THEIA Innovation Project

LiDAR based Accurate Perception

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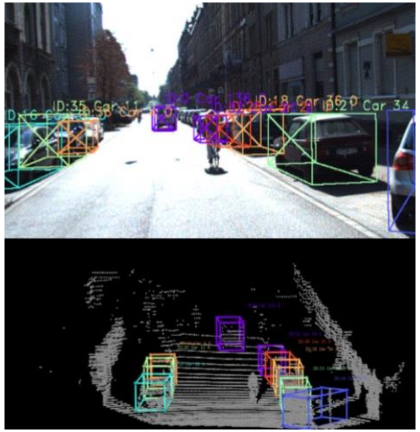
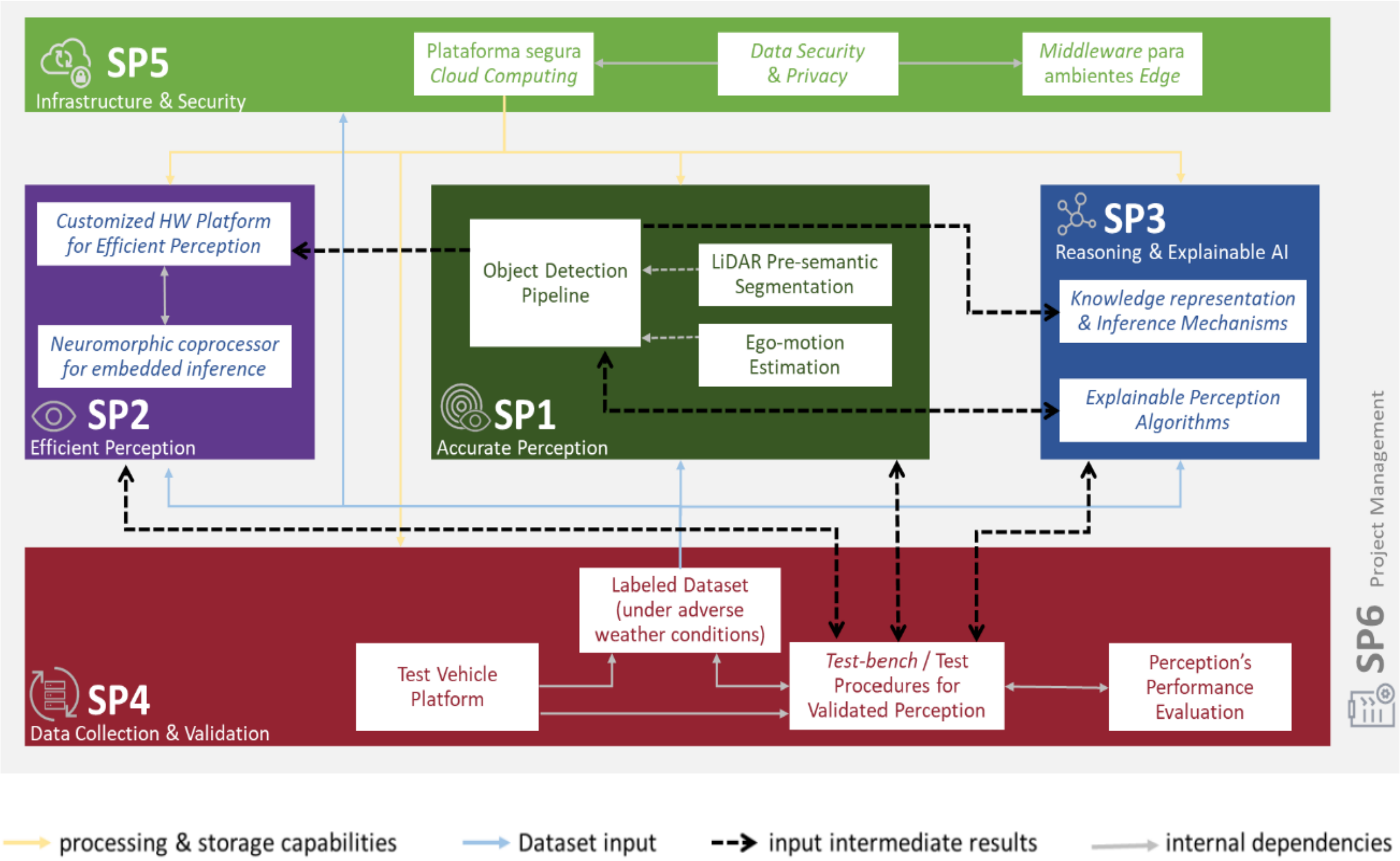
THEIA Innovation Project
Project Overview



AI Development

Innovation & Deep Learning for Perception



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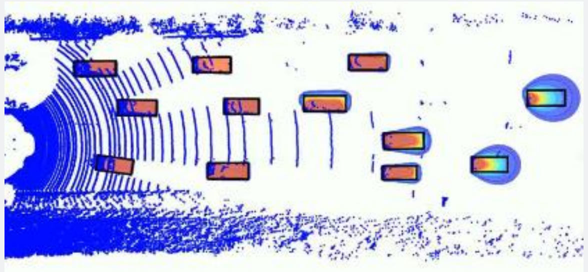
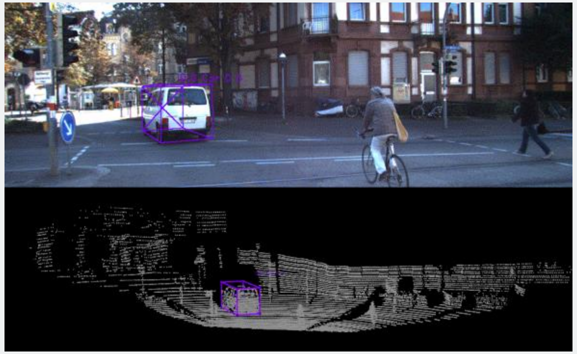
Core Tasks



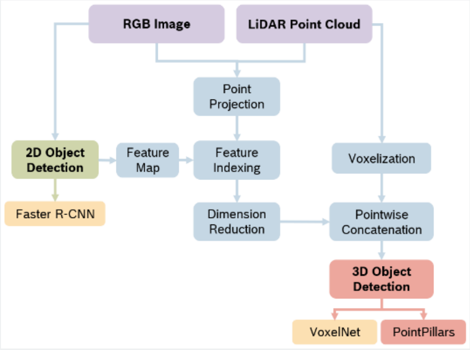
Explainable and Safe AI

- Definition of Safety Aware KPIs
- Development of Uncertainty Quantification Methods



Temporal Deep Learning

- Multi-sequence method
- Temporal consistency and context association



Multi-Modal Deep Learning

- Multi-sensor scalable Fusion Architectures
- Multi-task Networks (i.e., Semantic Segmentation with Object Detection)

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PER AI Team


Filipe Gonçalves

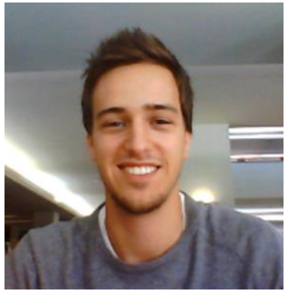

João Teixeira


Ricardo Cerqueira


Bernardo Araújo


Sofia Beco


Carolina Pinto


Guilherme Santos


Mariana Xavier


José Guerra

Points of Contact:

