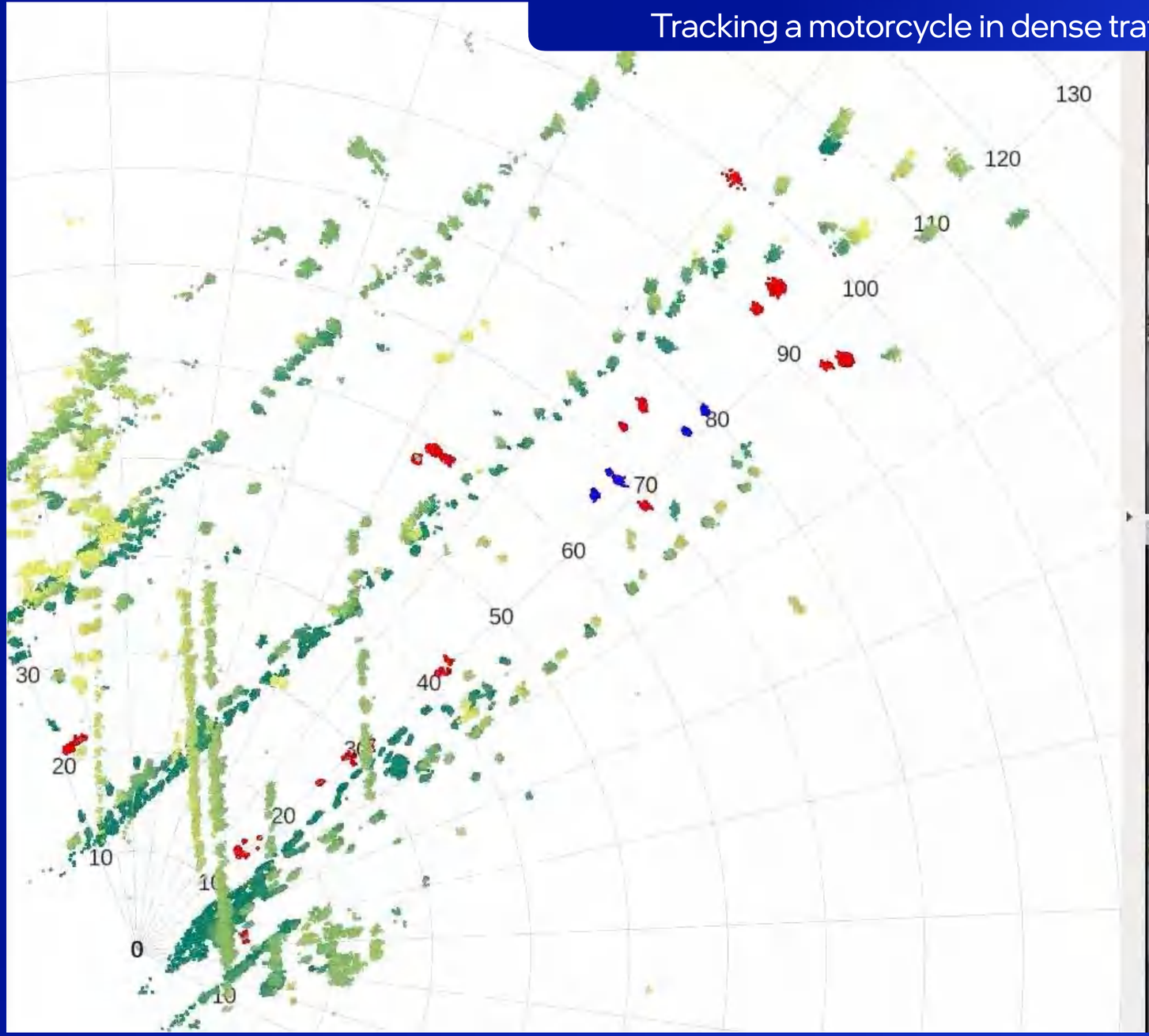
State-of-the-art signal processing
High BW RF samples interface

Separating objects in dense traffic
Construction area and path delimiters detection

Object detection in a noisy environment (metal fence, tunnel)

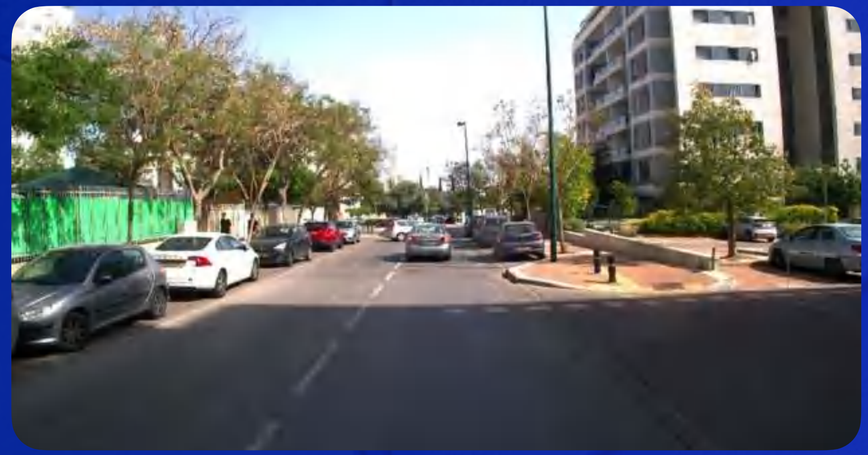


Tracking a motorcycle in dense traffic off-boresight

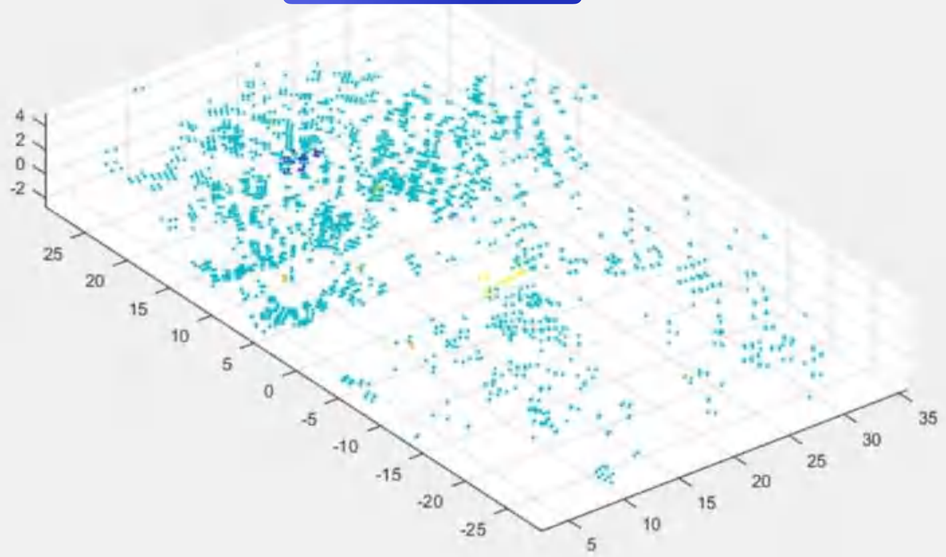


RESEARCH THEORY 1:

