The Development of Automated Driving

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Founder and Principal
Vision Systems Intelligence (VSI)
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Who is VSI?

• VSI serves clients that are planning automated vehicle technologies.

• VSI research portals help R&D departments pre-qualify components, systems and development tools.

• VSI research portals help planning departments with technology roadmaps and detailed information about the direction of AV technologies.

• VSI Labs (part of VSI) examines leading components and tools through applied research using simulation tools as well as real vehicle testing.
  • VSI Engineers are skilled in OpenCV, Neural Networks, Python, C++, control theory, robotics (ROS), and real time computing.

• VSI provides thought leadership to companies around the world and is actively involved in some of the most advanced AV development programs.
• There is a rush to develop the **AV stack** – the HW/SW elements of automated driving. This is being lead by the major chip companies, often in collaboration with tier-ones.

• The AV Stack is a massive collection of IP and is further supported by cloud assets, and a lot of them!

• There is a new round of development platforms for AV technologies – open source, open interface, and SDKs to entice developer activities and build up eco-system partners.

• AV technologies are being targeting by the tech giants (nothing new) – but, they don’t plan on building cars… rather they want to control the brains that drive automated vehicles.

• Incremental AV is happing rapidly and in production now… Who will build a better Tesla?

• Meanwhile, Level 4 development is well under way for share mobility platforms… Commercial vehicles operating in urban environments.
The AV Stack
Developing Automated Vehicle Systems – The “AV Stack”

The AV Stack
Autonomous Vehicle Domain

Application Development Platforms

Run Time SW Components & Basic SW Services

<table>
<thead>
<tr>
<th>Perception</th>
<th>Localize &amp; Plan</th>
<th>Decision / Behavior</th>
<th>Control</th>
<th>Connectivity &amp; I/O</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASIC/FPGA</td>
<td>Data Path Processing</td>
<td>Motion Engine</td>
<td>Lockstep Processor</td>
<td>RF Processors</td>
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<tr>
<td>GPU Accelerators</td>
<td>DDR Memory</td>
<td>ECC Memory</td>
<td>DDR Memory</td>
<td>Network switches</td>
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<tr>
<td>SIMD Memory</td>
<td>Localization datasets</td>
<td>Behavior Modules</td>
<td>Safety Monitors</td>
<td>Deterministic Bus</td>
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<tr>
<td>Sensors</td>
<td>Inertia Measurement</td>
<td>Arbitration</td>
<td>Fail Safe Fallback</td>
<td>NAND/NOR Memory</td>
</tr>
<tr>
<td>Detectors/CNNs</td>
<td>GNSS</td>
<td>Predictors/RNNs</td>
<td>By-Wire Controllers</td>
<td>Data Recording</td>
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Developing Automated Vehicle Systems – Platforms

<table>
<thead>
<tr>
<th>Company</th>
<th>AV Domain Controller</th>
<th>Production Platform</th>
<th>Development Platform</th>
<th>Automation L1-L2</th>
<th>Automation L3-L5</th>
<th>Remarks</th>
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<tr>
<td>Audi</td>
<td>zFAS</td>
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<td>SOP* - Audi A8</td>
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<td>Nvidia</td>
<td>DrivePX2 (used in Tesla AV 2.0)</td>
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<td>SOP* Tesla AP 2</td>
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<td>TTA Drive</td>
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<td>High-end Platform</td>
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<td>Visteon</td>
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<td>Renesas</td>
<td>HADP</td>
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<td>TTA Drive w/Renesas</td>
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<td>Renesas</td>
<td>R-Car HAD Solution Kit</td>
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<td>ADAS Solution</td>
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<tr>
<td>Bosch</td>
<td>AI Car Computer</td>
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<td>Nvidia-based</td>
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<td>NXP</td>
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<td>Full HW Stack</td>
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<tr>
<td>TI / RT-RK</td>
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<td>Delphi</td>
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<td>Prototype</td>
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<td>ZF PRO AI (passenger/commercial)</td>
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<td>Hitachi</td>
<td>Autonomous Self Driving ECU</td>
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<tr>
<td>Intel</td>
<td>GO AV Platform (w/Mobileye vision)</td>
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<td>Full HW Stack</td>
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Remarks:

* Start of Production
## Developing Automated Vehicle Systems – Software

<table>
<thead>
<tr>
<th>Company</th>
<th>Product</th>
<th>Sensor Fusion</th>
<th>Detection</th>
<th>Interfacing Abstraction</th>
<th>Decision Path Planning</th>
<th>Processing</th>
<th>Control Kit</th>
<th>Testing Simulation</th>
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<tbody>
<tr>
<td>Nvidia</td>
<td>Driveworks / Drive PX</td>
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<td>Robinos</td>
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<td>Autonomos</td>
<td>Autonomos Core Framework</td>
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<td>Xilinx</td>
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<td>Ricardo</td>
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<td>Comma AI</td>
<td>Neo / OpenPilot</td>
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Does not include RTE/BSW or MCAL Layers

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Developing Automated Vehicle Systems
Developing Automated Vehicles -- Defining Operating Domains

1. **NHTSA’s HAV policy**, published in September 2016, is a regulatory framework and best practices for the development, testing, and deployment of AVs.

2. Automated vehicle systems must be defined with one or more **Operational Design Domains (ODD)**.

3. A SAE Level 2, 3 or 4 vehicle could have one or multiple ODDs – e.g. geo-fenced urban, divided highways, automated parking, traffic jam assist, etc.

