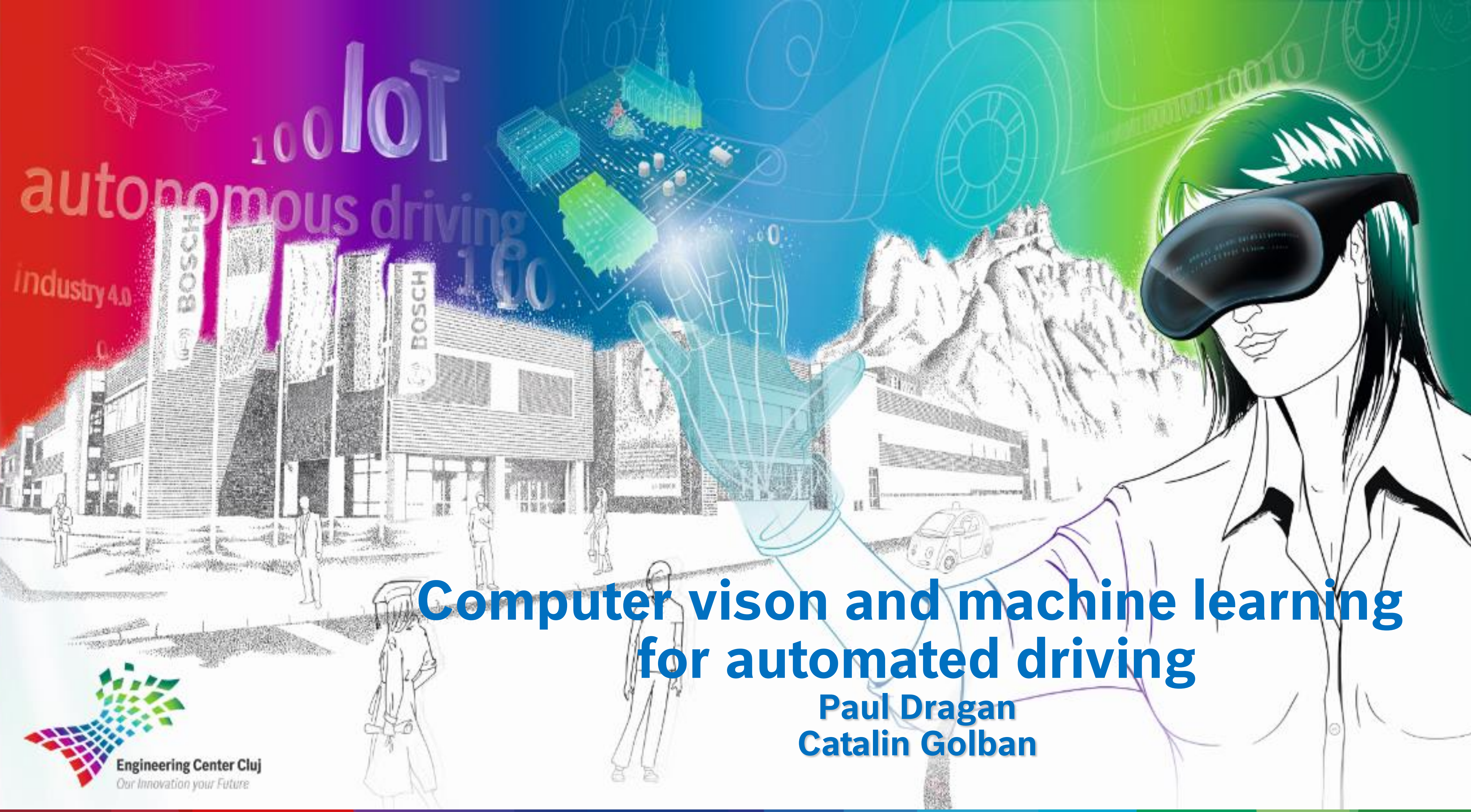


Computer vison and machine learning for automated driving

Paul Dragan
Catalin Golban

Engineering Center Cluj
Our Innovation your Future

Bosch in Cluj-Napoca

Engineering Center Cluj

@offices in the city center, Cluj-Napoca (The Office and Someșului St. 14)

SOFTWARE PROJECTS

Engineering Center Cluj

@Jucu

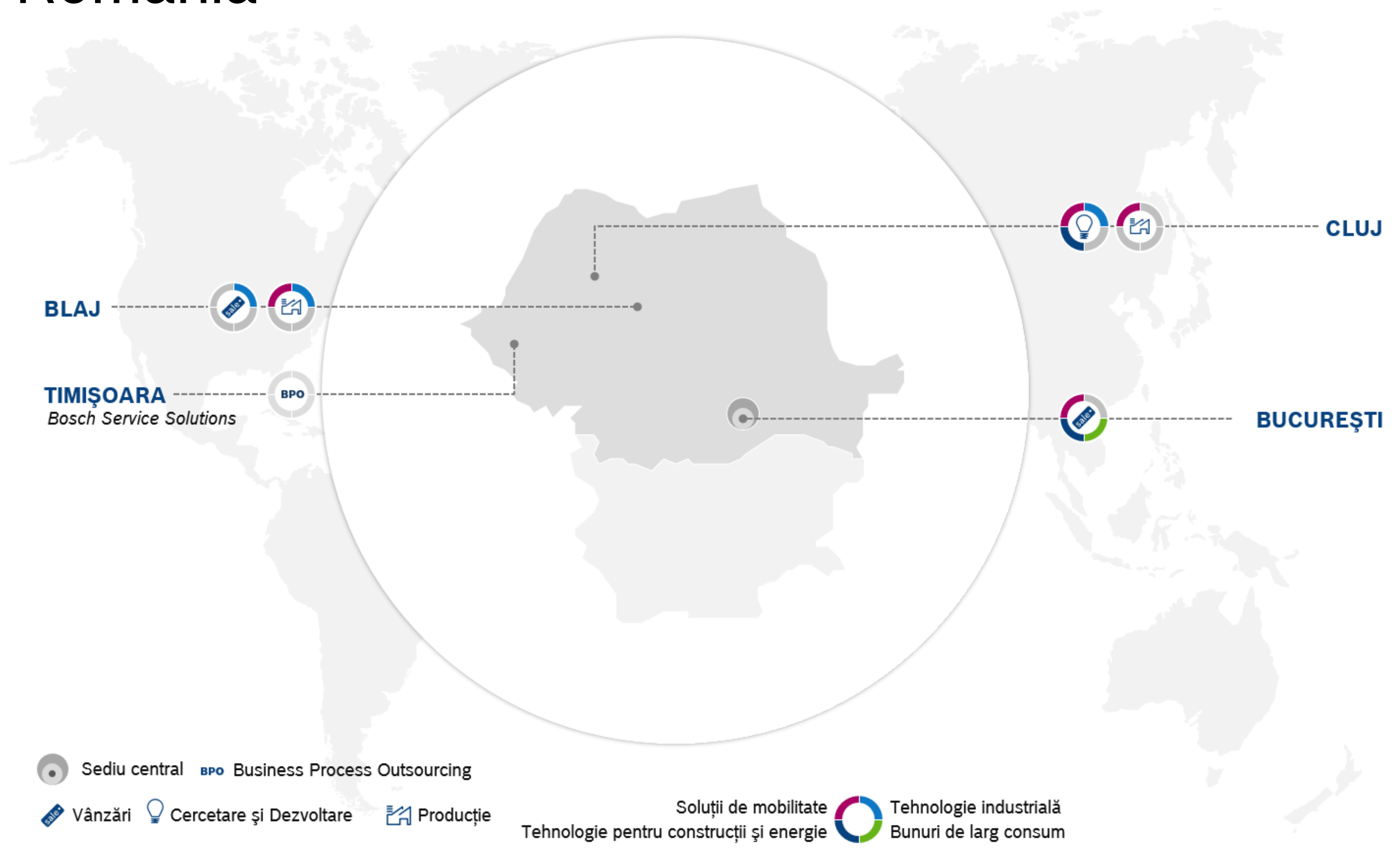
HARDWARE & MECHANICS + RELIABILITY ENGINEERING PROJECTS

Bosch Plant

@Jucu

PRODUCTION

Bosch Romania



Computer vision in today's intelligent cars

Four business sectors at Bosch

Automotive is the main business @Bosch

Mobility solutions

Industrial Technology

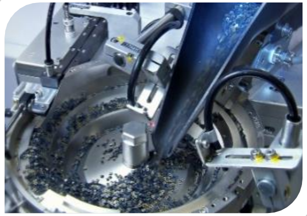
Energy and Building Technology

Consumer Goods

Engineering Center Cluj

SOFTWARE ENGINEERING

RELIABILITY ENGINEERING & VALIDATION



HARDWARE & MECHANICAL ENGINEERING

Ultrasonic Systems

Video Systems

Engine Control Unit

Light Electric Mobility

Radar systems

Electric Power Steering

Industry 4.0 Sensor Solutions

Computer vision in today's intelligent cars

Future Mobility - Electrified, automated and connected

costs hybrid e-motor
eBike power electronics
electrified
plug-in eScooter range
fun-to-drive battery
charging infrastructure

legislation driver assistance
emergency braking autopilot
automated
highway-pilot sensors
redundancy electric steering
valet parking

electronic horizon
smartphone integration
connected
eCall cloud
services fleet management
car2car augmented reality

