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The Building Blocks of Autonomous Control

Phil Magney, Founder & Principal Advisor
July 2016

Agenda

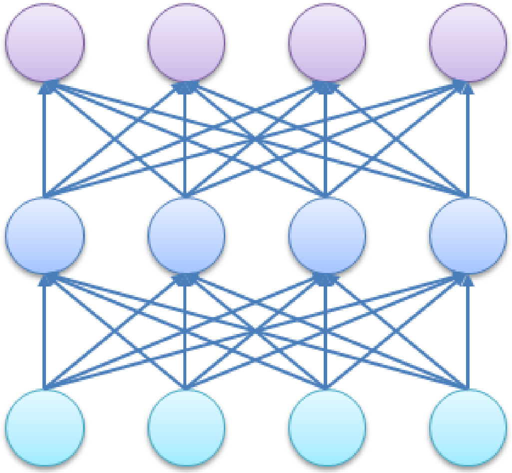
- VSI Remarks
- The Building Blocks of Autonomy
- Elements of Autonomous Control
- Motion Control (path, maneuver, trajectory)
- Sensor Fusion
- Processing for Autonomous Control
- ECU Consolidation
- Software Defined Car
- Functional Safety Requirements

Changing Balance of Power

- AV solutions are very complex
- Nobody owns the whole value chain – various domains of expertise
- Big Tech cannot go it alone – they need OEM and tier-one expertise
- Traditional auto cannot go it alone – they need robotics, AI, machine learning, deep learning and massive IT support!
  - Active safety is largely rules based -- “deterministic” approach
  - Full autonomy may not be rule based – there are too many corner cases
- Traditional suppliers can stay relevant with focus on the mechatronics – where the digital world meets the mechanical world!
- The balance of power is definitely changing, particularly in the context of “new mobility”

The Challenges of Autonomy

- Level 2 autonomy well under way, but L3 challenging
- L4/L5 imminent over time – heavy tech push
- Take lots of software expertise: Perception, Motion Control, Predictive Learning, Safety, Security, etc. Lots of M&A activity
- Machine learning will be vital for L4/L5:
  - For training the classifiers to handle nearly infinite scenes and images
  - For training predictive control (maneuvers and trajectories) as there are infinite possible situations in which an AV will need to react.
- The sensing problem is largely understood – motion planning, decision and arbitration is the big challenge now!
- The processor companies are in a race to deliver the best instruction sets that can consolidate perception and control
- The AV Cloud = Data Aggregation + Deep Learning + OTA + Supervision + Security + Enterprise Management



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VSI Perspective

The Building Blocks of Autonomy

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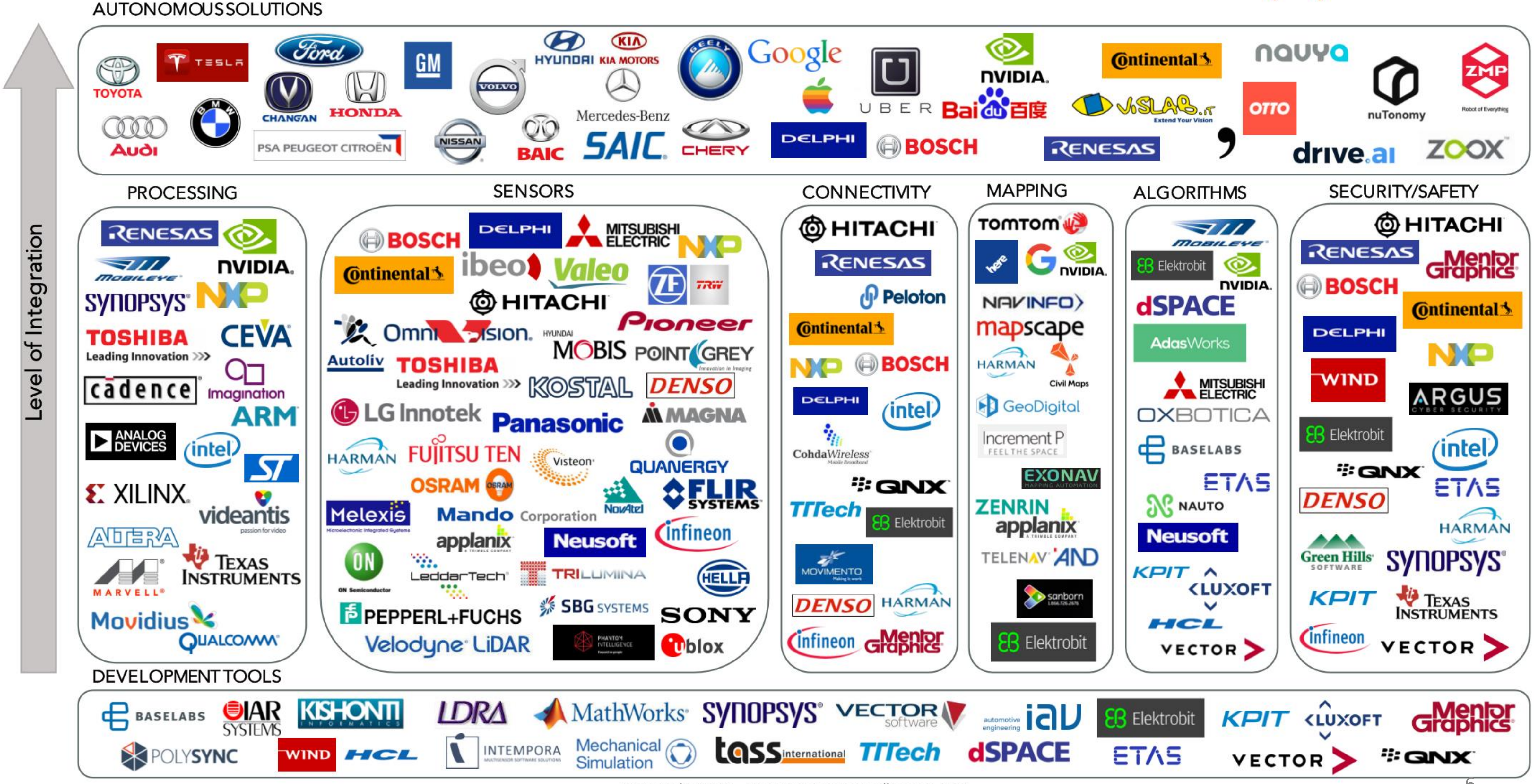

AUTONOMOUS SOLUTIONS

TOYOTA TESLA Ford GM VOLVO HYUNDAI KIA MOTORS GEELY Google UBER NVIDIA Continental navya ZMP Robot of Everything
Audi BMW CHANGAN HONDA PSA PEUGEOT CITROËN NISSAN BAIC Mercedes-Benz SAIC CHERY DELPHI BOSCH Baidu 百度 VisLab.it Extend Your Vision RENESAS OTTO nuTonomy drive.ai ZOOX

PROCESSING

RENESAS NVIDIA MOBILEYE SYNOPSYS NXP TOSHIBA Leading Innovation CEVA cadence Imagination ARM ANALOG DEVICES intel ST XILINX videantis passion for video ALTERA TEXAS INSTRUMENTS MARVELL Movidius QUALCOMM

SENSORS

BOSCH DELPHI MITSUBISHI ELECTRIC NXP Continental ibeo Valeo ZF TRW HITACHI OmniVision HYUNDAI MOBIS Pioneer POINT GREY Innovation in Imaging Autoliv TOSHIBA Leading Innovation KOSTAL DENSO LG Innotek Panasonic MAGNA HARMAN FUJITSU TEN Visteon QUANERGY OSRAM NovAtel FLIR SYSTEMS Melexis Microelectronic Integrated Systems Mando Corporation applanix A TRIMBLE COMPANY Neusoft infineon ON ON Semiconductor LeddarTech TRILUMINA HELLA PEPPERL+FUCHS SBG SYSTEMS SONY Velodyne LiDAR PHANTOM INTELLIGENCE u-blox

CONNECTIVITY

HITACHI RENESAS Peloton Continental NXP BOSCH DELPHI intel Cohda Wireless Mobile Broadband QNX TTTech Elektrobit MOVIMENTO DENSO HARMAN infineon Mentor Graphics

MAPPING

TomTom here Google NVIDIA NAVINFO mapscape HARMAN Civil Maps GeoDigital Increment P FEEL THE SPACE EXONAV MAPPING AUTOMATION ZENRIN applanix A TRIMBLE COMPANY TELENAV AND sanborn Elektrobit

ALGORITHMS

MOBILEYE Elektrobit NVIDIA dSPACE AdasWorks MITSUBISHI ELECTRIC OXBOTICA BASELABS ETAS NAUTO Neusoft KPIT LUXOFT HCL VECTOR

SECURITY/SAFETY

HITACHI RENESAS Mentor Graphics BOSCH Continental DELPHI NXP WIND ARGUS CYBER SECURITY Elektrobit intel QNX ETAS DENSO HARMAN Green Hills SOFTWARE SYNOPSYS KPIT TEXAS INSTRUMENTS infineon VECTOR

DEVELOPMENT TOOLS

BASELABS IAR SYSTEMS KISHONTI INFORMATICS LDRA MathWorks SYNOPSYS VECTOR software automotive engineering IAV Elektrobit KPIT LUXOFT Mentor Graphics
POLYSYNC WIND HCL INTEMPORA Mechanical Simulation tass international TTTech dSPACE ETAS VECTOR QNX

