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Stereo and the City

Uwe Franke, Daimler AG Research and Development, Böblingen

The Dream has become Reality

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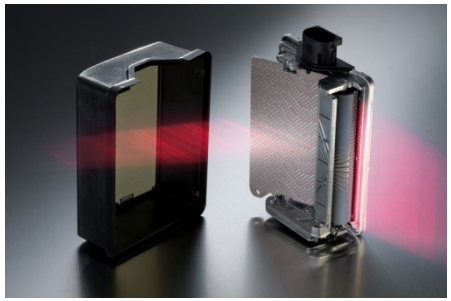
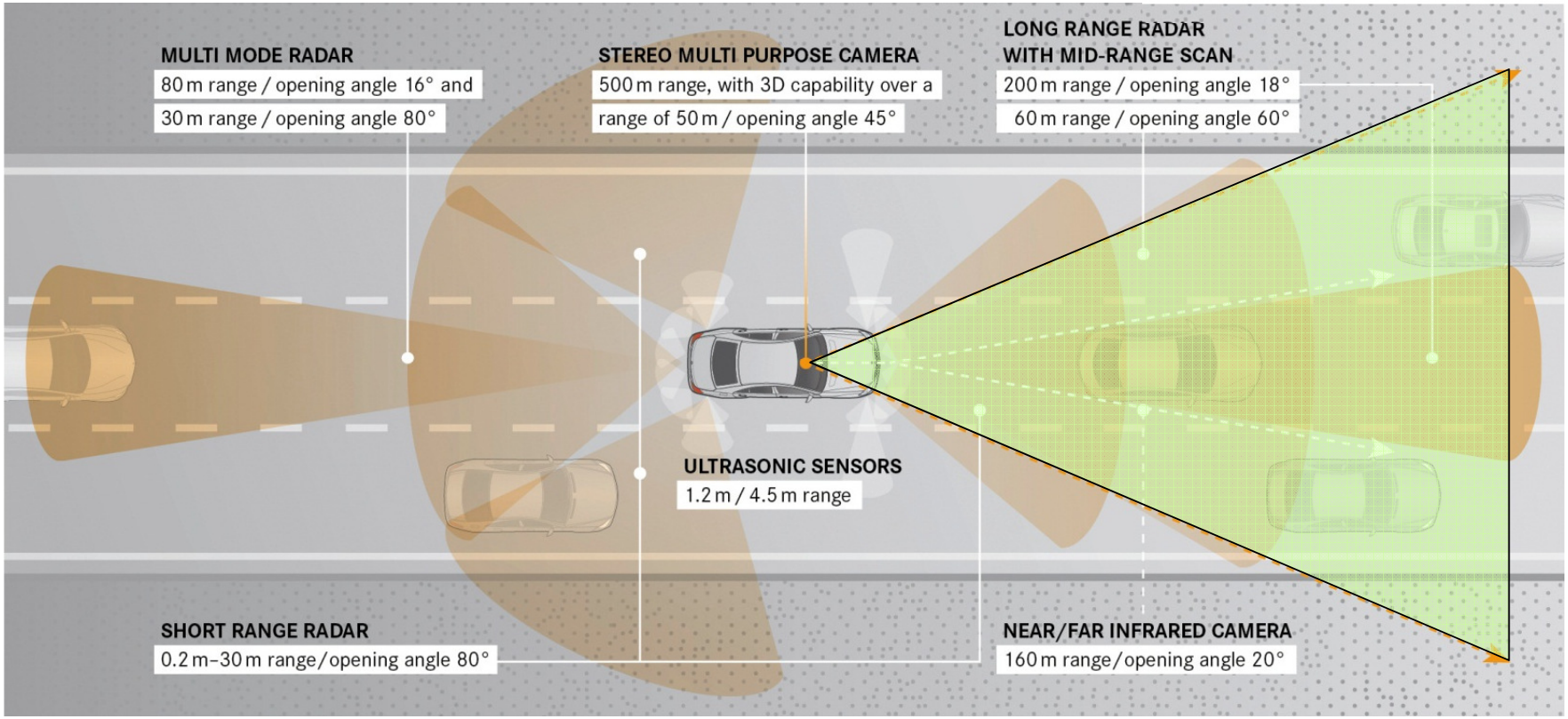
Mercedes-Benz Intelligent Drive

The new Mercedes-Benz S-Class and E-Class offer:

- Pedestrian collision avoidance up to 50km/h by **autonomous braking**.
- Active braking assistant reacting to crossing traffic.
- Lateral and longitudinal control up to 200km/h even under adverse weather conditions (hands-on recognition).
- Low speed **autonomous driving** in traffic jams.
- Magic Body Control (active body control utilizing road profile).

Sensors in Modern Cars

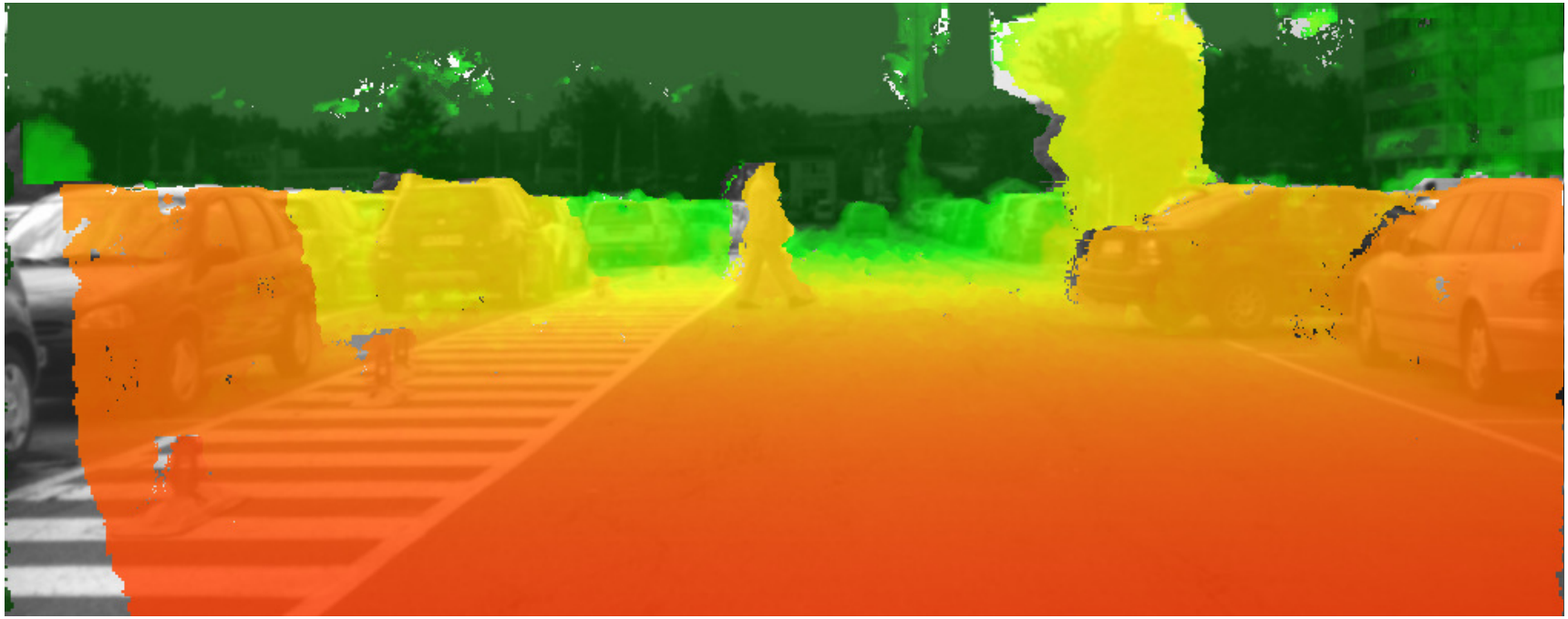




Outline

- **Stereo Vision – today.**
  - **Stereo Vision – tomorrow.**
    - **Stereo Vision for the day after tomorrow.**

The Principle of Stereo Vision



Disparity Image

Challenge: on-line calibration to guarantee perfect results for the whole lifetime of the car.