- filipe.goncalves@pt.bosch.com / joaof.teixeira@pt.bosch.com

Theia
Automated Perception Driving

THEIA – Accurate Perception

LiDAR based Weather Estimation

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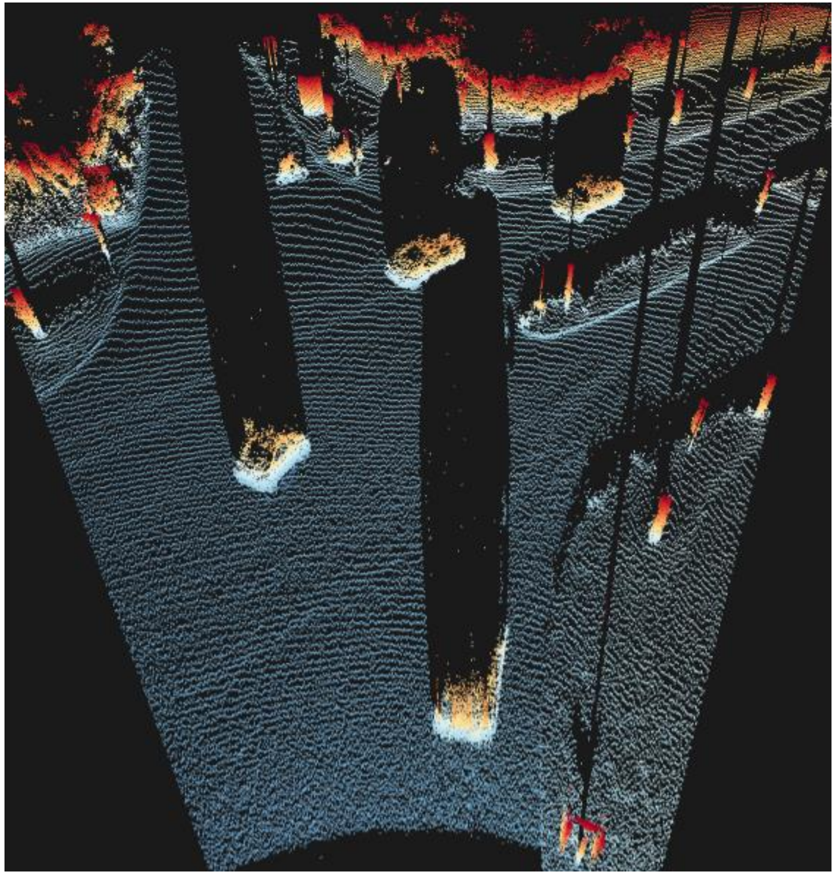
What is a Point Cloud?



- List of points
- Accurate location of each
- Can be captured by:
  - LiDAR sensor (Light Detection And Ranging)
  - Stereo camera system
- Unordered
- Unstructured
- Sparse data
- Uneven density of points

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LiDAR based Weather Estimation
Overview & Objectives

- Weather Estimation motivations for the Autonomous Driving (AD) domain:
  - Understand **LiDAR sensor's degradation caused by adverse weather**;
  - Provide an estimate of weather's **impact on vehicles visibility**;
  - **Enable safety adjustments** in AD behaviour in **real-time.**

- Classifying weather conditions will inform subsequent perception tasks about a degree of confidence or robustness regarding captured sensor data.

Main Goal: Develop new models/methods based on Machine/Deep Learning capable of detecting weather conditions (sun, rain, fog).

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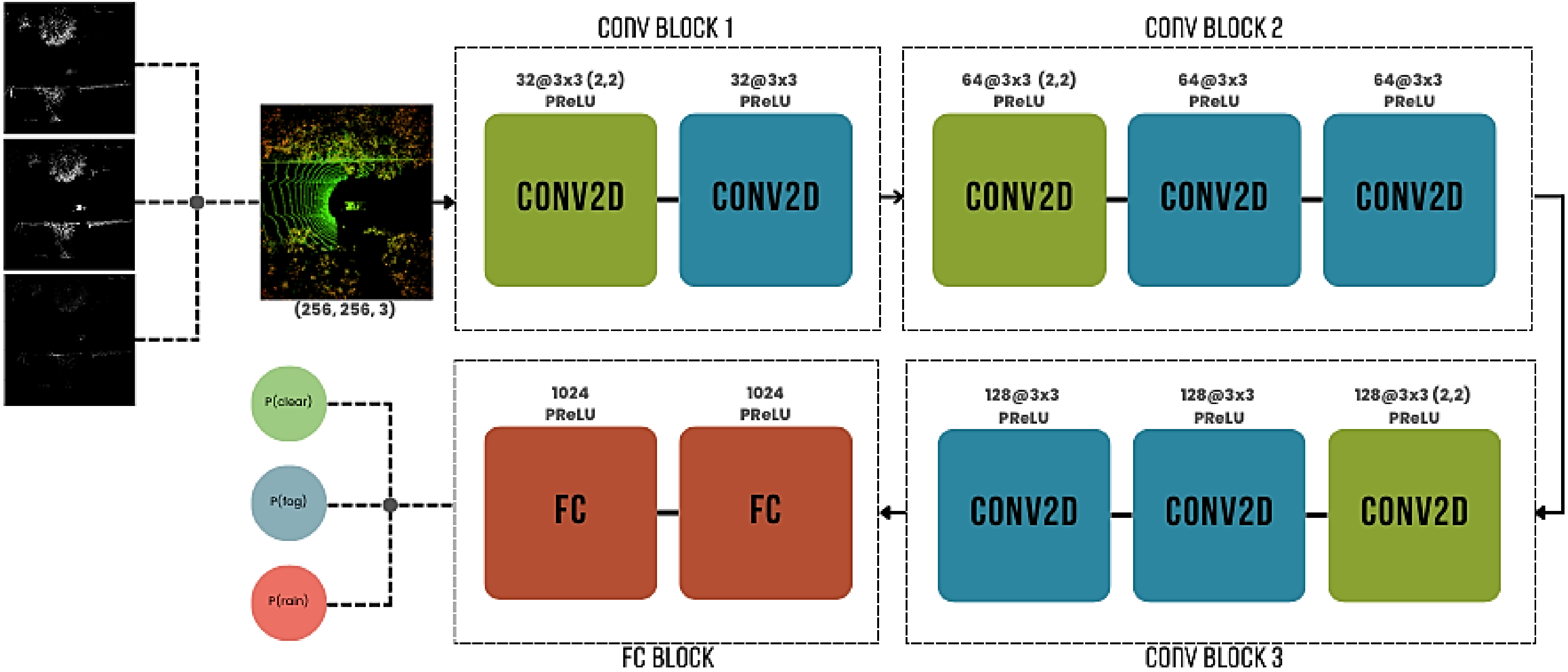
[1] M. P. Silva, D. Carneiro, J. Fernandes, and L. F. Teixeira. "MobileWeatherNet for LiDAR-only weather estimation". In 2023 International Joint Conference on Neural Networks (IJCNN), pages 1–8, 2023. doi: 10.1109/IJCNN54540.2023.10191333

LiDAR based Weather Estimation

MobileWeatherNet Architecture



Overview of the MobileWeatherNet input, architecture and output [1].

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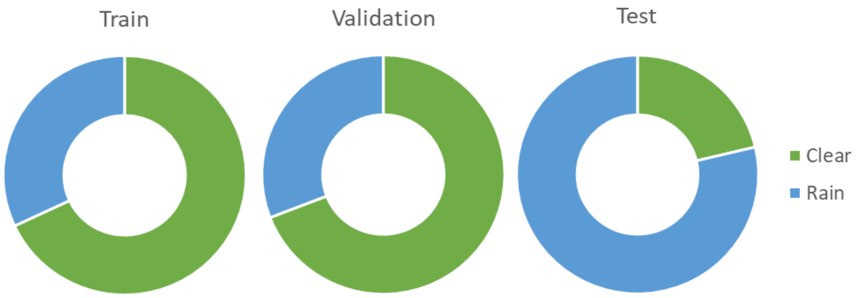
LiDAR based Weather Estimation
Results on THEIA_DC#2

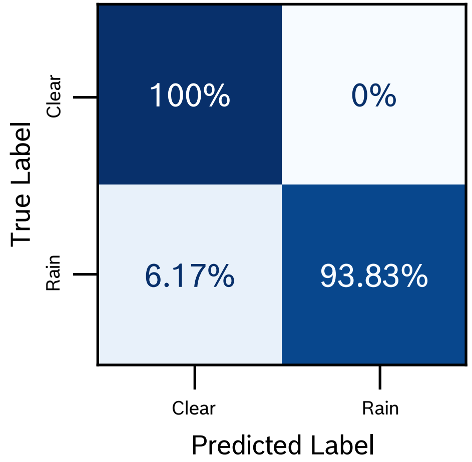
- **Dataset:** Theia_DC#2 (LiDAR Bosch X)
  - Two weather conditions (**clear** weather, **rain**) under diverse driving scenarios (scenario, time of day, blockage).
  - Sequential test set, allowing post-processing for evaluation.