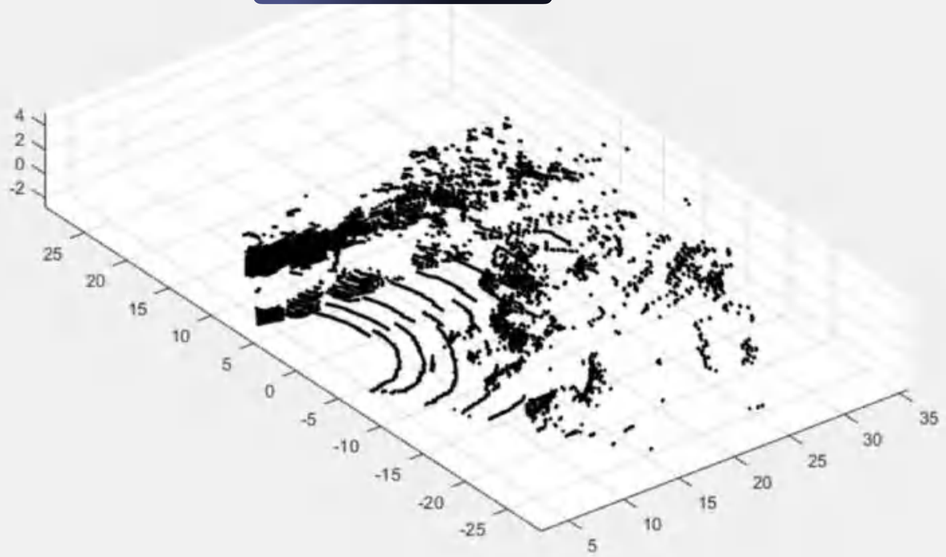
Can EyeC Radar output be presented like LiDAR?



RADAR



LiDAR



RESEARCH THEORY 1:

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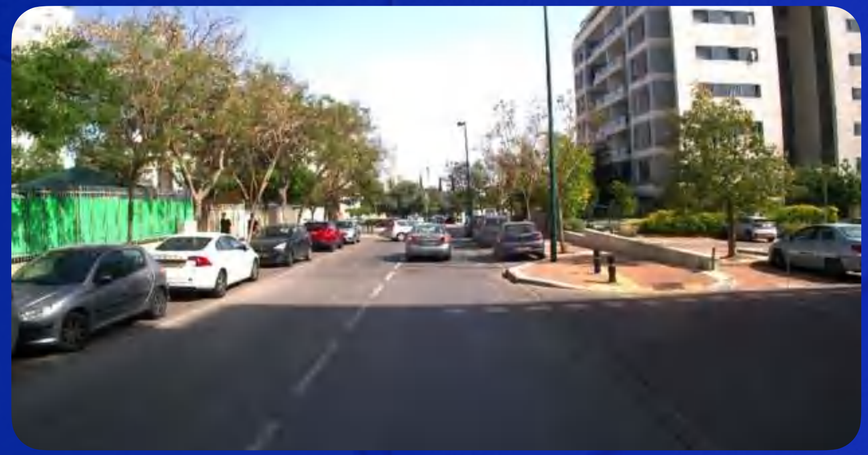
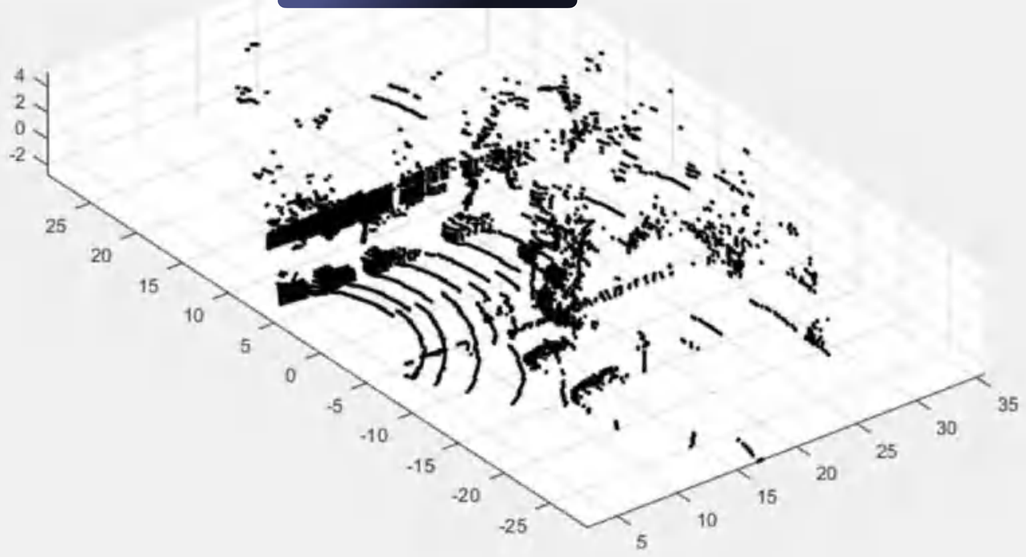
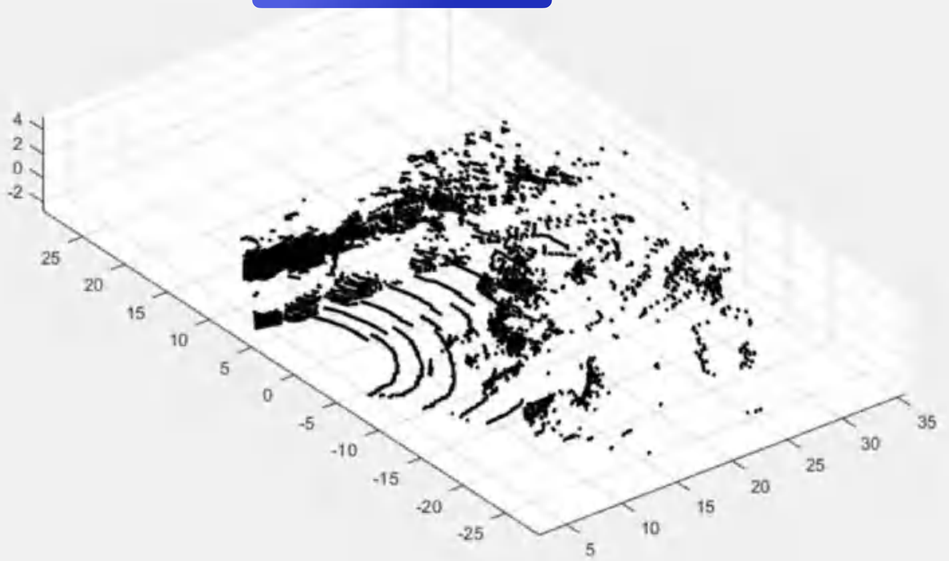
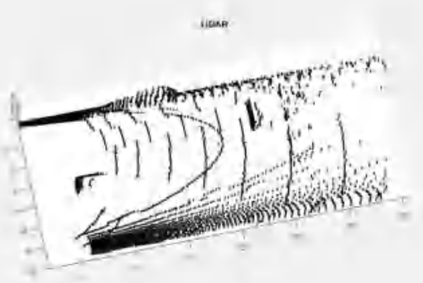


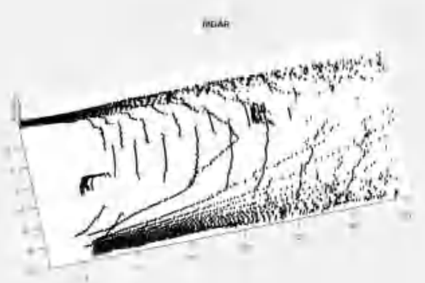
LiDAR



~~LiDAR~~ RADAR!

