KIT
Karlsruhe Institute of Technology

Technologies Towards Automated Vehicles

Institute of Measurement and Control Systems

Christoph Stiller

What is the State of the Art of Automated Vehicles?

Selected Challenges & Public Demonstrations

Karlsruhe Institute of Technology

Stanley 2005
Darpa Grand Challenge

Boss 2007
Darpa Urban Challenge


BMW 2011
Automated Highway Drive

GCDC 2011
Cooperative Longitudinal Control

Bertha Benz Tour 2013
Mannheim to Pforzheim


GCDC 2016
Cooperative Intersection Crossing

Long Distance Automated Driving

Bertha Benz Memorial Route

- 100+ km
  on historic route
- 3 large cities
- 23 smaller towns

Are We There Yet?

State of the Art

- Automated Driving is feasible
  - >10 Mkm on Road Automated Driving
  - Safety Driver or Restricted Area needed
  - Limited Cooperation with Others

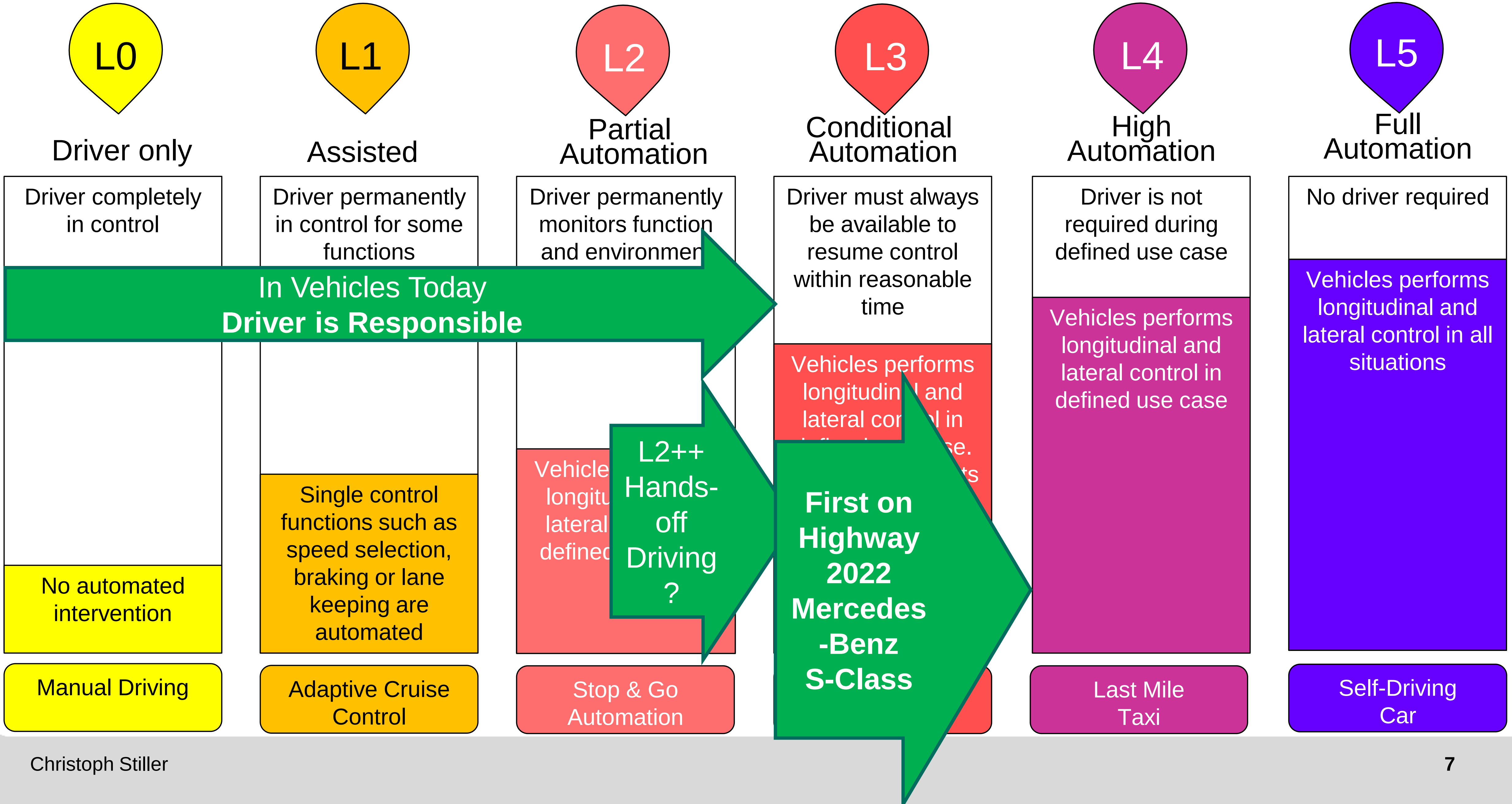
Challenges of Automated Vehicles

- Provable Behavioural Safety
  - Reliable Maps & Perception
  - Planning based on „What could happen?“-Reasoning
  - Risk Assessment

- Cooperativity

- Safety Validation and Testing

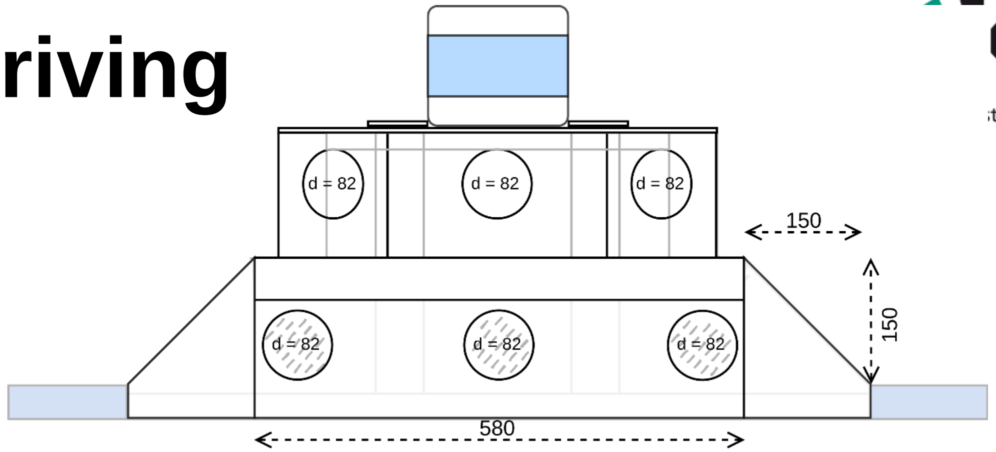
SAE Automation Levels – Automotive Industry