Train, validation and test splits for weather estimation.

Key metrics obtained on test set with post-processing.

	Theia_DC#2
Cohen Kappa	0.87
F1-Score	93.29%
Balanced Accuracy	96.91%



Confusion matrix on test set with post-processing.

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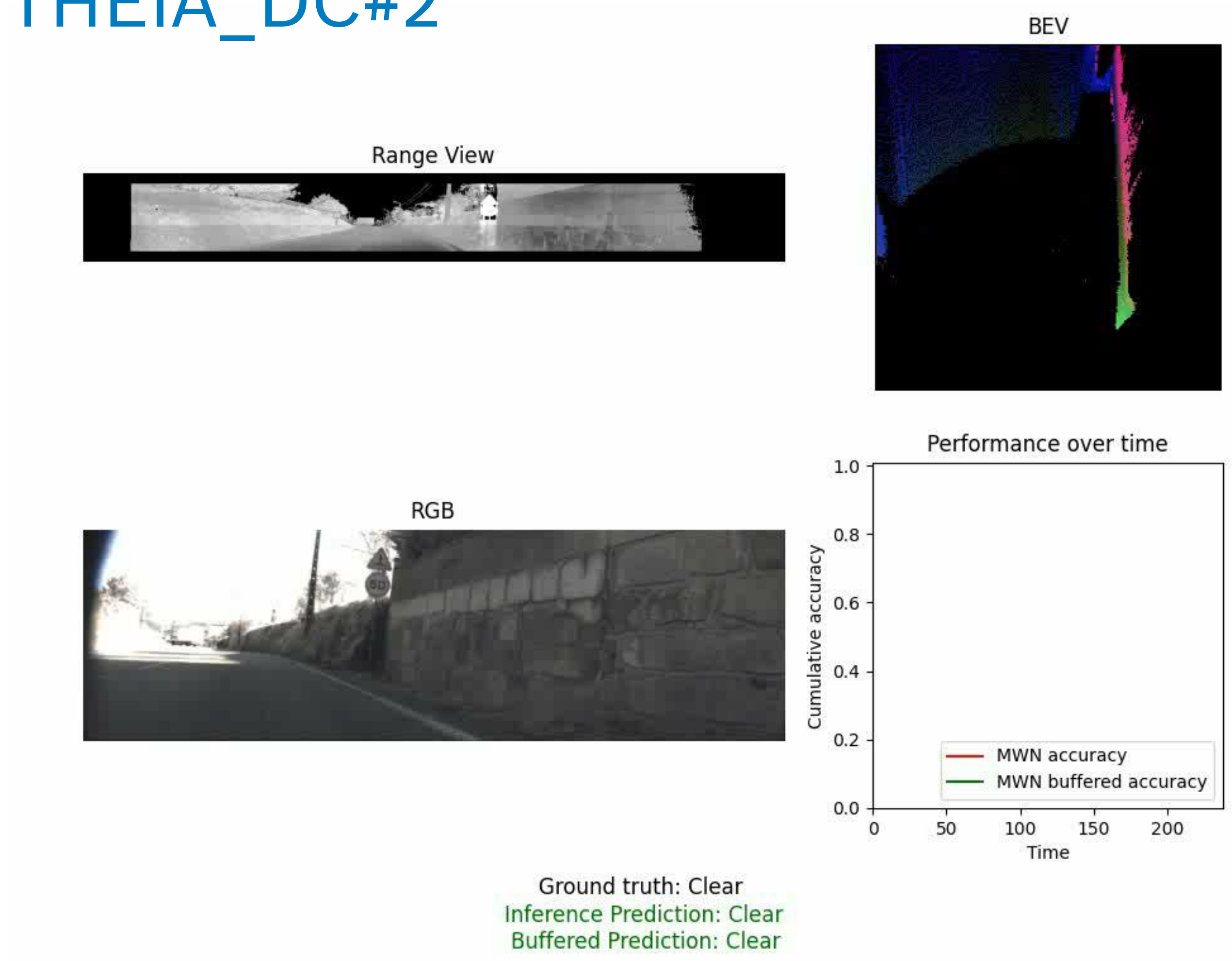
LiDAR based Weather Estimation
Results on THEIA_DC#2



MWN accuracy: calculated from raw inferences.

MWN buffered accuracy: calculated from post-processed inferences – weighted moving average with sliding window of size 10.