Computer vision in today's intelligent cars

Bosch sensors portfolio

Long-range radar
Detection range: ~250 m | Field of View: horizontal 12° at 250 m; 30° at 30 m

Night vision camera
Detection range: ~150 m | Field of view: horizontal 32°

Mid-range radar front
Detection range: ~160 m |
Field of View: horizontal 12° at 160 m; 90° at 25 m

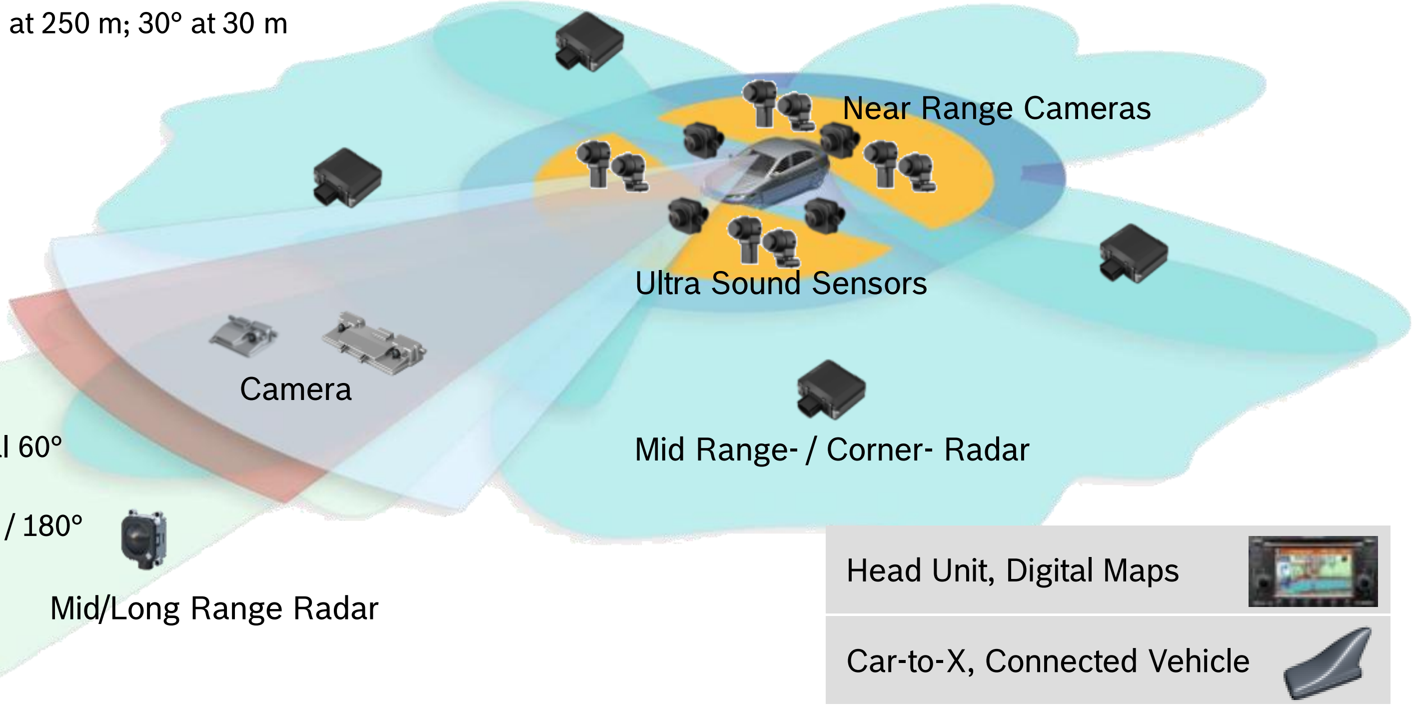
Multi purpose camera / stereo video camera
Detection range: ~150 m (for objects) |
Field of View: horizontal 50°

Ultrasonic sensor
Detection range: ~2.5 m / 5 m | Field of View: horizontal 60°

Near range camera
Detection range: ~15 m | Field of View: horizontal 130° / 180°

Multi-camera system
Detection range: ~15 m | Field of View: horizontal 360°

Mid-range radar rear
Detection range: ~80 m | Field of View: horizontal 150°



Computer vision in today’s intelligent cars

Driver assistance functions portfolio

Light & sight at night functions

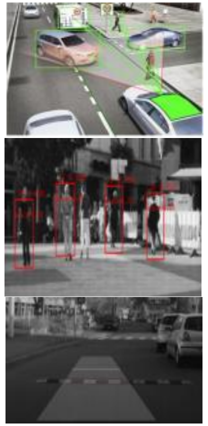
- **High Beam Control**
- **Adaptive Headlight Control**
- Masked Continuous High Beam
- Night Vision with Pedestrian Detection

Road Sign functions

- Speed Limits
- Stop Signs
- Give Way Signs
- Additional signs (Pictograms)
- Fusion with digital map
- general signs (triangular, rectangular)

Object / Surface functions

- **Adaptive Cruise Control**
- **Emergency braking on cars**
- **Emergency braking on pedestrians**
- Maneuver Assistance
- Distance information & warning
- Cross Traffic Alert
- Forward Collision Warning
- Speed Bump Assist
- **Adaptive Suspension**
- Height clearance assist



Lane functions

- Lane Departure Warning
- **Lane Keeping Assist**
- Lane Change Assist / Blind Spot
- **Construction Zone Assist**
- **Narrow Passage Assist**
- Traffic Jam Assist
- Evasion Assist
- Driver Drowsiness Detection

Computer vision in today's intelligent cars

Vision of automated driving

Light & sight at night fu

- **High Beam Control**
- **Adaptive Headlight**
- Masked Continuous
- Night Vision with Pe
  Detection

Road Sign functions

- Speed Limits
- Stop Signs
- Give Way Signs
- l signs (Pictograms)
- l map
- ctangular)

Object / Surface

- **Adaptive Crui**
- **Emergency**
- **Emergency**
- Maneuver A
- Distance info
- Cross Traffic Alert
- Forward Collision Warning
- Speed Bump Assist
- **Adaptive Suspension**
- Height clearance assist