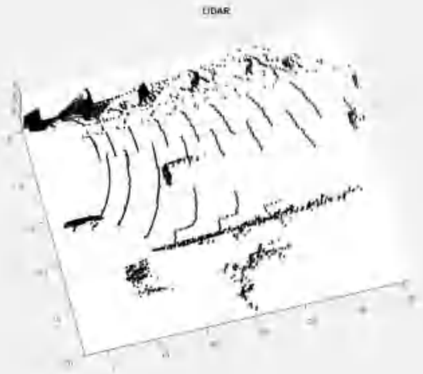


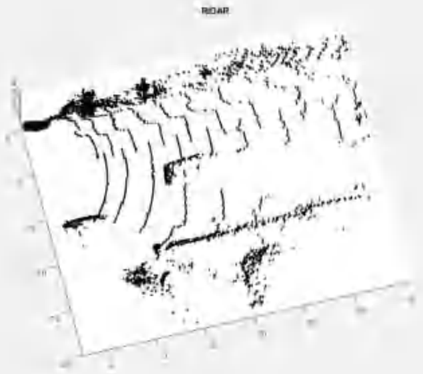




LiDAR

RADAR!





LiDAR

RADAR!

RESEARCH THEORY 2:

Can we train a network to create camera-like video based on our Imaging Radar point Cloud?

Building the Best-in-Class FMCW LiDAR

Main attributes

+ Best point density (600pt/deg^2, over 2M discrete 4D PPS over 1000 lines/sec)
+ Doppler content provides objects velocity and heading without dependencies on multi-frame tracking/registration
+ Long range (300m, over 200m for 10% refl)
+ Higher immunity (no sun or retro-reflectors impairments)
+ Price target under $1000 (design for manufacturability)

GoldBox- optical head enabling
90 vertical lines per scan

LiPRO- the worlds first-ever multi-channels FMCW LiDAR processor SoC

Multi-channel FMCW HW Accelerators handling up to 50GSPS

16 DSP cores enabling additional processing flexibility

4 CPU cores for scanner control, host Interface, maintenance, etc.

2 safety islands for FuSa and eye safety monitoring

What We Have Covered So Far

Game-changing developments going forward:

AV-on-Chip

SW-defined imaging radar becomes a heavy lifter in the self-driving architecture

Front FMCW LiDAR, yielding tri-fold redundancy in the front sector

Lean Compute enabled by RSS Driving Policy Methodology

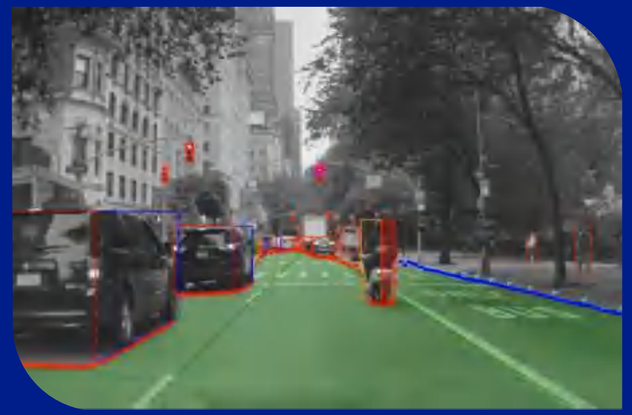
- Purpose-built SoC
- SW-defined imaging radar
- Lean Compute
- REM crowdsource mapping

Sense / Plan / Act Methodology

Sense

Perception of the environment.

Building a world model of the vehicle's surroundings: where we are, other road users, obstacles, traffic lights...



Plan (Driving Policy)

Decision making

“What would happen if" type of reasoning

Act

Execute the plan (Control): transform speed and curvature commands to pedals and steering wheel commands

About Driving Policy

Definition:

Sensing state

The sensing state contains our location, static obstacles, lane semantics, traffic lights, kinematic state of other road users, etc.

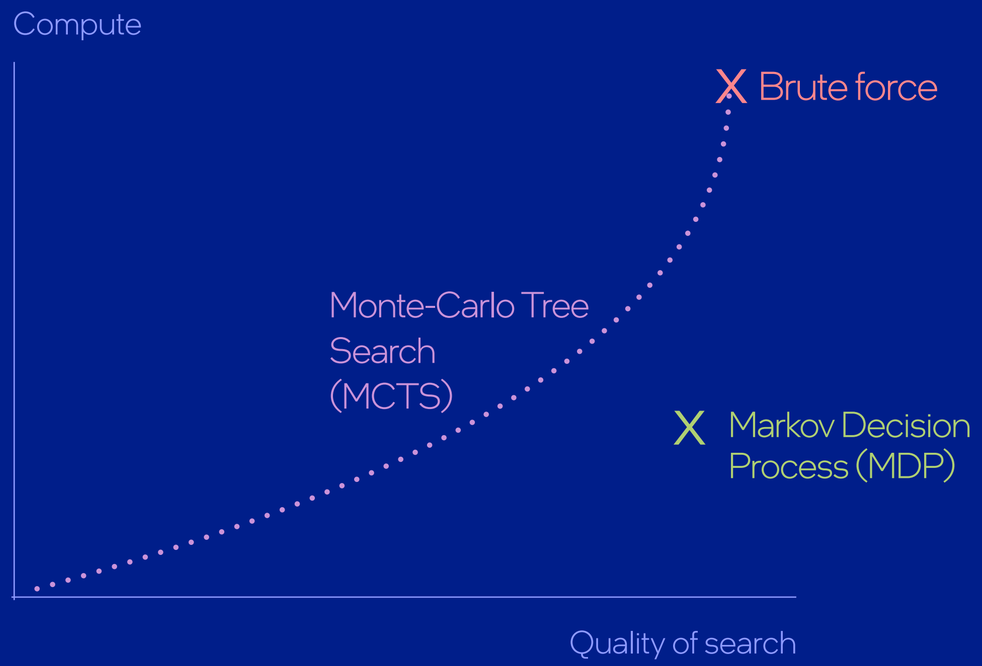
Action

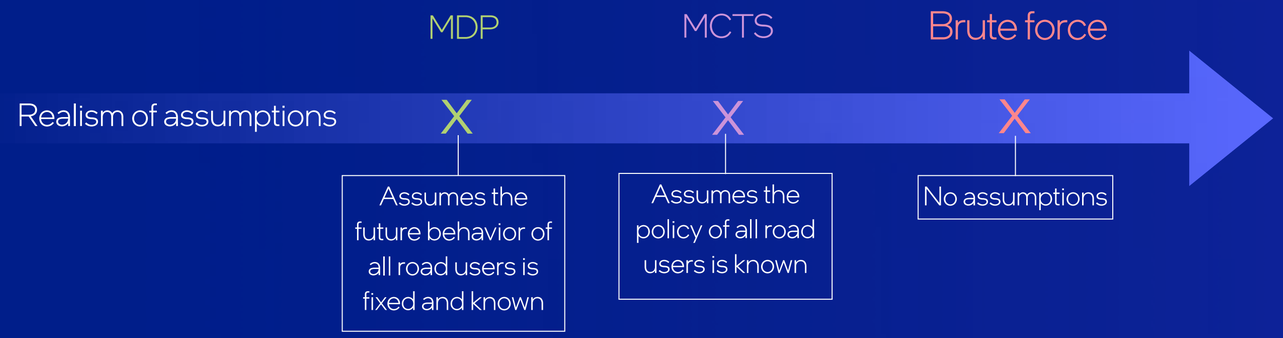
The desired action is the speed and curvature of the car

Why it is hard?