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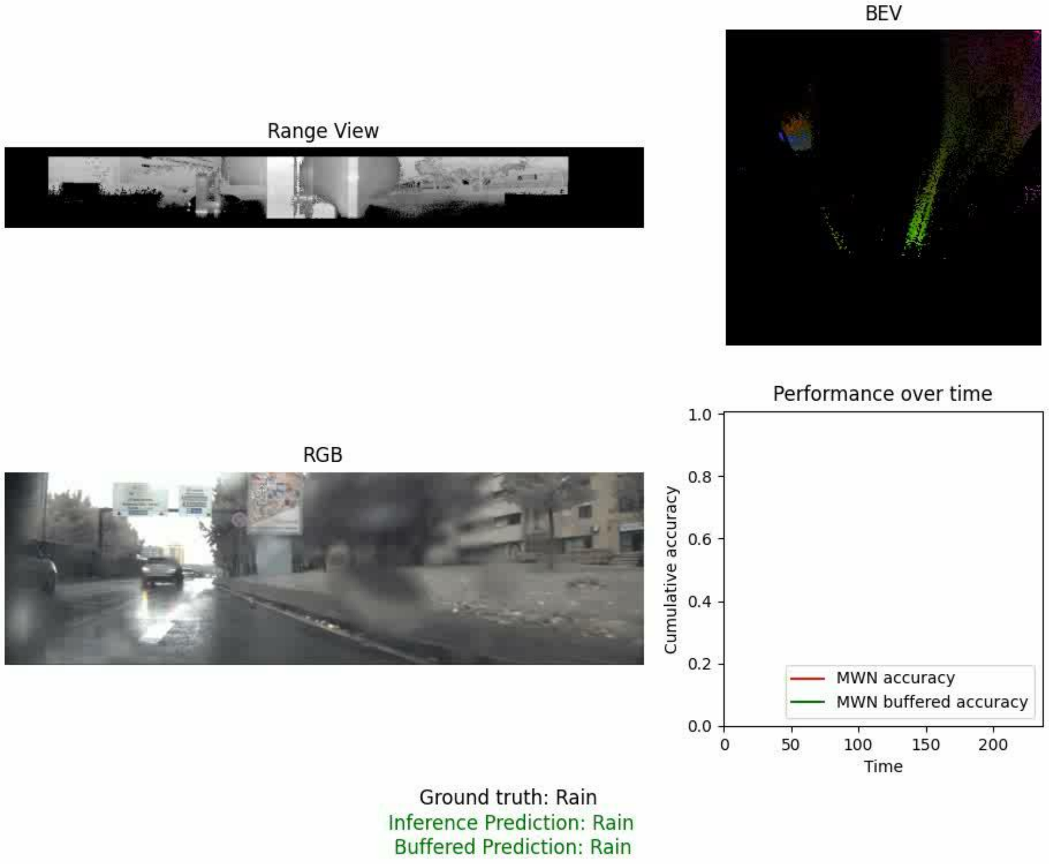
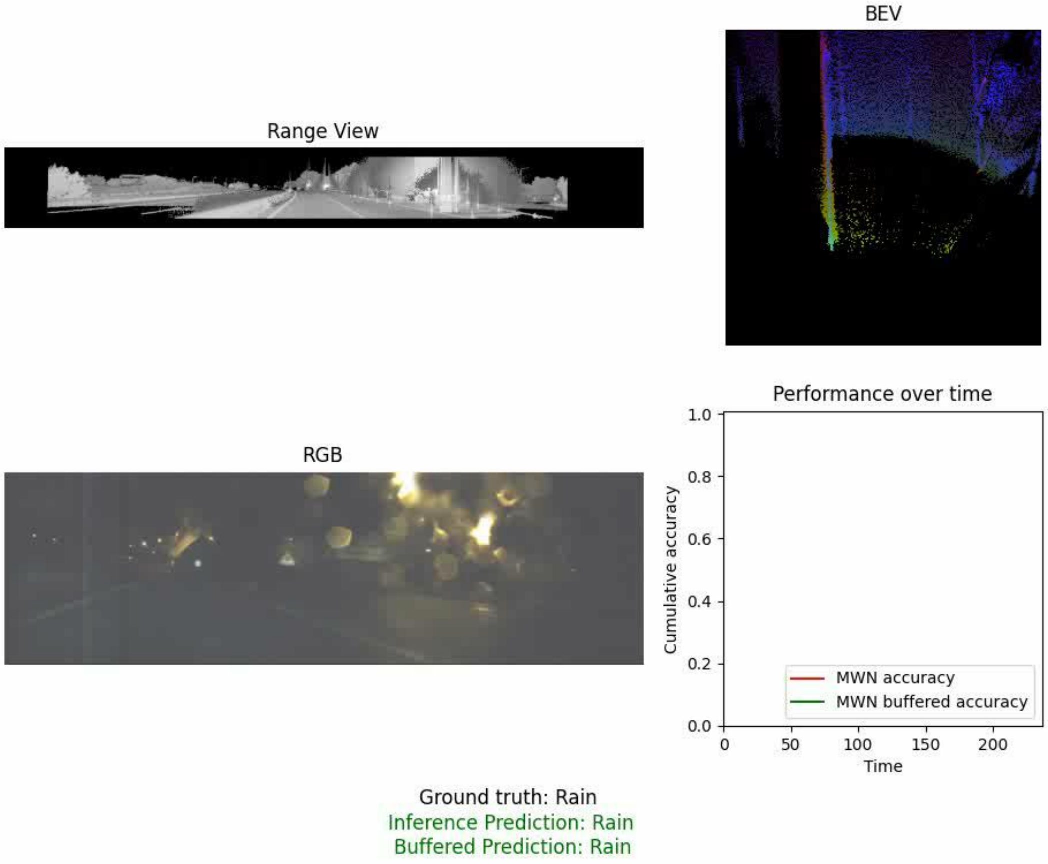
LiDAR based Weather Estimation
Results on THEIA_DC#2





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THEIA – Accurate Perception

LiDAR based Semantic Segmentation

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LiDAR based Semantic Segmentation
Motivation and Objectives

- **Semantic Segmentation:**
  - **Autonomous driving** requires a **detailed and precise perception** of the surrounding environment, that goes **beyond object detection**.
  - Essential for **safe vehicle navigation** as it enables perception of:
    - **Static environment:** road, buildings and vegetation.
    - **Dynamic environment**: vehicles, pedestrians and obstacles.

  - LiDAR sensor pros & cons (compared to RGB images)

✓ **depth information**

✓ less vulnerable to **light exposure**

✗ **data is sparse**

✗ sensitive to **material reflection**

✗ sensitive to adverse weather conditions (also true for RGB)

Main Goal: Develop a perception point-based algorithm using only LiDAR for semantic segmentation.

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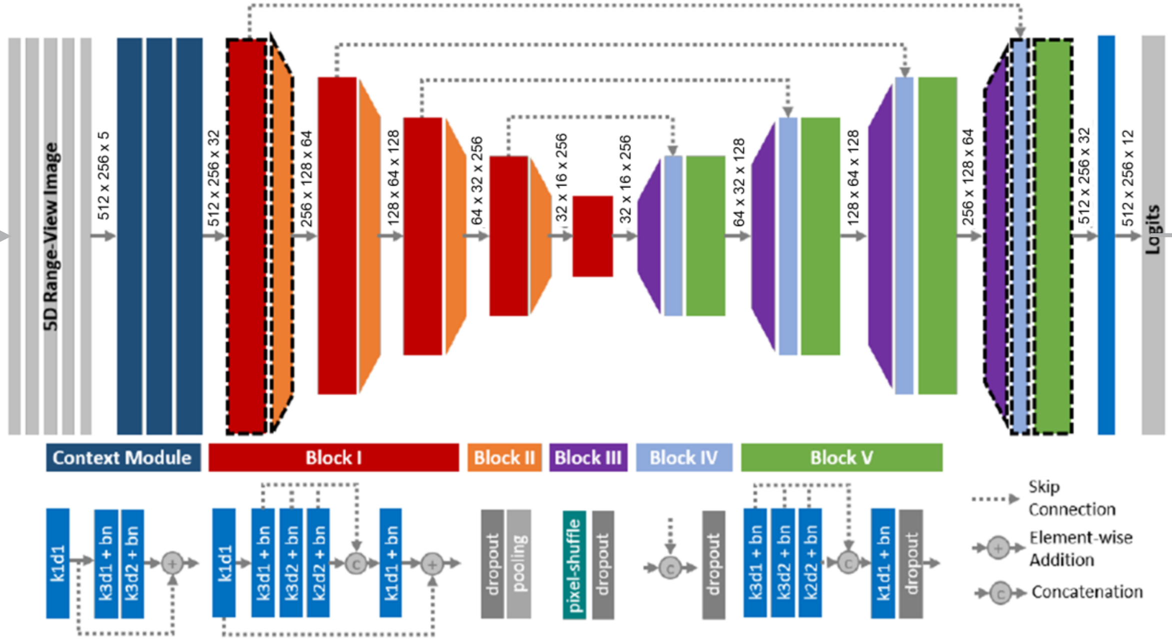
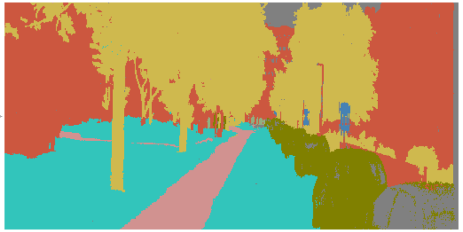
LiDAR based Semantic Segmentation
SalsaNext Architecture

Input: LiDAR Range View





Output: Prediction

Overview of the SalsaNext architecture. Adapted from [3].

Number of parameters: 6.7M
Inference time: 20.47 ms +/- 0.051

[3] Cortinhal, T., Tzelepis, G., & Aksoy, E. (2020). “SalsaNext: Fast, uncertainty-aware semantic segmentation of LiDAR point clouds.”