Selected Research in Perception

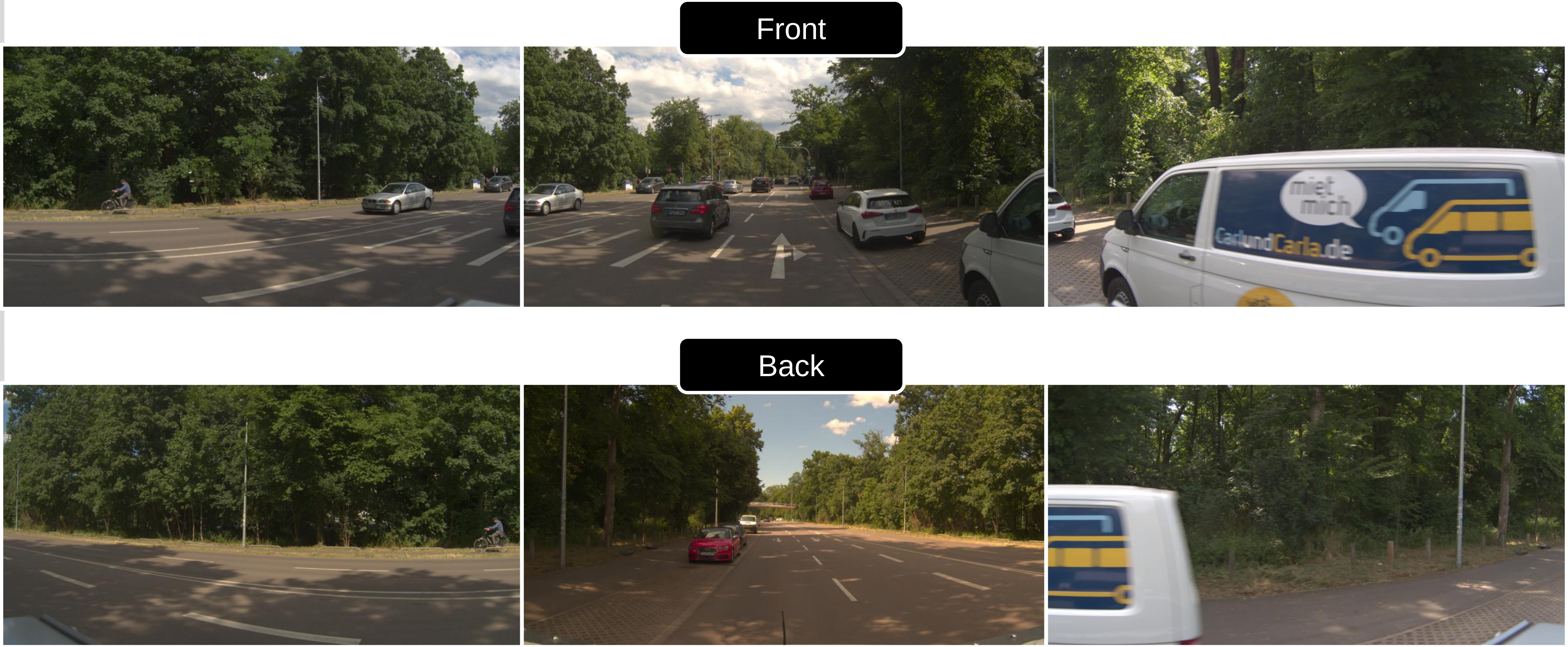
Sensor Box for Automated Driving

- VLS-128 Alpha Prime Lidar
- 2x Hesai XT-32 for near range
- 6 x 90° low-distortion cameras
- Stereo HDR cameras
- Trigger box, IMU, GNSS



Sensor box: Base Cameras

Sensor box: Cameras in Ring



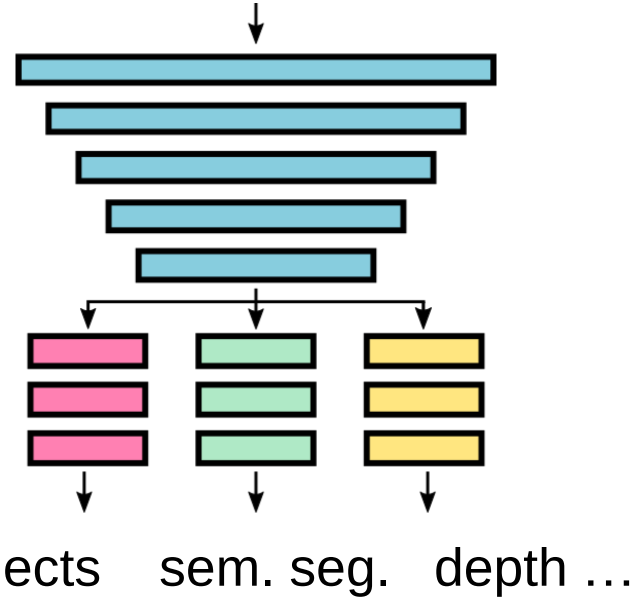
Multi Task Learning

Rich information required:

- Object pose and motion
- Semantic segmentation
- 3d geometry
- Optical flow
- …