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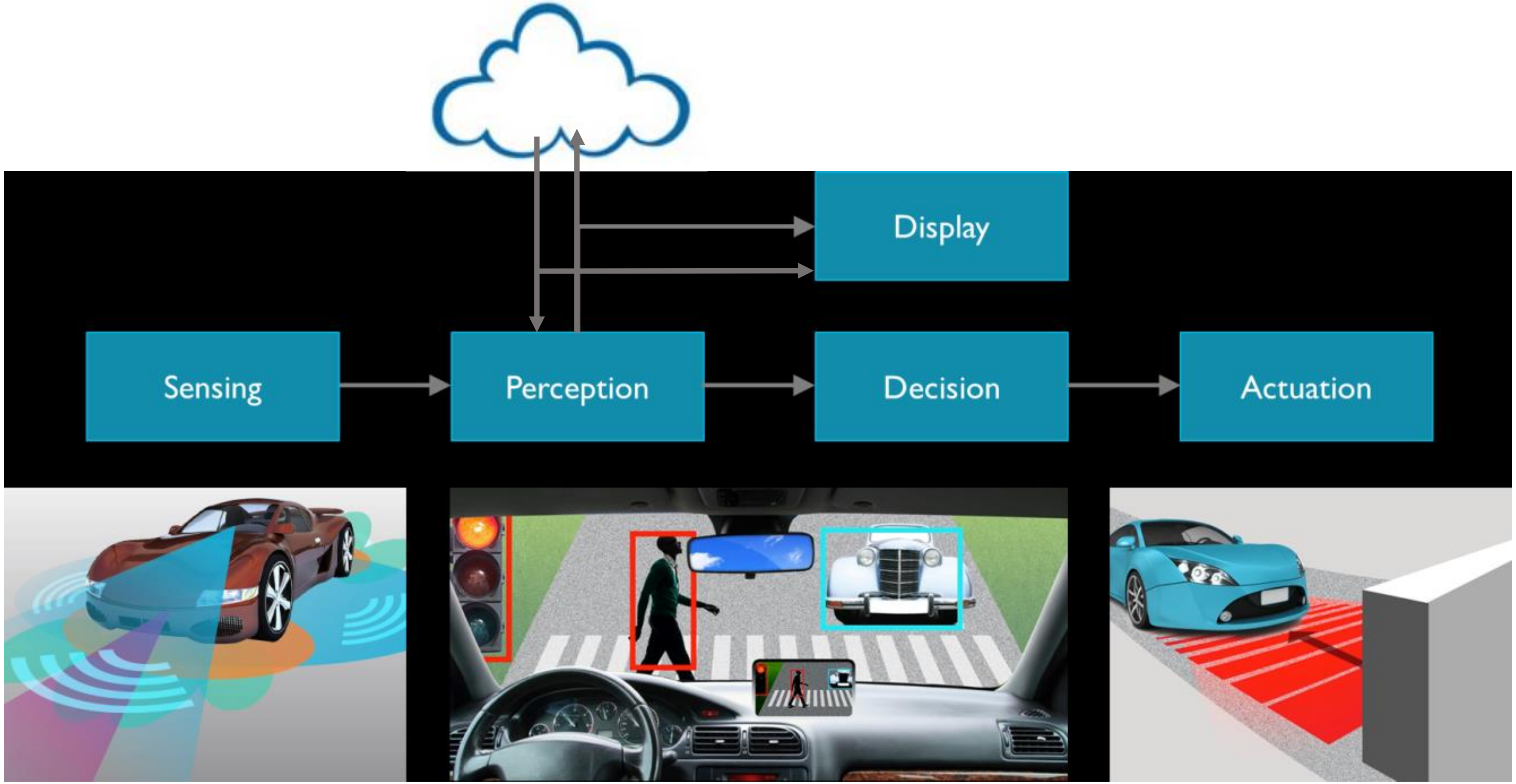
What is Driving Auto Tech?



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From ADAS to Autonomous Control

Two Approaches to Autonomy – Not a Zero Sum Game!

Automated Driving

Highly/Fully Automated Driving

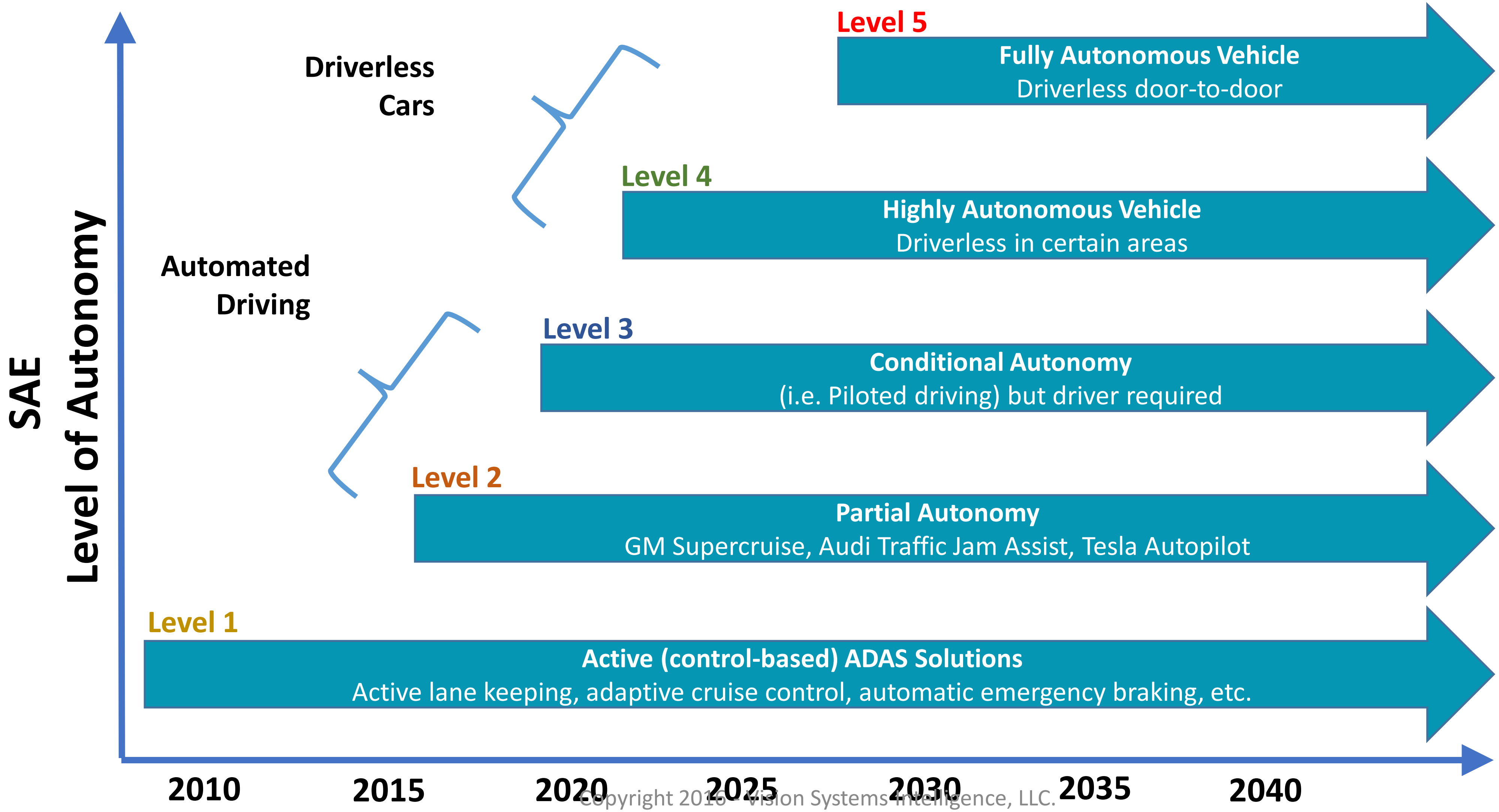
Incremental Approach

- Evolution of ADAS
- SAE Levels 1,2,3
- Conditional Autonomy
- Step by Step approach
- Convenience and safety
- Existing automotive strategy

Driverless Car Approach

- Mobility as a Service (MaaS)
- SAE Levels 4 and above
- Full or highly automated
- Pursued by tech industry
- Requires machine learning
- Requires AV Cloud

The Evolution of Autonomy



Level 5

Fully Autonomous Vehicle
Driverless door-to-door

Level 4

Highly Autonomous Vehicle
Driverless in certain areas

Level 3

Conditional Autonomy
(i.e. Piloted driving) but driver required

Level 2

Partial Autonomy
GM Supercruise, Audi Traffic Jam Assist, Tesla Autopilot

Level 1

Active (control-based) ADAS Solutions
Active lane keeping, adaptive cruise control, automatic emergency braking, etc.

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Elements of Autonomous Control Systems

Technologies for Autonomous Control

Technologies	Reasoning
Sensors	Camera, Radar, LiDAR, IR, inertia, Ultrasonic, etc.
Safety Domain Controllers	These controllers can acquire, sense, interpret, classify and make decisions to actuate control
Vision Processing	Vision processing is very compute intensive. Requires massively parallel computing architectures
Machine Learning	Training the algorithms -- classifiers, pooling, semantic labeling, etc. Machine learning also includes CNN, DNN, SVM
Sensor Fusion	Requires a unique set of software tools for development of algorithms -- data association, clustering, segmentation, filtering, estimation, and motion prediction
Control Systems	Predictive control for optimal vehicle trajectory using information from environmental sensing systems
Reference Maps	Road features, road geometry, and very dynamic – enables autonomous method called "sense and align" -- Also enables advanced safety
Communications	V2V, V2I, V2P, V2C (**V**ehicle, **I**nfrastructure, **P**edestrian, and **C**loud)
High Capacity Networks	Necessary to handle the flow of information being generated in the vehicle. Transition from CAN to higher performance networks such as Ethernet

Sensors

Sensor	Attributes
Mono Camera	Single focal point – good for identification of objects, improving for 3D attributes
Stereo Camera	Dual stereoscopic focal points – very good for depth and motion within sweet spot of converged focal points
Tri-Focal Camera	Three different focal points – like 3 monocams – increases range and field of view (FOW)
Radar	24-79GHz – many applications, very accurate ranging – new millimeter wave using CMOS – can sense pedestrians
Flash Lidar	Very low resolutions – ToF (time-of-flight), restricted for identification – good for sensor fusion applications
Solid State Lidar	Good resolutions via point cloud – better at identification – good for L3/L4/L5 perception
360 Degree Lidar	Good resolution via point cloud – best for data acquisition – required for L4/L5
Infrared (IR)	Thermal camera – useful for night vision and driver monitoring – sometime IR emitters used for ToF
HD Maps	Useful for localization – necessary for L4/L5 – very useful when combined with dynamic content on road situation
IMU	Inertia Measurement – necessary for localization and path planning – need high resolution dead reckoning