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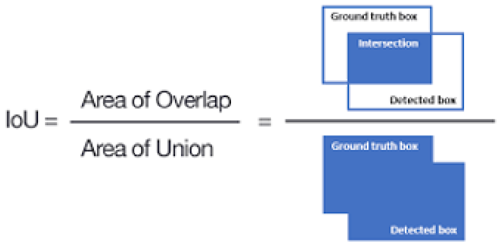
LiDAR based Semantic Segmentation

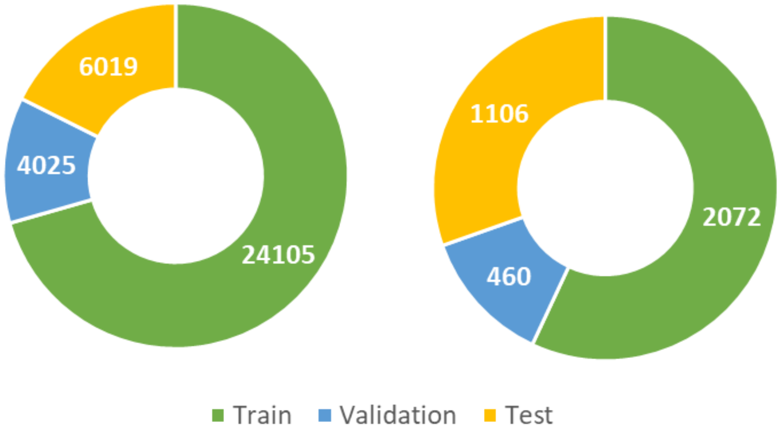
Datasets and Results



https://www.baeldung.com/wp-content/uploads/sites/4/2022/04/fig1.png

nuScenes Dataset 16 classes

THEIA Dataset 11 classes



	nuScenes	THEIA
IoU	**0.6924**	**0.5522**
Dice	0.8062	0.6550
Precision	0.7746	0.6693
Recall	0.8499	0.6580

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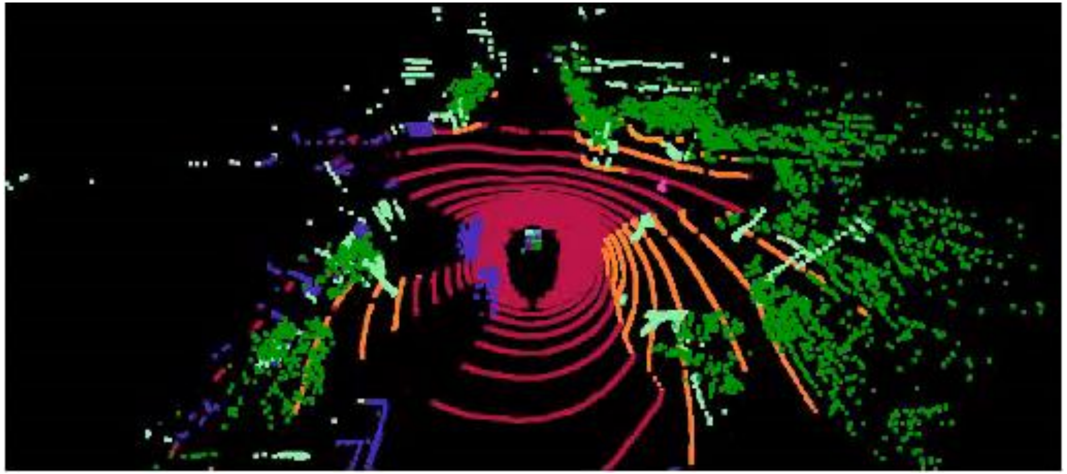
LiDAR based Semantic Segmentation
Results: nuScenes dataset

- noise
- barrier
- bicycle
- bus
- car
- construction_vehicle
- motorcycle
- pedestrian
- traffic_cone
- trailer
- truck
- driveable_surface
- other_flat
- sidewalk
- terrain
- manmade
- vegetation

RGB camera view.

Bird-eye view results.



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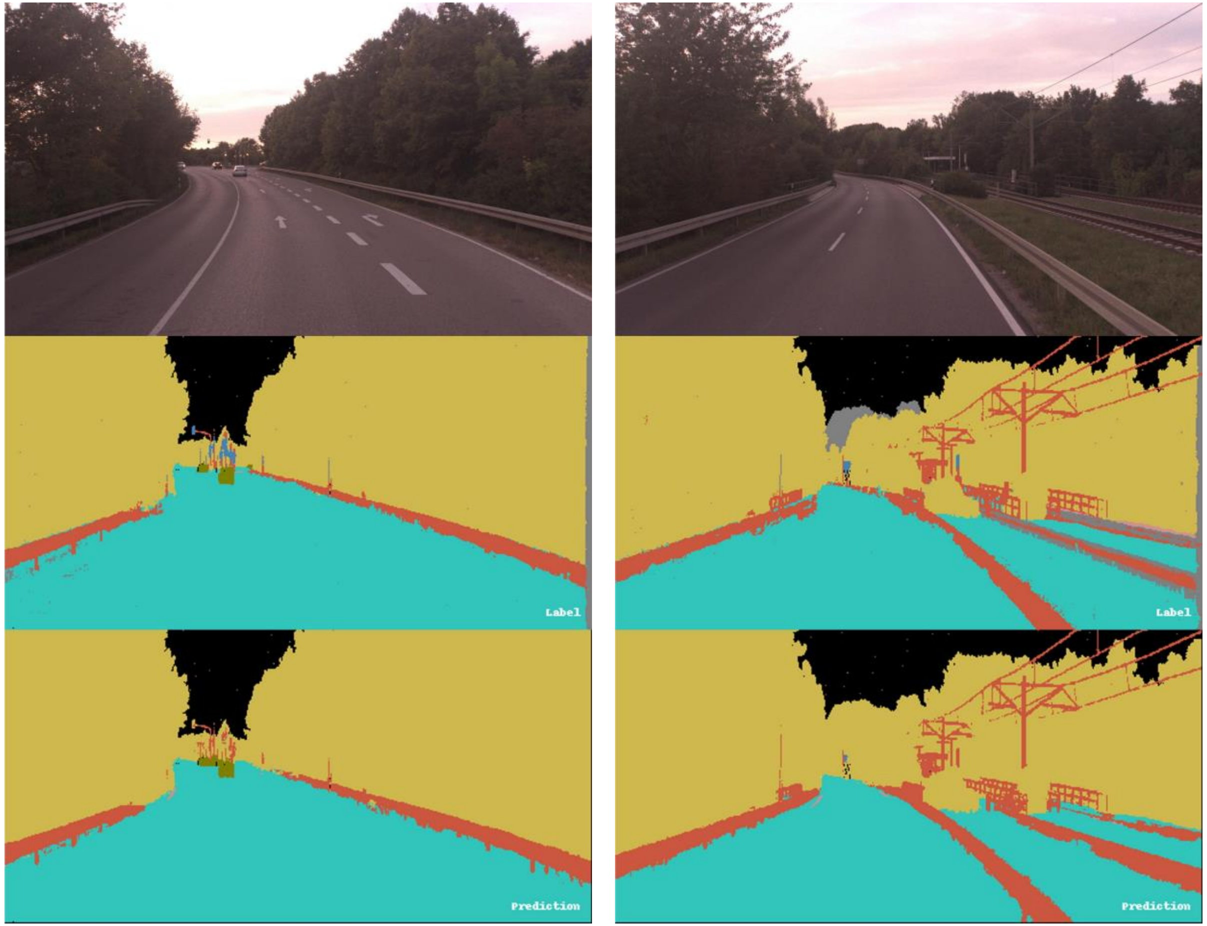
LiDAR based Semantic Segmentation
Results: THEIA dataset

- **Results with improved detail** thanks to LiDAR higher resolution
- **Top classes** with respect to IoU evaluation metric:
  - **Vegetation:** 87.1 %
  - **Drivable surface**: 86.2 %
  - **Structure**: 84.5 %