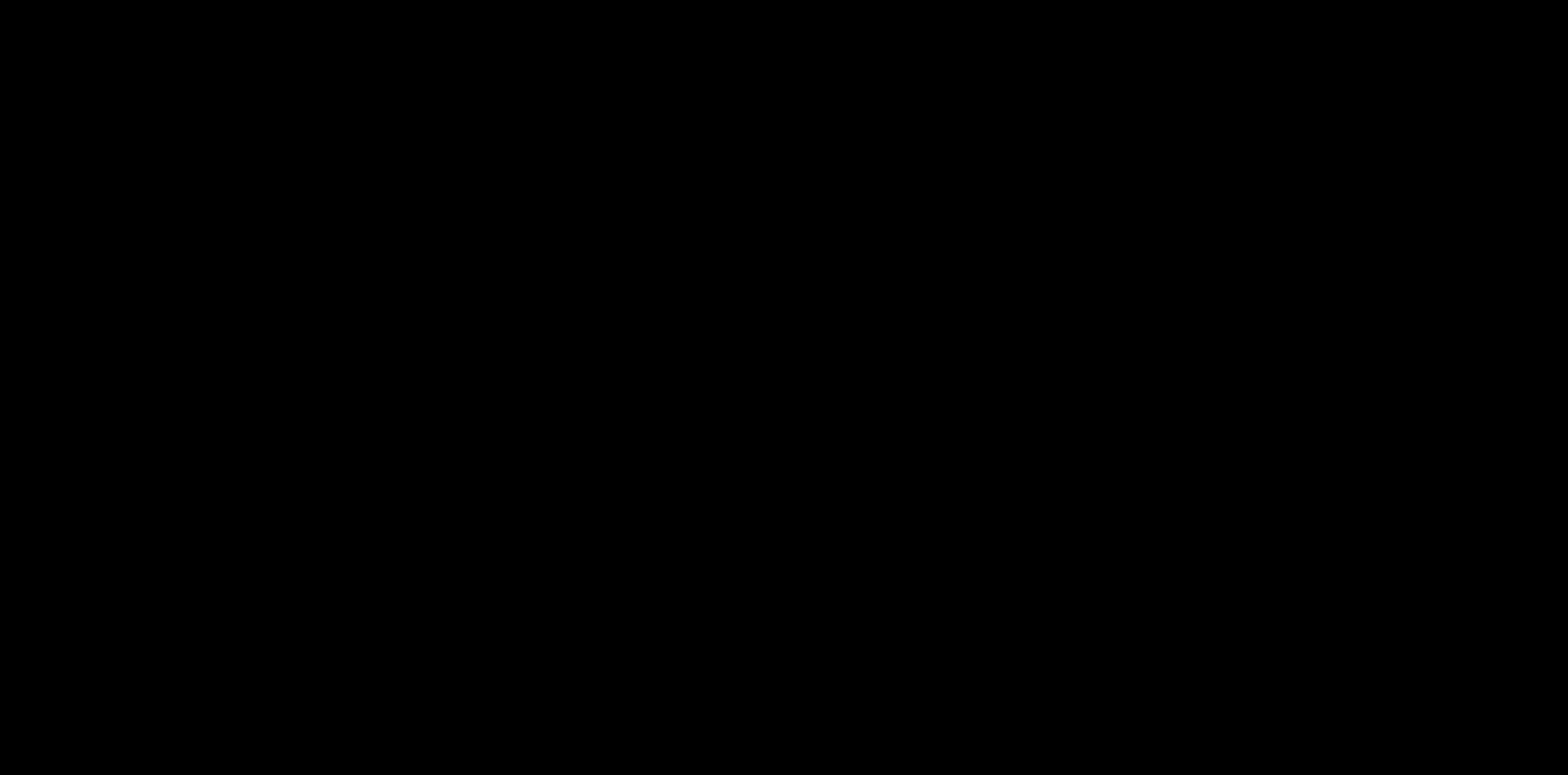
shared CNN backbone

task-specific network heads



[Niels Ole Salscheider 2020: “Simultaneous Object Detection and Semantic Segmentation”. International Conference on Pattern Recognition Applications and Methods]
[Niels Ole Salscheider 2021: “Object Tracking by Detection with Visual and Motion Cues.” arXiv: 2101.07549]

co-founder SafeAD



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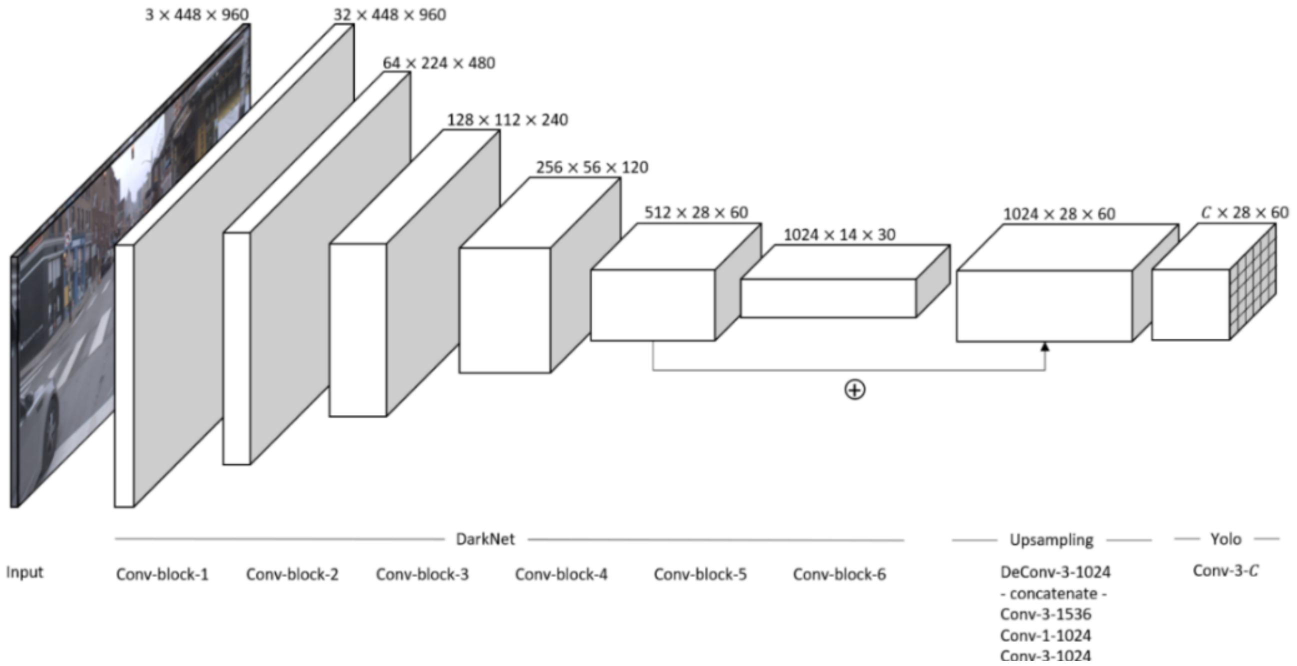
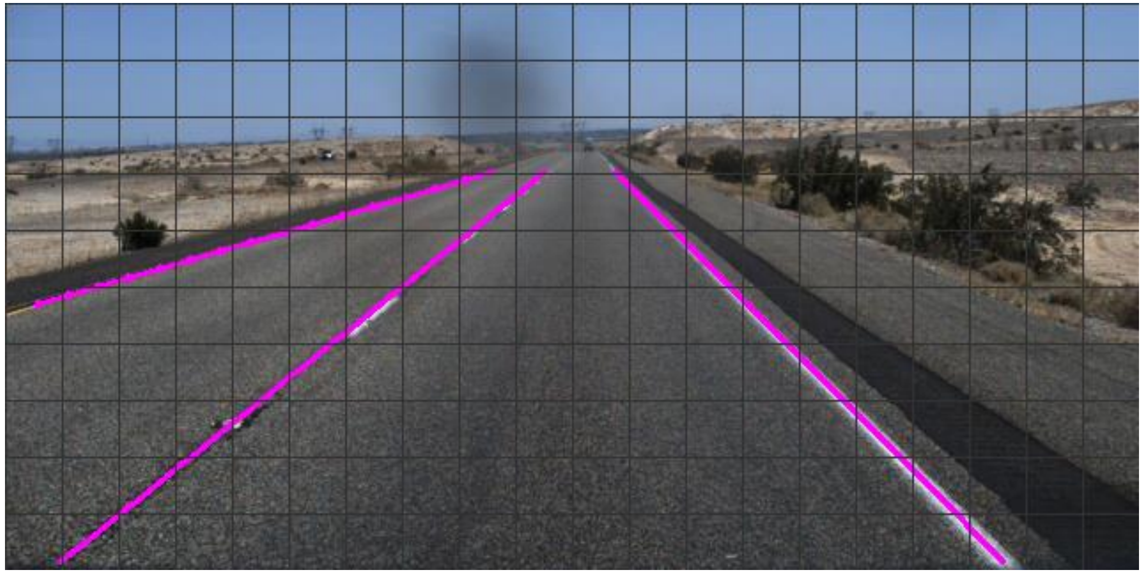
YOLinO – Generic Single Shot Line Detection

- Inspired by YOLO: Split image into grid cells
- Predict generic line segments
- Detection and classification
- Multiple predictions per cell allows for detection of crossing and branching lines



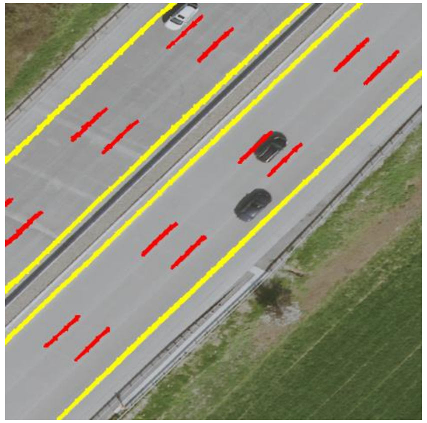


[Annika Meyer et al. "YOLinO: Generic Single Shot Polyline Detection in Real Time." arXiv preprint arXiv:2103.14420 (2021)]

