KI Data Tooling

The Data Kit for Automotive AI

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

KI Data Tooling is a project of the KI Familie. It was initiated and developed by the VDA Leitinitiative autonomous and connected driving and is funded by the Federal Ministry for Economic Affairs and Climate Action.

www.ki-datatooling.de   @KI_Familie   KI Familie

Welcome

Dear Reader,
It is with great pleasure that we present to you our final KI Data Tooling results booklet.

As part of the VDA Leitinitiative and one of its “KI Familie” projects, KI Data Tooling has taken place on the backdrop of the policy whitepaper of the European Commission and the initiative of the European AI Act. We have witnessed an intensifying debate about the risks incurred by and the need for regulation of AI. While developing approaches capable of addressing the requirements placed on high-risk AI applications and methodologically sound development of safety-relevant AI-based vehicle functions, we have also seen real AI hazards materialize on roads. Actual road fatalities serve as a clear beacon underscoring the need for a safety-first approach also when developing AI and with AI for automated driving applications.

Historically, premium German automaker’s pride always encompassed a safety-focused approach. The German automotive industry and its partners were already at the forefront of functional safety standardization in e.g. ISO 26262 and is now continuing this commitment with substantial contributions to AI-aware enhancements such as ISO PAS8800. They also took a clear stance with their safety-first for automated driving whitepaper in 2019. Predictably, in 2023, the world first SAE L3 deployments to receive regulatory approval in accordance with UNR-157 are offered to the market by German OEMs.

We are very happy that these OEMs and their development partners are also key players in the VDA Leitinitiative. Together with world-class partners in academia and industry, we have defined and followed a research mission to extend this safety-focussed approach towards applications of AI in automated driving functions. In KI Data Tooling, we have emphasized the role of systematic engineering of high-quality data for the successful development of robust and dependable AI-based driving functions, both from real sensor recordings in the wild and also synthesized from high-end simulation. To make automated driving functions suitable for everyday use, it is essential to safely and reliably navigate an almost unmanageable and unpredictable multitude of situations. The KI Data Tooling project addresses this long tail of very narrow ODD extension and exceptions, pursuing the goal of a complete solution for generating and processing data for the development safety-relevant AI functions fit for type approval.

Traditionally, the development of AI functions requires complex campaigns to record training data in the wild, sending out a fleet of probe vehicles with dedicated sensor data recording capacities. Nevertheless, all these real data recordings often only depict frequent traffic situations well. They do not include rare or even dangerous situations to an extent to be considered sufficient for the training of machine learning functions. Or are not allowed to, again for the sake of road traffic safety, compliance and responsibility. Synthetically generated data can, must, and will close these gaps with simulations. In this way, ODD-relevant situations and conditions can be specifically varied and (re-)produced in almost any level of detail.

KI Data Tooling was able to further contribute to results from other significant and accomplished projects from the VDA Leitinitiative, thanks to foresighted program definition and funding by Federal Ministry for Economic Affairs and Climate Action BMWK and the very professional expert monitoring and support by TÜV Rheinland Consulting‘s project agency.

Thanks to a dedicated collaboration within a consortium of 17 partners, we were able to rally behind the shared vision of a Data Kit for Automotive AI. Although having had to face significant risks and need for pivoting just as any other research initiative, project KI Data Tooling concludes with significant contributions beyond the state of the art, witness to which is given with this booklet and many other materials that will be made publicly available or presented at our final event.

A clear lesson learned is that when it comes to GDPR-compliant, legally cleared publishing of data sets jointly developed, more innovative collaboration structures are required, beyond the mere classical consortium contract in accordance with public funding rules.

As coordinators of KI Data Tooling, our sincere thanks for spirited, professional and collaborative team-work go to all who contributed during the project‘s runtime.