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RBRO/ESA1 | 11/19/2016

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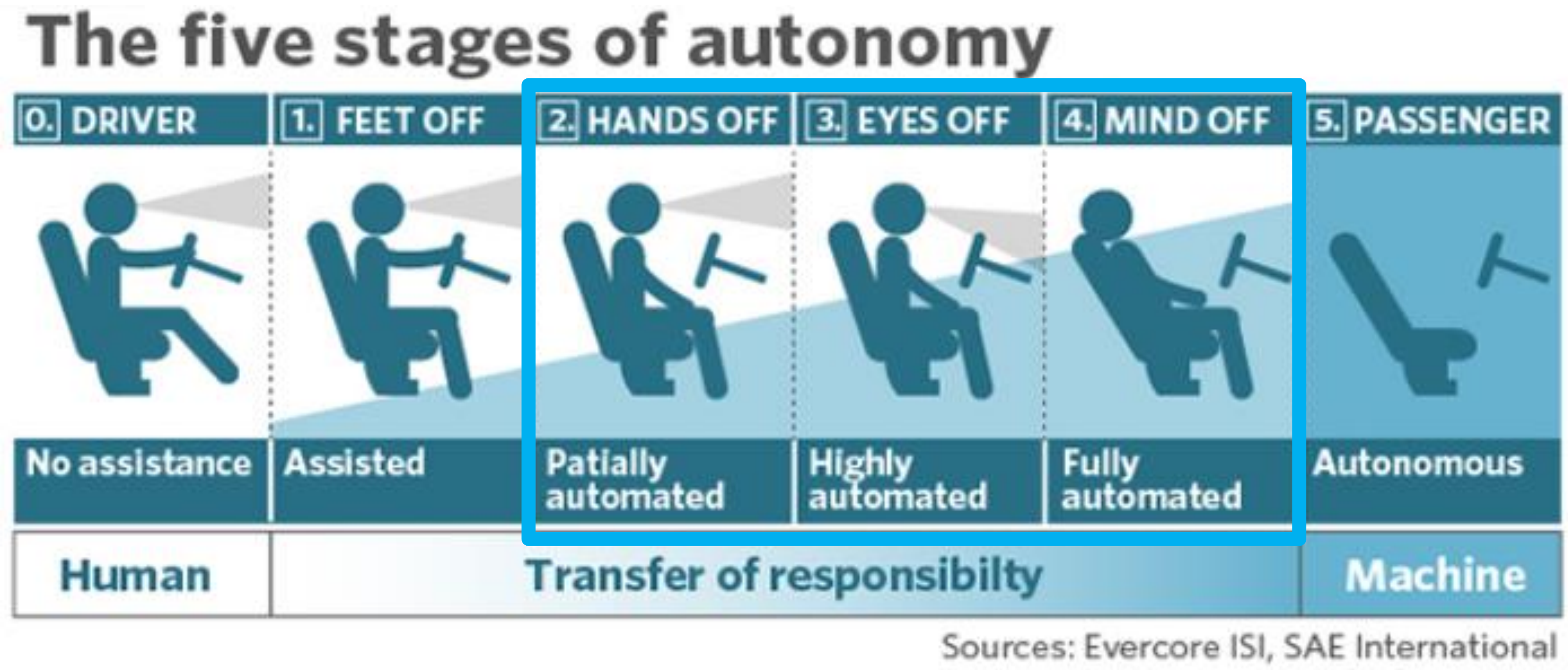
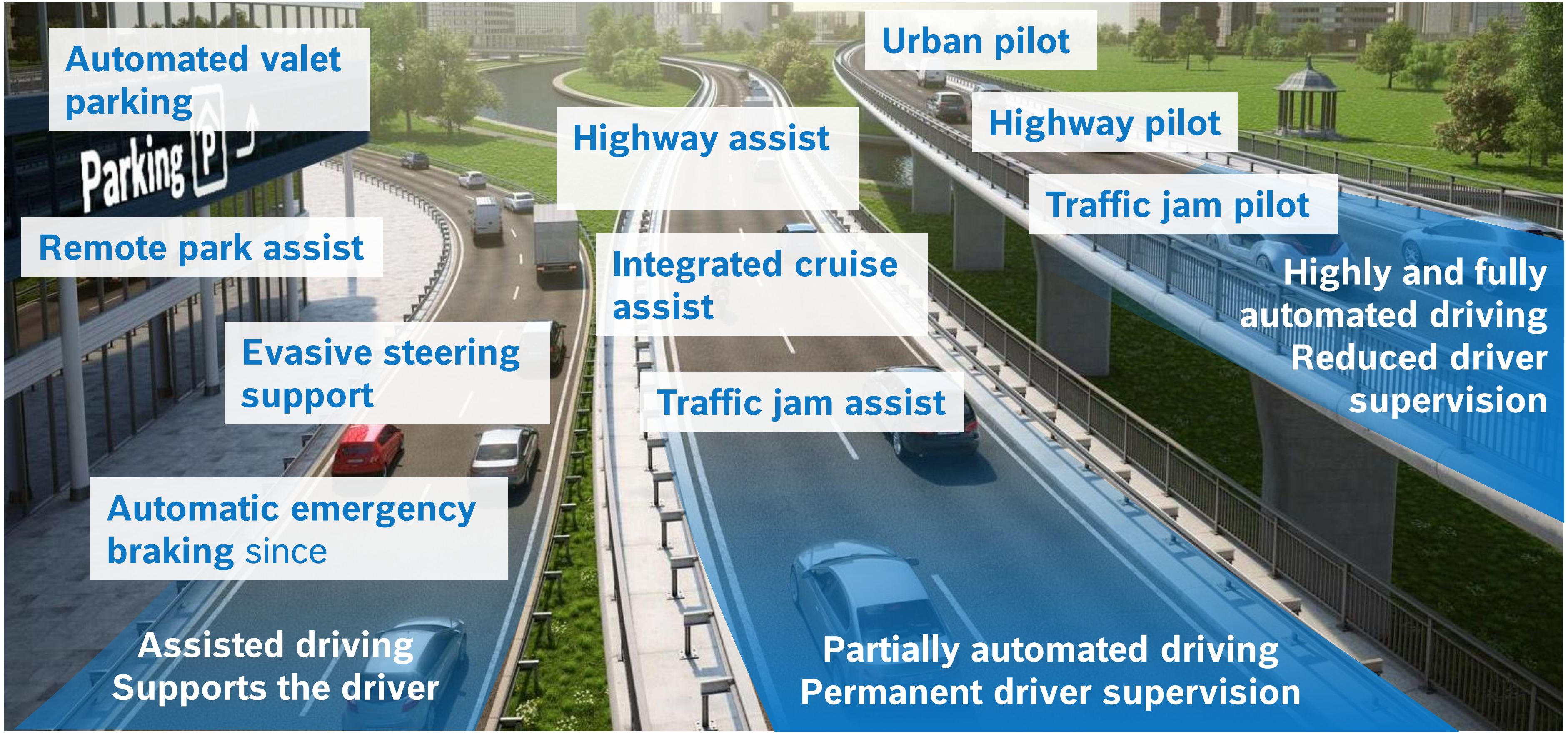
Computer vision in today's intelligent cars
Levels of automation



Computer vision in today's intelligent cars
Roadmap Highly Automated Driving Functions



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Computer vision in today's intelligent cars
Heavy rain example

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Computer vision in today's intelligent cars
Technologies for automated driving

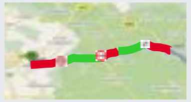
Surround Sensors

are highly robust
in all use cases; fusion

Driver Monitoring

Mandatory for partly automatic

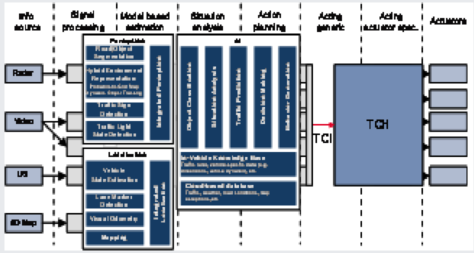
Online Map Data



is precise & up to date every moment

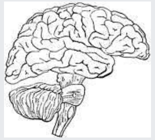
Functional Safety
guarantees high standard @ reasonable effort

Architecture
supports safety, performance & cost targets



Perception and Localization
leads to unambiguous & comprehensive
360° environment model

Reasoning and Decision Making
allows for correct decisions,
even in highly dynamic situations & at incomplete information



Motion Control
works safe, fast & precise in all dimensions

Bosch has all necessary key technologies available and is getting them ready for market entry

Computer vision in today's intelligent cars
What are we doing in Cluj?

- Main responsibilities
  - **Software development** and pre-development for mono and stereo video sensors
  - **Computer vision,** image processing and **machine learning** algorithms development for driver assistance and automated driving

stereo camera

mono camera

Computer vision in today’s intelligent cars

What is computer vision?

- Understand images content algorithmically
- 3D perception (measurements) from images
  - Mono cameras
  - Stereo camera
- **AI course brings you the basics**

knowledge for working in this field

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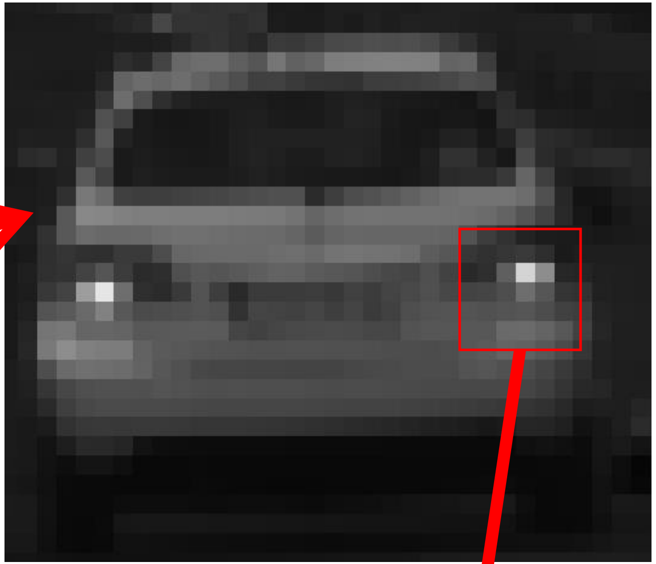
Computer vision in today's intelligent cars
Image representation

- Robustly detect elements in the traffic:
  - Cars
  - Pedestrians
  - Cyclists
  - Guardrail
  - Lanes
  - Poles
  - Road signs

  etc



120	120	121	122	70	40
60	50	40	41	7	8
100	120	121	122	1	0
200	120	200	122	12	14
200	220	225	250	30	40

Bi-dimensional array of values between 0 (black) and 255 (white) for 8bits per pixel

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Computer vision in today's intelligent cars

Example – starting point for lane detection

- Partial derivative the math formula: $$\frac{\delta F(x,y)}{\delta x} = \lim_{\epsilon \to 0} \frac{F(x+\epsilon, y) - F(x,y)}{\epsilon}$$

  Concept since 1600 – Newton, Leibnitz

➔ Partial derivative – for discrete values: $$\frac{\delta F(x,y)}{\delta x} \approx \frac{F(x+1, y) - F(x,y)}{1}$$

-1	0	+1
-2	0	+2
-1	0	+1

Convolution with Sobel filter to get horizontal and vertical edge **features**

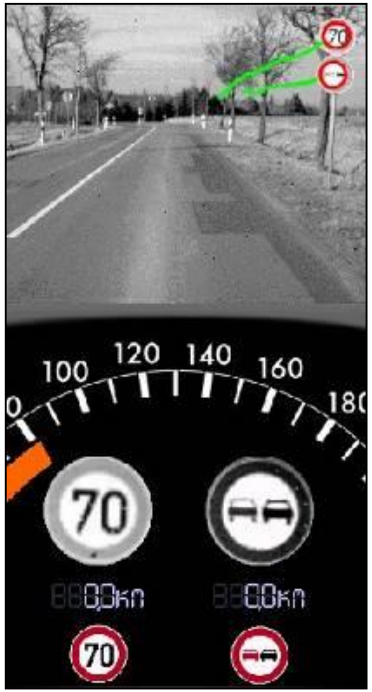
+1	+2	+1
0	0	0
-1	-2	-1

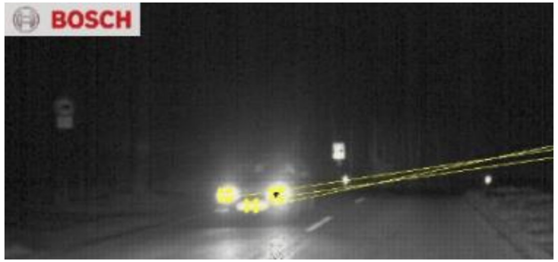
➔ Lane detection can be done by clustering gradient points together based on magnitude & orientation