Color encoded distance:
close ..... far

H.Hirschmüller: "**Accurate and Efficient Stereo Processing by Semi-Global Matching and Mutual Information**", DAGM 2005, CVPR 2005

The Principle of Stereo Vision

S.Gehrig, F.Eberli, T.Meyer, "**A Real-time Low-Power Stereo Vision Engine Using Semi-Global Matching**", ICVS 2009 (Best Paper Award)

Will he – or will he not turn?

Will he – or will he not turn?

- Seeing like humans implies *simultaneous* perception of position and motion to recognize dangerous situations on time.
- 6D-Vision is our approach to give the car this competence – at *every* pixel of the image and *always* with highest attention.

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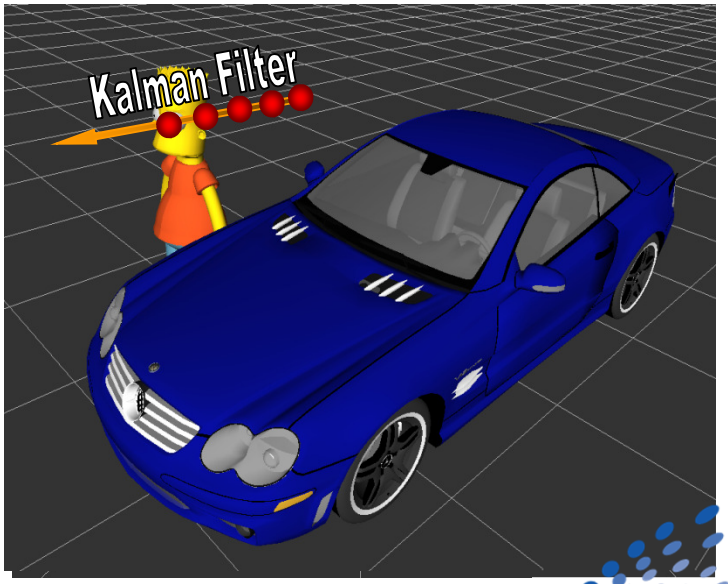
6D-Vision: Optimal Fusion of Stereo and Optical Flow



6D-Vision simultaneously estimates position (3 dimensions) and motion (another 3 dimensions) of all tracked points. Thus the name 6D-Vision.

DEUTSCHER ZUKUNFTSPREIS
Preis des Bundespräsidenten
für Technik und Innovation

U.Franke, C.Rabe, H.Badino, S.Gehrig: „**6D-Vision: Fusion of Stereo and Motion for Robust Environment Perception**", 27th DAGM Symposium 2005, pp. 216-223

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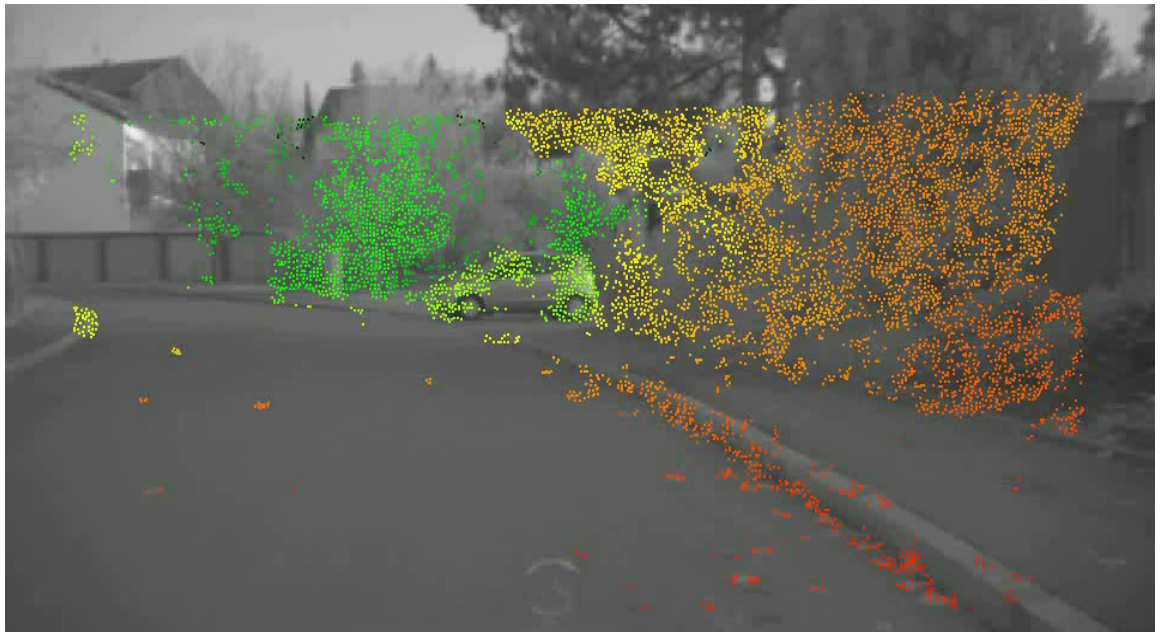
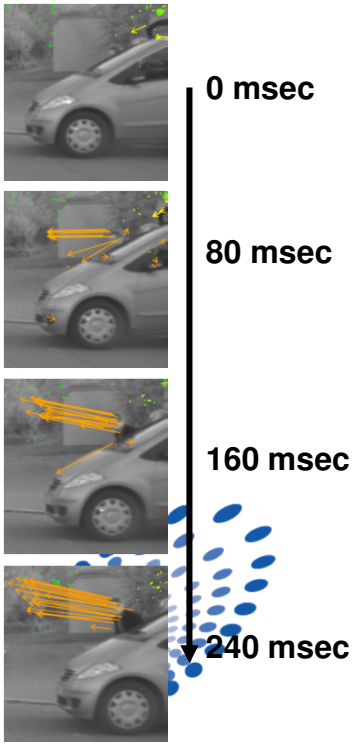
Fast Recognition of Moving Objects





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Autonomous Emergency Braking with 6D Vision

6D-Vision allows to critical situations with moving obstacles und to avoid serious accidents.