Hans-Jörg Vögel
BMW Group
Project Coordinator KI Data Tooling

Armin Köhler
Bosch
Scientific Co-Lead KI Data Tooling

Greeting from the Federal Ministry for Economic Affairs and Climate Action

Artificial Intelligence plays a not yet assessable large role in all fields of society. The “KI Familie” has at an early stage recognized its potential and was therefore set up to push for AI competencies in the diverse and dynamic field of autonomous driving. With its four “KI Familie” flagship projects, the Federal Ministry for Economic Affairs and Climate Action is fostering a cooperative research approach that brings together the expertise of numerous participants to tackle different problem areas of AI. Started off as part of the “VDA Leitinitiative”, the projects were set up to complement each other, to make more out of scarce resources and to be faster by sharing data, tools and results. We happily supported this approach. Mastering automation with AI in safe, autonomous driving, with high complexity requires adaptable and intelligent systems. Although there is still much to be done, essential foundations have been laid here for the industry, to harness AI for safe, autonomous driving functions. The KI Data Tooling project has made a distinctive contribution to the field of AI and data in its project runtime. Methods and tools for the generation and preparation of training, validation and safeguarding data for AI functions in autonomous vehicles were explored and a resilient AI data kit for the training of AI functions was developed. The data kit shall ensure that AI functions for highly automated driving can be effectively and efficiently trained with the right set of high-quality data, approved methods and reliable tools. As the BMWK, we are fortunate to support important and excellent projects like KI Data Tooling and thank the 17 partners who have worked jointly to take the important step from a Data Set to the Data Kit, which is presented in this booklet next to other, successful project results.

Ernst Stöckl-Pukall
Head of Division for Digitalisation and Industry 4.0, Federal Ministry of Economic Affairs and Climate Action

Federal Ministry for Economic Affairs and Climate Action

Collaboration in Artificial Intelligence

Classic automotive questions are re-emerging with regard to AI. AI technology know-how and its safe use in modern vehicles will determine the leading role in the mobility markets of the future. The German automotive industry addresses this challenge with the projects of the **KI Familie**. The KI Familie was initiated and developed by the **VDA Leitinitiative Connected and Autonomous Driving**. 80 leading partners from science and industry are involved receiving funding from the Federal Ministry for Economic Affairs and Climate Action (BMWK).

In this unique setting, all KI Familie projects are working together. The partners are sharing knowledge while fostering pre-competitive collaboration which is essential in an ever more competitive and complex environment with fast pace innovations. Exchanging findings across project boundaries accelerates the knowledge buildup in cutting edge technologies for the good of industries, research institutions and society. The joint commitment to share pre-competitive knowledge helps each partner to stay technologically ahead and multiplies resources and investments of each partner.

The KI Familie has four sibling projects which all are focusing on special AI topics.

KI ABSICHERUNG
Methods and measures to safeguard AI-based perception functions for automated driving.
https://www.ki-absicherung-projekt.de

KI WISSEN
Development of methods for the integration of knowledge into machine learning.
https://www.kiwissen.de

KI DELTA LEARNING
Development of methods and tools for the efficient expansion and transformation of existing AI modules in autonomous vehicles to meet the challenges of new domains.
https://www.ki-deltalearning.de

KI DATA TOOLING
Methods and tools for the generation and refinement of training, validation and safeguarding data for AI functions in autonomous vehicles.
https://www.ki-datatooling.de

Facts & Figures

Hans-Jörg Vögel
BMW Group
Project Coordinator

45 Months
Project Duration: (01/04/2020 - 31/12/2023)

17 Project Partners
8 Industry Partners
6 Academic Partners
3 Research Institutes

€ 25.7 M
Project Budget

€ 16.2 M
Funding Budget

Funding Body
Federal Ministry for
Economic Affairs and
Climate Action (BMWK)

KI Data Tooling Big Picture – The Data Kit for Automotive AI

The Project
KI Data Tooling followed a dual project approach to achieve a complete data solution for the training and validation of AI functions for highly automated driving. Starting position was the definition of a comprehensive database of real data, synthetic data and augmented data for various sensor modalities (camera, lidar, radar). Complemented by methods and tools for preparing, storing and processing this data, the involved 17 project partners developed the KI Data Tooling Data Kit.