Computer vision in today's intelligent cars

Perception capabilities of a mono-video system

- **Example 2D information from one camera**
  - Traffic signs (machine learning):
    - Speed Limits
    - Stop Signs
    - Give Way Signs
    - Additional signs (Pictograms)
    - General signs (triangular, rectangular)
  - Lane markings & road segmentation
  - Vehicle lights / traffic lights
  - Object classification (machine learning)

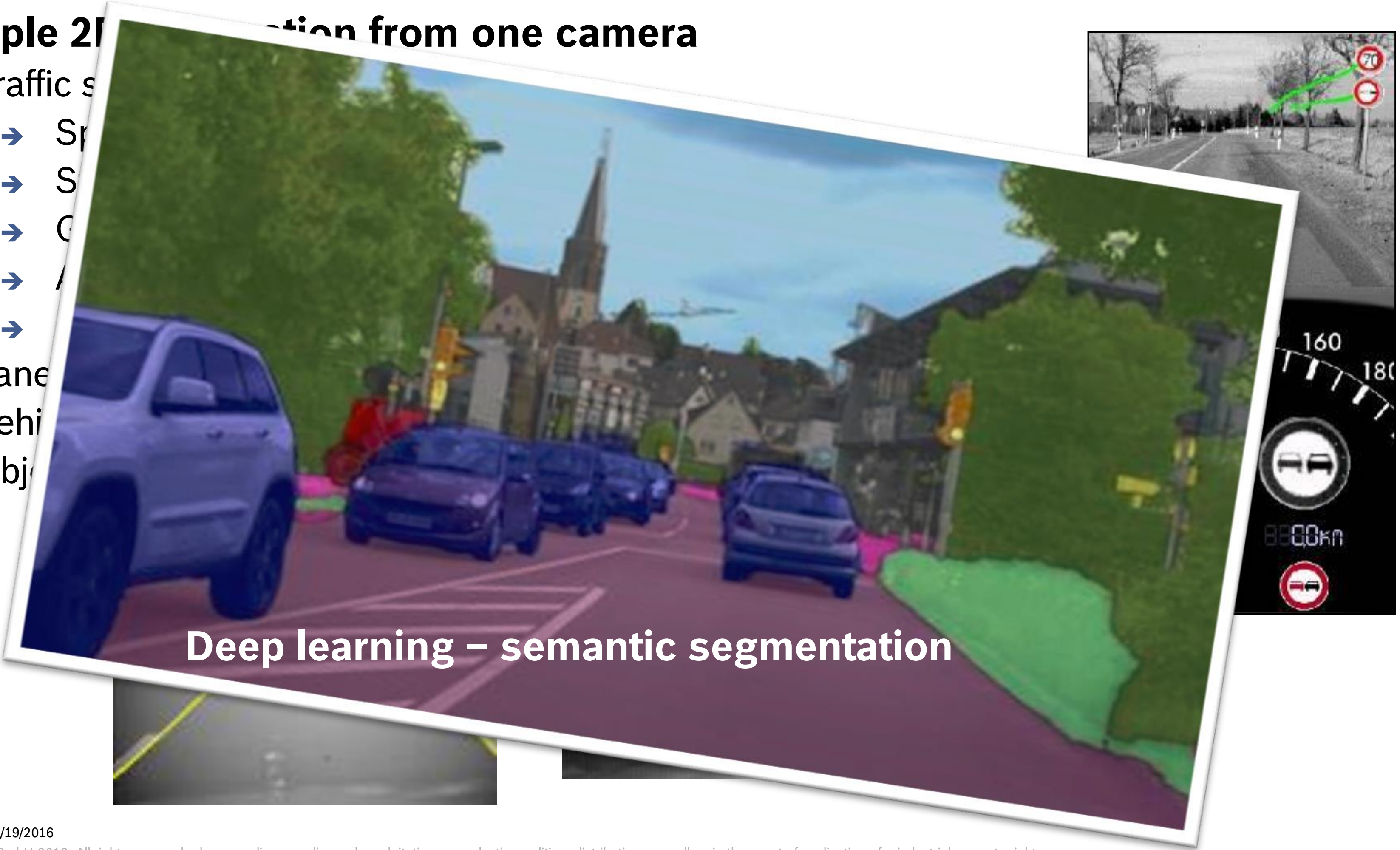




Computer vision in today's intelligent cars

Perception capabilities of a mono-video system

- **Example 2D ... ation from one camera**
  - Traffic s
    - Sp
    - S
    - G
    - A
  - Lane
  - Vehi
  - Obj