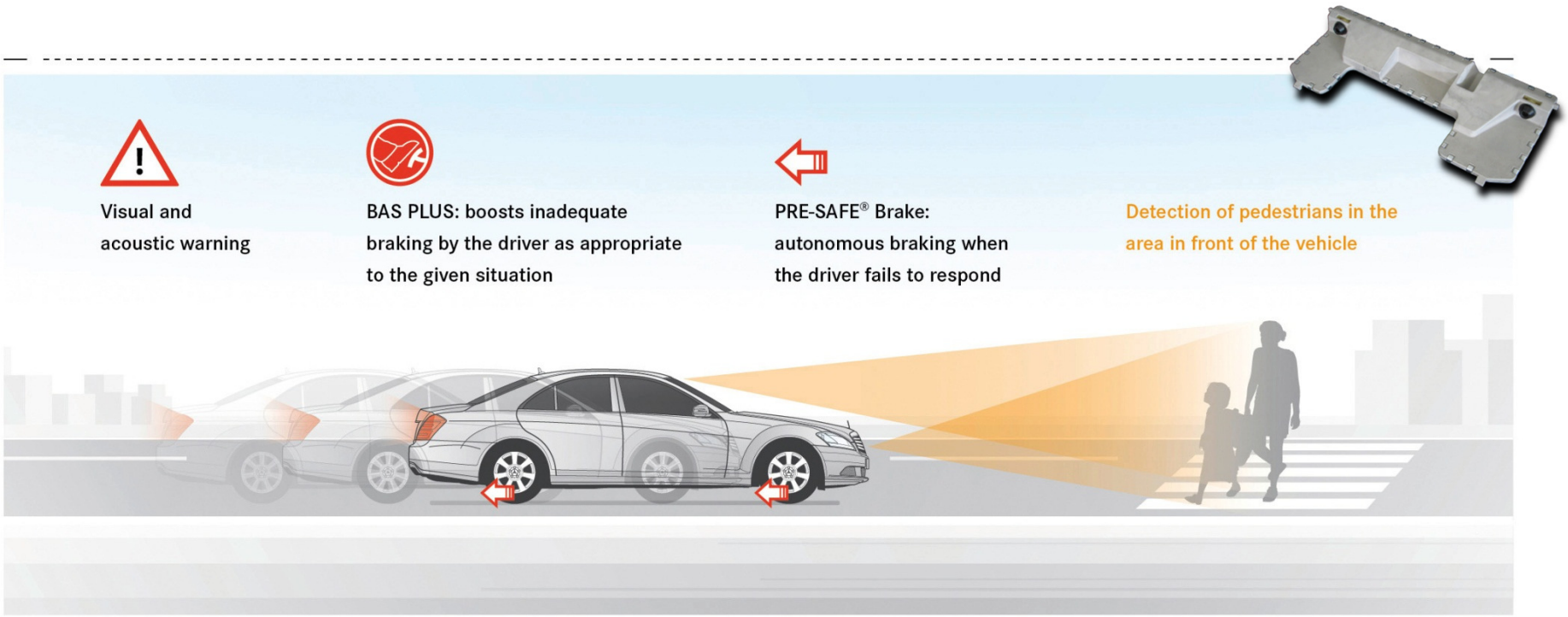
Final Demonstration BMWi-Project INVENT, Munich April 2005

Collision Avoidance in Practice

2013: 6D-Vision has become available in Mercedes-Benz S- and E-Class

The Dream has become Reality

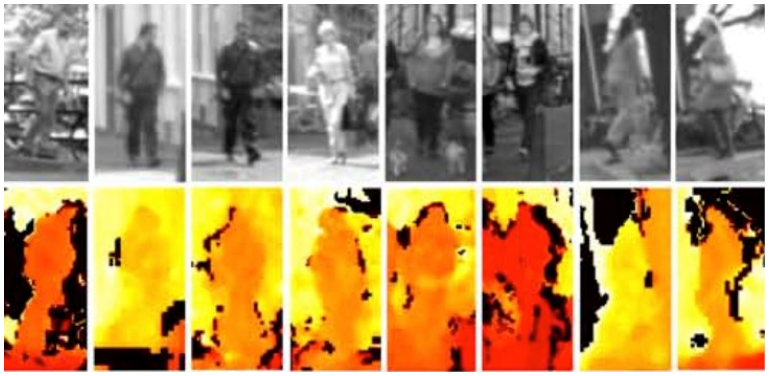
PRE-SAFE® Brake with Pedestrian Recognition



- 1.24 million traffic fatalities per year worldwide, 50% vulnerable road users.
- No false reaction during the whole test phase.
- High performance even at night-time.

Object Recognition: Pedestrians

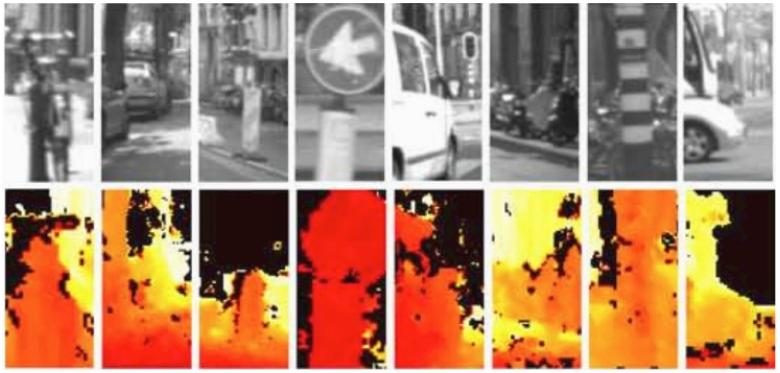
Pedestrian examples



Non-Pedestrian examples

Image

Depth



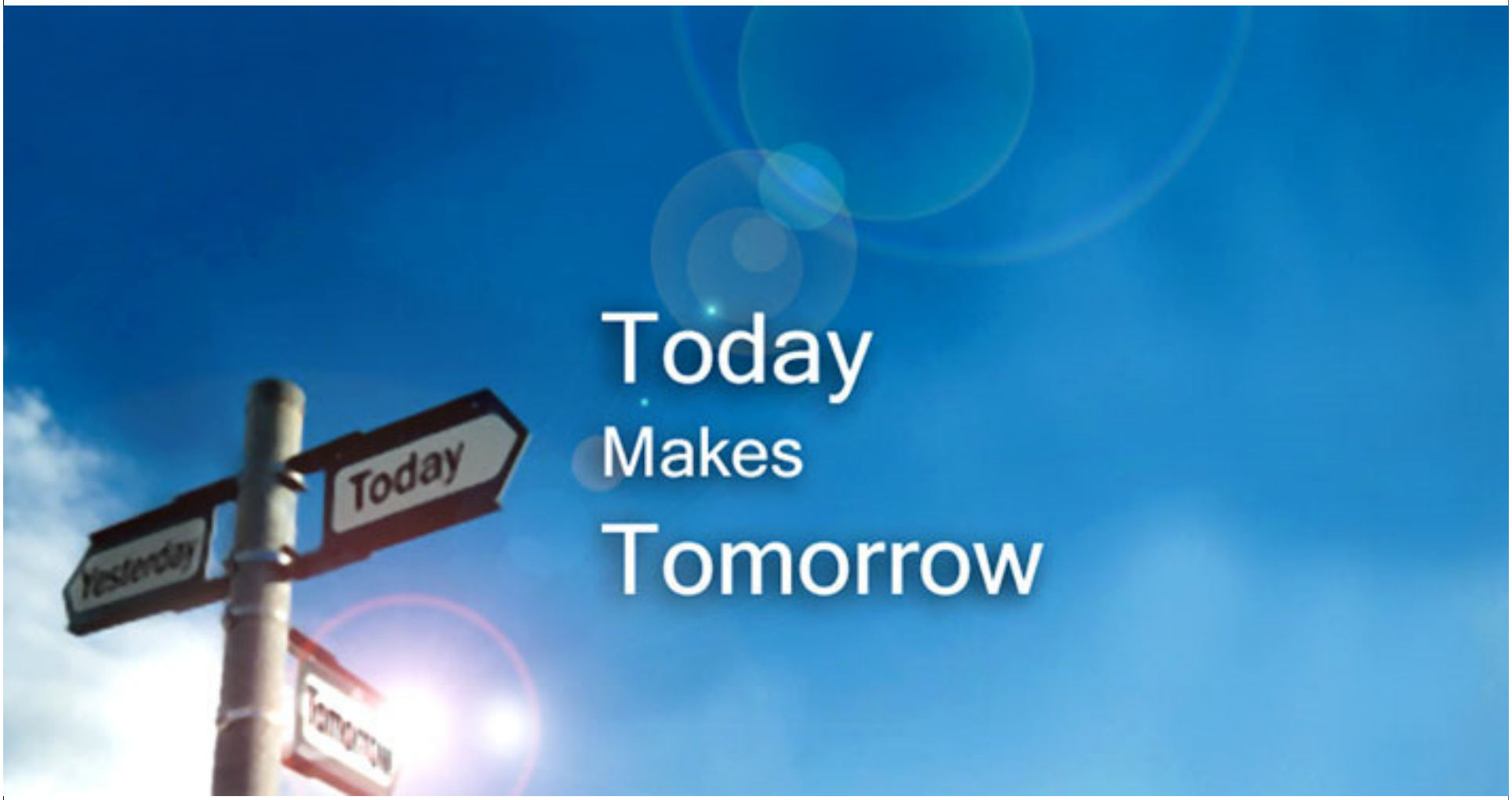
2 Million examples in data base

M.Enzweiler, D.M.Gavrila: "**A Multi-Level Mixture-of-Experts Framework for Pedestrian Classification**", IEEE Transactions on Image Processing, 2011

