AGENDA

1. HARMAN – Who We Are & What We Do

2. Connected Car & SBU Autonomous Driving - Activities

3. HD Map Motivation

4. HD Map Data Science Challenges

5. Summary
WHO WE ARE & WHAT WE ARE DOING

GLOBAL GROWTH CONTINUES

Innovation breeds quantifiable success

- **30,000** Professionals worldwide
- **15,000** Engineers ~80% Software
- **30+** Countries: Americas, Europe and Asia
- **16+** Legendary brands

GLOBALLY DIVERSE

- **6,529** Patents and patents pending
- **42** Design awards in 2017
- **3** GRAMMY® Awards - AKG, JBL, LEXICON
- **2** Academy Awards

INNOVATION LEADER
WHO WE ARE & WHAT WE ARE DOING

TECHNOLOGIES FOR A CONNECTED WORLD

CONNECTED CAR
- Navigation, Multimedia, Connectivity, Telematics, Safety & Security Solutions

LIFESTYLE AUDIO
- Premium Branded Audio Products and Sound Management Software for Car, Home and on the Go

PROFESSIONAL SOLUTIONS
- Audio, Lighting, Video Switching and Automation for Enterprise and Entertainment

CONNECTED SERVICES
- Cloud, Mobility and Analytics Solutions with OTA Updates for Car, Mobile and Enterprises
**WHO WE ARE & WHAT WE ARE DOING**

**WE ARE A HOUSE OF BRANDS**

<table>
<thead>
<tr>
<th>CONNECTED CAR</th>
<th>LIFESTYLE AUDIO</th>
<th>PROFESSIONAL SOLUTIONS</th>
<th>CONNECTED SERVICES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BANG &amp; OLUFSEN</td>
<td>JBL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flowers &amp; Wilkins</td>
<td>AKG</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>AMX</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crown</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soundcraft</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>dbx</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Martin</td>
<td></td>
</tr>
</tbody>
</table>
WHO WE ARE & WHAT WE ARE DOING

36+ GLOBAL AUTO BRANDS AND GROWING

LONG-TERM CUSTOMERS
- Audi
- BMW
- Mercedes-Benz
- Ferrari
- Hyundai
- Maserati
- Porsche
- Harley-Davidson
- Toyota
- Fiat Chrysler Automobiles
- Volkswagen

BRIC CUSTOMERS
- Great Wall
- Changan
- GAC Group
- Dongfeng
- JAC
- SAIC
- Geely
- Tata

NEW CUSTOMERS
- GM
- Subaru
- Honda
- Suzuki
- Ford
- MAN
- Scania
- Jaguar
- Land Rover

©2018 HARMAN INTERNATIONAL INDUSTRIES, INCORPORATED
WHO WE ARE & WHAT WE ARE DOING

SAMSUNG AND HARMAN SYNERGIES

- Infotainment / UX
- Telematics
- ADAS / Autonomous
- Cloud / Services
- IoT
- Digital Health
- Mobile
- Semiconductor
- Sensors
- Display
Realizing the most advanced infotainment and digital cockpit systems

**Features**

- Augmented Reality Displays
- Best-in-class Navigation
- Cloud Based Driver Profiles
- Virtual Personal Assistants
- Multi-modal approach to interact with different UI/UX systems (i.e., haptic, gestural, driver monitoring, etc…)

**5G always connected**

- First automotive grade 5G ready solution
Example Data Science tasks in today’s systems

- Map Compilation for Navigation Service
- Processing of Fleet information for up-to-date information layers to onboard navigation systems
- Predicted Traffic Information
- Voice Input
- Destination Input

Data Fusion
Stream Mining
Machine Learning
NLP
Entity Resolution
HD MAP MOTIVATION

WHAT IS AN HD MAP?

HD Map Characteristics

• Highly detailed + accurate
• Up-to-Date
• Topology
• Geometry
• Geo-Reference Services

The HD Map...