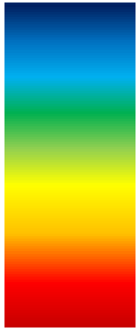


Computer vision in today's intelligent cars

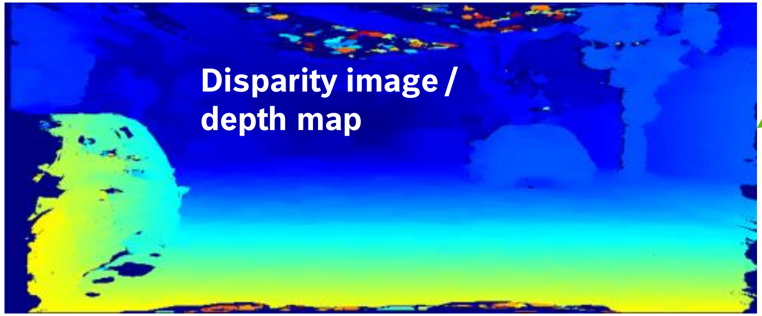
Example 3D point cloud from images

Legend

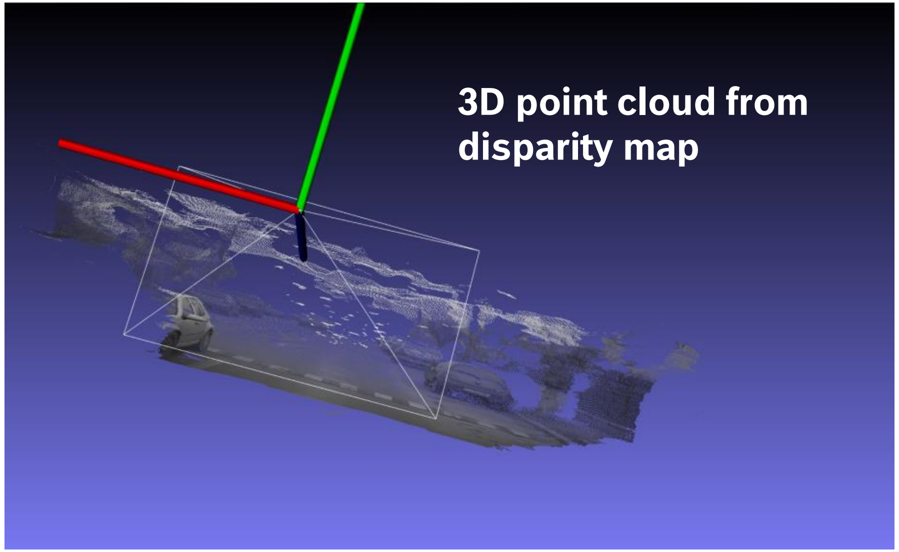
Far objects



Close objects



3D reconstruction



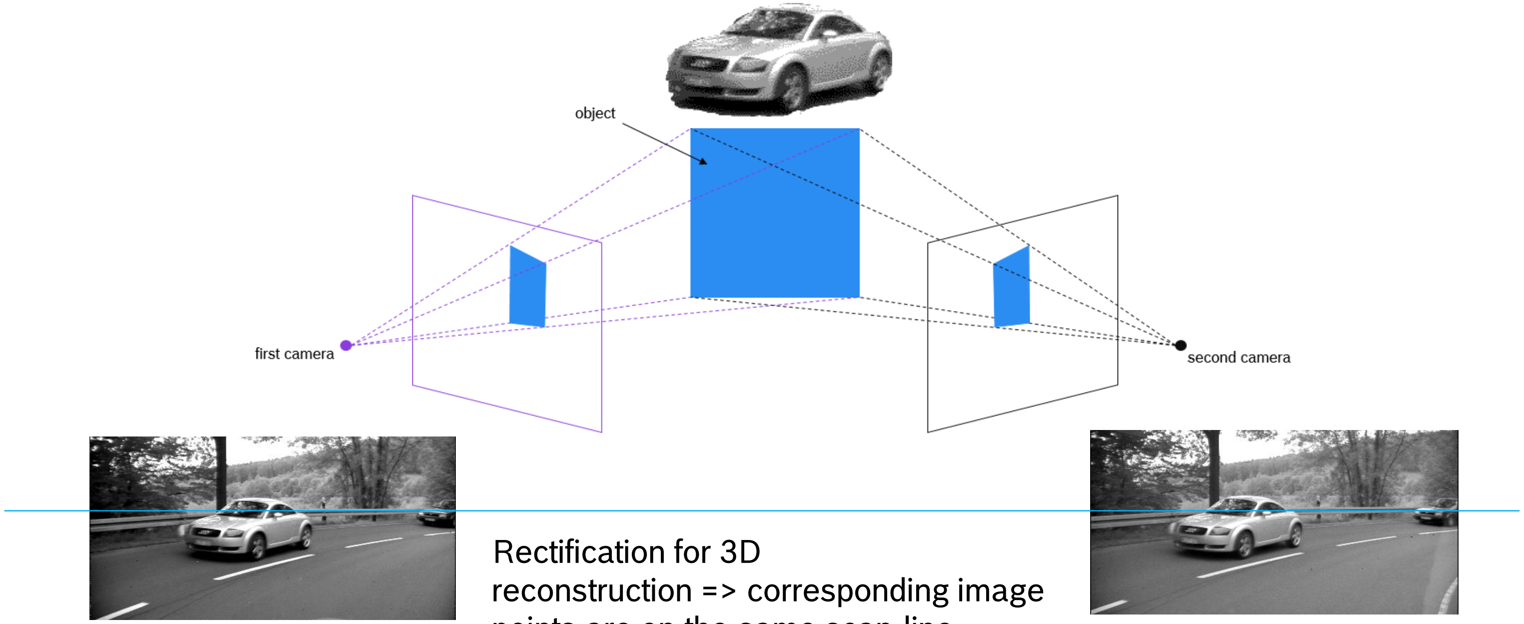
- Big advantage compared to other sensors: density of the data.
- Challenge: process this amount of relatively noisy data on low power embedded hardware.
- Highly optimized algorithms needed.

3D RECONSTRUCTION
General concepts

stereo camera

mono camera

- 3D reconstruction – the process of creating the 3D shape and position of real objects from images
- in computer vision for automated driving
  - using the stereo system - two cameras from different positions, targeting the same scene
  - using the mono system - same camera, targeting the same scene at different points in time



Rectification for 3D reconstruction => corresponding image points are on the same scan-line

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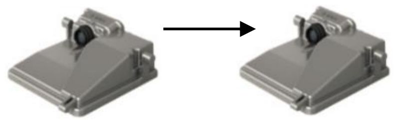
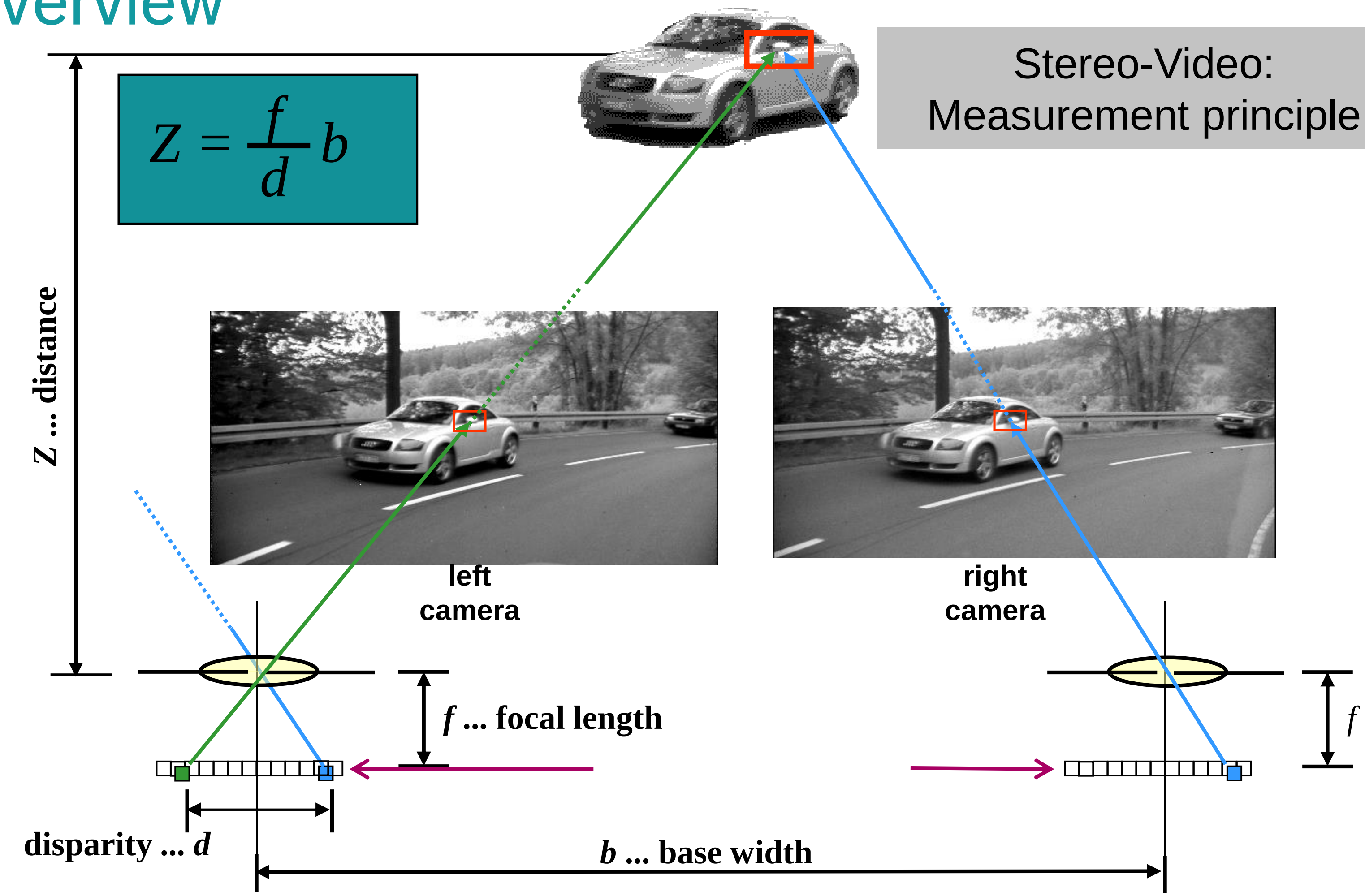
Computer vision in today's intelligent cars