Object Recognition: Pedestrians

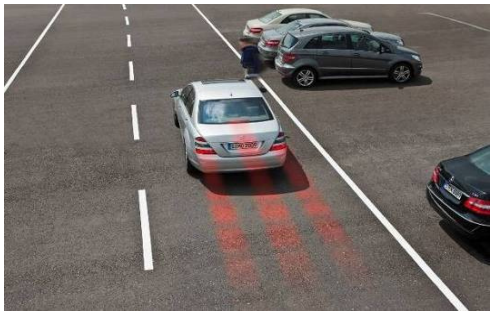
M.Enzweiler, D.M.Gavrila: "**A Multi-Level Mixture-of-Experts Framework for Pedestrian Classification**", IEEE Transactions on Image Processing, 2011

Stereo Vision – Tomorrow



Autonomous Collision Avoidance by Steering

In future we will try to avoid accidents not only by emergency braking but also by steering.



2009: Press event at Daimler test track

C.Keller, T.Dang, A.Joos, C.Rabe, H.Fritz, and D.M.Gavrila: "**Active Pedestrian Safety by Automatic Braking and Evasive Steering**", IEEE Trans. on Intelligent Transportation Systems, vol.12, nr.4, pp.1292-1304, 2011.

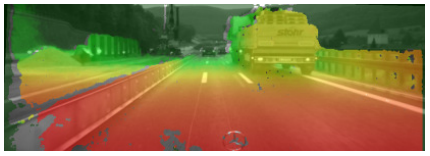
Tracking Vehicles at Large Distances

Distance [m]	400	200	100	50	25
Disparity [px]	1	2	4	8	16

Most times we are measuring small disparities. Subpixel precision is a must.

P.Pinggera, R.Mester, and U.Franke: **„Highly Accurate Depth Estimation for Objects at Large Distances“**, GCPR (German Pattern Recognition Conference), Saarbrücken, September 2013.