4. A L5 vehicle has only one ODD as it can (in theory) work anywhere!

5. AVs should be developed, tested and validated against all sceneries that could happen within the ODDs.

6. Each scenario is backed with a **Object and Event Detection and Response (OEDR)** – details how the AV will handle expected and unexpected events.

7. Each scenario must have a **fall back** plan... what to do when system fails.

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Developing Automated Vehicles – Defining Functional Domains

1. The **perception domain** considers all environment sensors such as camera, radar, LiDAR, ultrasonic, as well as other sensors such as inertia, positioning, throttle position, steering angle etc.
   1. 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.

2. The **localization domain** couples knowledge (ground truth) to its environmental model in order to understand its relative position against the real world.

3. The **behavior domain** is where decision are made with respect to motion control.
   1. Active safety systems or L2 automation rely on traditional deterministic algorithms but higher levels of automation will rely on probabilistic algorithms (such as AI) to better predict maneuvers.

4. The **safety domain** (aka Safety Monitor) encases the system as a whole and validates all outputs.
Developing Automated Vehicles – Validation and Testing

- **Simulation** -- allows for the thorough testing of complex systems.
  - These environmental models allow you to define the actors, sensor packages, conditions and scenes

- **Test Tracks** -- Test Tracks allow the creation of some unique scenarios and apply real physics.
  - However, even with excellent test track design and availability, it is impossible to fully test complex systems

- **Field Tests/Real World Data Collection** -- It is important to drive as many miles as possible.
  - Unfortunately, field tests cannot provide enough scenarios (edge cases) to fully qualify a complex system.

- **Artificial Intelligence** – You can use real data or simulated data to train a the Neural Network.
  - To validate, you can examine the layers to see what activates the network... isolate the problems... adjust the weights in the inference model, then test again to check the outcomes.
It is recommended to utilize detailed simulations to develop the systems, test-track tests to validate components and full-vehicles, and field tests to verify the real-life system robustness, whose results can be utilized to train a neural network for further testing and simulating of a specific system.
Developing Automated Vehicles – Fleet Testing Using *Shadow Mode*

**What is it?**
- The AV Engine runs in **shadow mode** only – for data collection and evaluation
- Actual AV output commands are recorded alongside real driver inputs
- Once new scenarios are captured, the network is trained and validated, the new feature is then enabled via software OTA

**Purpose**
- Supplements testing and validation
- Discover new edge cases
- Evaluate machine performance
- Examine human performance vs. machine performance

*Tesla is Running Shadow Mode to test and refine features, even before making them available.*
Developing Automated Vehicles – Subject Matter Expertise

Data Scientist

Simulation / Testing

AI Engineer

Control Theory Engineer

Vehicle Actuation

Perception/CV Engineer

Localization/Mapping Engineer

Behavior algorithms Engineer

Embedded Systems Engineer

Recorded Data or Vehicle Data

Generated Control Data for Validation

Simulated Synthetic Data

Simulated Environmental Model

Generated Path or Trajectory Data for Validation

Trained Inference Models

Developed Control Algorithms

Completed Code / but also back to Testing

Map Data

Simulated Perception Data

Generated Environmental Model for Validation

Trained Inference Models

Uses the Environmental Model

Uses the Environmental Model

Uses the Environmental Model

Improves the Environmental Model

Creates the Environmental Model

Developed Perception Algorithms

Developed Localization Algorithms

Developed Behavior Algorithms
The Cloud Assets
Using the Cloud to Manage the Software Stack

**Data Collection**
- Record sensor data and uploading the data to the cloud
- Record sensor inputs against human driver output (shadow mode)
- Collect raw data for training the AI-based algorithms
- Collect performance and diagnostic information
- Capture edge cases
- Record objects for localization assets

**Data Distribution**
- AV Software updates – version control
- Firmware updates to distributed ECU systems
- Updated localization assets – maps and supplemental
- Distributing new inference models
- Distributing fail safe and fall back instructions which will always be changing
## Cloud Assets Necessary for Automation

<table>
<thead>
<tr>
<th>The Internet of Vehicles</th>
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</thead>
<tbody>
<tr>
<td><strong>Hardware Device Management</strong></td>
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<tr>
<td><strong>OTA Software Enablement</strong></td>
</tr>
<tr>
<td><strong>Developer Eco-System Management</strong></td>
</tr>
<tr>
<td><strong>Software Skills / AI</strong></td>
</tr>
<tr>
<td><strong>Transactions</strong></td>
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<tr>
<td><strong>Swarms of Geocoded Metadata</strong></td>
</tr>
<tr>
<td><strong>Mapping Assets</strong></td>
</tr>
<tr>
<td><strong>Data &amp; Analytics management</strong></td>
</tr>
</tbody>
</table>
• Incremental automation (L2/L3) is born out of ADAS and becomes a big selling factor over the next 10 plus years before fleet automation starts to dent private ownership.

• Tiers gaining a critical role in AV – handling integration, safety and automotive grade requirements. These company are the bridge between the mechanical and digital worlds.

• OEMs will play a vital role if they play their cards right – building the proper vehicles that meet the requirements of the buyers – nothing new here!

• The balance of power in mobility is changing as the service providers are probably at of top of the list in the era of shared commercial mobility.

• Data acquisition including highly detailed mapping and crowd sourced dynamic content becomes vital to autonomy and to “learning.” This will be an important pillar within the AV stack!

• Understanding Operational Design Domains (ODD) is a required specification that explain under what conditions a HAV will operate, how it handles events, and what is the fall back strategy.
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2016 SCCA ITE Central Divisional Champion