The Data Kit
More than three years of collaborative research and development have been necessary to create a technology solution that represents a crucial building block for deploying safe and reliable AI in highly automated driving functions: a resilient AI data kit for AI function training. This data kit guarantees the effective and efficient training of AI functionalities for highly automated driving by employing a carefully selected data set, approved methods, and reliable tools.

Training AI across various driving domains and complex traffic scenarios is paramount for achieving safe, robust, and reliable AI functionalities throughout the entire process chain. This journey begins with data acquisition, followed by processing, enrichment, curation, validation, and ultimately the application of refined data within the ML training loop.
A specific framework architecture, complete with relevant tools and methods, defines the workflow.
Throughout the project‘s progression and through close collaboration with the sister project, KI Absicherung, it became evident that standardization activities, for example ISO 8800 starting in 2024, had an influence on the project‘s work packages and decisions. As a result, all 17 consortia partners from industry, technology, and scientific institutions unanimously agreed to design and develop the AI data kit with standardized specifications in mind, particularly concerning the ML framework architecture of the AI data kit.
The proposed solution of the project’s KI-DT framework architecture, which outlines the data and ML workflow in a structured manner and maps potential tool building blocks that support this process. Describing such a

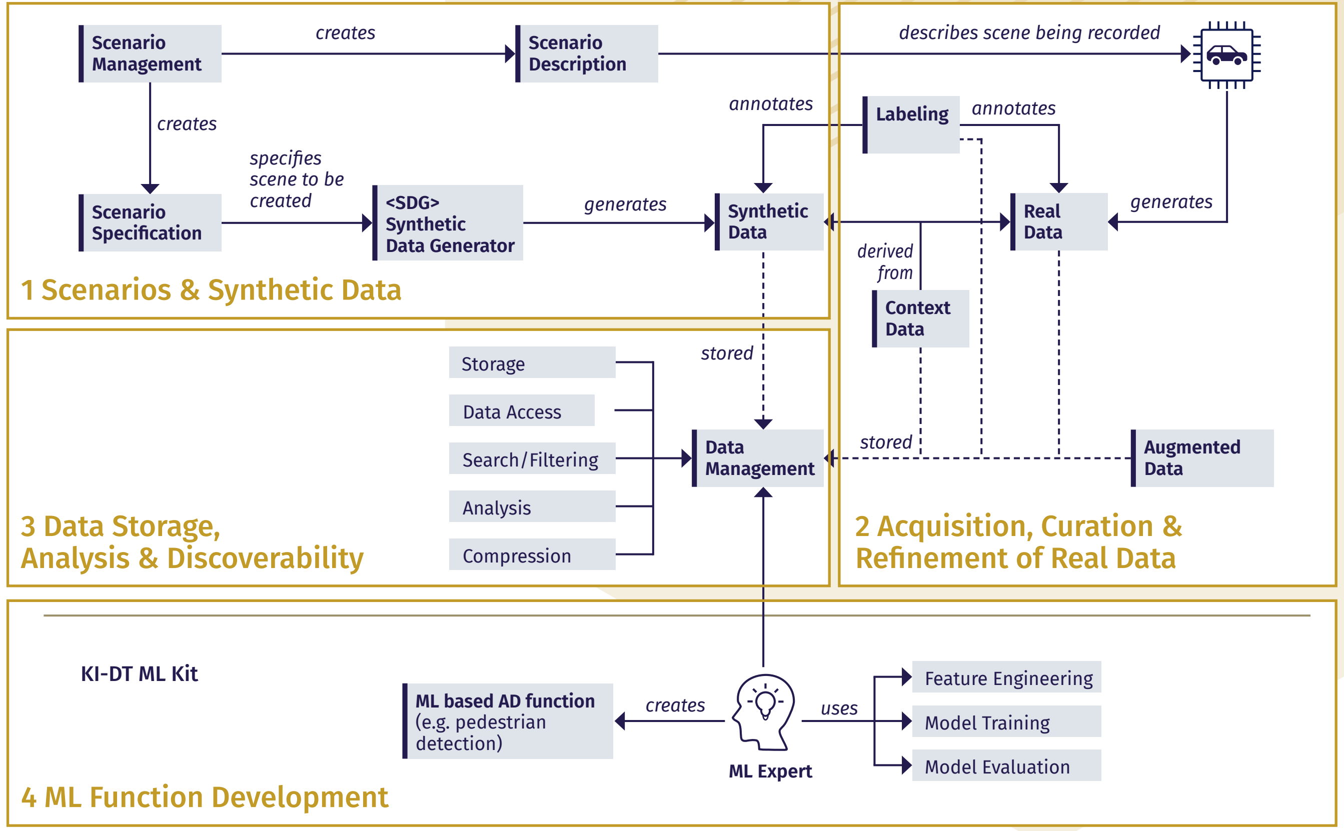
structured framework architecture forms the foundation for confidence in the completeness, quality, and efficiency of the interacting elements. The entire framework can be grouped into four main categories: (1) scenarios and the production of synthetic data, (2) real-world data recording, curation, and refinement, (3) data storage, analysis, and discoverability, and (4) data set usage for ML function development. Within these four sections, designated methods, such as taxonomies for describing and detecting corner cases, metadata enrichment, data search, curation, and active learning, synthetic data generation, style transfer, and usage in mixed training approaches, are being developed.