+ No “Ground Truth”
+ Actions may have a long-term effect
+ Close-loop: actions affect other road users
+ Must handle uncertainties about the future

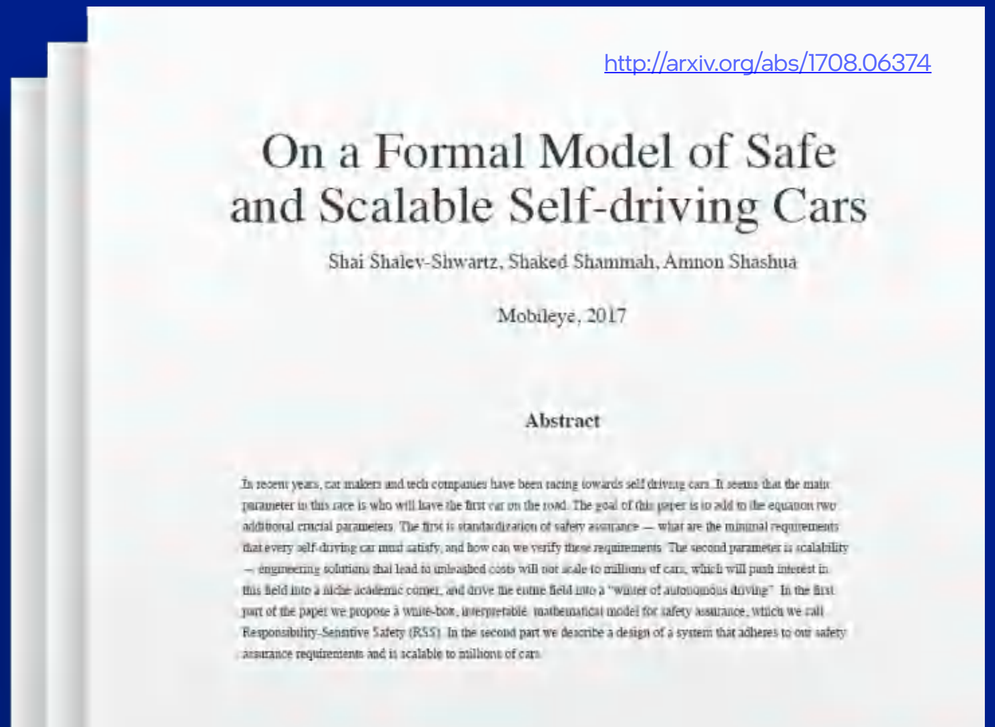
Driving Policy — Existing Approaches





Our Approach - RSS

A formal model for safety,
that provides mathematical formalization
for the AV's driving policy to never
cause an accident



http://arxiv.org/abs/1708.06374

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.

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

RSS Standardization and Government Efforts

IEEE
Advancing Technology for Humanity

IEEE WORKGROUP TO DEFINE A FORMAL MODEL FOR AV SAFETY CHAIRED BY INTEL-MOBILEYE

- Workgroup consists of 30 leading industry players
- Publication of final version - Q1, 2022
- This standard will provide governments the framework for setting the acceptable safety/usefulness balance

ISO

ISO/TR 4804:2020

SAFETY AND CYBERSECURITY FOR AUTOMATED DRIVING SYSTEMS

- World's first ISO Technical Specification defining a Safe-By-Design Automated Driving System
- RSS featured as a key element to implementing a safe Driving Policy

U.S. Department of Transportation

ADVANCED NOTICE OF PROPOSED RULE MAKING: FRAMEWORK FOR AV SYSTEM SAFETY

- US DOT Seeking public comment on the development of a framework for Automated Driving System (ADS) Safety
- RSS cited and recognized as a "Notable Effort Under Consideration" as an Engineering Measure for Safety

Law Commission
Reforming the law

AV CONSULTATION, PROPOSING A REGULATORY FRAMEWORK FOR AV'S IN UK

- RSS proposed as a way to define "how safe is safe enough" by defining a "does not cause a fault"
- RSS featured as a way to define "road craft" - a safety envelope around the AV defined by safe distances

Our Approach - RSS

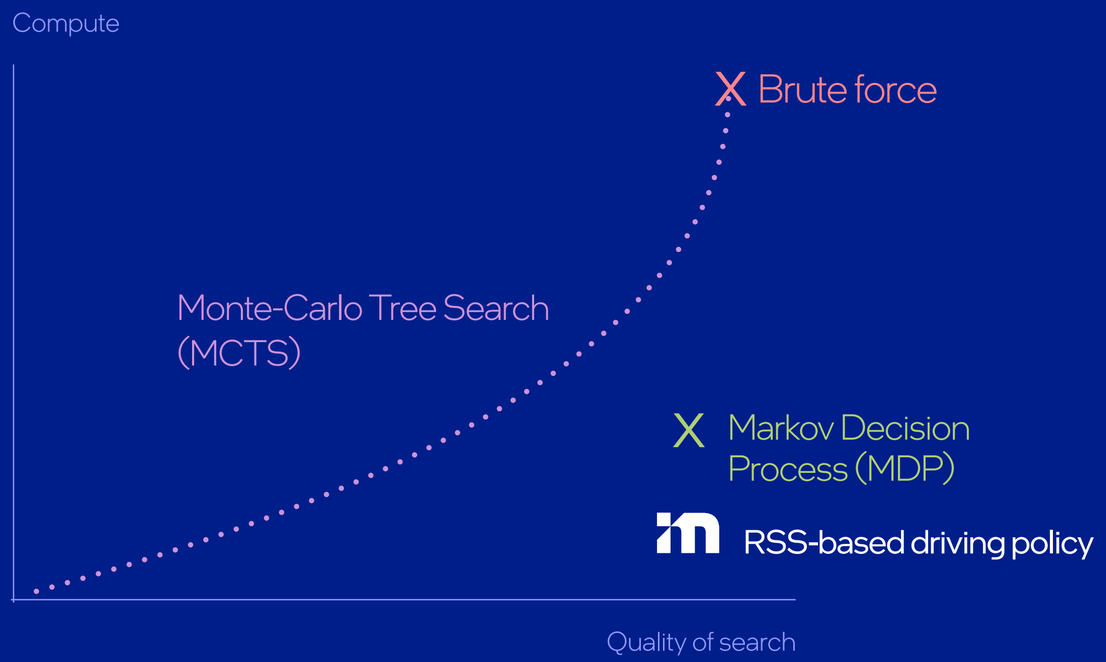
By using induction and analytical calculations,
the RSS couples all plausible futures into the present