YOLinO – Generic Single Shot Line Detection

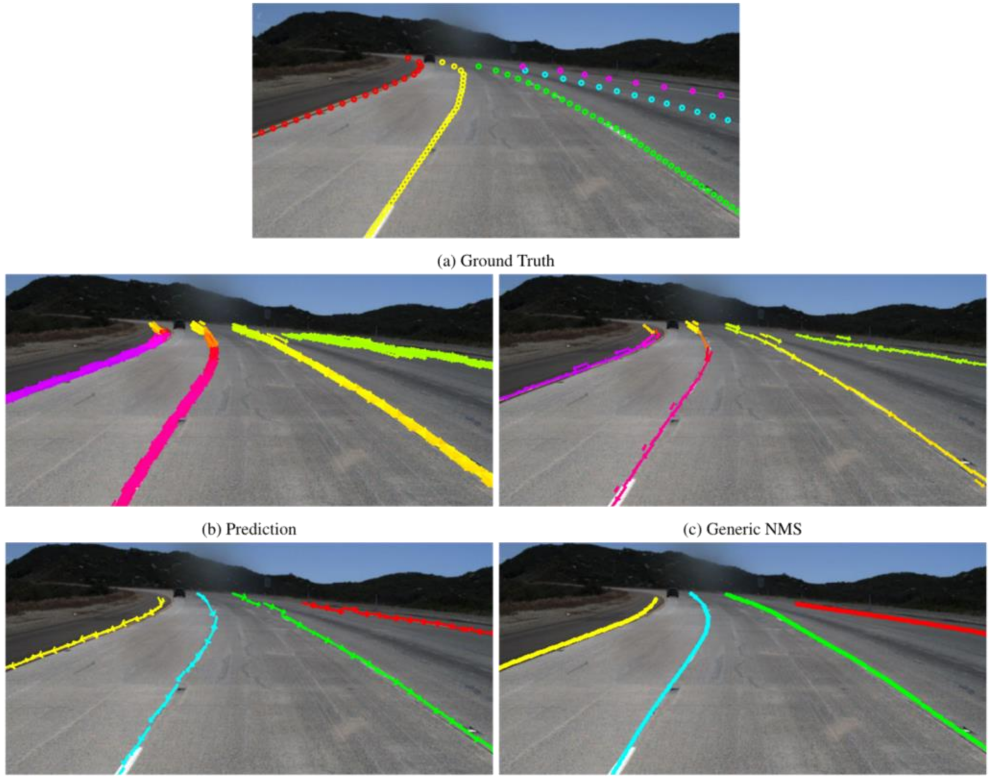
- Real-time applications

Markings in Aerial Images



Centerlines in Argoverse

Road Boundaries in TuSimple



(a) Ground Truth

(b) Prediction

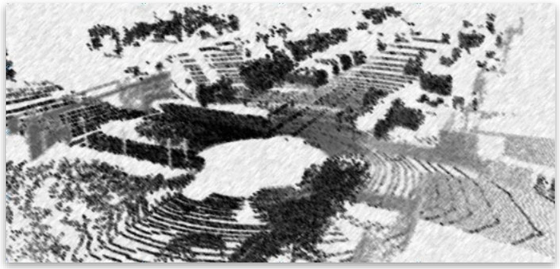
(c) Generic NMS

(d) Breadth-first search and weighted averaging

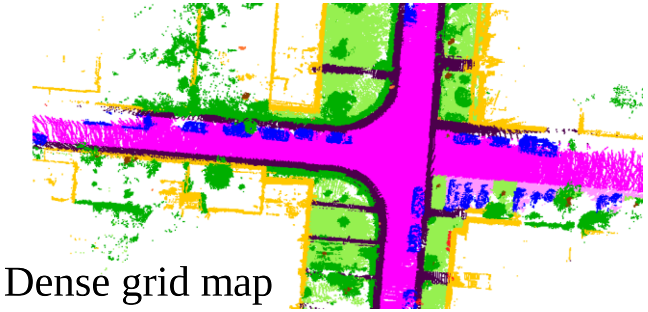
(e) Spline fit

[Annika Meyer et al. "YOLinO: Generic Single Shot Polyline Detection in Real Time." arXiv preprint arXiv:2103.14420 (2021)]

Tasks of Lidar Processing


Point cloud measurement

→


Dense grid map prediction

1 **Scene Understanding**

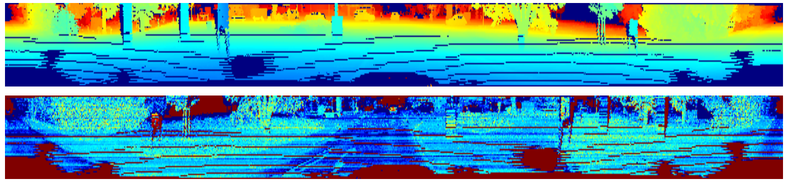
2 **Self-Localization**

3 **Mapless Driving**

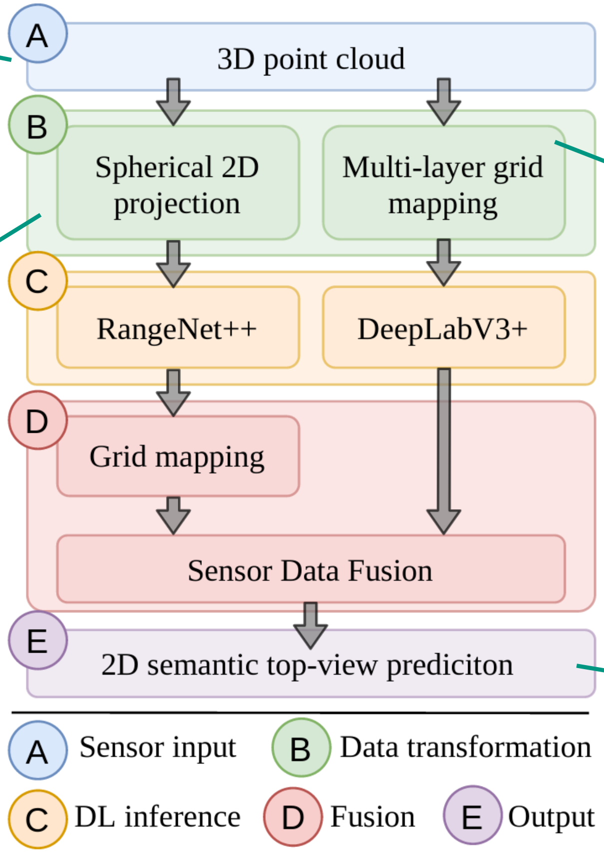
[Bieder, Link, Romanski, Hu, Stiller: Improving Lidar-Based Semantic Segmentation of Top-View Grid Maps by Learning Features in Complementary Representations, FUSION 2022]