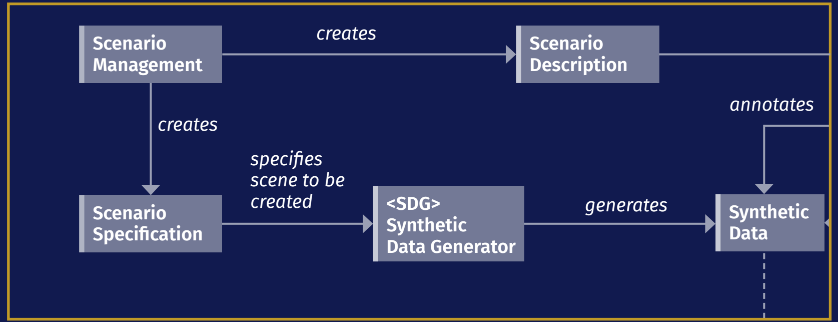
Next steps toward deployment

It is crucial that the theoretical framework architecture aligns with applicable methods to meet the requirements for a comprehensive data and ML training loop. When addressing future standardization requirements, evaluating each of the above-mentioned methods and solutions is essential to gain trust and confidence. Furthermore, presenting and even demonstrating suitable method examples are indispensable steps toward real-world application and establishing credibility in the approach.

Caption figure on the right: The KI-DT Data Kit Framework Architecture with all four assigned categories: (1) Scenarios & Synthetic Data, (2) Acquisition, Curation & Refinement of Real Data, (3) Data Storage, Analysis & Discoverability and (4) ML Function Development

KI-DT Data Kit Framework Architecture





1 Scenarios & Synthetic Data

Scenarios & Synthetic Data

The category #1 of the KI Data Tooling framework architecture called "Scenarios & Synthetic Data" combines those methods in the data life-cycle workflow model that are needed to define and describe data needs (scenarios used for developing methods supporting an AI based perception task) as well as the production and evaluation of synthetic data.

Goals

A data and scenario request management process had to be established for the project. For that we needed to define scenario descriptions and specification formats that allow to formulate the data requirements according to the specific needs for data and AI method development. The interfaces to the next life-cycle category which is "real data recording and labelling" as well as for the internal synthetic data production had to be established. And finally, we needed a synthetic data generation and evaluation pipeline, capable of producing the specified synthetic data needs.