This yields **efficiency, realism, quality, and explainability**

Instead of “Predictions” we Construct “intentions” of other agents

- Those “intentions” control parameters
  of the “reasonable assumptions”
- Yields a “human-like” behavior
- We use deep learning to construct intentions

Our Approach - RSS

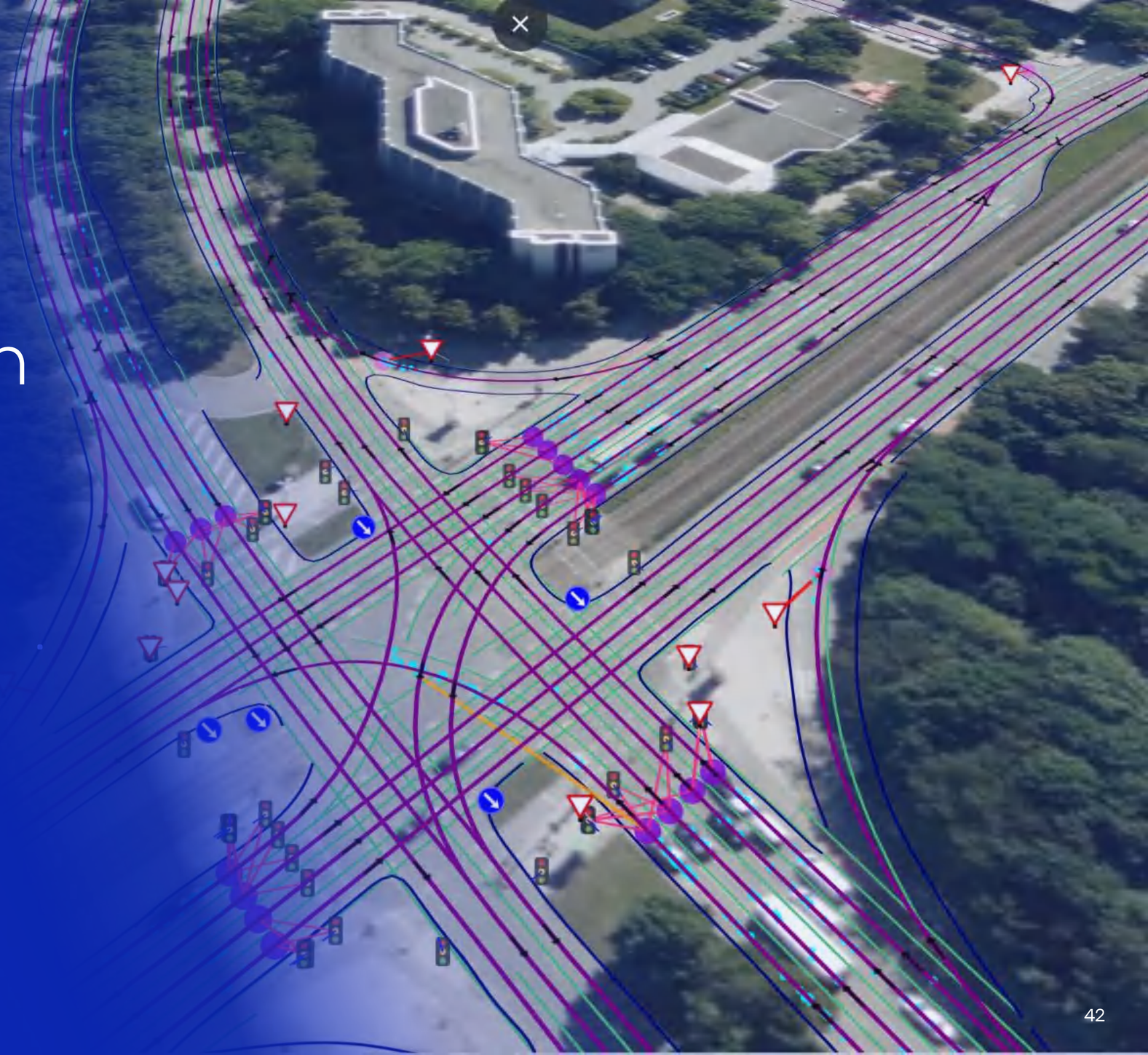


More on Mobileye's Lean Driving Policy
From our CTO, Prof. Shai Shalev-Shwartz

Search: "*Mobileye's Lean Driving Policy*"

Advancements in **REM Mapping**

- Purpose-built SoC
- SW-defined imaging radar
- Lean Compute
- REM crowdsource mapping