Sensors – RAW Sensors, Sensor Modules, Sensor Fusion

DELPHI
MITSUBISHI ELECTRIC
Pioneer
TOSHIBA
Leading Innovation
ibeo
OmniVision
Continental
NXP
PEPPERL+FUCHS
ZF
TRW
HITACHI
OSRAM
DENSO
BOSCH
HYUNDAI
MOBIS
MAGNA
KOSTAL
Visteon
LG Innotek
POINT GREY
Innovation in Imaging
Autoliv
FLIR
SYSTEMS
FUJITSU TEN
Velodyne LiDAR
QUANERGY
Melexis
Microelectronic Integrated Systems
SONY
LeddarTech
Mando Corporation
applanix
A TRIMBLE COMPANY
infineon
HARMAN
ON
ON Semiconductor
ublox
PHANTOM INTELLIGENCE
Focused on people
TRILUMINA
Panasonic

Perception Plus Control – Sense, Decision, Action…

Image Sensors
- Camera(s)
- Thermal
- Scanning LiDAR

Ranging Sensors
- Radar
- Flash LiDAR
- Ultrasonic

Map Data
- Path planning
- Localization
- Dynamic content

Sensor Fusion Algorithms
- Object
- Track-to-track fusion
- RAW data fusion

Wheel speed sensor

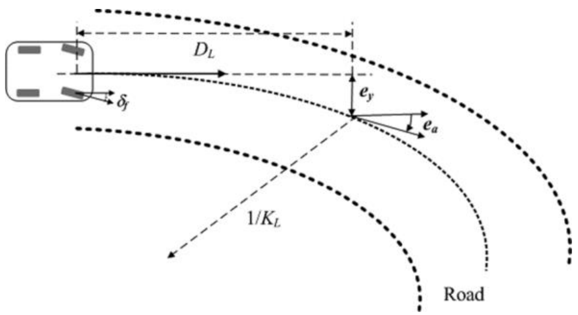
Inertia measurement

Control Algorithms
- Trajectory control
- PID Control
- State Machines
- MPC Control

Throttle position

Steering Angle

Longitudinal Control



Latitudinal Control

Who is Assembling Autonomous Solutions (perception + control)

drive.ai

NVIDIA

HYUNDAI

KIA MOTORS

Continental

ZMP

Robot of Everything

TESLA

GM

Google

nauya

Ford

TOYOTA

CHERY

ViSLAB.iT

Extend Your Vision

nuTonomy

CHANGAN

VOLVO

BOSCH

DELPHI

BMW

Mercedes-Benz

GEELY

Baidu 百度

UBER

HONDA

BAIC

SAIC

NISSAN

OTTO

RENESAS

Audi

PSA PEUGEOT CITROËN

ZOOX

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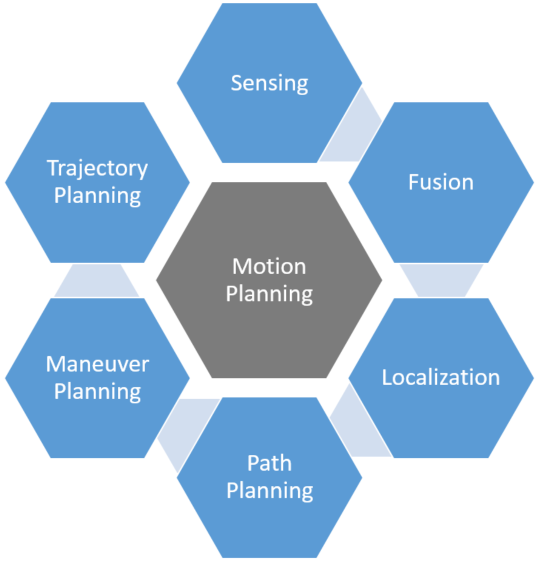
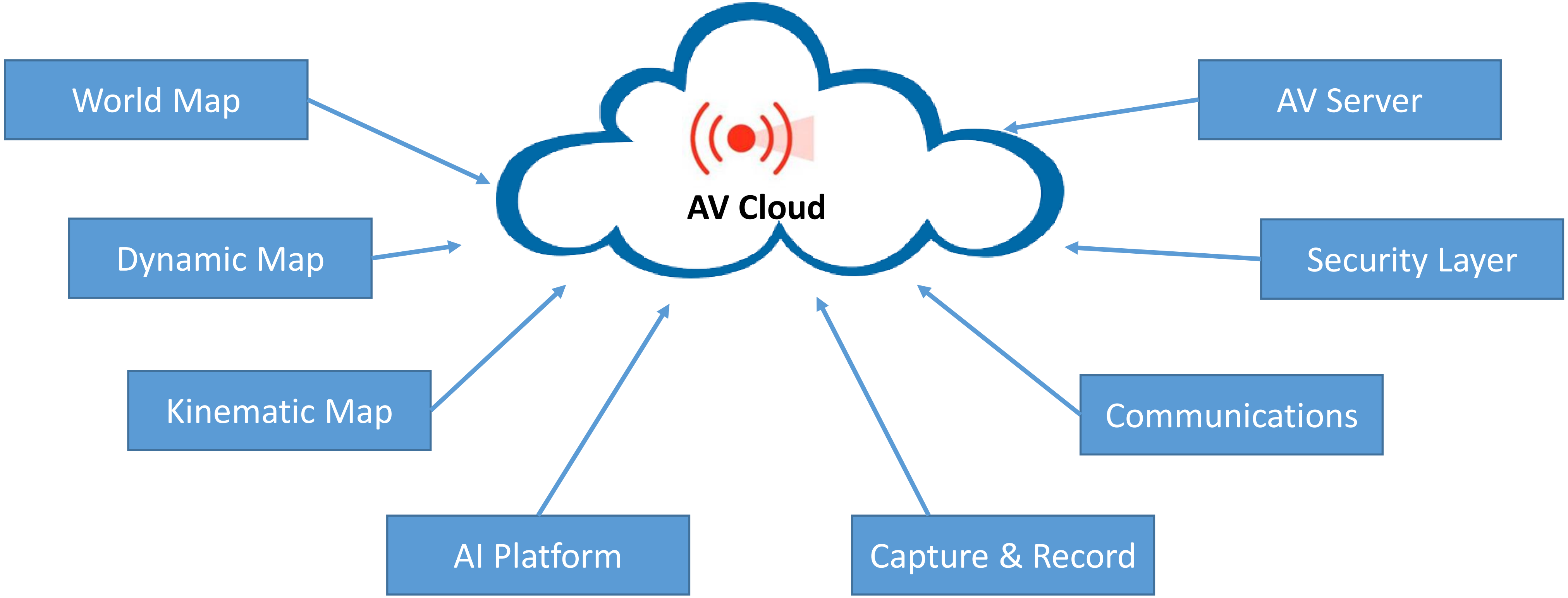
Motion Planning

Motion Planning – Model Predictive Control

- **Path Planning** – Dependent on the digital reference maps as well as the incremental data that supplement this. Incremental data includes dynamic content such as lane closures, detours, or traffic conditions.
- **Maneuverer Planning** – these are the decision algorithms that have to assess risk and evaluate dynamic elements. These algorithms are based on decision theory and best trained through massive data collection and rigorous training.
- **Trajectory planning** – this has a higher level role compared to a path or maneuvers. It contains the geometric concept of a path but it also encompasses vehicle states plus the kinematic properties.



Elements of the Autonomous Vehicle Cloud

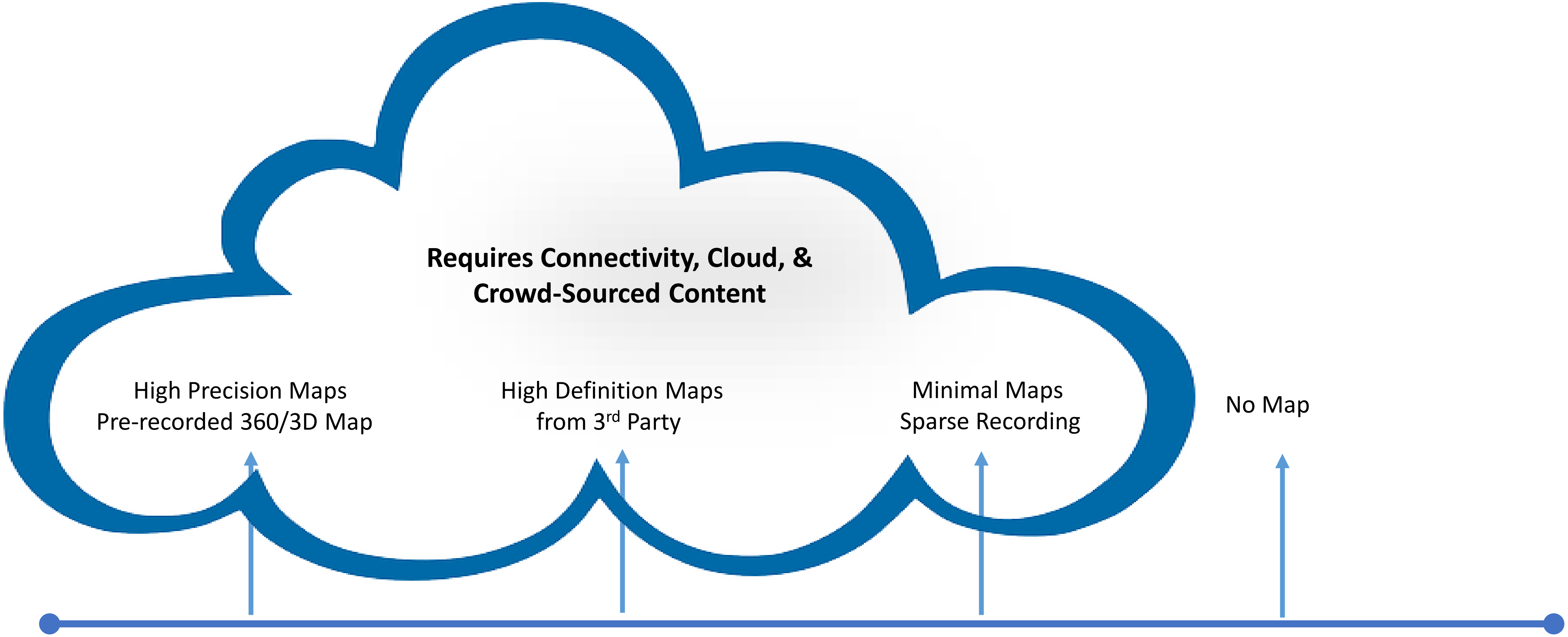


Leading Issue → Petabytes of geospatial data generated from 3D scans are essential for the creation of 3D semantic maps. Data collection will become commoditized. Extracting features from the data remains bottlenecked. The culprit: a process dominated by manual labeling and vectorization of the input data.