Going 3D - overview



Stereo-Video:
Measurement principle



Computer vision in today's intelligent cars

Perspective projection model

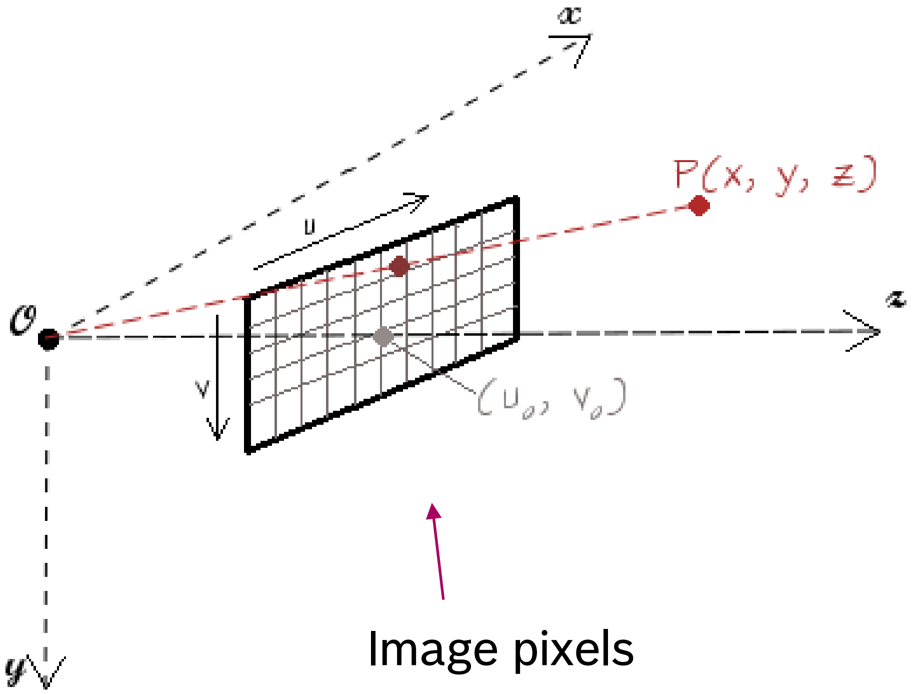


Image pixels

O - camera centre

u_0, v_0- principal point

u, v - image coordinates

f- $d(O, \text{principal point})$

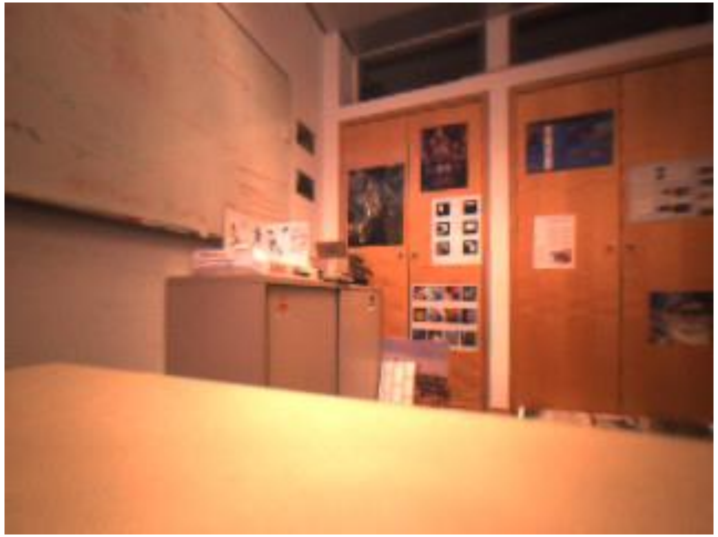
dpx, dpy- size of pixels

f_x, f_y- Focal length in pixels

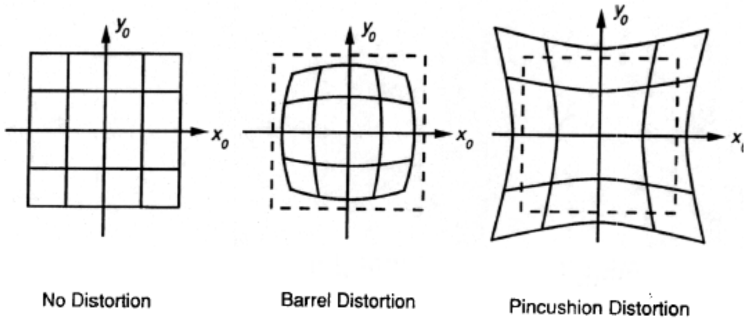
Intrinsic calibration parameters needs to be determined by calibration:

- Distortion parameters
- Principal point
- Focal length

Computer vision in today's intelligent cars
Lens distortion removal



Dynamic Vision, T. Schon



- Basic idea for **offline calibration**: us a pattern with known geometry that can be detected in images and then warp the image such that the projection of the calibration pattern follows the pinhole model.
- **Online calibration** also performed in the series products.

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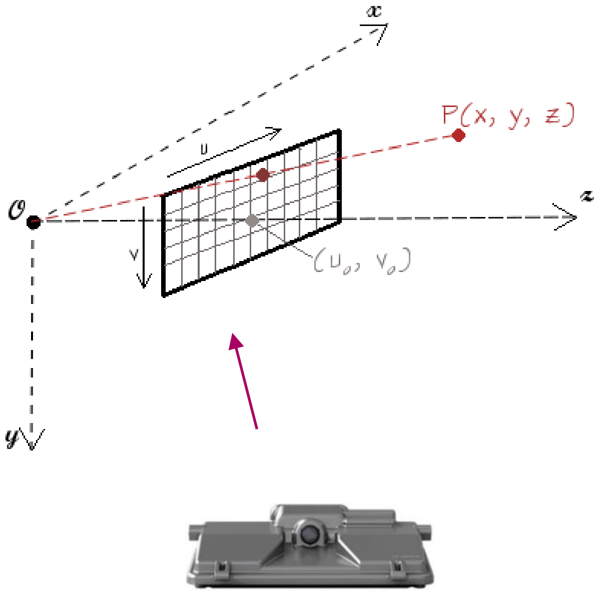
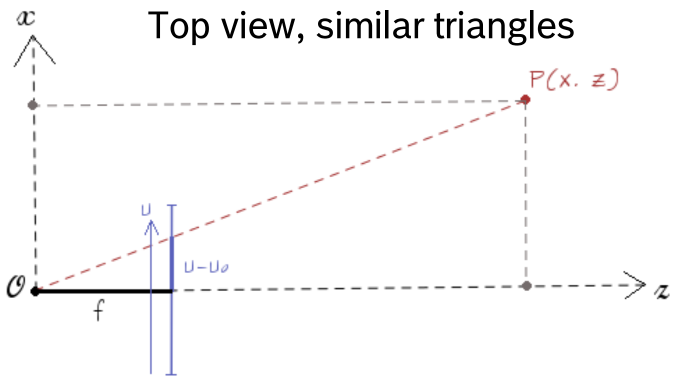
Computer vision in today's intelligent cars
Going 3D



Top view, similar triangles



z is unknown from single image

$$x = \frac{\color{red}{z} * (u - u_0)}{f_x}$$

$$y = \frac{\color{red}{z} * (v - v_0)}{f_y}$$

- Remark: 3D reconstruction can be achieved with lower accuracy form consecutive frames (structure from motion)

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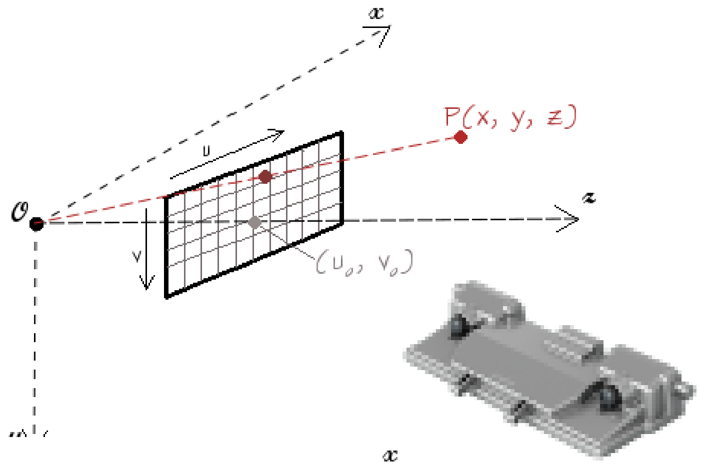
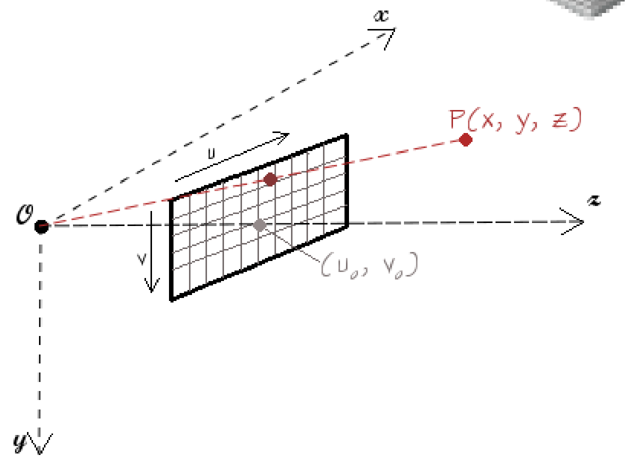
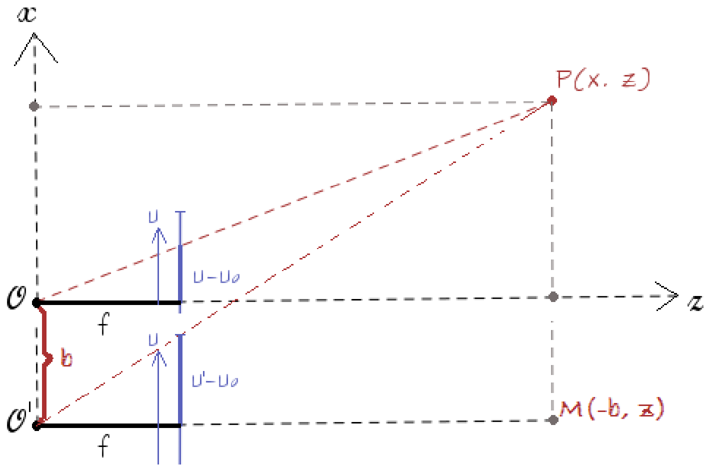
Computer vision in today's intelligent cars
Going 3D





Top view, similar triangles, 2 cameras



z is unknown from single image

$$x = \frac{\mathbf{z} * (u - u_0)}{f_x}$$

$$y = \frac{\mathbf{z} * (v - v_0)}{f_y}$$

$$z = \frac{b * f_x}{d}$$

- For precision:
  - Matching between left & right image are important.
  - Alignment between left & right camera is important
- Remark: 3D reconstruction can also be achieved with lower accuracy form consecutive frames od a mono camera with a similar geometric model (**structure from motion**)