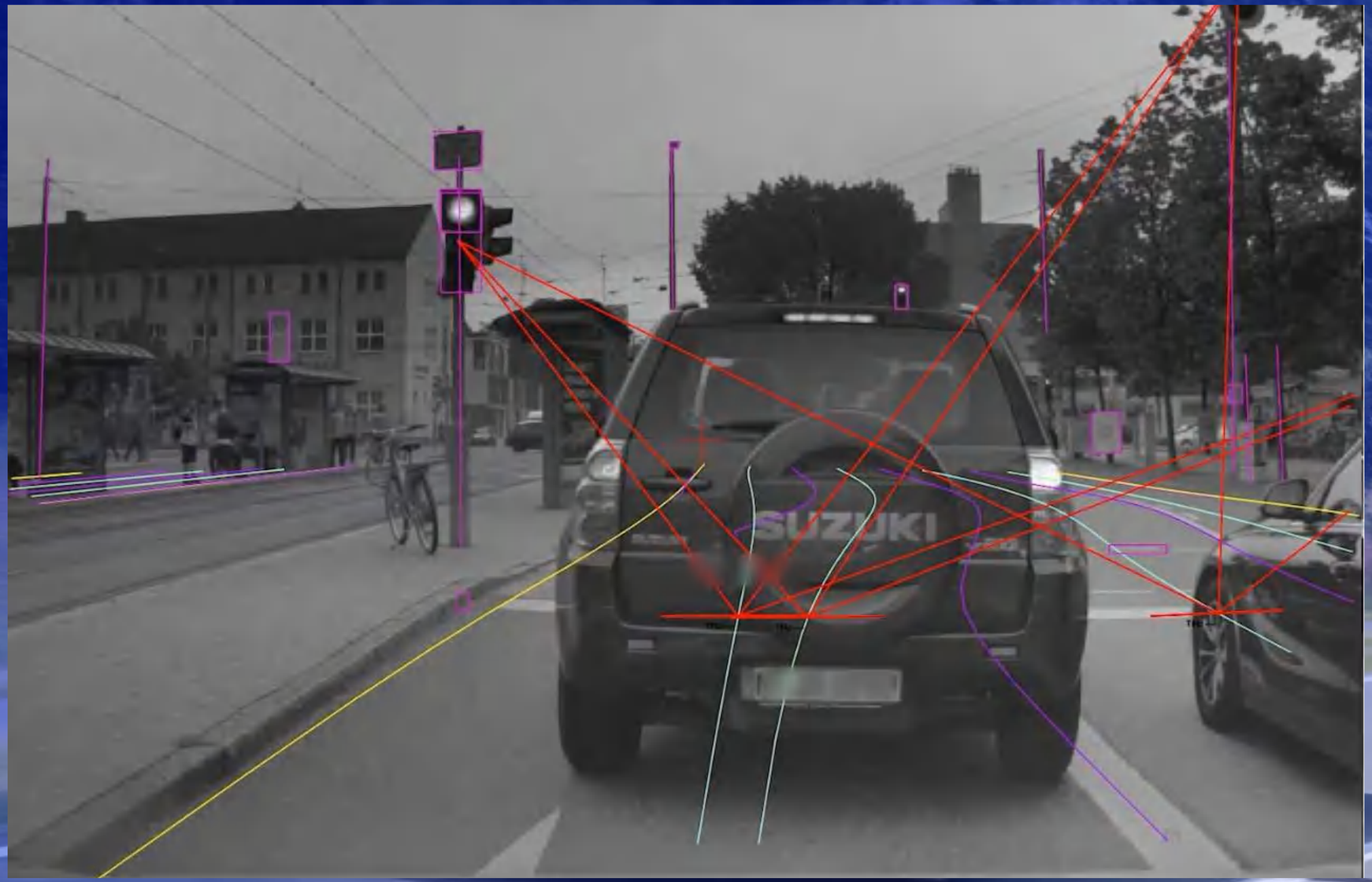
Volkswagen
Travel Assist 2.5

The first L2+ system to widely use
Mobileye's **REM technology**

Volkswagen
Travel Assist 2.5

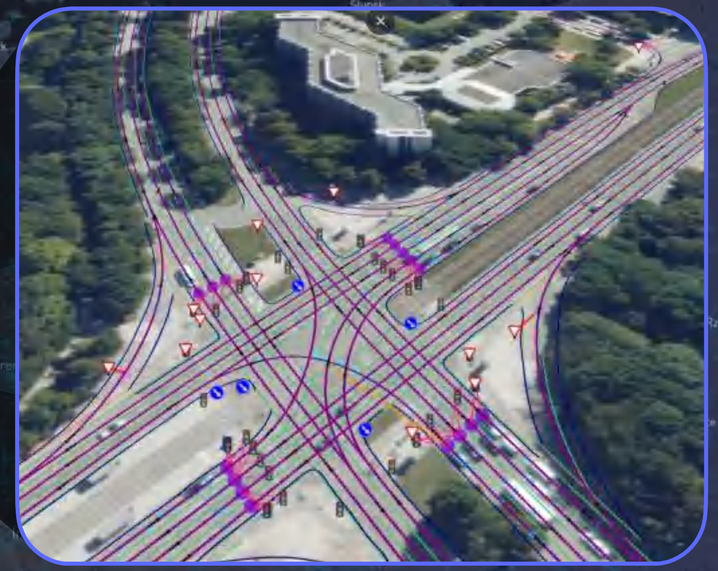
The first L2+ system to widely use Mobileye's **REM technology**

Traffic light-to-lane association based on REM map

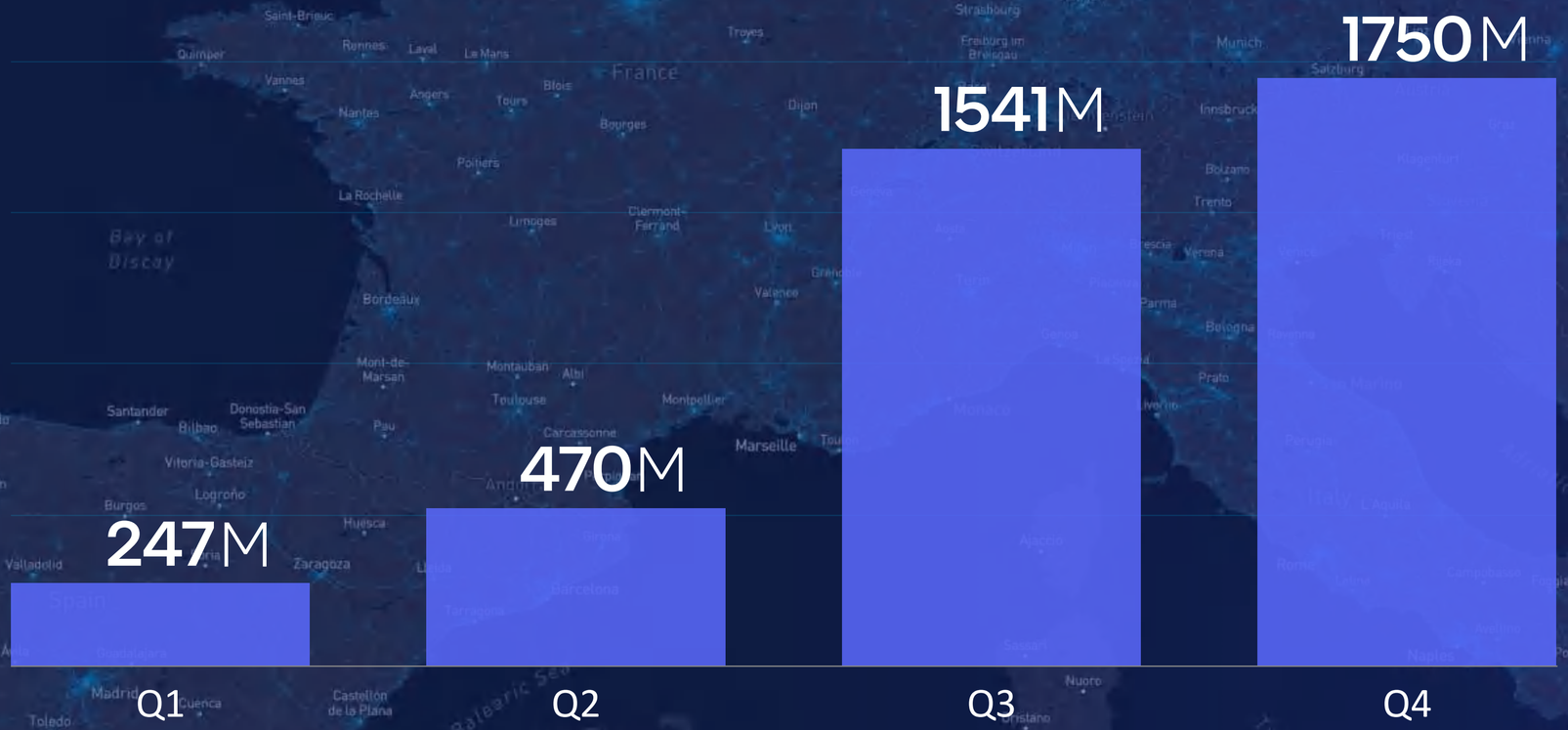


Europe REM RoadBook Coverage

- 2.5 million km
- Generated fully automatically in the cloud in less than a week