Vegetation
Drivable surface
Structure



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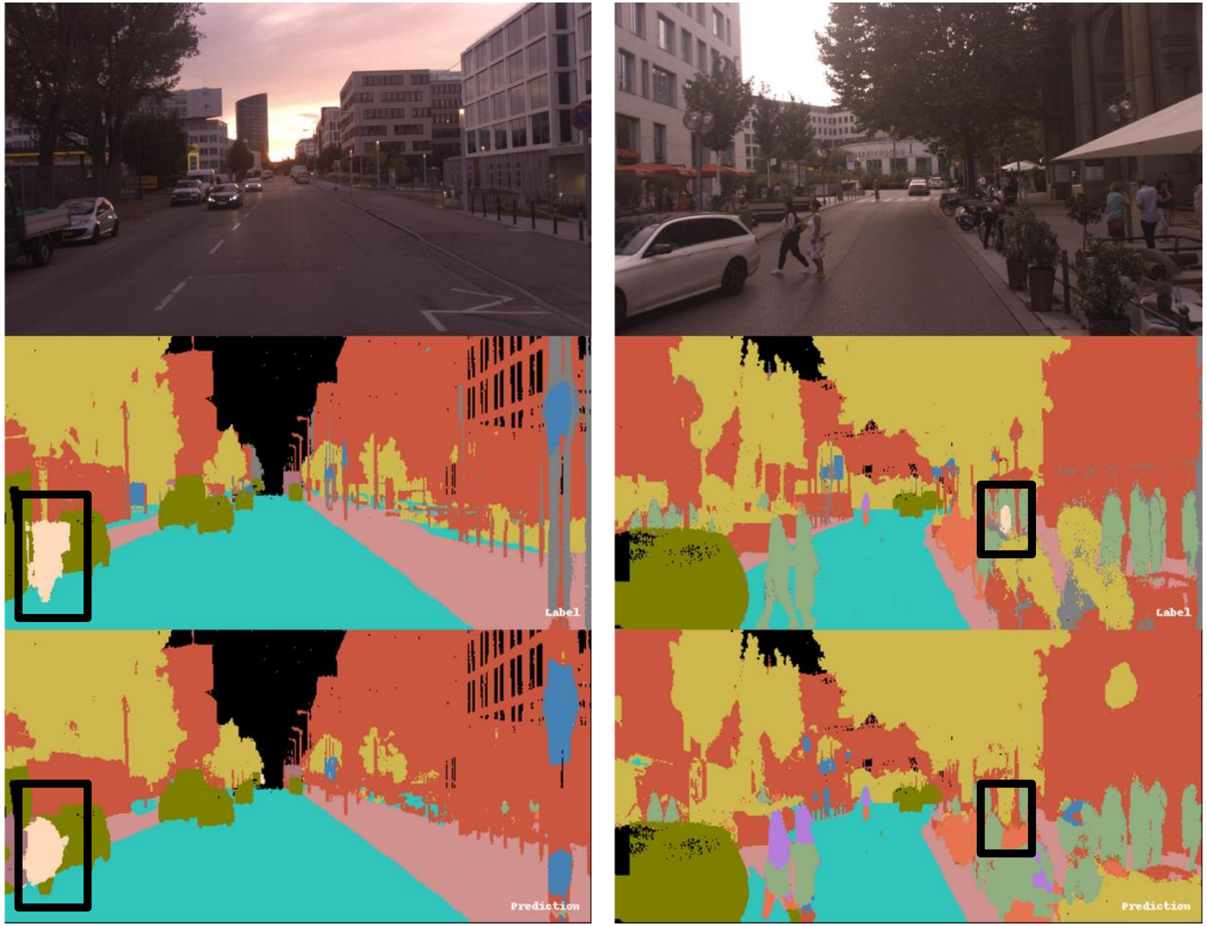
LiDAR based Semantic Segmentation
Results: THEIA dataset

- **Worst classes** with respect to IoU evaluation metric:
  - **Dynamic vehicle**: 2.6 %
  - **Rider:** 10.3 %
  - **Ridable vehicle**: 24.9 %



Dynamic vehicle

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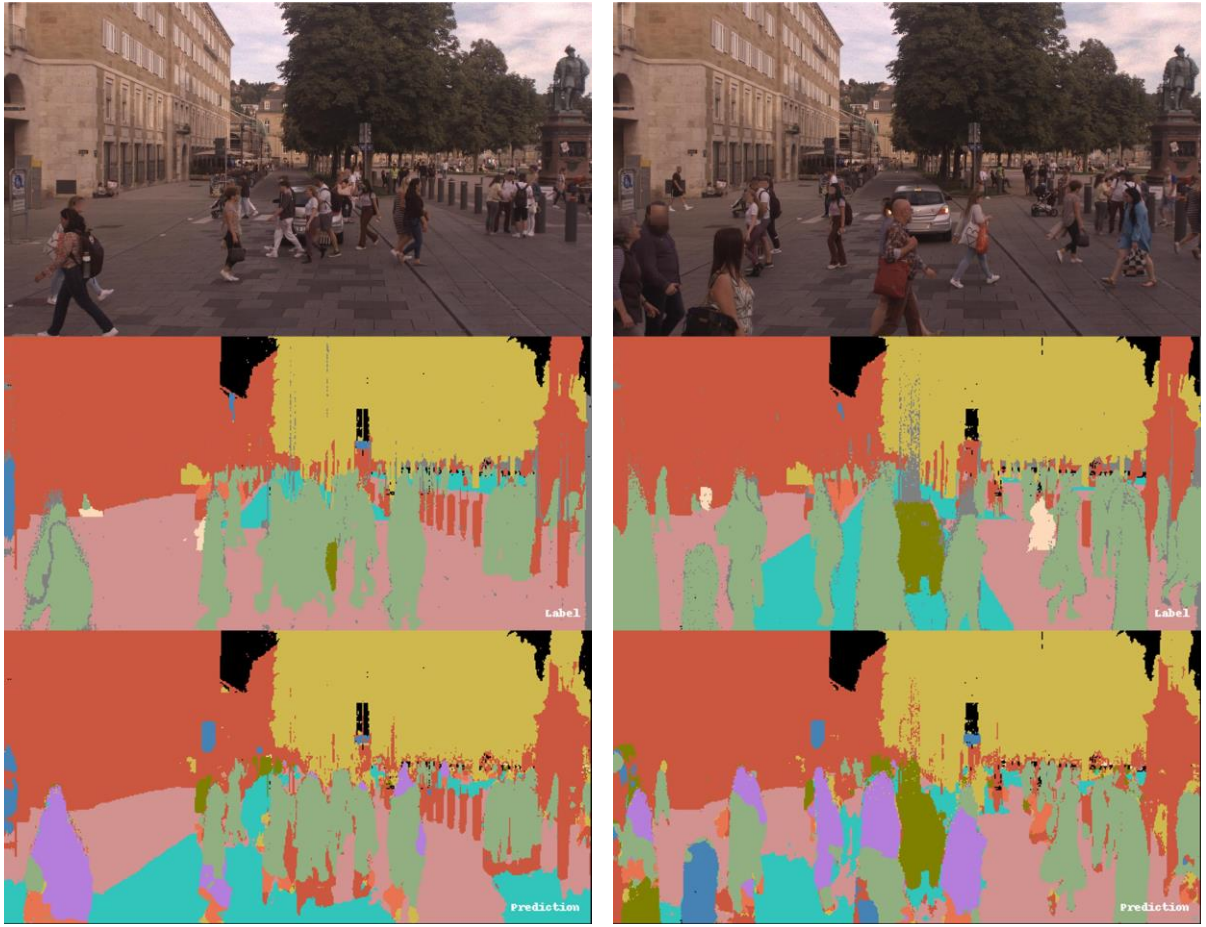
LiDAR based Semantic Segmentation
Results: THEIA dataset

- **Worst classes** with respect to IoU evaluation metric:
  - **Dynamic vehicle**: 2.6 %
  - **Rider:** 10.3 %
  - **Ridable vehicle**: 24.9 %

Pedestrian
Rider
Ridable vehicle



LiDAR based Semantic Segmentation
Results: THEIA dataset

- Other **relevant classes** in Autonomous Driving context:
  - **Car vehicle:** 77.8 %
  - **Sidewalk**: 67.8 %
  - **Pedestrian**: 54.5 %