Autonomous Control: The Use Case for Maps

- Maps enable **redundancy of sensors**.
- Maps better **optimize perception** systems – takes some load off of the environmental sensors.
- Maps aid in the **localization and path planning** for autonomous control – provides a guidance method.
- Autonomy requires **dynamic content** such as ice, potholes and construction-related course adjustments and/or obstacles.
- Autonomous Vehicle needs map to separate unlabeled objects from the static picture of the world with which to compare what it sees.

Maps for Autonomous Driving



Requires Connectivity, Cloud, & Crowd-Sourced Content

High Precision Maps
Pre-recorded 360/3D Map

High Definition Maps
from 3rd Party

Minimal Maps
Sparse Recording

No Map

Store & Align
Hi-Precision Maps

Sense & Understand
No Maps

Mapping Assets That Will Enable Autonomy

3D laser mapping

TOYOTA

mapscape

Civil Maps

ZENRIN

applanix
A TRIMBLE COMPANY

G

Increment P
FEEL THE SPACE

GeoDigital

NVIDIA

IXBLUE
DEEP INSIGHT. SHARPER SENSES.

MOBILEYE

AND

sanborn
1.866.726.2676

here

EXONAV
MAPPING AUTOMATION

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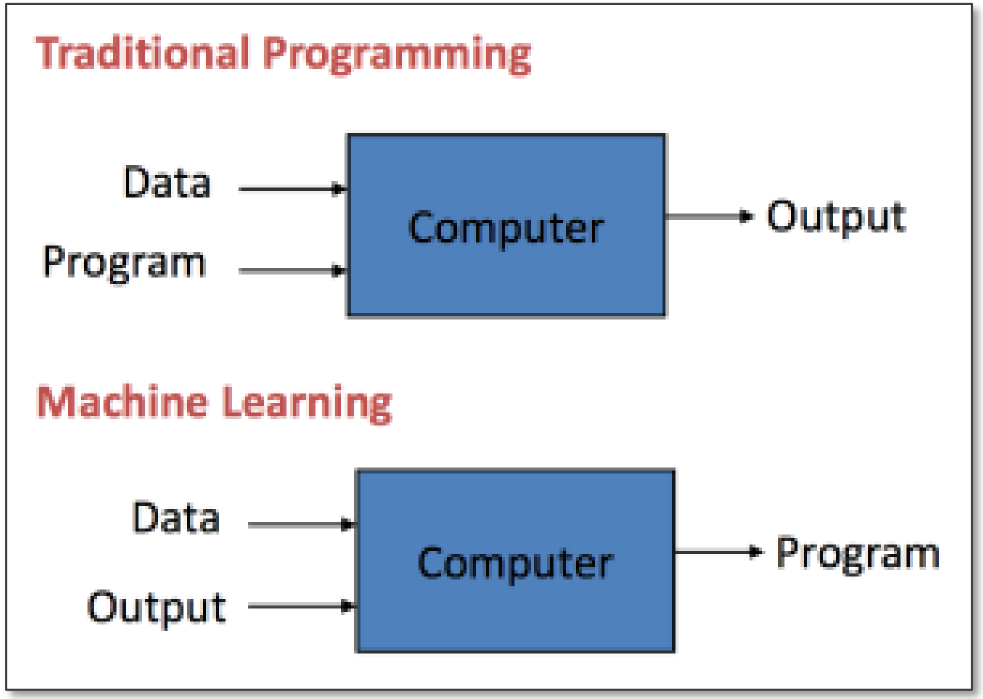
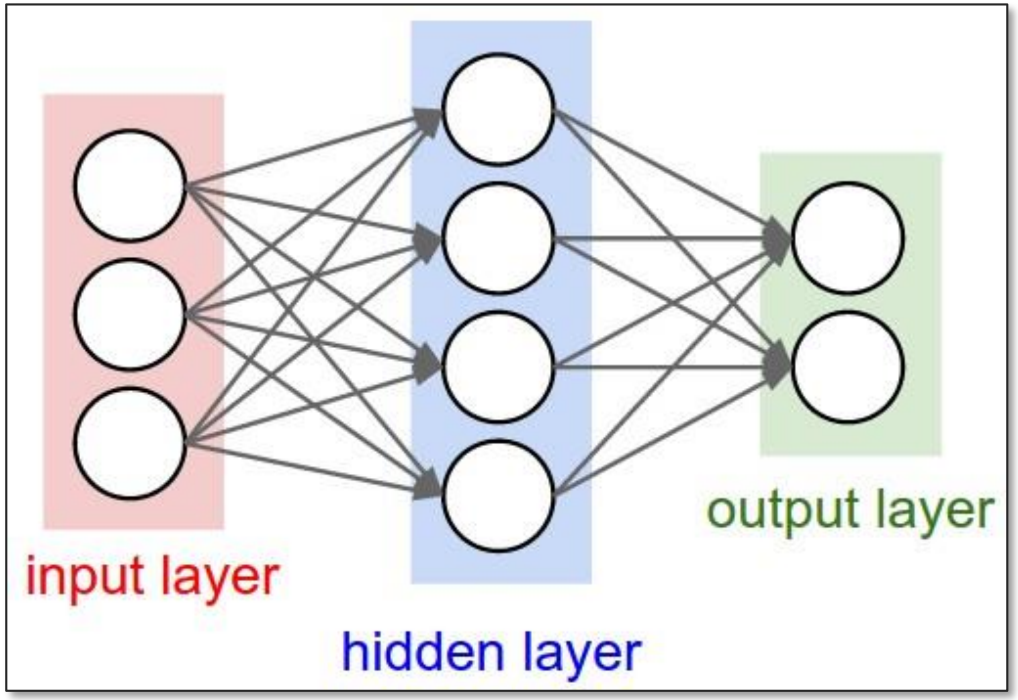
Machine Learning: Teaching Cars To Drive

Machine Learning vs. Deep Learning





Deterministic

This approach to self-driving cars comes with a measure of verifiability that gives confidence that the design works and why it doesn't. The problem with this "engineering" approach is that the system can't cope with anything that it encounters that is new.

Probabilistic

This approach can generalize to situations it has never been trained on. This means that a self-driving car using an end-to-end approach could be more capable, but also perhaps less predictable..

Neural Networks

- Deep Neural Networks (DNN) is the latest hot topic for autonomous vehicle development.
- The goal is to “train” algorithms to handle limitless possibilities and outcomes – this is also known as “machine learning”
- Is applied to both ***perception*** (sense and understand) and ***control*** (maneuvers and trajectories)
- Algorithms need to be trained with real or simulated data
    - Supervised learning: Learn by examples as you try to predict output a target vector y, from a matrix of inputs, x. Training is done with known inputs and associated known outputs.
    - Unsupervised learning: Attempt to predict the target vector y (unknown) using the very same matrix x as the inputs. The network learns something intrinsic about the data without the help of a target or label vector that is often created by humans. Uses weights.
    - Semi-supervised learning: Training data includes a few desired outputs.
    - Reinforcement learning: Rewards from a sequence of actions.
- NVIDIA approach → purports “end-to-end” training for self driving car project, called Dave-2. The neural network learns to steer by being shown videos of a human driving and what the human driver did to the steering wheel as a result.
- Mobileye approach → favors semantic abstraction which breaks up the learning into blocks. Mobileye says there are too many corner cases with NVIDIA approach.
- Conventional approach → current self-driving car approach breaks the task into different components – sense & identify; localize against surroundings; then you plan your motions.