• extends the car’s view
• supports autonomous driving in challenging scenarios
• compensates for sensor/detection errors
• improves localization
• is utilized in simulation environment
HD MAP MOTIVATION

AUTONOMOUS VEHICLES NEED HD MAPS

“Baidu sees Maps for Self-Driving Cars as Bigger Business Than Web Search”
MIT Technology Review, Jan 9th, 2018

Current Maps

- SD Maps (sufficient for navigation)
  - Large coverage
  - Not very accurate (i.e., street – level)
- HD Maps (from survey campaigns)
  - Low coverage
  - Collected with expensive sensors, manual postprocessing

→ HD Map is a key part towards Autonomous Driving and DS is a crucial part of the solution
HD MAP MOTIVATION

CROWDSOURCING INFRASTRUCTURE

Car Fleet / User Devices

Fleet observations

Map Creation

Map Data
- SD Map
- Survey campaigns

HD Map

Other Inputs
- Road Weather
- Accidents
- Traffic Models
- ...

©2018 HARMAN INTERNATIONAL INDUSTRIES, INCORPORATED
HD MAP DATA SCIENCE CHALLENGES

GENERAL CHALLENGES

Accuracy
• Lanes, traffic signs, ... should have an accuracy < 10cm
• Positioning and measurement errors sometimes several meters

Up-to-date
• Updates should be visible in global map as fast as possible
• Tradeoff: update speed vs. confidence

Resource constraints
• Bandwidth: accuracy vs. model size
• Computational limitations

Variability
• Sensor heterogeneity
• Data, quality and ecosystem heterogeneity
Semantic Feature Detection

Traffic Signs
- Semantic Information + Landmarks
- Object Detection = Region Proposal + Classification
- Detection Speed vs. Accuracy Tradeoff

Traffic Lane
- Positioning perpendicular to driving direction
- Computer Vision vs. Deep Learning

Semantic Segmentation
- Supports traffic sign and lane detection
- Enriches the map content
- Quality assessment of landmarks

Transformation Gap: Image Space ⇒ Real-World
Simultaneous Localization and Mapping
Perfect map $\Rightarrow$ localization is „easy“
Perfect localization $\Rightarrow$ mapping is „easy“

SLAM
• Identification of landmarks that are visible from different positions
• Measurement of position change
• Construct Triangles (= Posegraph)
• Adjustment of measurement errors

Visual SLAM
• Landmarks = Image Keypoints
• Position Change = Bundle Adjustment
• Byproduct: image to world correspondence
HD MAP DATA SCIENCE CHALLENGES

OFF BOARD CHALLENGES

Building the global map
OFF BOARD CHALLENGES

Building the global map

Vehicle Data (simplified)
- Trajectories
- Observations
  - Traffic Signs
  - Traffic Lanes (ego)
HD MAP DATA SCIENCE CHALLENGES

OFF BOARD CHALLENGES

Building the global map

Vehicle Data (simplified)
- Trajectories
- Observations
  - Traffic Signs
  - Traffic Lanes (ego)
Building the global map

Topology

- Challenges:
  - GPS Quality/Errors/Outliers/Resolution
  - Scalability
  - Automatic Adaptation
  - Border Effects

Vehicle Data (simplified)
- Trajectories
- Observations
  - Traffic Signs
  - Traffic Lanes (ego)
Building the global map

Topology

- Challenges:
  - GPS Quality/Errors/Outliers/Resolution
  - Scalability
  - Automatic Adaptation
  - Border Effects

- Methods:
  - Trajectory Clustering
  - Map Construction Algorithms
  - Self-Organizing Maps
  - ...

Vehicle Data (simplified)
- Trajectories
- Observations
  - Traffic Signs
  - Traffic Lanes (ego)
Building the global map

Geometry

• Challenges:
  • Outliers/Quality/Misdetections
  • Border Effects
  • Scalability
  • Association

Local Maps (simplified)
- Trajectories
- Observations
  - Traffic Signs
  - Traffic Lanes (ego)
Building the global map

Geometry

- Challenges:
  - Outliers/Quality/Misdetections
  - Border Effects
  - Scalability
  - Association

- Methods:
  - Assignment Algorithms
  - Clustering
  - Probabilistic Models
  - Graph Optimization
  - …

Local Maps (simplified)
- Trajectories
- Observations
  - Traffic Signs
  - Traffic Lanes (ego)
HD Map is a key part towards Autonomous Driving and Data Science is a crucial part of the solution!

**On Board**
- Neural Networks, Computer Vision, Pattern Recognition, Probabilistic Filters, SLAM, NLP, …

**Off Board**
- Graph Optimization, Clustering, Big Data, Machine Learning, Entity Matching, Genetic Algorithms, Data Integration, Uncertain Data Processing, Spatial Modeling, Assignment Algorithms, Outlier Detection, …