From Pixel to Stixel

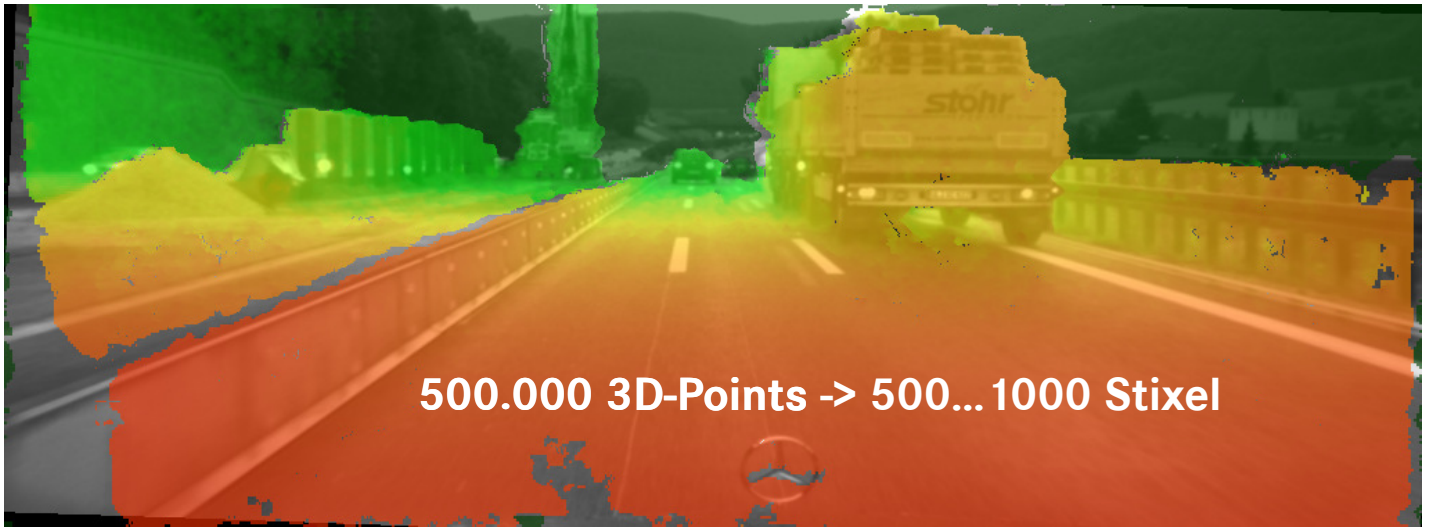


Stereo matching

Generic Representation

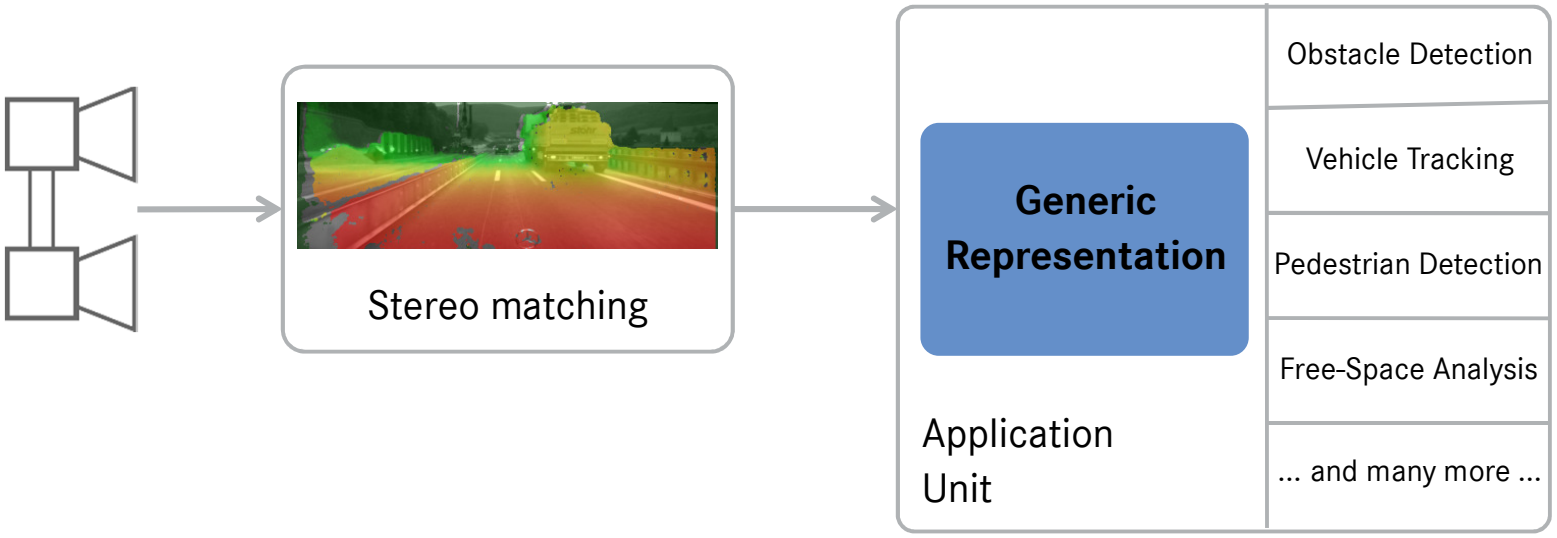
Application Unit

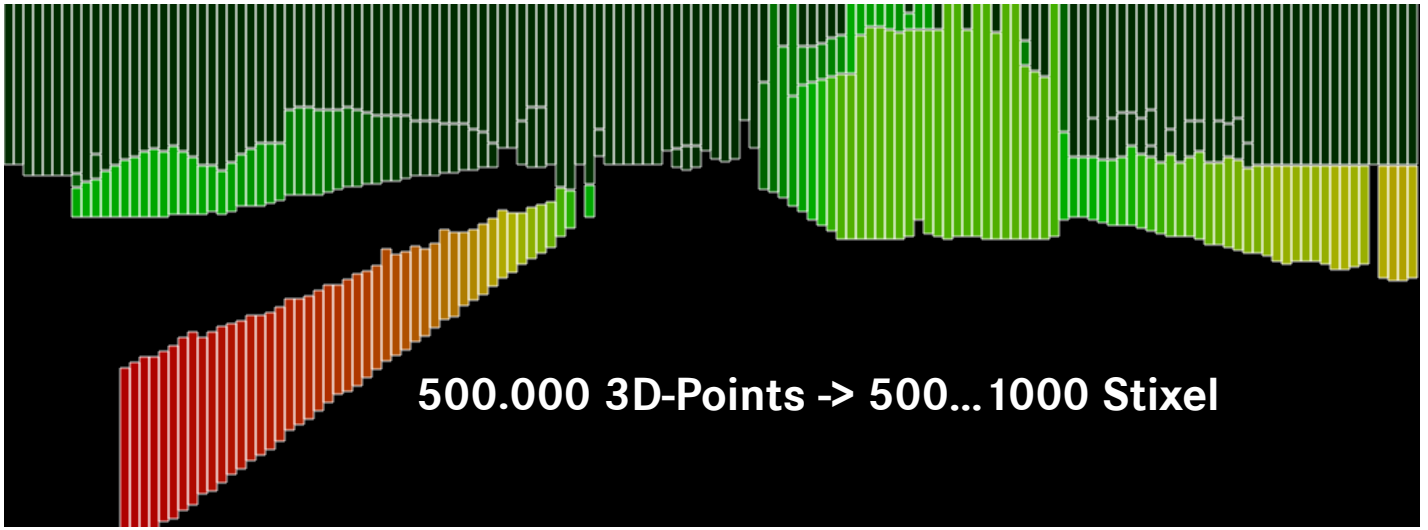
- **Obstacle Detection**
- **Vehicle Tracking**
- **Pedestrian Detection**
- **Free-Space Analysis**
- **... and many more ...**



H.Badino, U.Franke, D.Pfeiffer: "**The Stixel World – A Compact Medium Level Representation of the 3D-World**", 31. DAGM Symposium 2009, Jena, 9.-11.September 2009

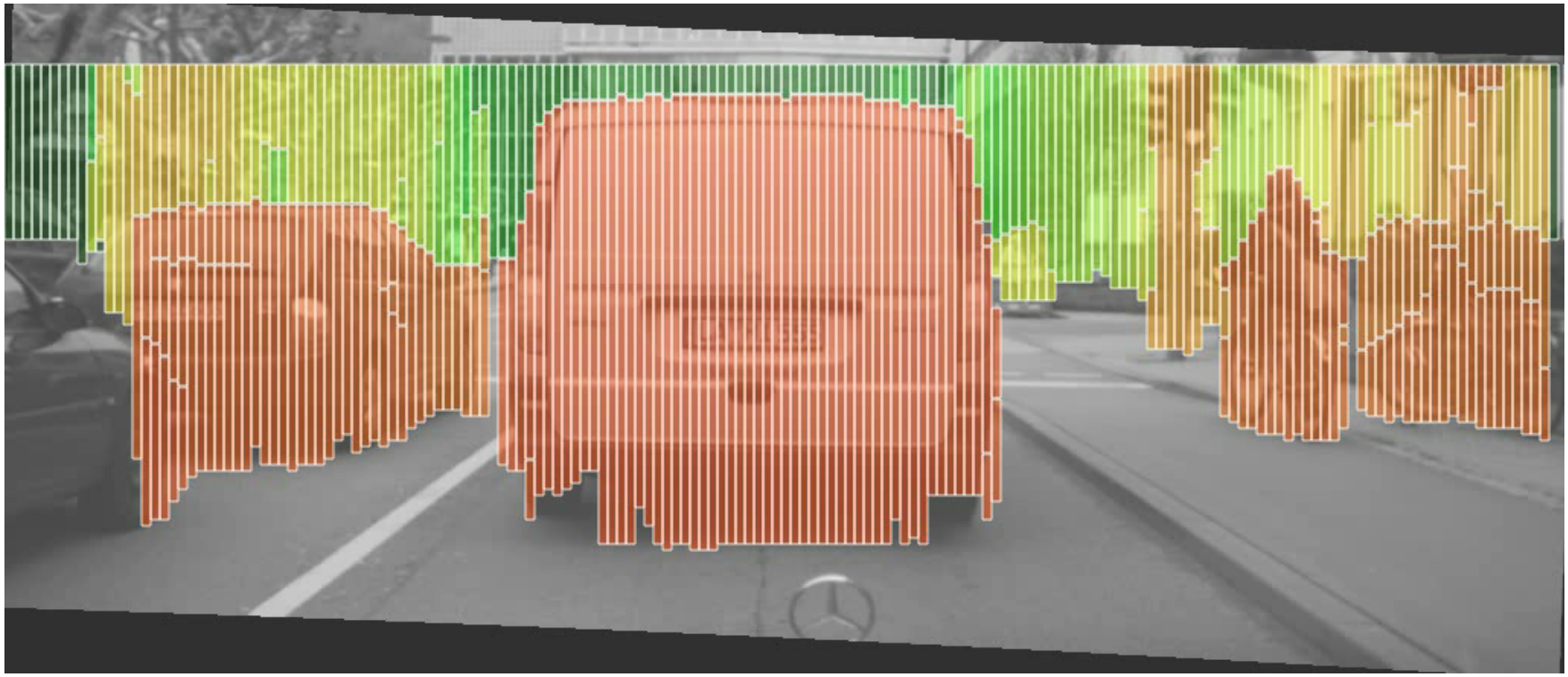
From Pixel to Stixel





H.Badino, U.Franke, D.Pfeiffer: "**The Stixel World – A Compact Medium Level Representation of the 3D-World**", 31. DAGM Symposium 2009, Jena, 9.-11.September 2009