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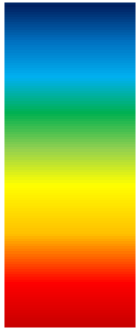
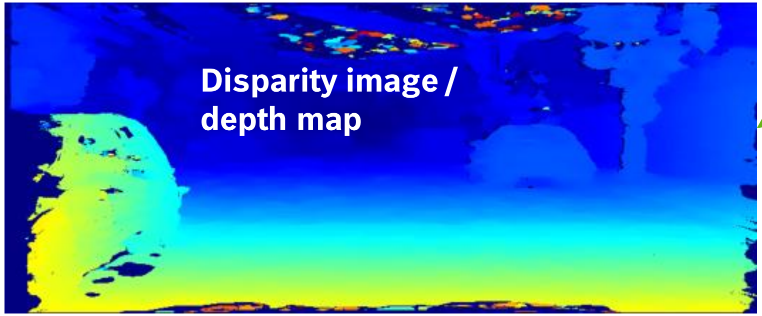
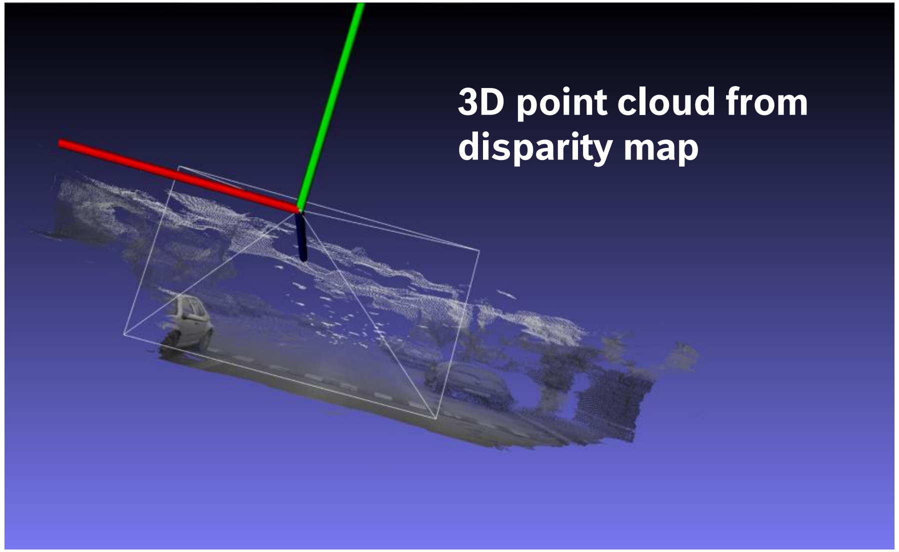
Computer vision in today's intelligent cars
Example 3D point cloud from images





3D reconstruction



- Big advantage compared to other sensors: density of the data.
- Challenge: process this amount of relatively noisy data on low power embedded hardware.
- Highly optimized algorithms needed.

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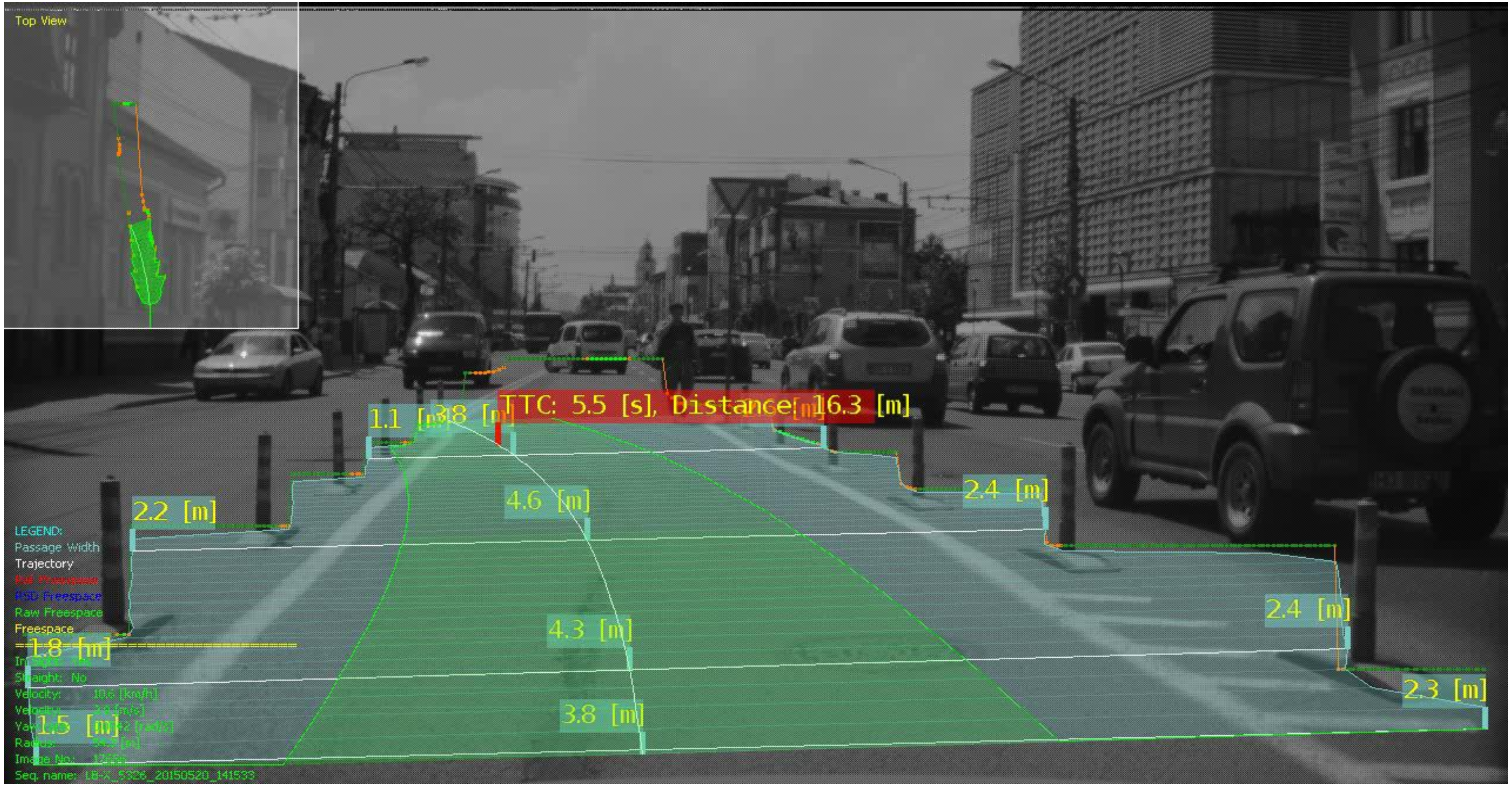
Computer vision in today’s intelligent cars
Perception capabilities of a stereo video system

- complete **3D environment information**
  - path topography (slopes, bumps, potholes, lane grooves)
  - height obstructions (bridges, trees)
  - path width (narrow passages, parking)
- complete **3D object information**
  - cars, trucks, cycles, pedestrians, ...
  - guard rails, poles, walls, trees, animals,...

Computer vision in today’s intelligent cars
Example free-space measurements



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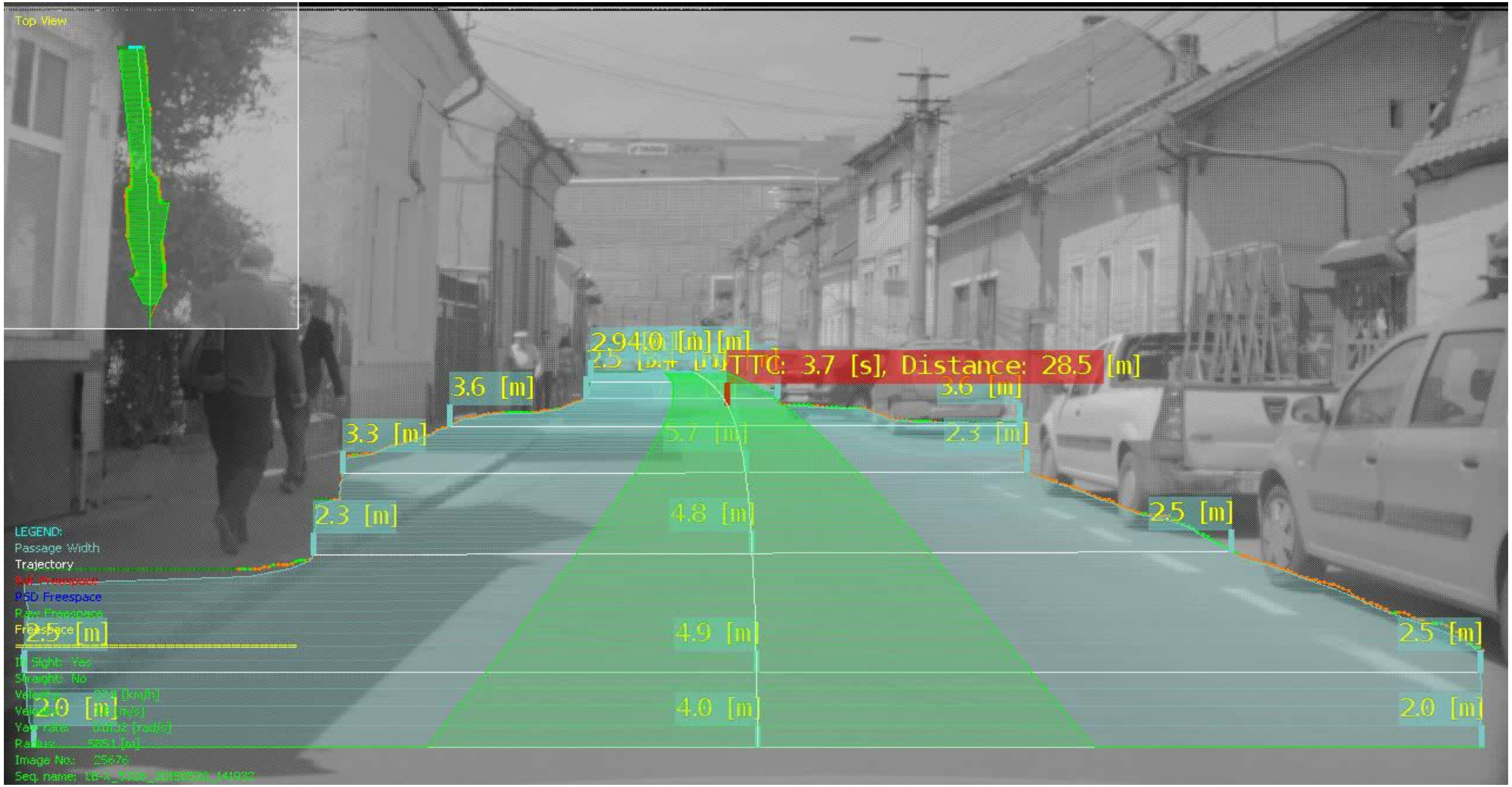
Computer vision in today's intelligent cars