Achievements

A cross project working group responsible for data ticketing process and the interfaces to real and synthetic data production was set up.

Secondly formats for scenario description and specification were defined and used: We used the Pegasus model for 1st level scenario definition. More detailed scenario descriptions for sensor challenges were defined using a corner case taxonomy, the KI-A ontology and Open-X standards. After having scenarios described, they had to be converted into scenario requests for the purpose of synthetic data production using Open-X standards and Zwicky Boxes. Next, synthetic data pipelines were set up including different scenario and digital twin generation processes, sensor models, 3D environment models & assets, materials, rendering and ray-tracing simulation, ground truth generation and using Open-X and glTF standards. After producing the synthetic data, evaluation methods and tools were developed to evaluate the quality of sensor models, 3D models and assets as well as evaluating the data themselves on their physical quality and the usefulness for training in AI based perception downstream tasks. This task was shared with the category #4 part of the framework that is responsible for the ML life-cycle.

Creation of Digital Twins of Urban Traffic Spaces for Sensor Simulation and Synthetic Data Generation

Ludwig Friedmann, BMW AG

Simulation-based generation of synthetic training data for AI-based automated driving functions and environment models for physics-based sensor simulation require so-called digital twins of the real world. These incorporate 3D models of the environment, associated materials, maps and scenarios describing traffic situations. The creation process comprises reconstruction of the environment, creation of 3D models, measurement of materials and validation of the mentioned artifacts. The use of standardized formats throughout the process reduces integration efforts, enables exchangeability of artifacts and scalability of the approach.

Digital Twins of Urban Traffic Spaces. (© BIT-TS GmbH)

3D Asset Creation for Synthetic Data Production

Marcel Sittner, machenschaft GmbH | **Jakob Kirner**, BIT Technology Solutions GmbH

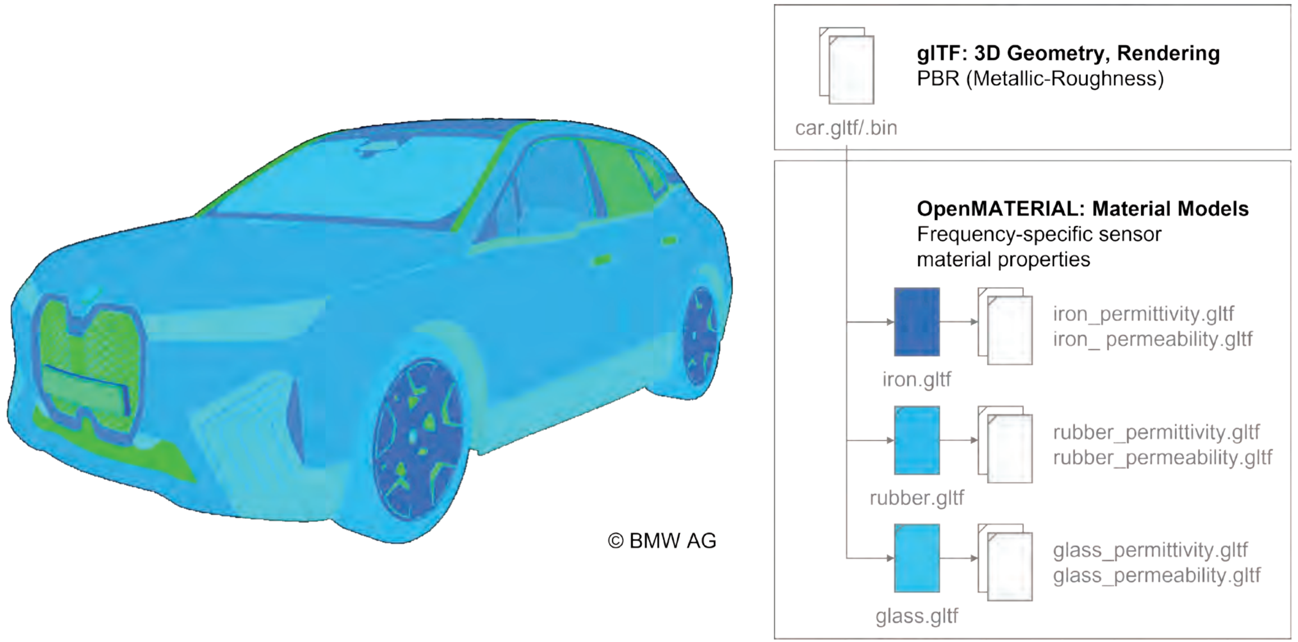
3D assets are the building blocks of virtual environments for simulation and synthetic data production. Toolchain specifications for sensor simulation, ground truth generation and metadata impose strict rules on the 3D assets created for the project. We showed how asset features are dependent on the project specifications. Furthermore, we walked through the creation steps of a simulation-ready cigarette machine 3D asset in the glTF format.