Stixel and the City

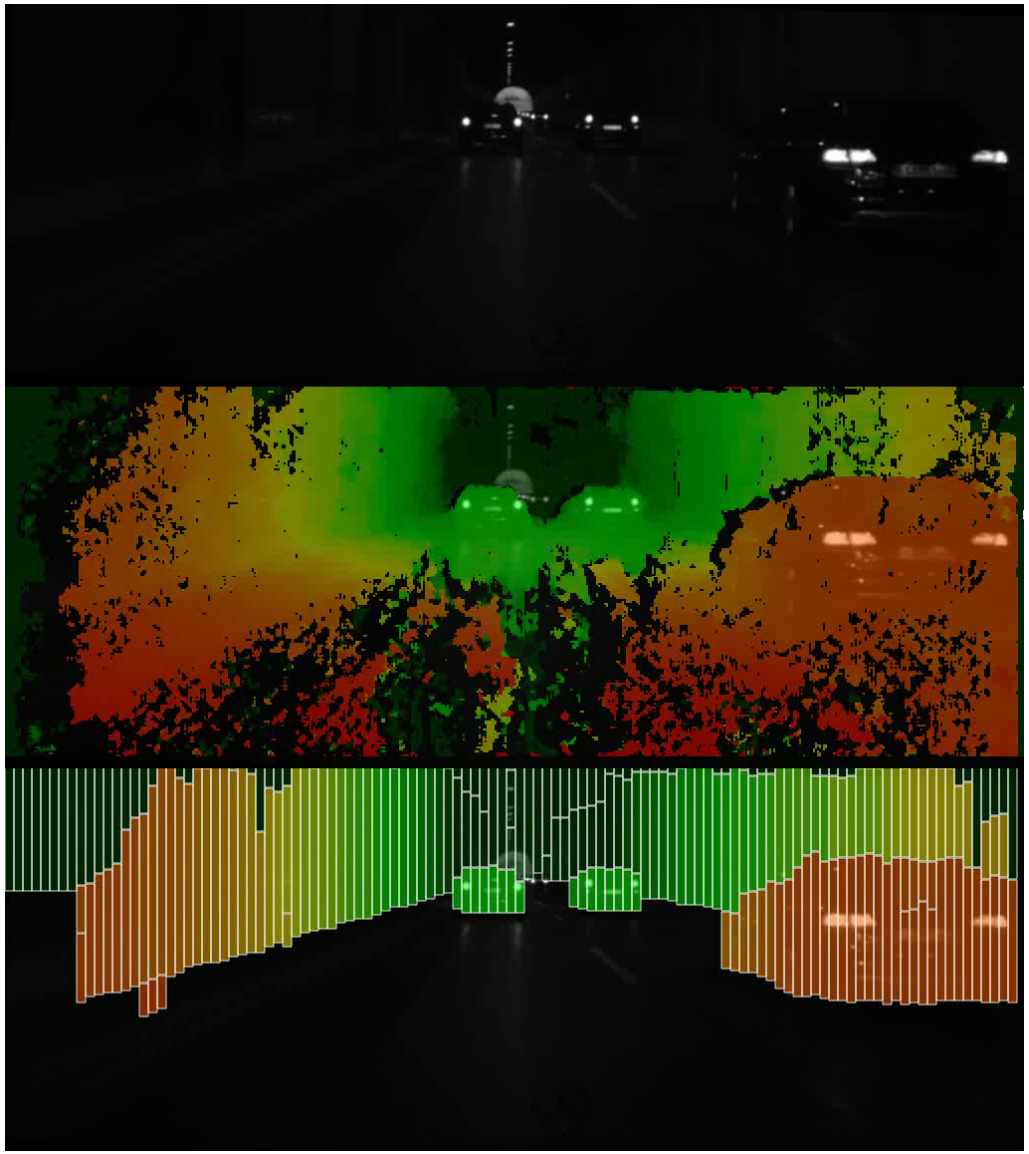


The available freespace (grey) is implicitly encoded by the first row of the Stixel-World.

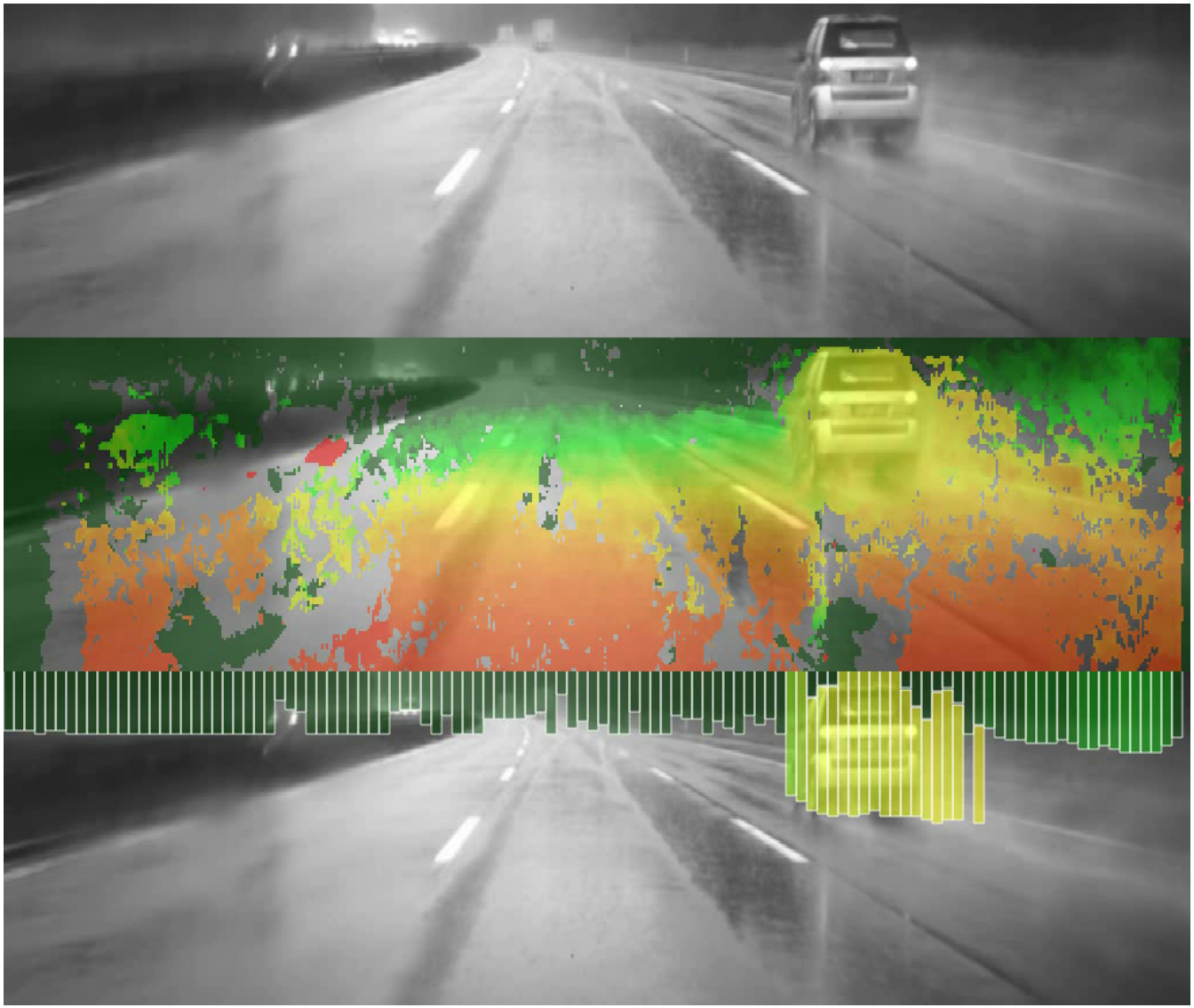
Color encoded distance:
close ..... far

D. Pfeiffer and U. Franke: **„Towards a Global Optimal Multi-Layer Stixel Representation of Dense 3D Data“,** British Machine Vision Conference (BMVC), Dundee, Scotland, September 2011.