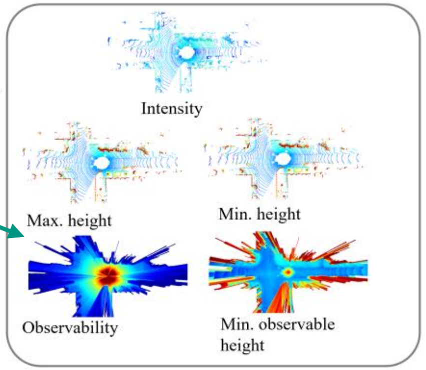
Fusion of BeV and Range Grid Maps

Point cloud measurement

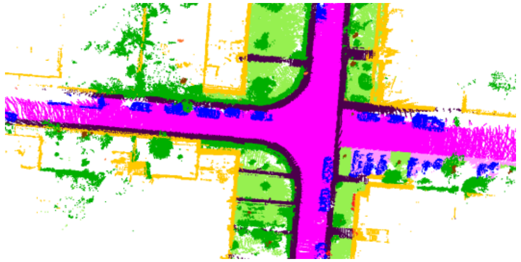


Range image



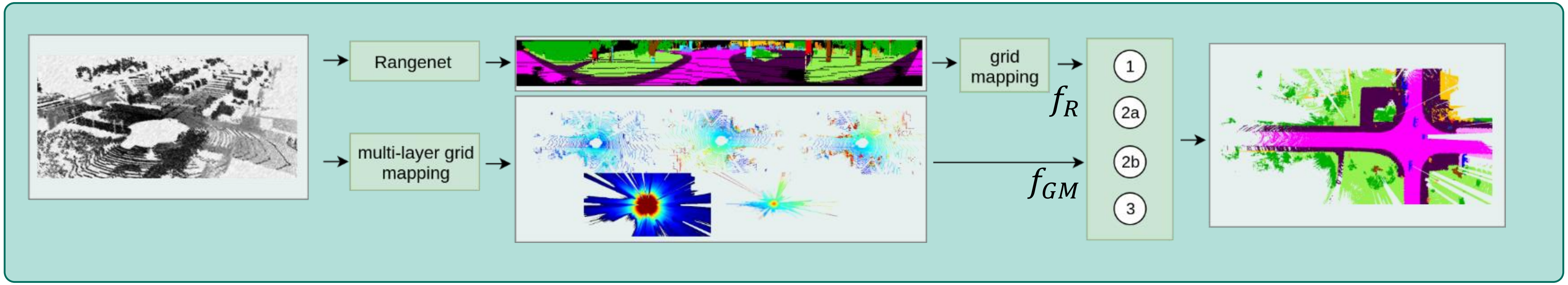


Input Grid maps



Dense grid map prediction

Pipeline Overview



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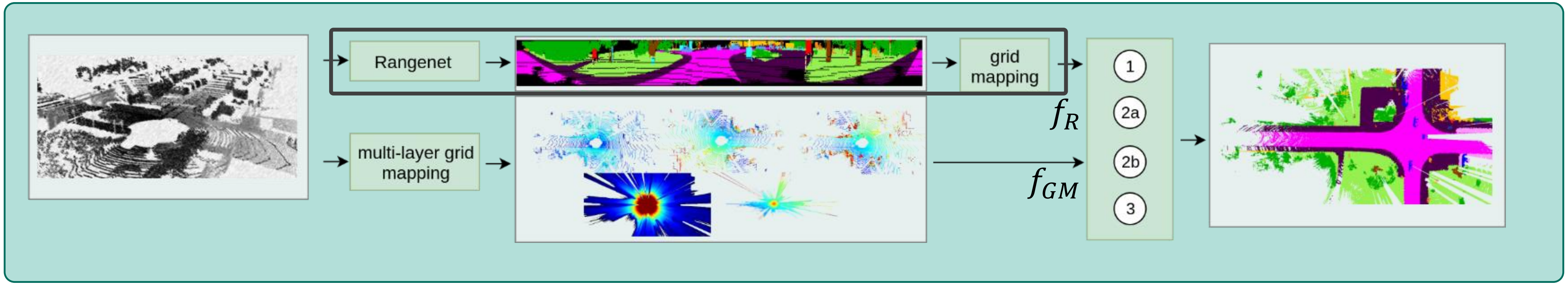