Example free-space measurements on narrow roads



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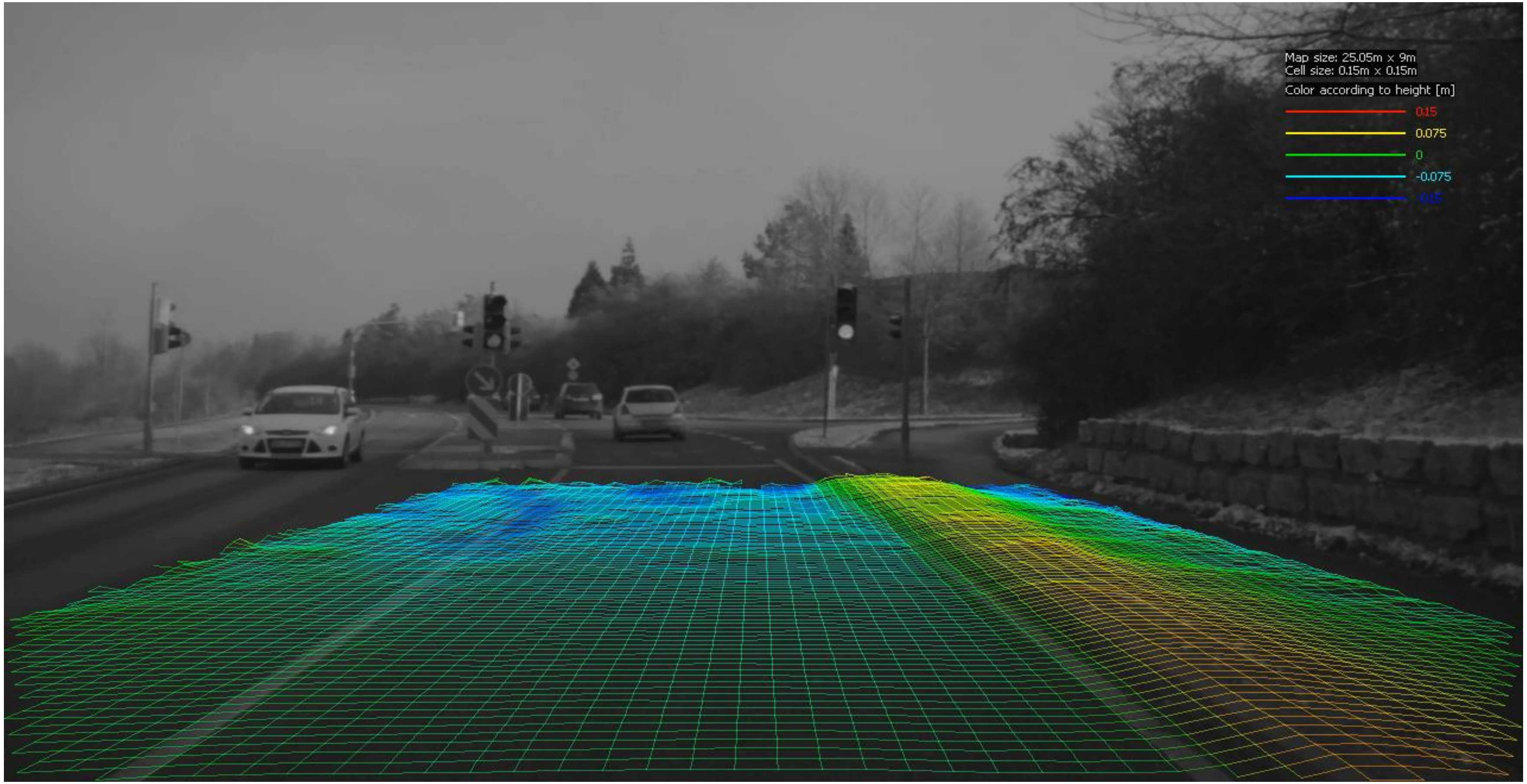
Computer vision in today’s intelligent cars
Example surface topography measurements



Computer vision in today's intelligent cars

Height obstructions

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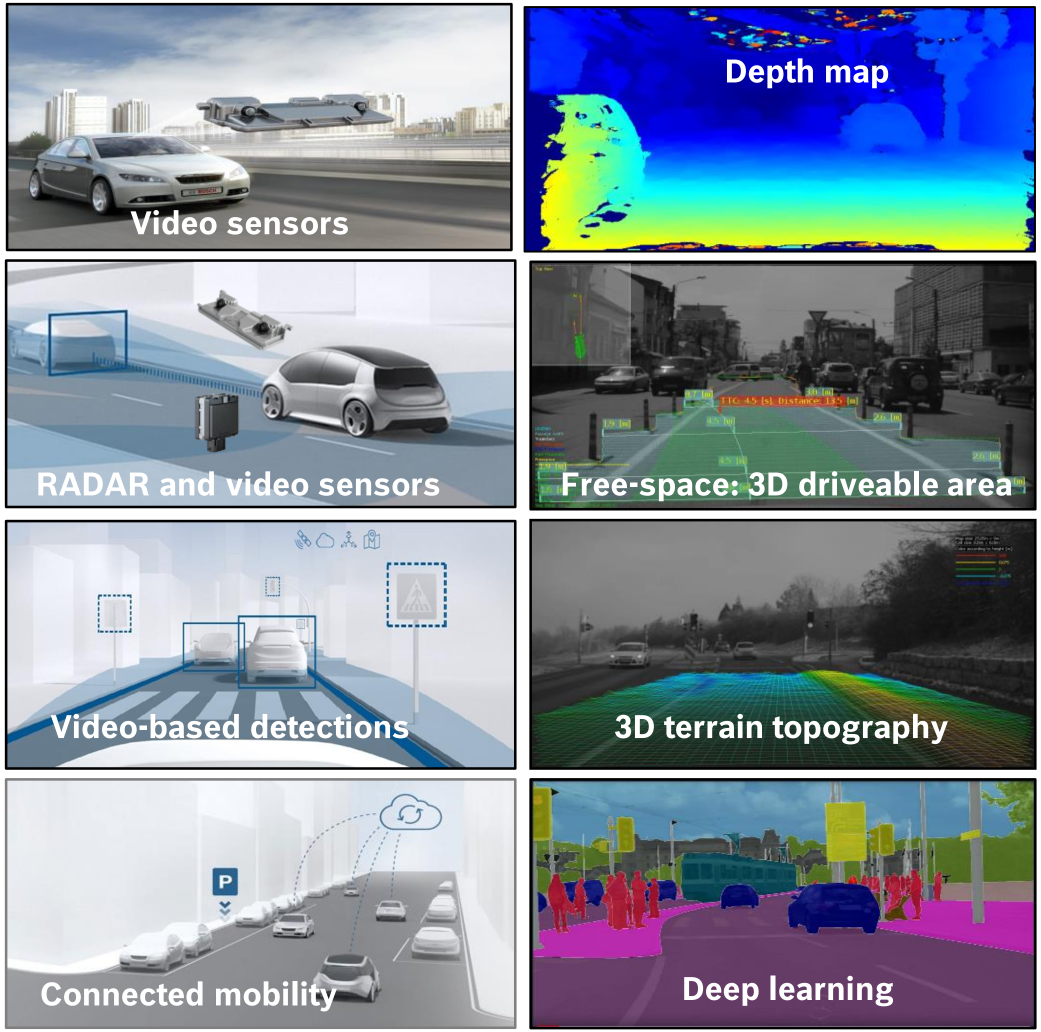
Computer vision in today's intelligent cars
Student topics

- **Computer vision topics for summer 2018**
  - (1) Algorithms development on automotive **parallel computing** architectures (like a GPU)
  - (2) **Tracking and data fusion** (radar, video, LiDAR)
  - (3) Algorithms for **3D data processing**:
    - All kind of objects detection from depth map (3D objects)
  - (4) **Machine learning and deep learning**
  - **Main technologies**: C/C++, python, Matlab, visualizations (ex: QT, OpenGL), Deep Learning (ex: TensorFlow)
- **Connectivity & tools development**
  - **Full stack web** development (Java or C#/.Net, Angular, JavaScript, IoT)
  - **Cloud Software** development (Spark, Hadoop, data **analytics** and visualization)



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Thank you!

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