A simulation-ready cigarette machine 3D asset created for the project.

Material Parameters in Radar Simulation

Helmut Schön, Robert Bosch GmbH | **Reinhold Herschel, Matteo Marone**, BIT Technology Solutions GmbH
Ludwig Friedmann, BMW AG | **Jacob Langner**, FZI Forschungszentrum Informatik

In radar simulation realistic results can only be obtained if the simulation input is realistic. This requires not only accurate 3D-models of the environment but also realistic material parameters. In KI Data Tooling, we measured materials typical for automotive scenarios and extracted the radar parameters such as permittivity and roughness. These parameters serve as input in the glTF extension OpenMATERIAL to obtain realistic assets that were then used in radar simulation.



Vehicle with Material Assignment. (© BMW AG)

Validation Tools for 3D Models and Materials

Ludwig Friedmann, BMW AG | **Tobias Denk**, BIT Technology Solutions GmbH

Training of AI-based automated driving functions requires high-quality synthetic data generated from 3D scenes. To ensure appropriate quality of corresponding 3D models and materials, (partially) automated quality assurance measures are required.

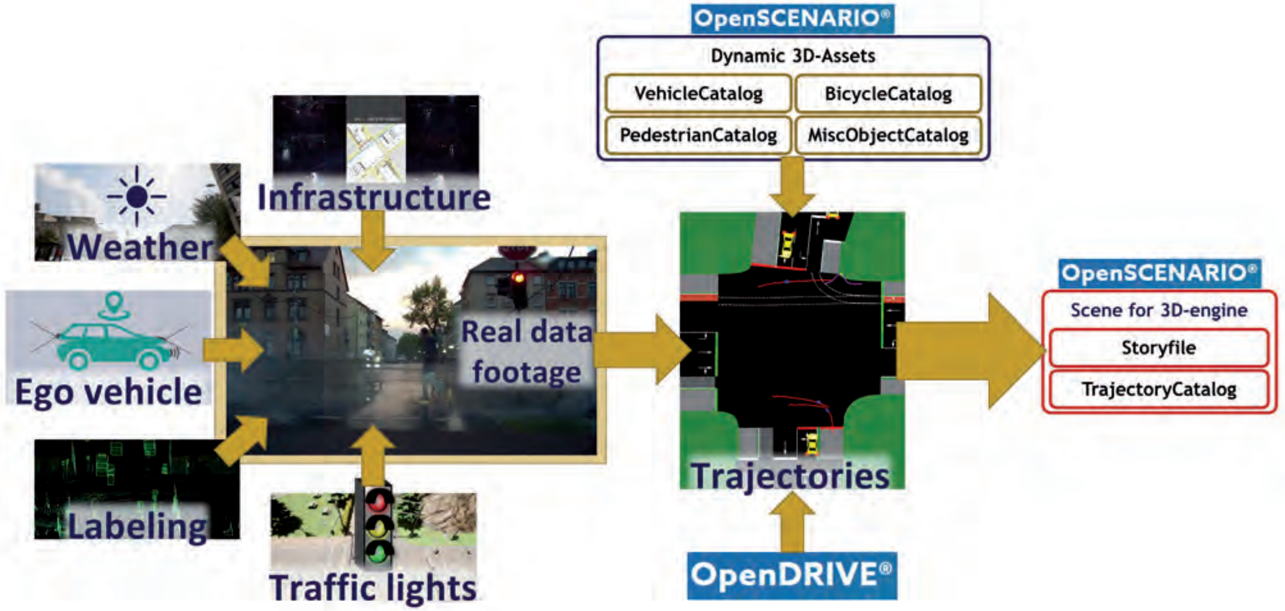
In KI Data Tooling, a path tracer software for physics-based rendering of 3D models and materials was developed. Implementation of two different reflection equations enables support for rendering materials (PBR Metallic-Roughness) and physics-based sensor materials (OpenMATERIAL). The software further provides false-color rendering modes for evaluation of mesh topologies, surface properties, primitive geometries and materials.