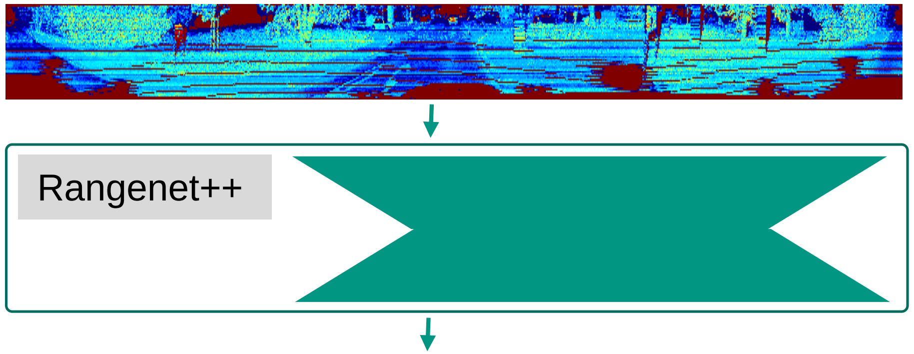

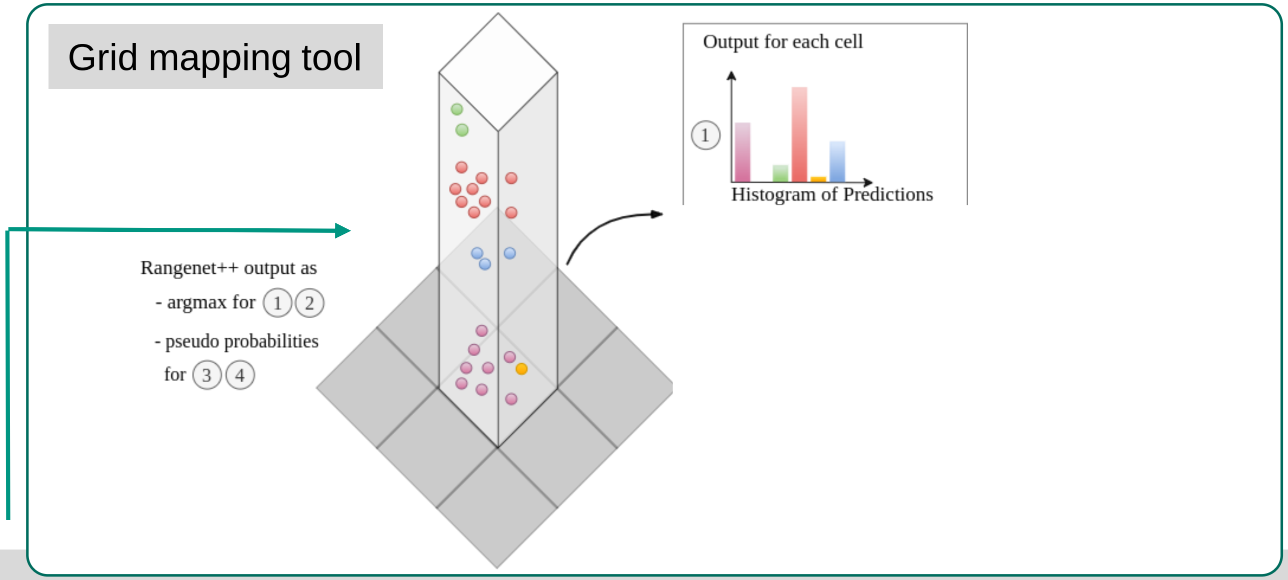

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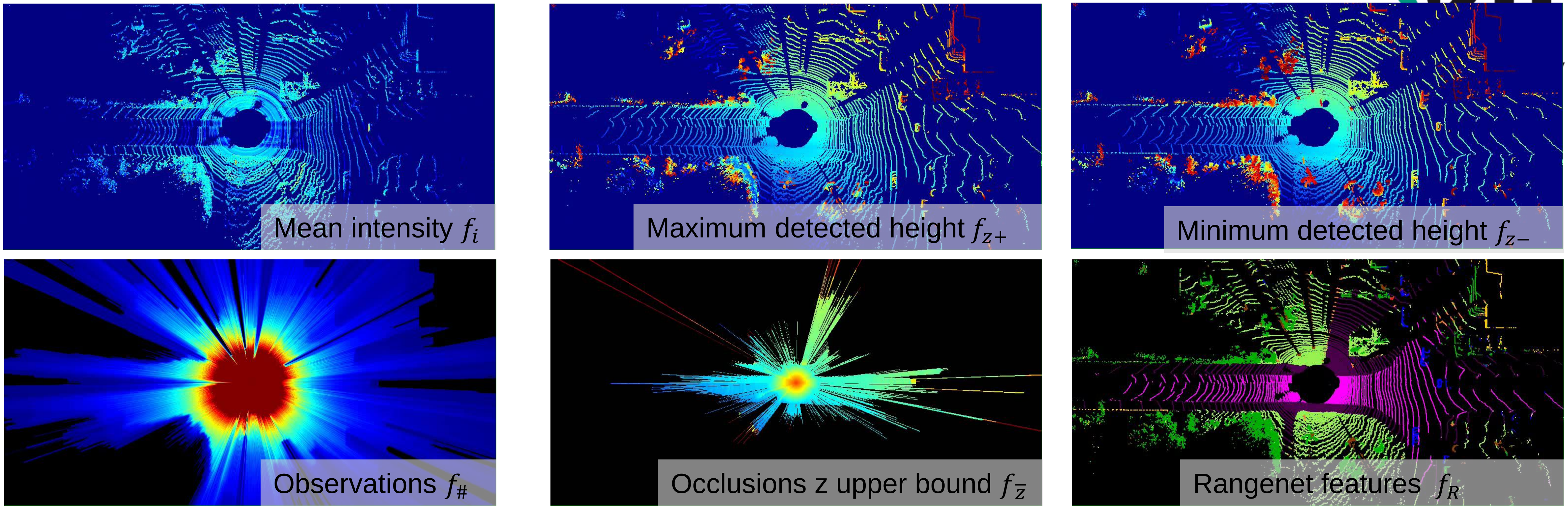
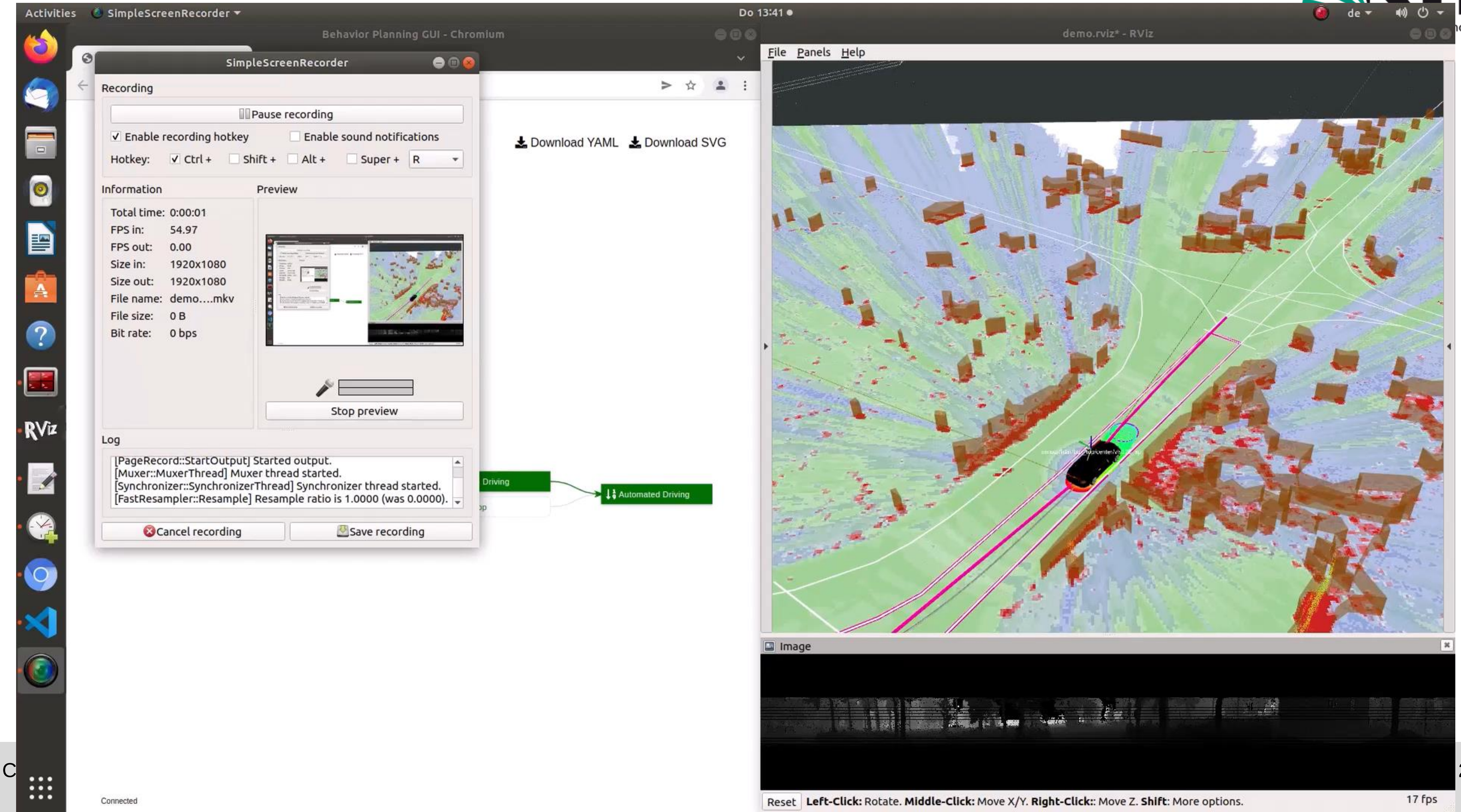
Feature Layer