Robust Results under Adverse Conditions

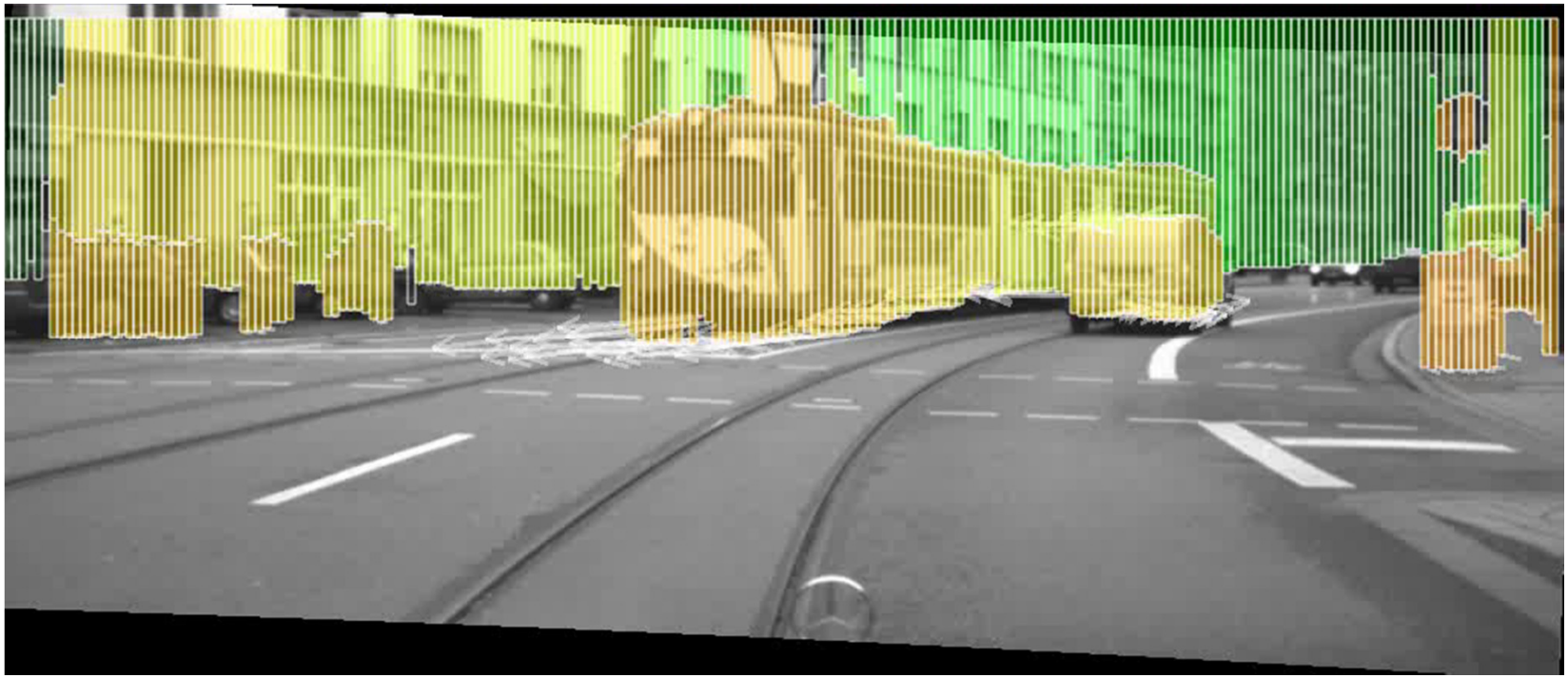


Robust Results under Adverse Conditions



Stixel Motion Estimation

- The 6D-Vision principle allows to estimate the motion of each Stixel.
- The „dynamic“ Stixel-World acts as the input for a subsequent grouping step.



T. Scharwächter: “**Stixel-Based Target Existence Estimation under Adverse Conditions**”,
34. DAGM Symposium 2012, Graz, August 2012

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Stereo Vision for the Day after Tomorrow

Autonomous Driving on Highways

- Today: autonomous driving at low speeds in traffic jams.
- Future: higher speeds will be allowed in an evolutional manner.

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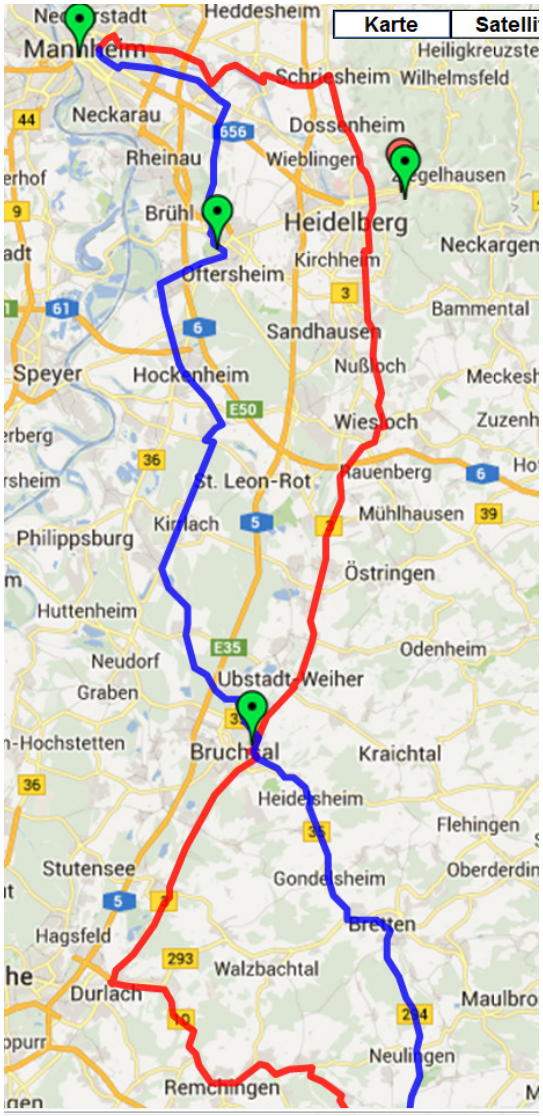
Autonomous Driving in Urban Environment