Validation of 3D Models and Materials. (© BMW AG)

Converting Real-World Measurements into Scenario-Based Simulations

Dominik Salles, Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

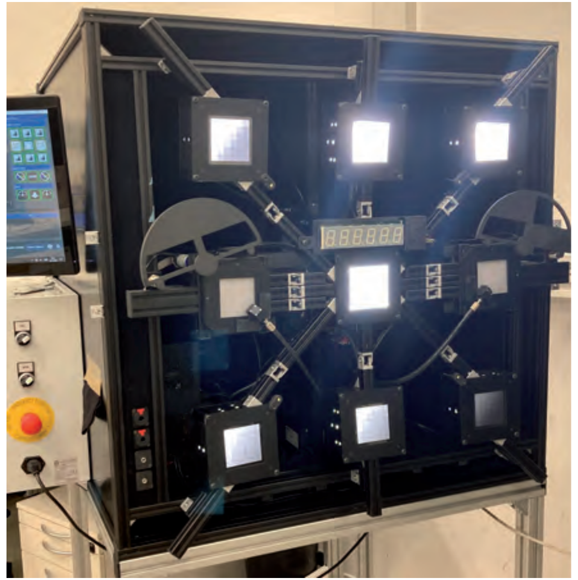
For the creation of digital-twin data, real-world measurements (frames) need to be converted into scenario-based scenes. We use multiple data sources for the conversion: ego vehicle data, 3D Bounding Boxes from labelled sensor data, and data from infrastructure sensors and from weather stations. The data is merged, processed, and smoothed before written into OpenSCENARIO files, which can be read by various simulation programs. The traffic simulation program SUMO is used as debugging device. The resulting sequences can then be replayed in the simulation, where synthetic data is generated.

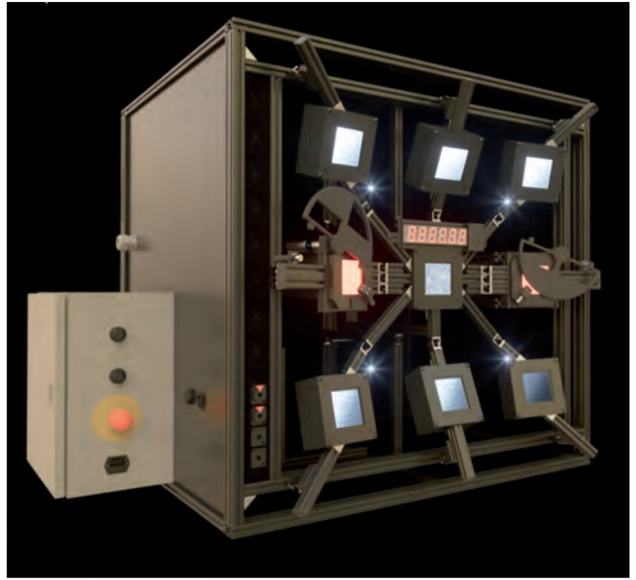


Camera Challenges and Evaluation of Camera Specific Properties

Marzena Franek, Falko Matern, Ulrich Seger, Robert Bosch GmbH

“World to camera” interactions lead to artifacts caused by camera constraints but the complete interactions in a scene are challenging to model in a virtual world. Since camera specific characteristics have a high impact on image appearance it is important to quantify and model them. Some camera challenges observed in real life can be provoked in a lab environment to measure camera specific behavior and compare sensor models against real measurements.