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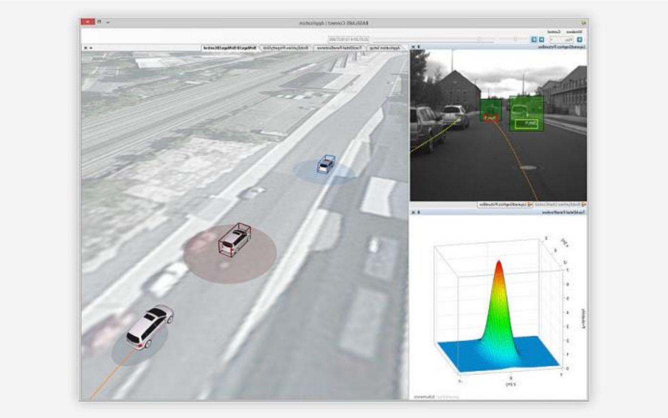
Sensor Fusion For Active Safety & Autonomous Control

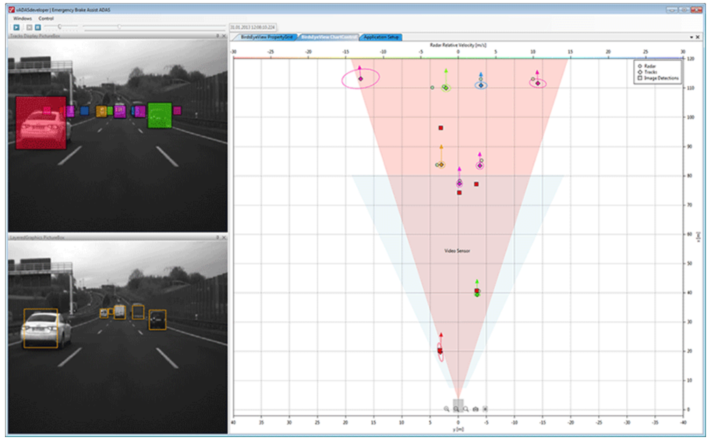
Developing Sensor Fusion – Step-by-Step

1. **Modeling tools** are necessary to examine functional requirements as well as to determine hardware and software requirements.
2. Sensor selection considers all **environment sensors** such as camera, radar, LiDAR, ultrasonic, as well as other sensors such as inertia, positioning, throttle position, steering angle etc.
3. Safety goals and hazard ratings must be established formally according to **ISO 26262** – most active safety and autonomous control will be ASIL D resulting very stringent requirements.
4. **Fusion of sensor data** can be done with objects (complete sensors modules such as Mobileye) or can be done with RAW data or a combination.
5. Special tools are necessary for sensor signal synchronization and timing such as **ADTF, ROS, RT Maps, Polysync**, etc. They record, playback and analyze the "fused" sensor data.



Developing Sensor Fusion – continued

6. Development will require a **hardware development platform** to test the feasibility of your applications – typically FPGA-based. This may be in advance of a chosen “target” processor.
7. Lots of **simulation software** will be required for Model-in-loop (MiL)for initial examination, Hardware-in-loop (HiL) for sensors and ECUs, Software-in-Loop (SiL) for application testing.
8. **Environmental** models (simulated roads, objects, signs etc.) will be necessary unless you have collected you own data sets.
9. Selection of a **target processor** for perception (typically SoC) that can handle the requirements of your applications (i.e. vision processor). You will need to select a target processor for control (typically duel-core lockstep)
10. You will need ISO 26262 compliant production code generation tools in accordance with **MISRA** requirements (Motor Industry Software Reliability Association).



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Processing Requirements

CPU Load for Object Recognition

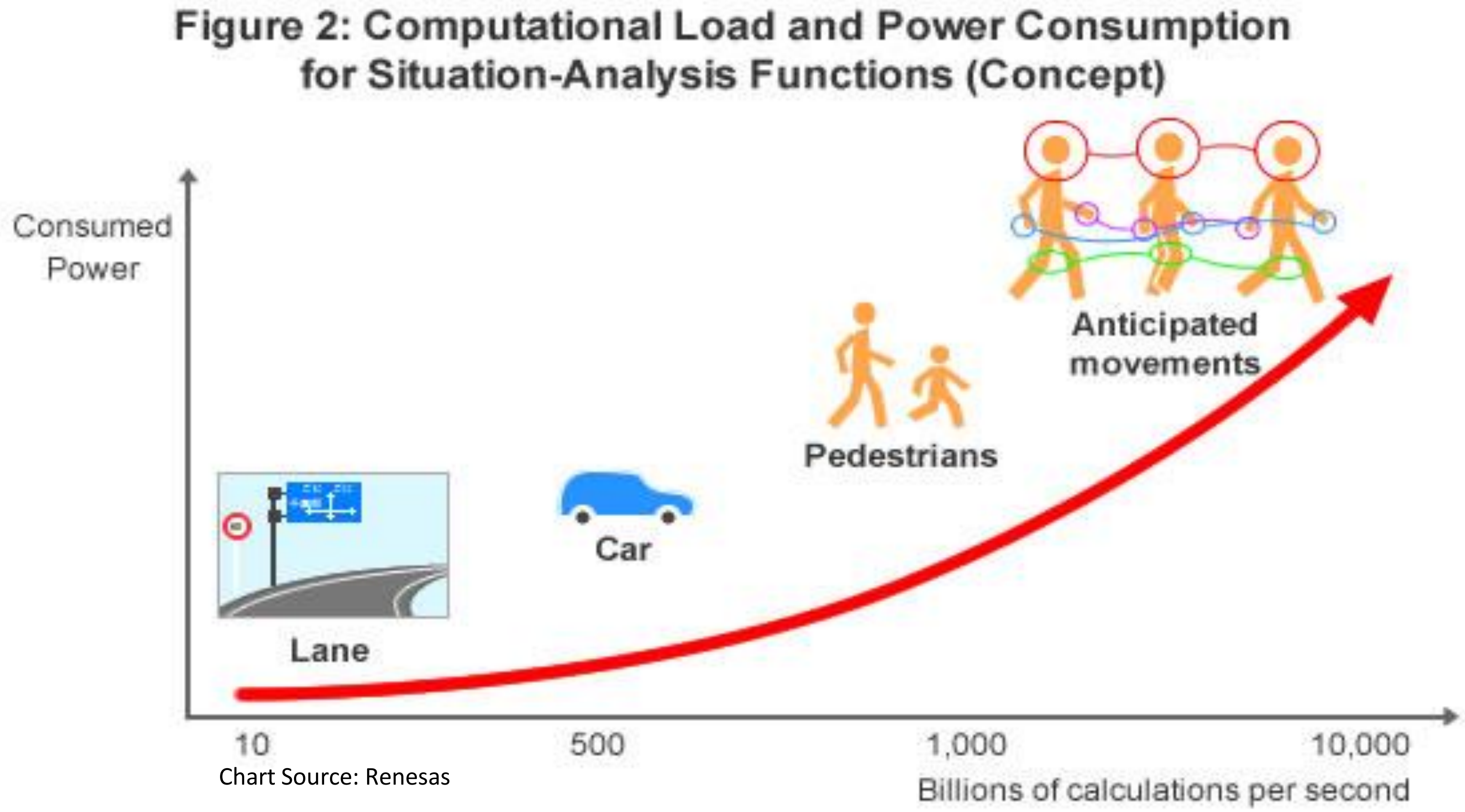


Chart Source: Renesas

Processing for Autonomous Functions

- **ASICs** – have the advantage of high performance and low power consumption. They are not suitable for rapid prototyping and they are not reconfigurable.
- **FPGA** – often used for prototyping to implement the architecture of a microprocessor “soft processor core” and the required additional custom hardware accelerators. they are not so good for the serial processing necessary in mid and high levels.
- **GPU** – Current GPUs are power hungry and are not ideal for embedded applications. However, GPUs are very good with vector processing and as well as deep learning routines.
- **DSPs** – Attractive for embedded automotive applications since they offer a good price to performance ratio. DSPs are essentially for signal processing which is a core element of sensor based solutions. DSP logic in now commonly found in SoCs.
- **MPUs** –a good option for high-level vision processing. Additionally, they are easy to program, since it is possible to use the same tools and libraries used for standard PC applications. ARM architectures are leading MPU instruction sets.
- **SoCs** – Many new products are entering the market which include the elements of the above approaches combining standard microprocessors with added functional such as FPGA fabric, DSP functionality and unique memory cores for pipelined processing.

Processor Activities Related to Active Safety & Autonomy

RENESAS

NXP

ALTERA

KALRAY

SYNOPSYS®

NVIDIA®

MOBILEYE®

ARM®

TOSHIBA
Leading Innovation >>>

CEVA®

ANALOG
DEVICES

videantis
passion for video

intel®

Imagination

cadence®

ST

TEXAS
INSTRUMENTS

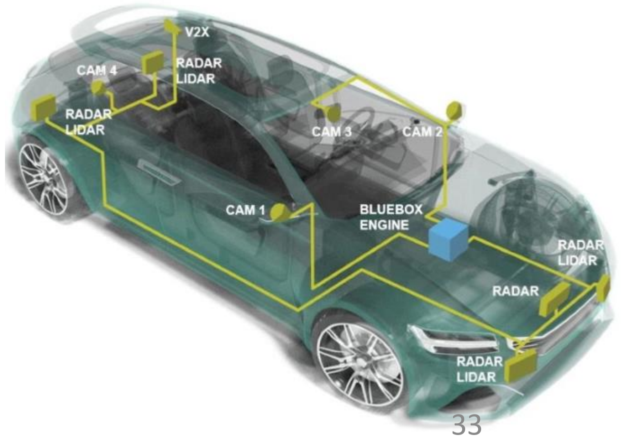
MARVELL®

XILINX®

Movidius

Key Enablement Platforms

- **NVIDIA DriveWorks** -- NVIDIA DriveWorks software development kit (SDK) gives developers a foundation upon which to build applications for object detection, map localization, and path planning.
- **NXP's BlueBox** -- is a central computing engine that enables all aspects of perception, decision and motion planning tasks. The NXP BlueBox platform is a Linux-based open-platform that is programmable in C allowing automotive manufacturers to customize their solutions.
- **Mobileye** – now engaged in AV development activities on two OEM programs with a pending third OEM. Most AV activities centered around EyeQ5 SoC.
- **Elektrobit** – robinos is an interface specification for autonomous development. Includes many EB blocksets and tools.
- **Polysync** – comes from start up (Harbrick) that has created an abstraction layer with APIs so that developers can add their applications for AV control. (pure tech vision as "software define car")
- **Renesas Skyline Concept** – aggregates all nodes into a vehicle, along with various partners, for test and development of AV solutions.
- **Texas Instruments RT-RK Platform** – a development kit for ADAS and autonomous solutions.



ECU Consolidation

ECU Bus Systems -- Distributed Systems

Vehicles are based on a distributed architecture where data is shared among different ECUs using high-speed deterministic networks!