Autonomous Driving in Urban Environment

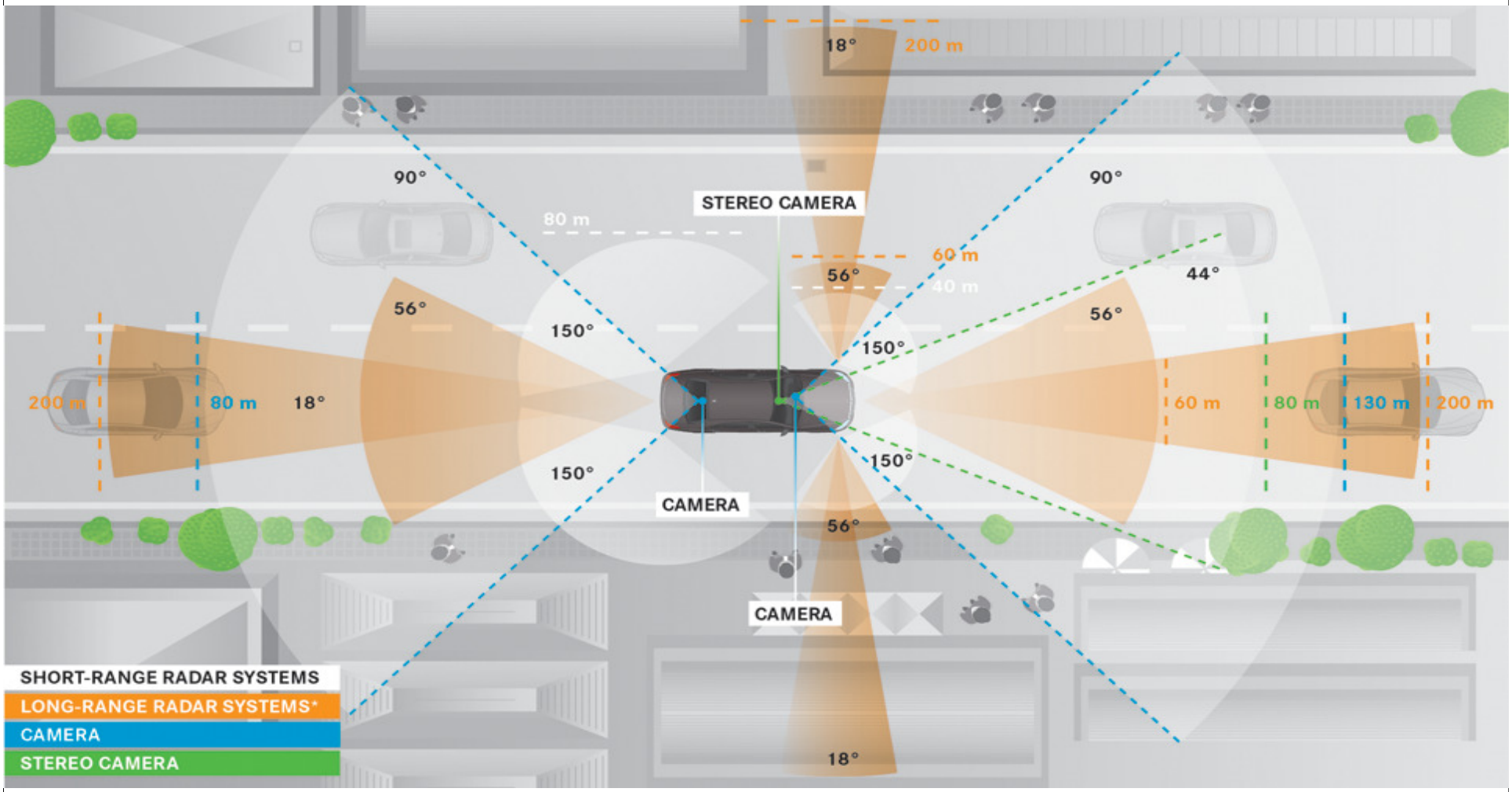


1888: Bertha Benz

2013: S-500 “Bertha”

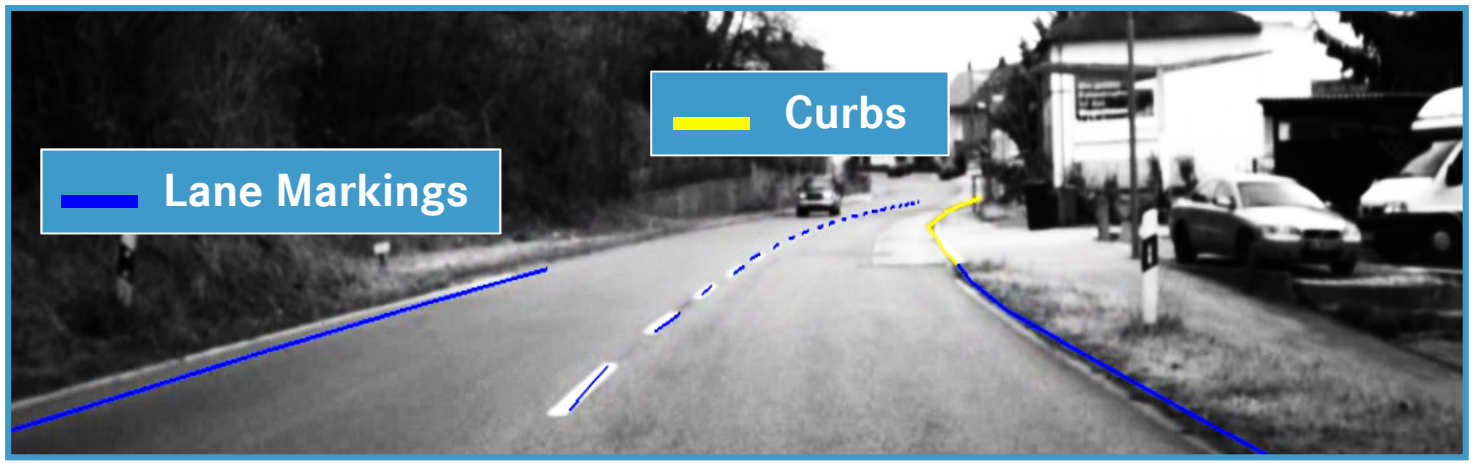
From Mannheim to Pforzheim in 60 Seconds

Bertha's Sensors



Lane Recognition and Localization

Different environments require different types of landmarks.



Rural:
"Lane Loc"

Urban:
"Feature Loc"

Collaboration with KIT Karlsruher Institut für Technologie

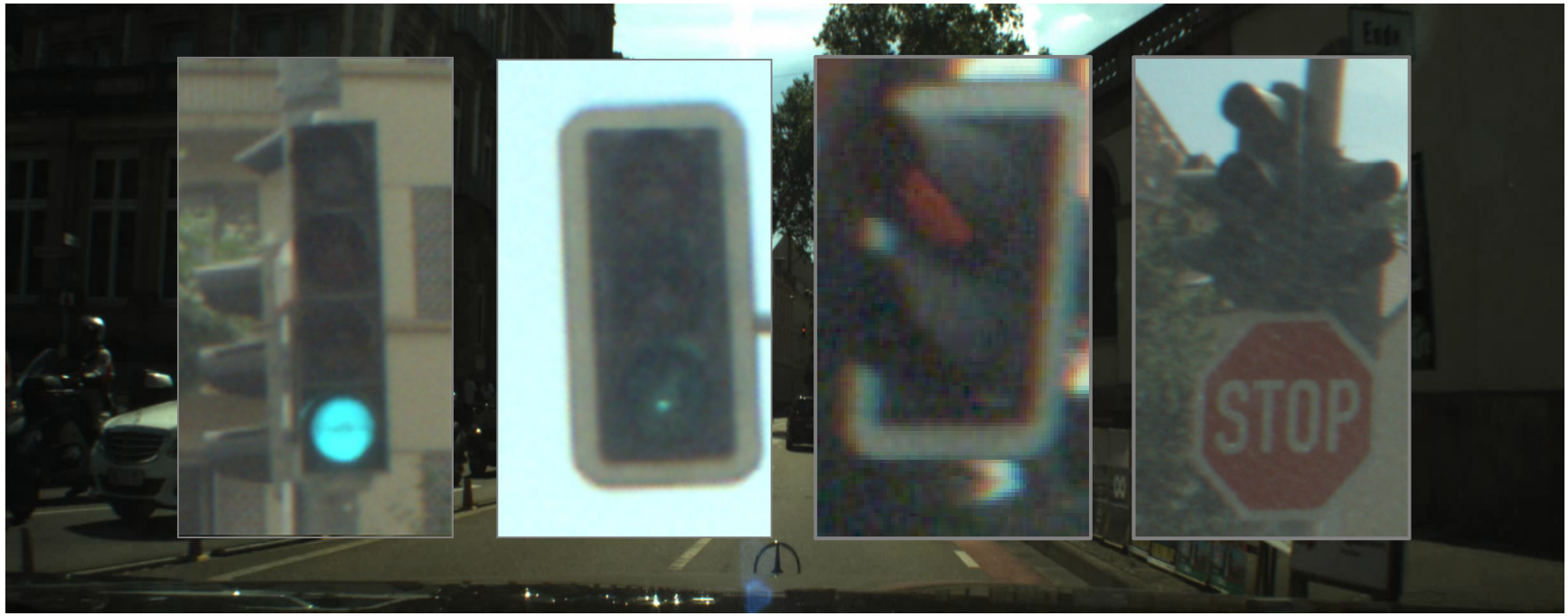
Traffic Light Recognition

Traffic light recognition is not as easy as one may think since

- When stopping in front of the traffic light, it must be in the field of view.
- When approaching a traffic light on rural roads, it must be visible at large distances.
- At intersections, we have to find “our” traffic light.

Traffic Light Recognition

Traffic light recognition seems to be easy, but reality is not since



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- When approaching a traffic light on rural roads, it must be visible at large distances.
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Bertha in the City


Please drive carefully, always !