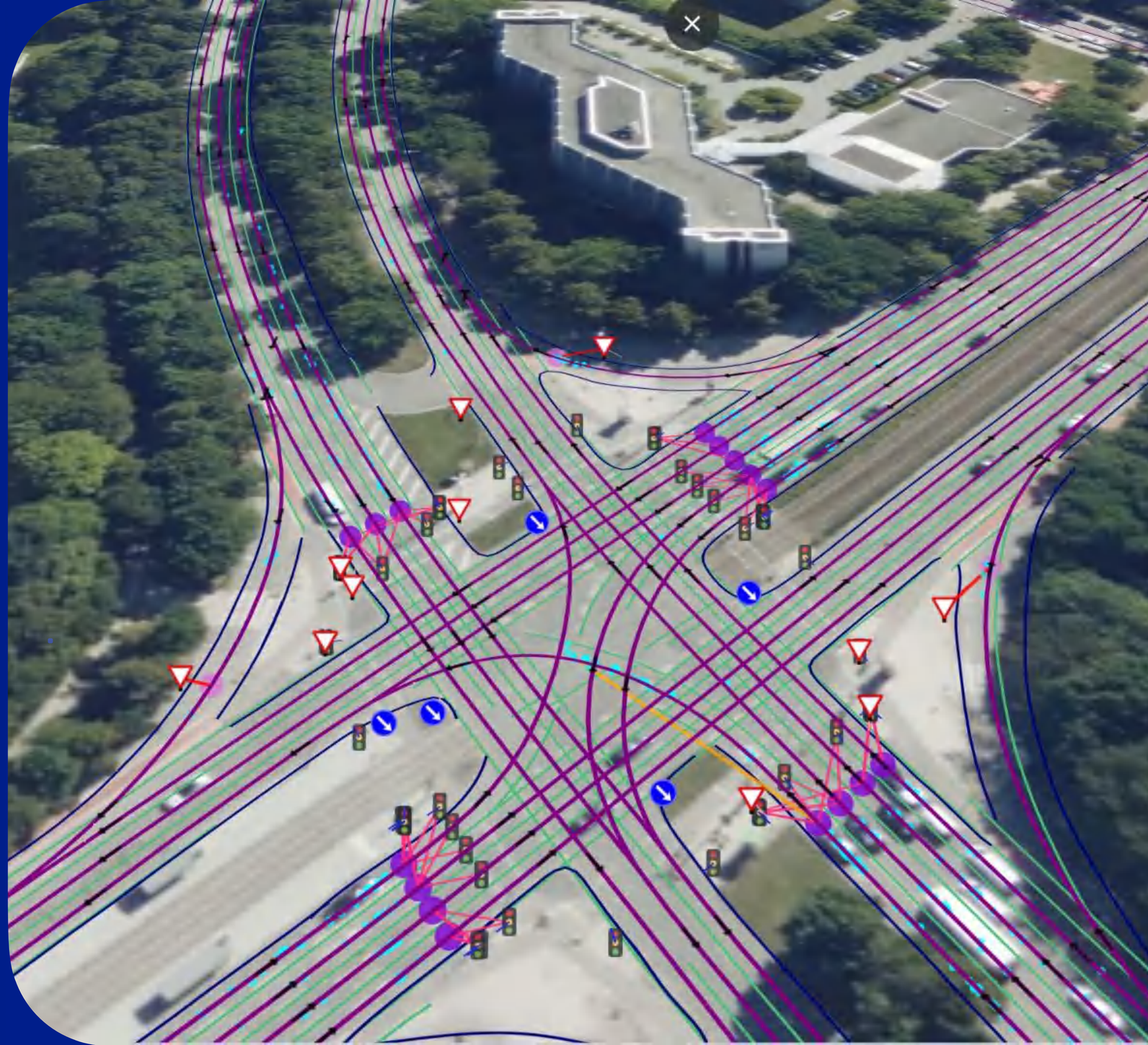
km harvested in 2021



The Richness of REM AV Maps

Main attributes of REM AV maps provided in any road type, as we revealed last CES:

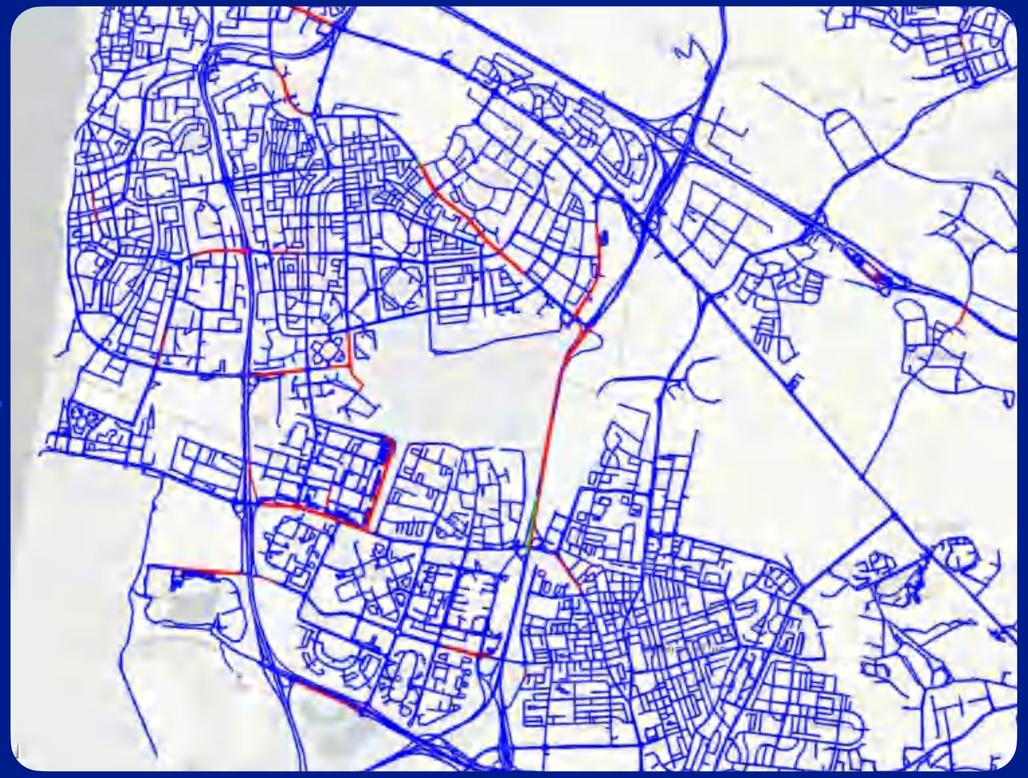
+ Drivable paths
+ Road edge
+ Traffic light and Traffic sign to lane association
+ Yield and priority
+ Crosswalks and crosswalks relevancy
+ Stopping points and stop lines
+ Common speed per lane