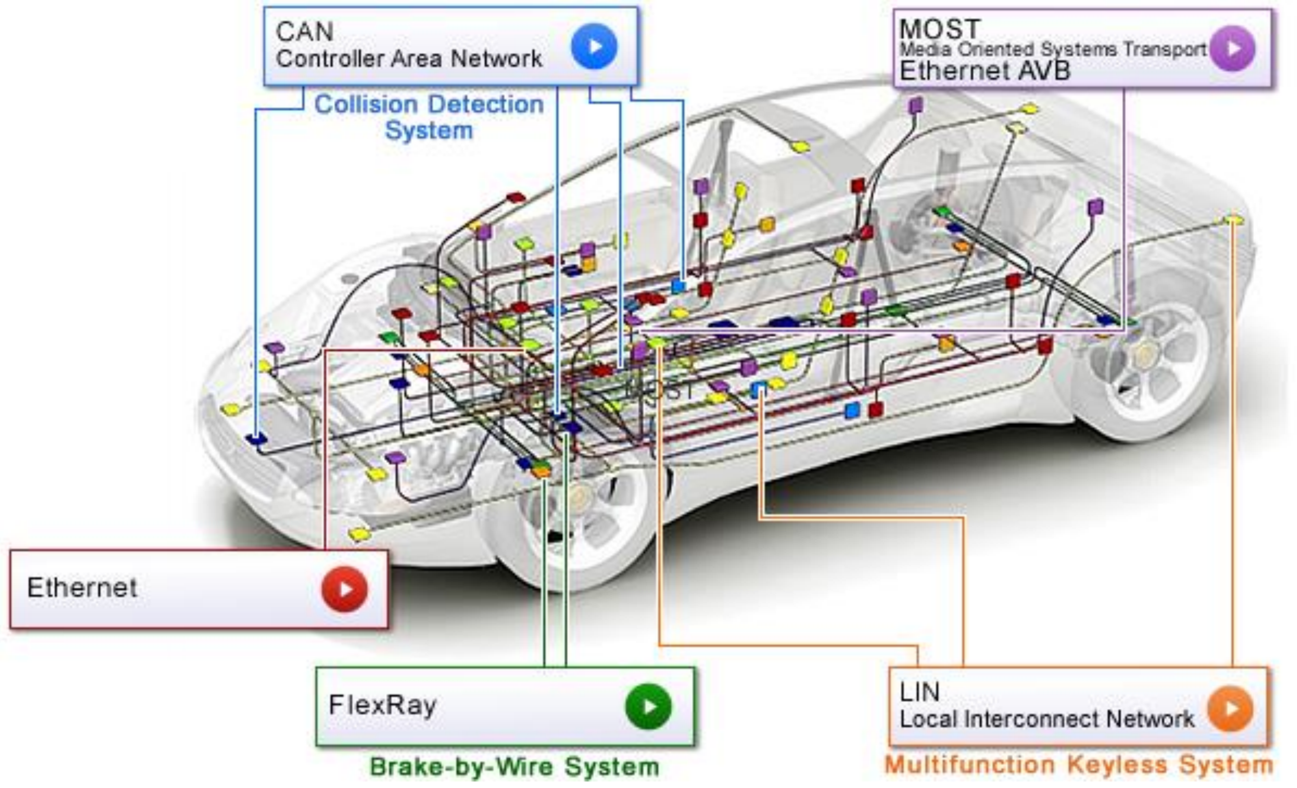


Image Source: Renesas

Sensing Network Requirements

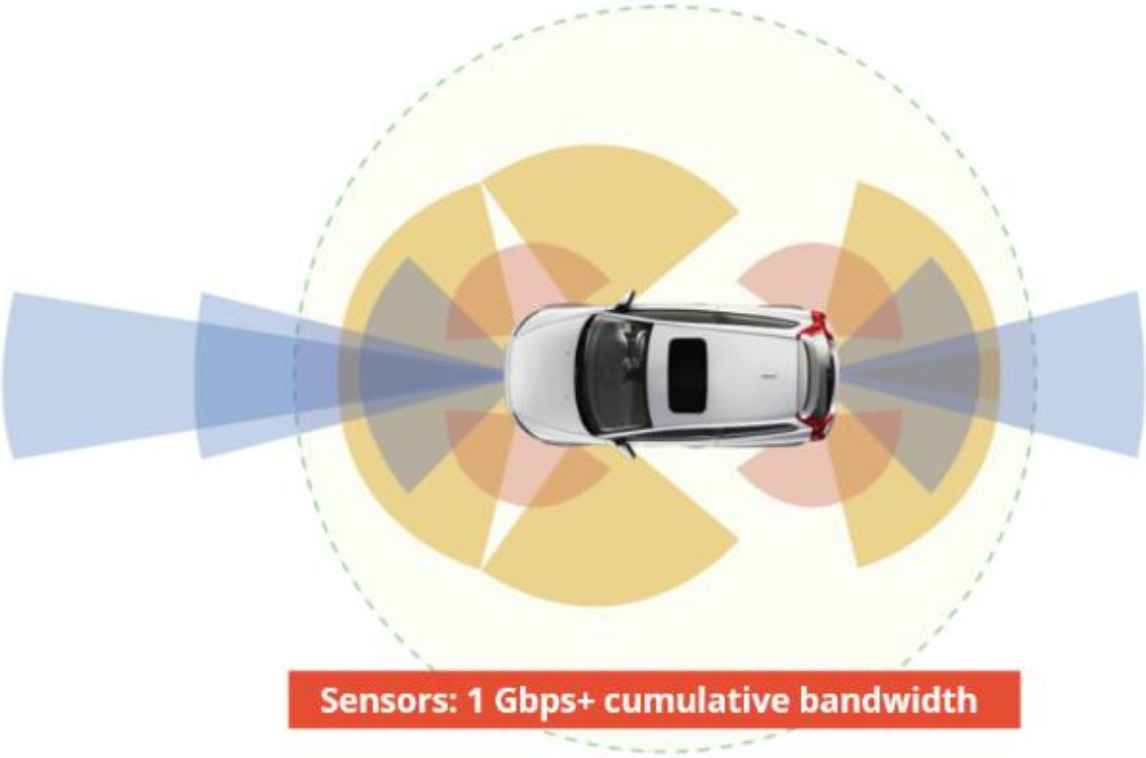
Camera
(~5 @100 mbps each)

Ultrasonic
(~15 @30 mbps each)

Radar
(~5 @50 mpbs each

LiDAR
(~1 @ 100 mbps each)

Infrared
(~1 @ 50 mbps each)

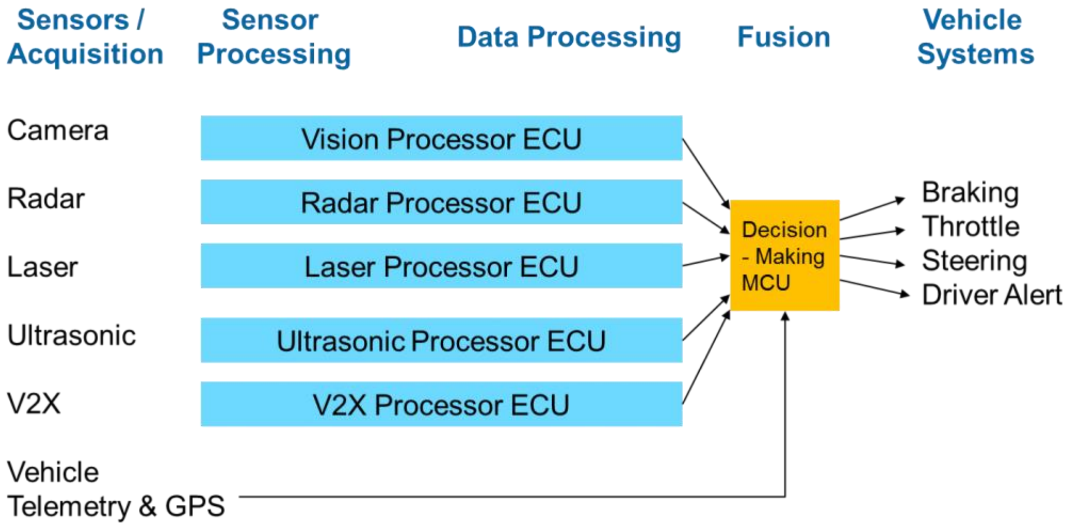


Sensors: 1 Gbps+ cumulative bandwidth

The amount of bandwidth necessary to handle raw data from all sensors is a big challenge for designers of active safety of autonomous control systems!

Consolidation of Sensing ECUs

Singular Approach



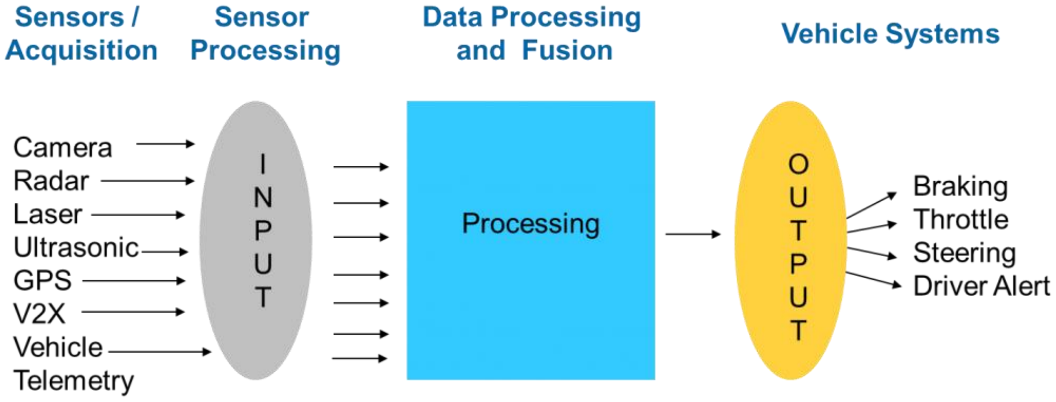
Sensors / Acquisition
Sensor Processing
Data Processing
Fusion
Vehicle Systems