Car vehicle
Sidewalk
Pedestrian

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THEIA – Accurate Perception

LiDAR based Lane Estimation

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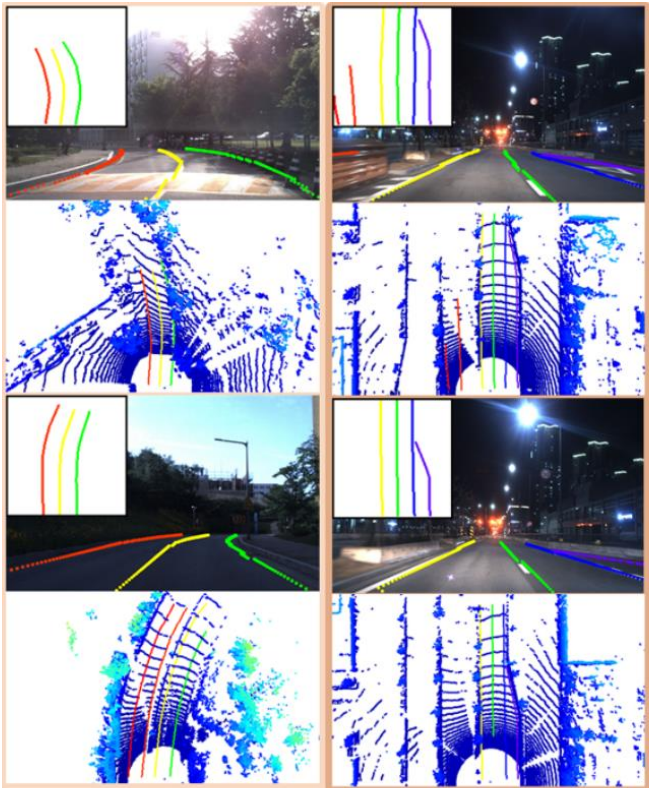
LiDAR based Lane Estimation
Motivation and Objectives

- **Lane estimation:**
  - Essential for **safe vehicle navigation** as it enables perception of **drivable space** such as:
    - Lanes;
    - Lane markings;
    - Traffic arrows;
    - Crosswalks.
  - **Supports** the layer of **planning** and **decision-making** for autonomous vehicles.



Examples of lane estimation. [4]

[4] Paek, D.-H. and Kong, S.-H. & Wijaya, K. T. (2022). K-Lane: Lidar Lane Dataset and Benchmark for Urban Roads and Highways.

Main Goal: Develop deep learning algorithms for lane marking detection.

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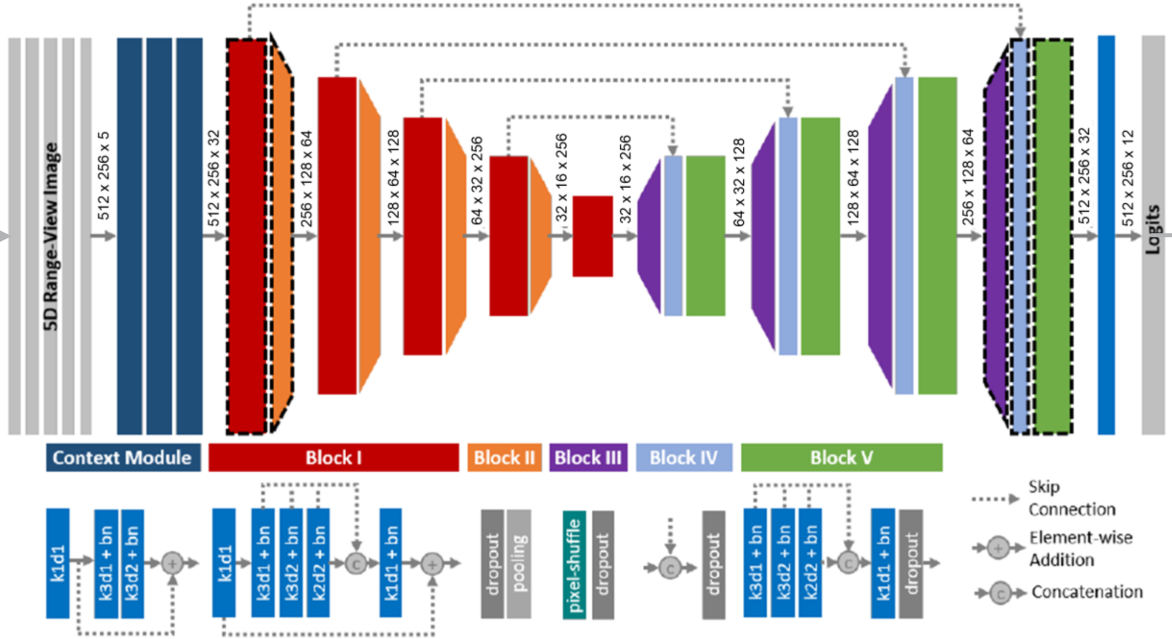
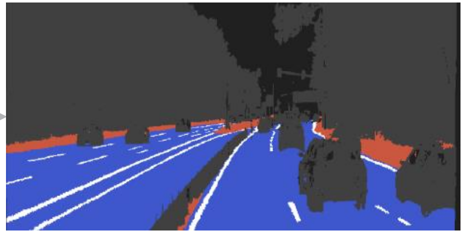
LiDAR based Lane Estimation
SalsaNext Architecture

Input: LiDAR Range View





Output: Prediction

Overview of the SalsaNext architecture. Adapted from [5].

[5] Cortinhal, T., Tzelepis, G., & Aksoy, E. (2020). "SalsaNext: Fast, uncertainty-aware semantic segmentation of LiDAR point clouds."

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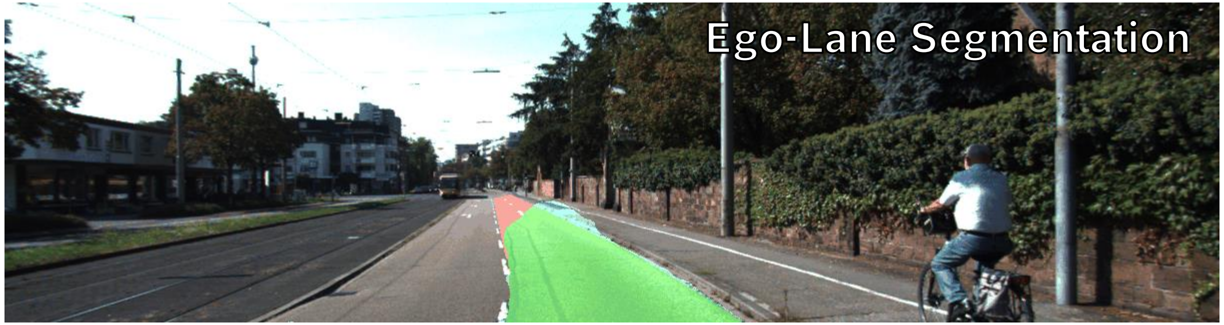
LiDAR based Lane Estimation
Results: KITTI Road dataset

Overall metrics results on test set (%):

Task	Sensor	F1-score	Precision
Road	LiDAR	93.44	**88.92**
	RGB	**95.27**	88.80
Ego-Lane	LiDAR	**88.76**	**79.80**
	RGB	82.29	70.81



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LiDAR based Lane Estimation
Results: THEIA dataset