Dense Task

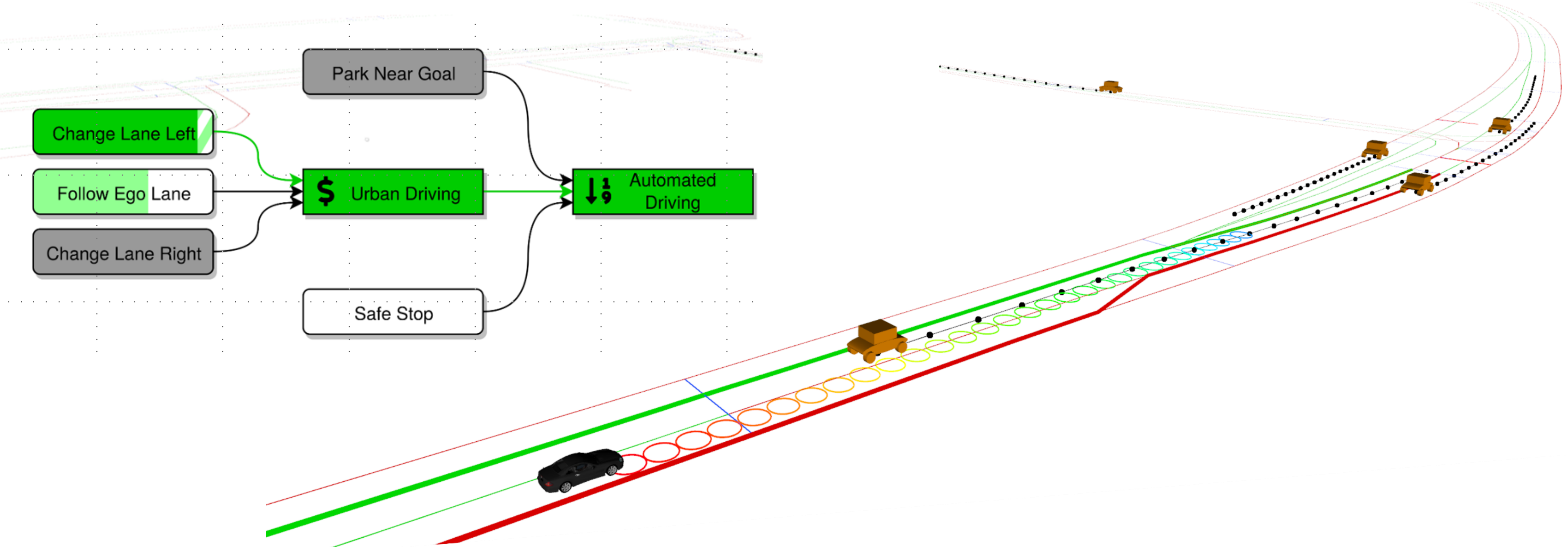
Lidar-Only Automated Driving



Behavioral Safety

Arbritrators for Safe Maneuver Decision

- Which action to take?
  - Skills
  - Invocation Conditions
  - Commitment



[Piotr Orzechowski et al., “Decision-Making for Automated Vehicles Using a Hierarchical Behavior-Based Arbitration Scheme.” IV 2021]

Lane Change Right

The ego vehicle approaches an intersection.
As soon as the exit lane is reached, ChangeLaneRight is applicable.

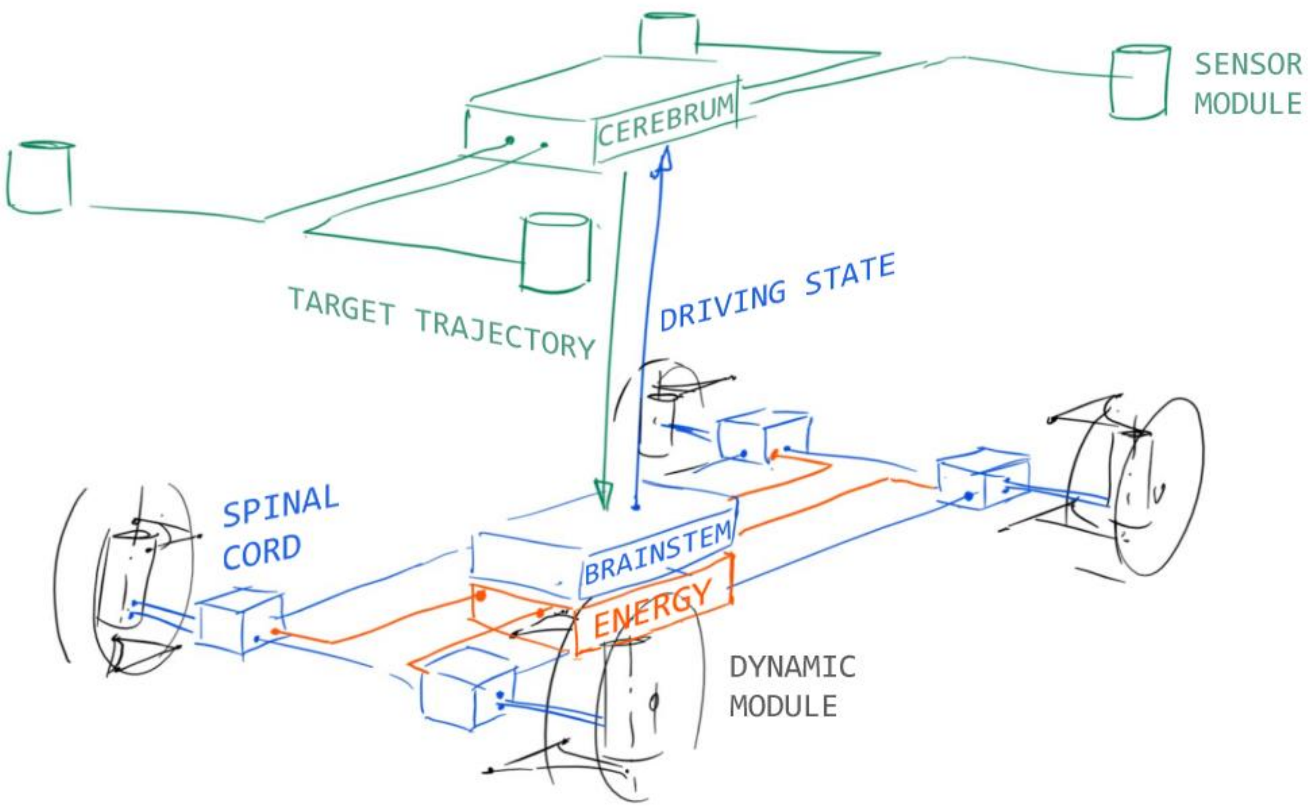
Because the route is turning right, ChangeLaneRight has the highest expected velocity (lowest cost) and is activated by the cost arbitrator.

[Piotr Orzechowski et al., "Decision-Making for Automated Vehicles Using a Hierarchical Behavior-Based Arbitration Scheme." IV 2021]