Camera
Vision Processor ECU
Radar
Radar Processor ECU
Laser
Laser Processor ECU
Ultrasonic
Ultrasonic Processor ECU
V2X
V2X Processor ECU
Vehicle Telemetry & GPS

Decision - Making MCU

Braking
Throttle
Steering
Driver Alert

Consolidated Approach



Sensors / Acquisition
Sensor Processing
Data Processing and Fusion
Vehicle Systems

Camera
Radar
Laser
Ultrasonic
GPS
V2X
Vehicle Telemetry

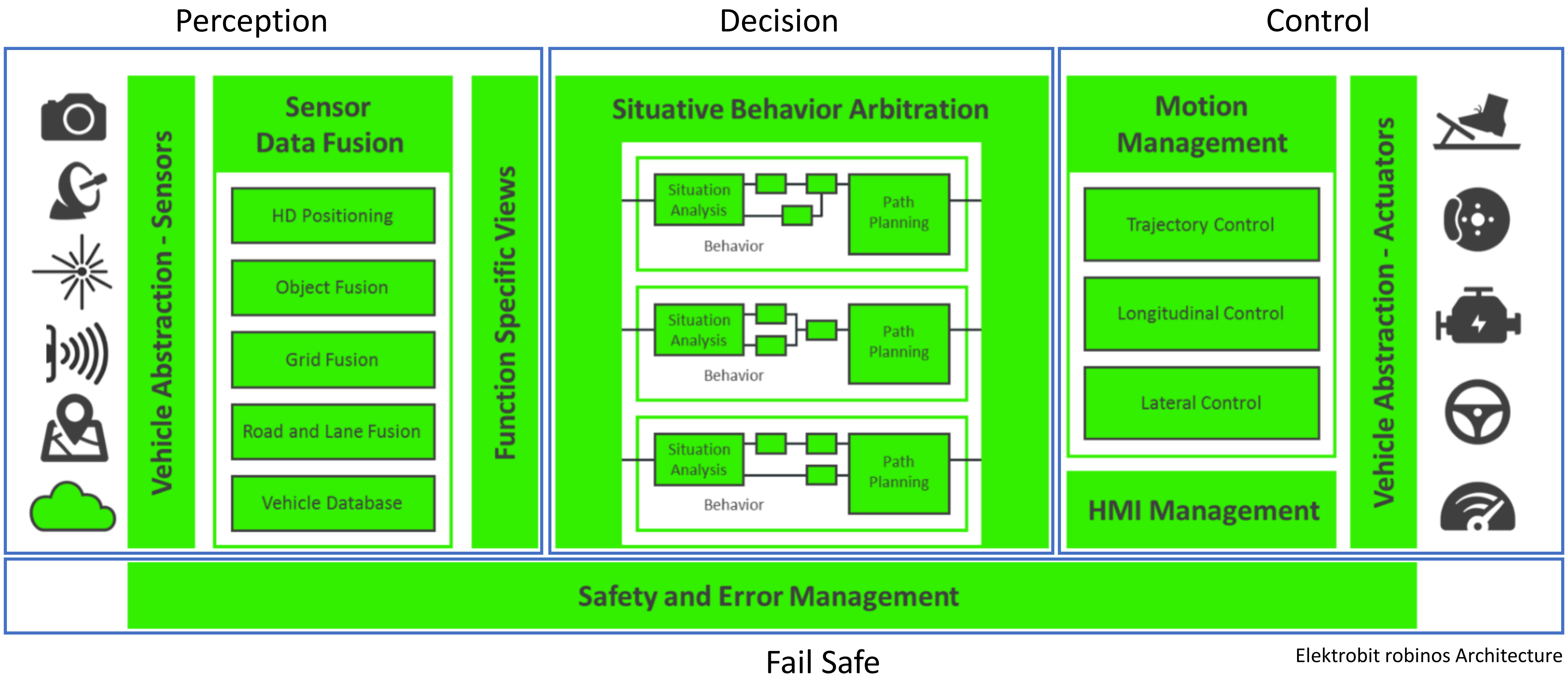
INPUT

Processing

OUTPUT

Braking
Throttle
Steering
Driver Alert

Functional Elements of Autonomous Control



Perception

Decision

Control

Vehicle Abstraction - Sensors

Sensor Data Fusion

- HD Positioning
- Object Fusion
- Grid Fusion
- Road and Lane Fusion
- Vehicle Database

Function Specific Views

Situative Behavior Arbitration

Situation Analysis → Path Planning (Behavior)

Situation Analysis → Path Planning (Behavior)

Situation Analysis → Path Planning (Behavior)

Motion Management

- Trajectory Control
- Longitudinal Control
- Lateral Control

HMI Management

Vehicle Abstraction - Actuators

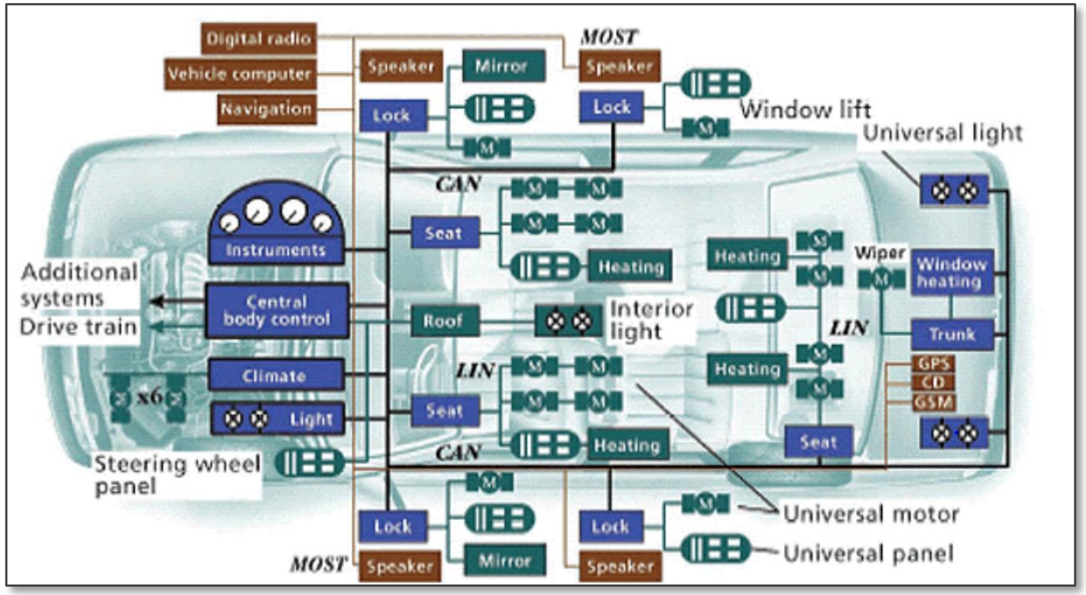
Safety and Error Management

Fail Safe

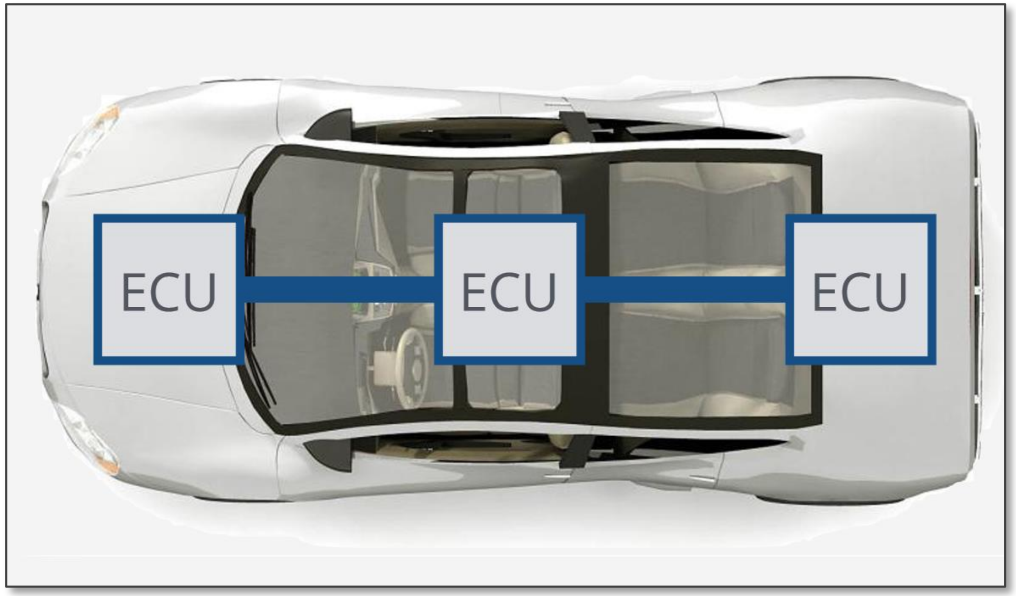
Elektrobit robinos Architecture

Software Defined Car

Conventional Architecture



Software Centric Approach



Audi zFAS Autonomous Domain Controller

Processors

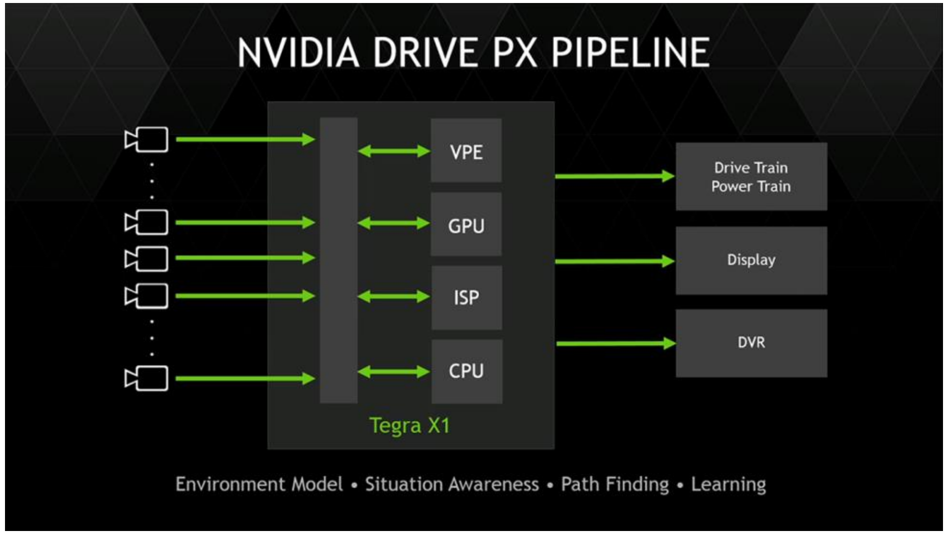
- nVidea Tegra K1 SoC
- Mobile EyeQ3 SoC
- TTTech NIC
- Infineon TC29xT (tri-core)
- Altera FPGA
- Delphi