Advancements in REM Development

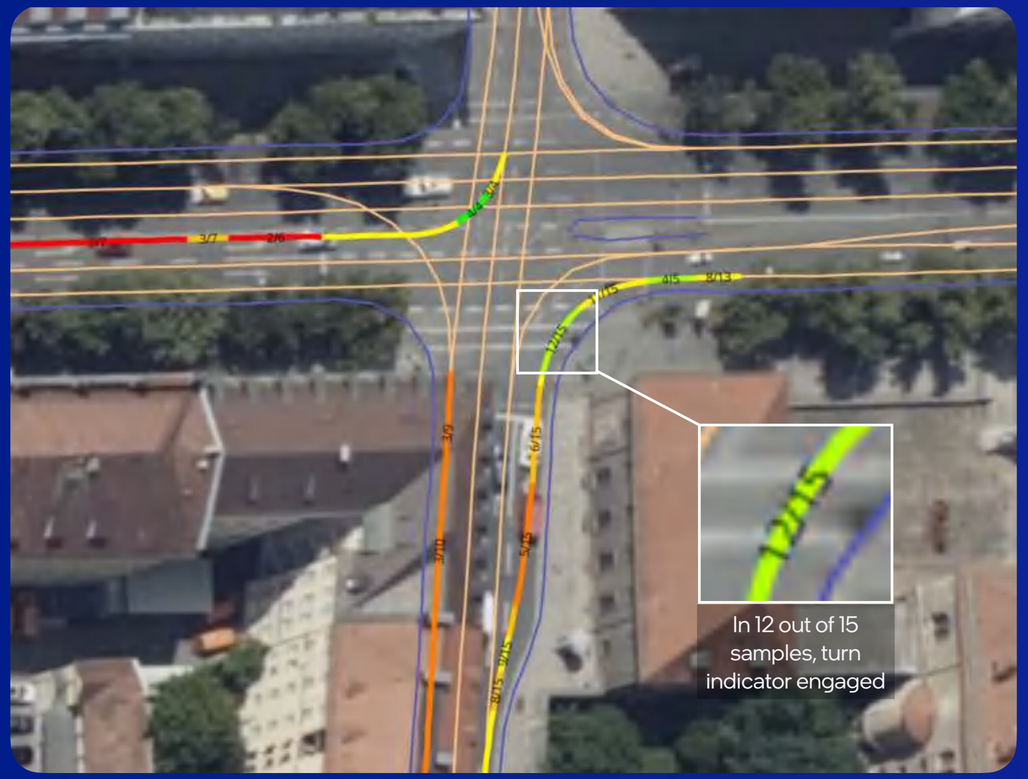
In 2021, we have added new features to REM maps, all based on crowd knowledge:

Construction Area Live Map



Crowd Turn Indicators

Determining where to apply the Turn indicators through crowdsourcing for true “Human-like” behaviour of the AV



Advancements in REM Development

In 2021, we have added new features to REM maps, all based on crowd knowledge:

Speed bumps

Enables smooth control in urban and rural areas

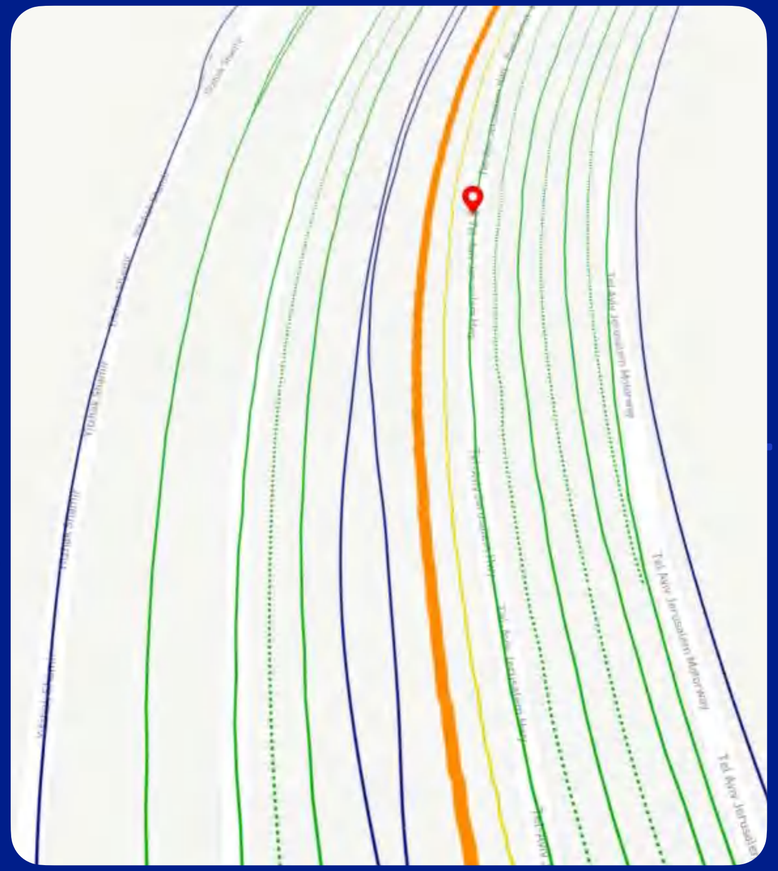
Legal speed

Lane Level Legal Speed Limit Indication
Accounting for Explicit Speed Limit Signs, Implicit Speed Limit Signs and Road Type Classification.

Advancements in REM Development

Enriching the map by adding Semantic Lane Types :

Public transportation lanes



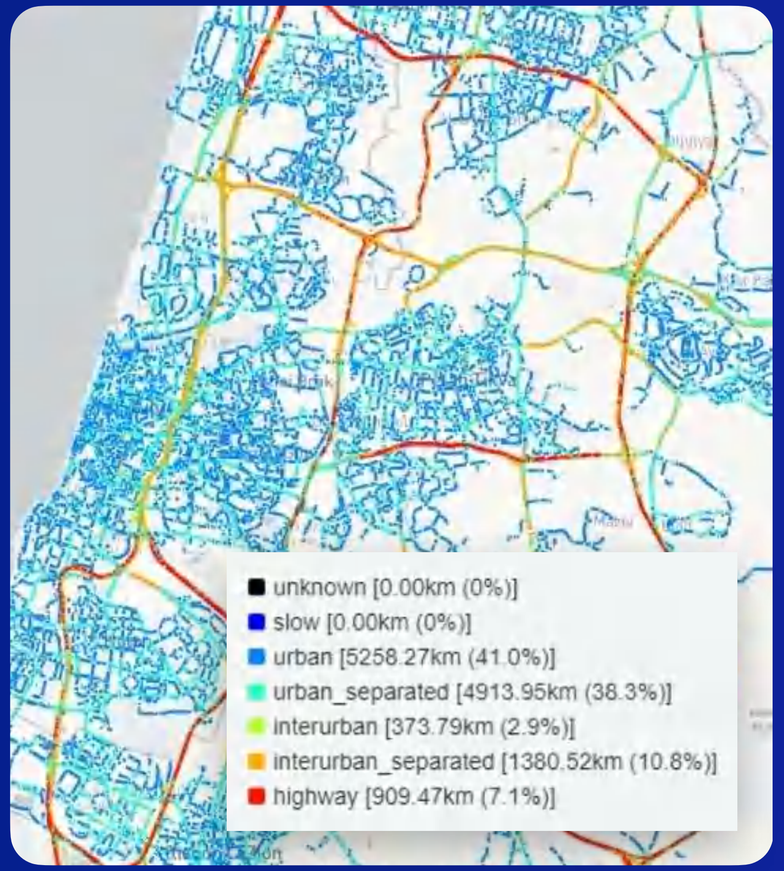
Toll areas

Also relevant for L2+ applications

Road type

Refining policy parameters accordingly

(e.g. pedestrian on a highway vs. deep urban)



Summary

The building blocks we have built:

01 Redefine the future of ADAS with REM mapping and CV subsystem

02 The right engineering design to achieve the needed MTBF and unlock MaaS

03 AV-on-chip and SW-defined imaging radar redefine the future of consumer L4

Thank You

Mobileye Under the Hood

Prof. Amnon Shashua

President & CEO

CES 2022