Eco System for Automated Driving

UNICARagil Vehicles

NEW MECHATRONIC ARCHITECTURE UNICARagil



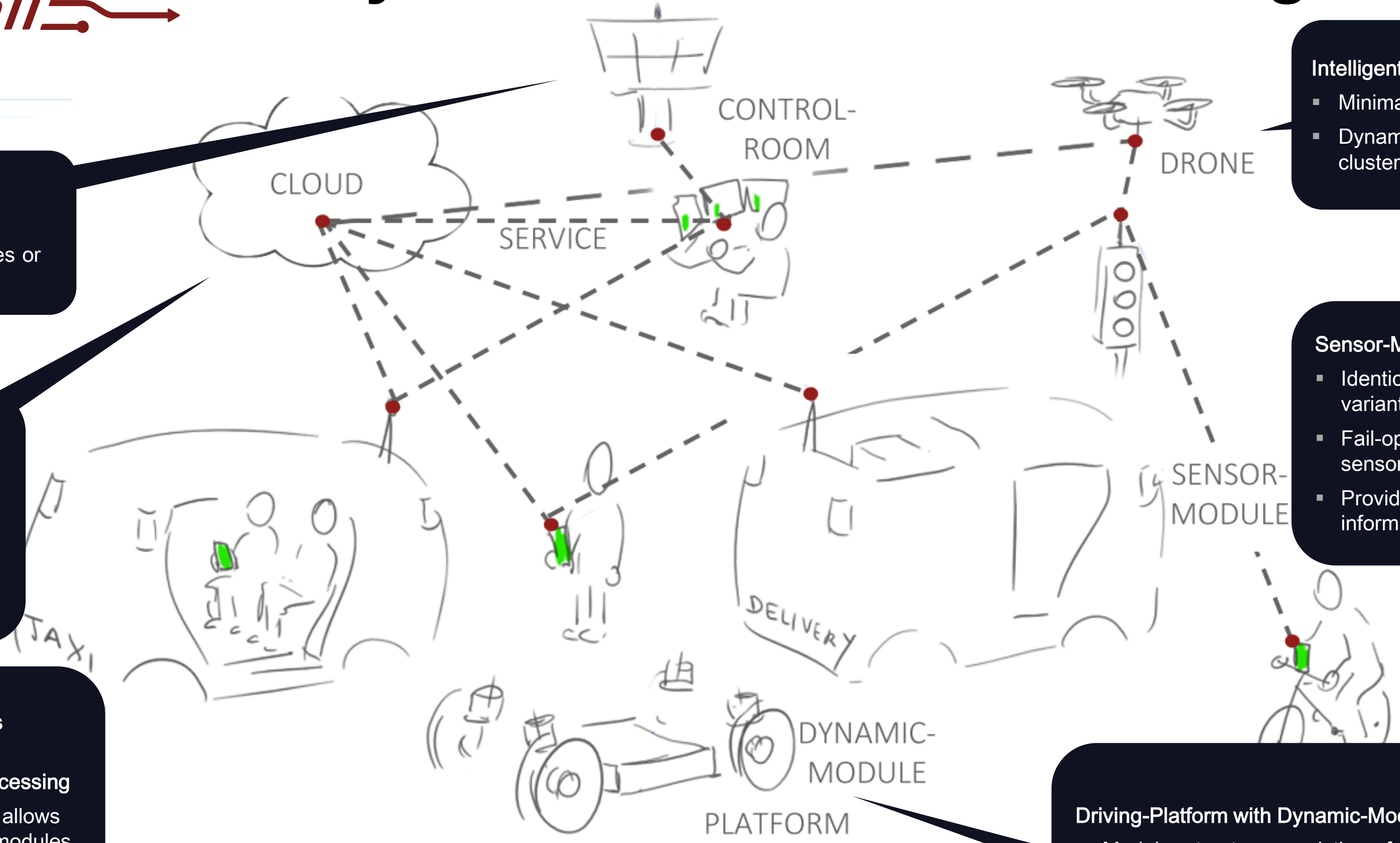
"Brain" Structure

"Cerebrum":
- Environment representation
- Behavior and trajectory planning

"Brainstem":
- Realization of desired trajectory
- Safety ECU
- Dedicated HW developed

"Spinal Cord":
- Steering angle and drive control
- Fallback in case of "Brainstem" failure

Eco-Sytem for Automated Driving



Control-Room
- Remote vehicle operation
- Service center, e.g. for emergencies or sovereign interventions

Cloud Functionality
- Additional information for automated driving function
- Collective environment model
- Collective traffic memory

Four Fully Automated and Driverless Vehicles

Enabled by Modular Information Processing
- Service-oriented SW architecture allows updates and additions to secure modules
- Vehicle fully functional without external Information

Intelligent Infrastructure
- Minimal stationary sensors
- Dynamic supplement through sensor cluster = drones

Sensor-Modules
- Identical integration for all vehicle variants
- Fail-operational due to 3 physical sensor principles
- Provides environment information as a service

Driving-Platform with Dynamic-Modules
- Modular structure consisting of 4 dynamic modules, energy module, brain stem + self-awareness
- Scalable, different vehicle sizes can be displayed
- Electric (48 Volt) and functionally safe

SAFETY

Safety Goal

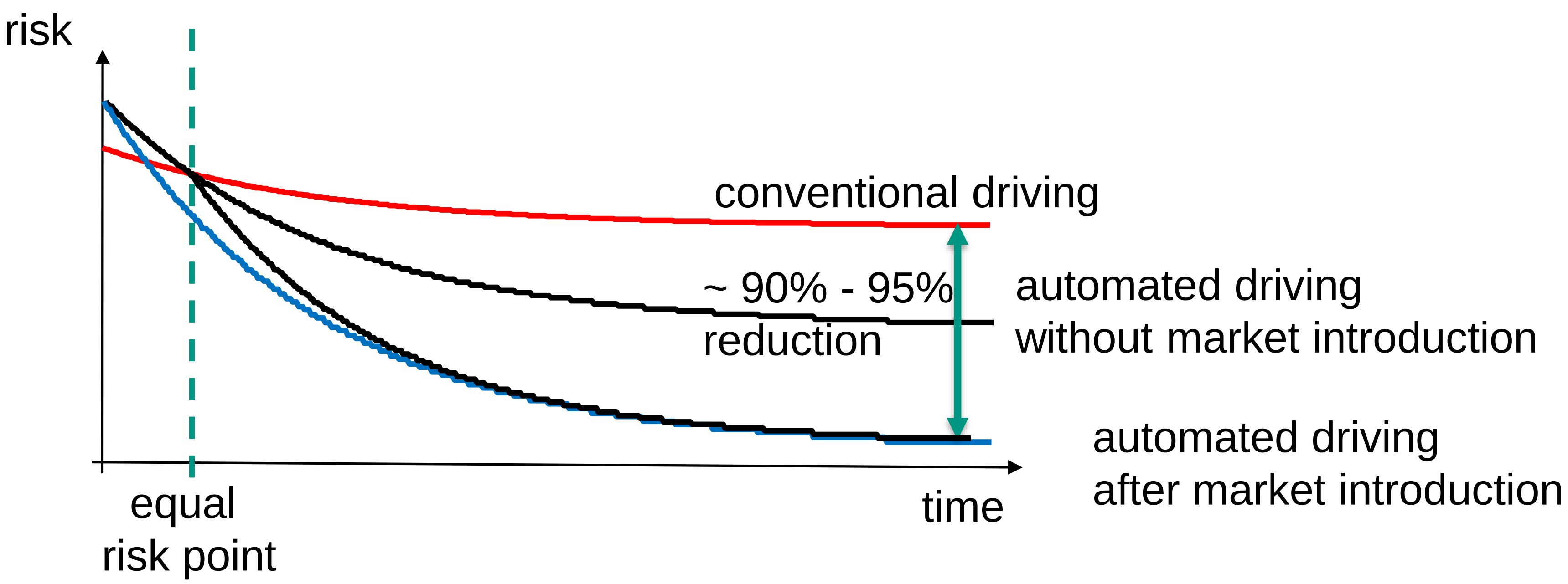
- Naive Thinking: The safety goal for SDA should be „Zero Accidents“

- Safety goal should be „safe as many persons as possible“, i.e. maximize SIF

$$\text{Safety Improvement Factor} = \frac{\text{Risk of Traffic with Conventional Driving}}{\text{Risk of Traffic with Self Driving Automobiles}}$$

- Which SIF level is societal acceptable?

Risk Balance of Automated Driving



- Late introduction with safety margin may support acceptance
- Earlier introduction will minimize total fatalities

Summary & Conclusions

- Automated Driving
  - is feasible, but requires restrictive ODD, or safety driver
  - will cause a revolution in human mobility
- Lidar and Vision
  - provide essential complementary information each
- Deep Learning
  - dominates perception and planning
  - is complemented by conventional validation
- Eco System for Automated Driving
  - dominates perception and planning
- Safety
  - dominates market introduction
  - Societal consensus required

Institute of Measurement and Control Systems

Department Mobile Perception Systems