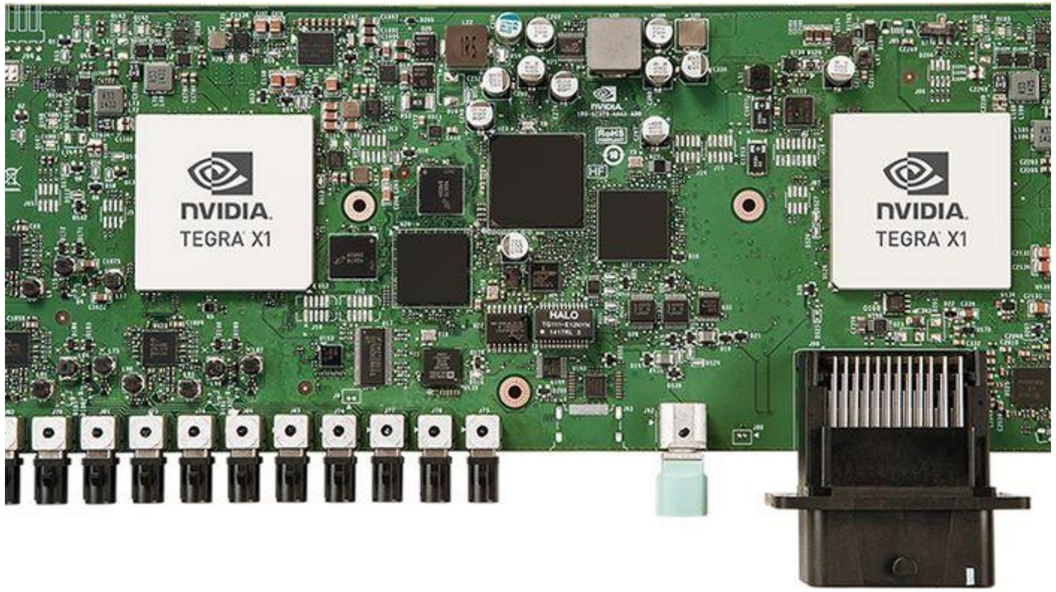
Sensors

- Ultrasonic
- Front Radar 250m
- Front Laser Scanner 80m
- Rear Radar
- Surround Cameras
- Wide angle front camera
- GPS up to 2cm
- LTE wireless
- Cloud-based Deep Learning

The zFAS controller represent the "brains" of autonomous control. Massive processing support is necessary to handle all sensor inputs, decipher objects and react in real-time!

Nvidia DrivePX





The NVIDIA DRIVE PX platform enables the development of systems that capture and process multiple HD camera and sensor inputs and supports advanced graphics, computer vision and machine learning.

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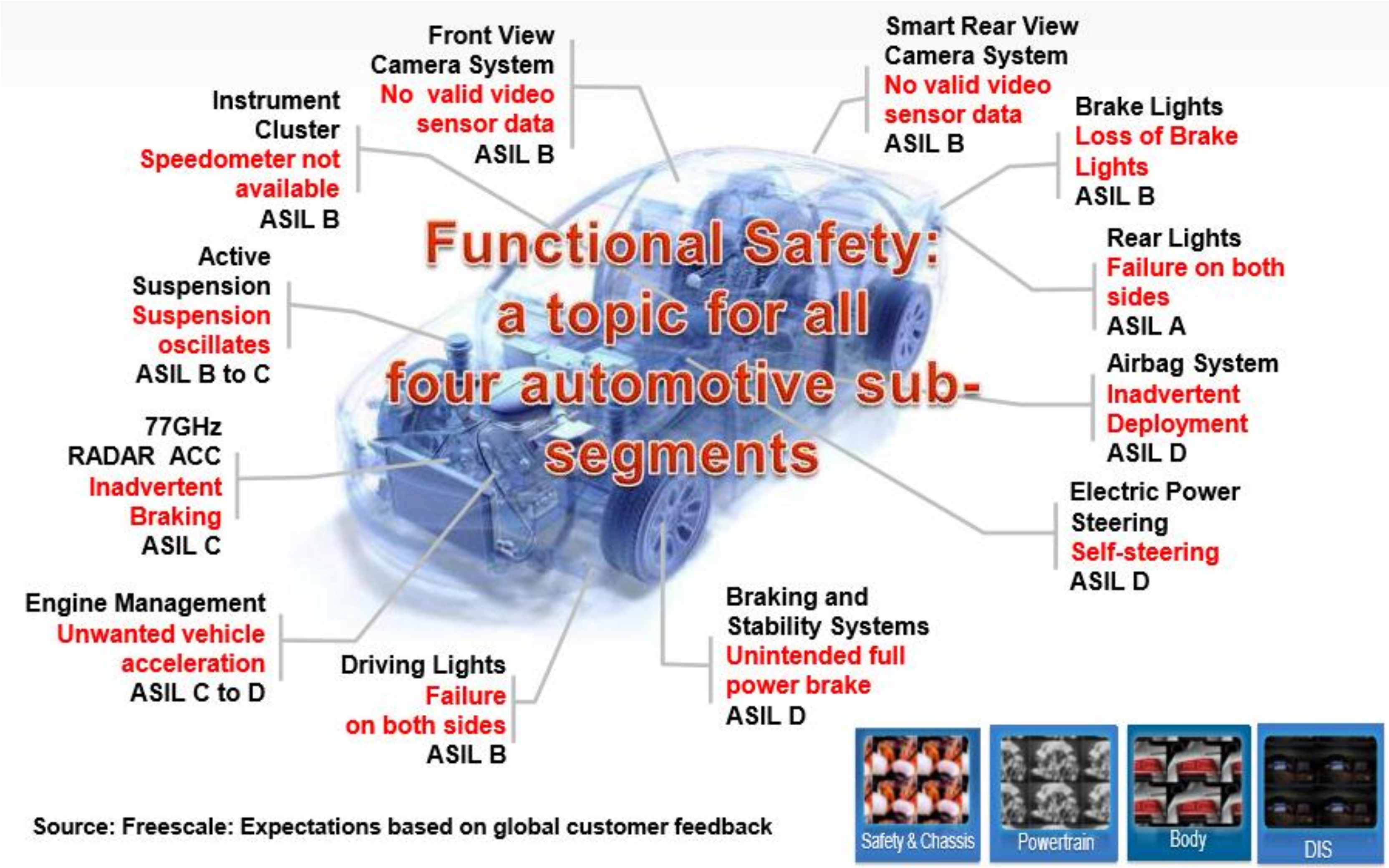
Functional Safety

Functional Safety ISO 26262

- Functional Safety means “absence of unreasonable risk due to hazards caused by malfunctioning behavior of E/E systems”
- ISO 26262 is still firmly grounded in the constraints of a traditional vehicle where the presence of a driver provides a failsafe mechanism. As such, under the current scope of ISO 26262, there are no current provisions for a driverless vehicle.
- It is applicable to safety-related automotive systems that include one or more E/E systems and that are installed in series production passenger cars with a max gross weight up to 3.5t”
- ISO 26262 addresses architectural & functional aspects and procedural aspects − to avoid systematic faults and to control random faults
- Automotive Safety Integrity Level (ASIL) are assigned values to systems from A (lowest) to D (highest)
- Key components that are part of a system can be certified as a Safety Element out of Context (SEooC)
- ASIL decomposition provides method for reducing ASIL levels (ASIL A+C = ASIL D)

ASIL Rating Examples



Functional Safety: a topic for all four automotive sub-segments

Instrument Cluster
Speedometer not available
ASIL B

Front View Camera System
No valid video sensor data
ASIL B

Smart Rear View Camera System
No valid video sensor data
ASIL B

Brake Lights
Loss of Brake Lights
ASIL B

Active Suspension
Suspension oscillates
ASIL B to C

Rear Lights
Failure on both sides
ASIL A

77GHz RADAR ACC
Inadvertent Braking
ASIL C

Airbag System
Inadvertent Deployment
ASIL D

Electric Power Steering
Self-steering
ASIL D

Engine Management
Unwanted vehicle acceleration
ASIL C to D

Driving Lights
Failure on both sides
ASIL B

Braking and Stability Systems
Unintended full power brake
ASIL D

Source: Freescale: Expectations based on global customer feedback

Key Take Aways

- Active ADAS systems are the building blocks of autonomous control and lend to the traditional OEMs in terms of strategy
- Companies (OEMs, tier-1s) wanting to go deeper into the value chain to have more control over the functionality – especially for autonomous control features
- Big Tech Brings disruptive technology to traditional automotive school of thought – probabilistic vs. deterministic architecture.
- New methods in machine learning offer great promise for autonomous control
- Data acquisition including highly detailed mapping and crowd sourced dynamic content becomes vital to autonomy and to "learning."
- HMI will see a lot of innovation from autonomous control features – lots of new research on this but current concepts appear fragmented
- Functional Safety practices do not currently align with driverless technologies. Should safety practices adopt "outcome-based" examination?

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