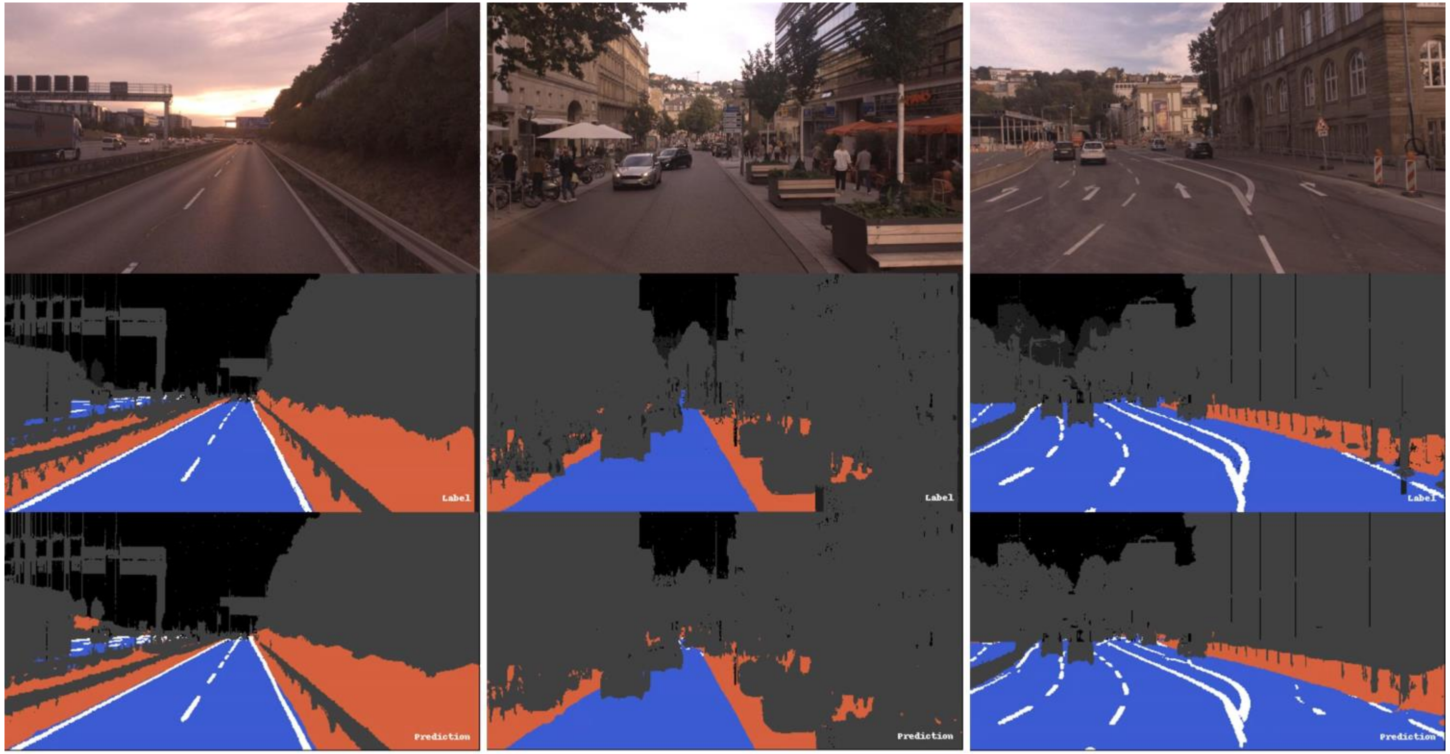
Line
Road
Other Surface
Background

Overall metrics results on test set (%):

IoU	Dice	Precision	Recall
75.50	84.49	84.52	84.81

- **Most important classes** for the lane estimation task and respective results:

	IoU (%)	Precision (%)	Recall (%)
Line	44.70	65.13	55.78
Road	85.96	94.29	90.68



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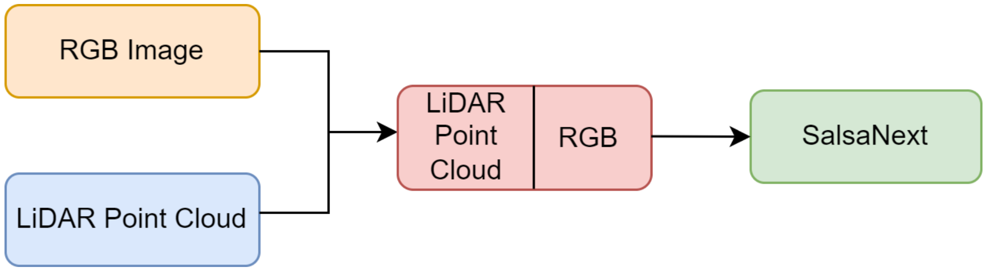
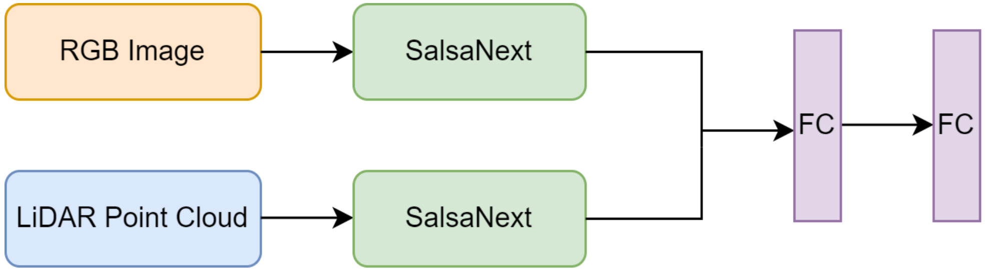
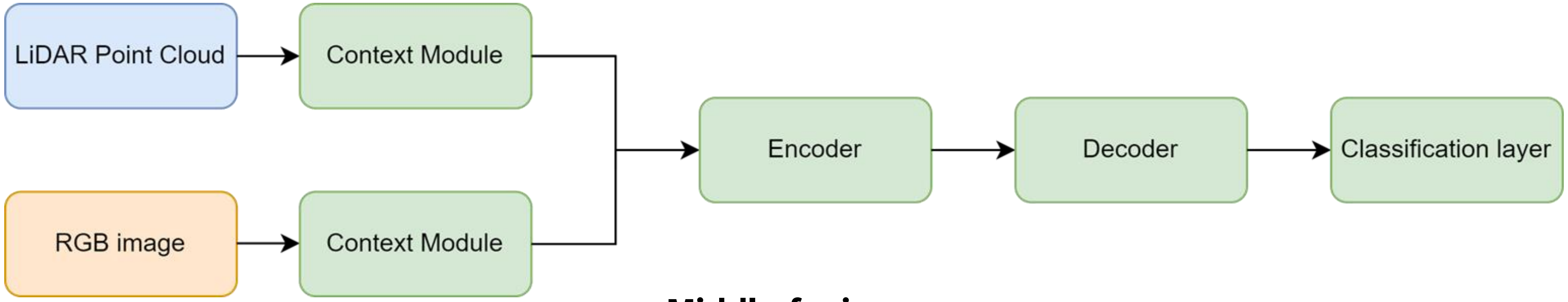
LiDAR based Lane Estimation
Multi-Modal Approaches



Early-fusion



Late-fusion



Middle-fusion

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LiDAR based Lane Estimation
Results: Multi-Modal

KITTI Road Dataset (Road Segmentation)	RGB	LiDAR	LiDAR +RGB (Early)	LiDAR +RGB (Middle)	LiDAR +RGB (Late)
F1-score	95.68	96.10	96.38	**96.69**	95.59
Precision	90.16	90.25	90.15	**91.18**	90.17

KITTI Road Dataset (Ego-lane Segmentation)	RGB	LiDAR	LiDAR +RGB (Early)	LiDAR +RGB (Middle)	LiDAR +RGB (Late)
F1-score	82.29	88.76	90.02	**91.42**	90.97
Precision	70.81	79.80	77.09	78.95	**83.95**

THEIA Dataset	RGB	LiDAR	LiDAR +RGB (Early)	LiDAR +RGB (Middle)	LiDAR +RGB (Late)
F1-score	-	**64.08**	-	62.29	-
Precision	-	**77.04**	-	76.90	-

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QUESTIONS?