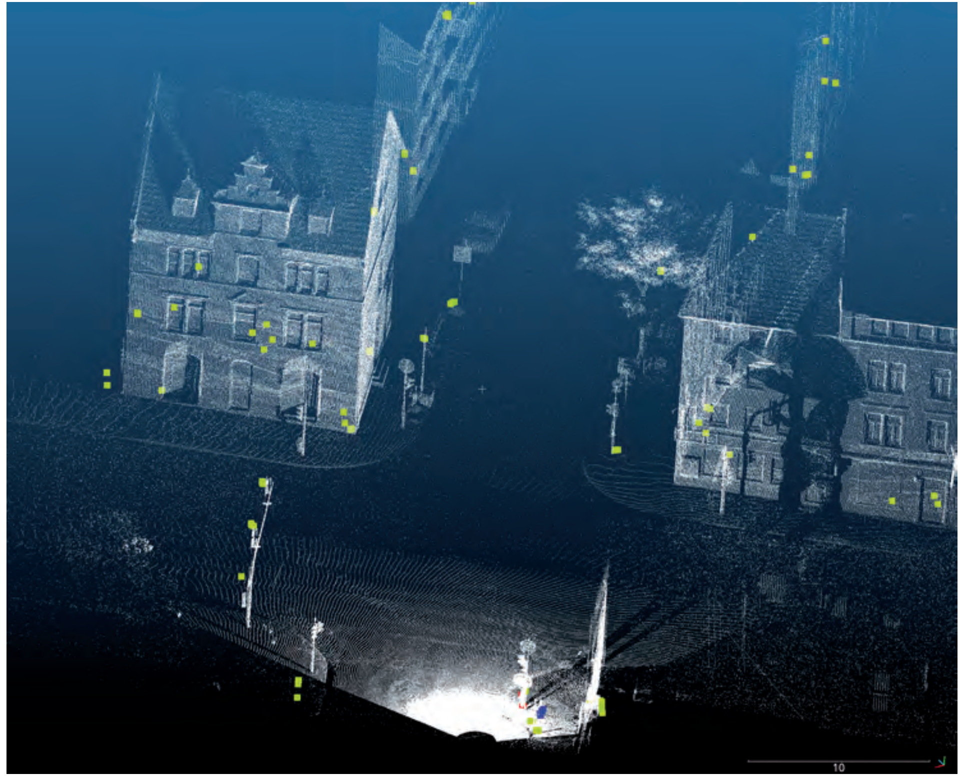
Dynamic Test Stand (Image Engineering [1]) to measure camera specific properties in laboratory (left) and as digital twin (right). (© Bosch)

[1] https://www.image-engineering.de/content/products/solutions/dynamic_test_stand/downloads/DTS_flyer.pdf

Radar Sensor Simulation

Fabian Roos, Helmut Schön, Robert Bosch GmbH
Matteo Marone, Reinhold Herschel, BIT Technology Solutions GmbH
Lukas Lang, Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

The objective of this study is to assess the quality of synthetic radar data by comparing it with measurements obtained from real sensors in digitally reconstructed environments. Multiple scenarios with varying levels of complexity have been considered. Initially, a simple open-space scene (Renningen) featuring a moving ego vehicle and static geometric objects was evaluated for calibration purposes. Subsequently, a more intricate urban scene at an intersection in Aschaffenburg was both measured and simulated. This urban scene included dynamic elements such as pedestrians and cars, with their movements reconstructed to reflect realistic trajectories.

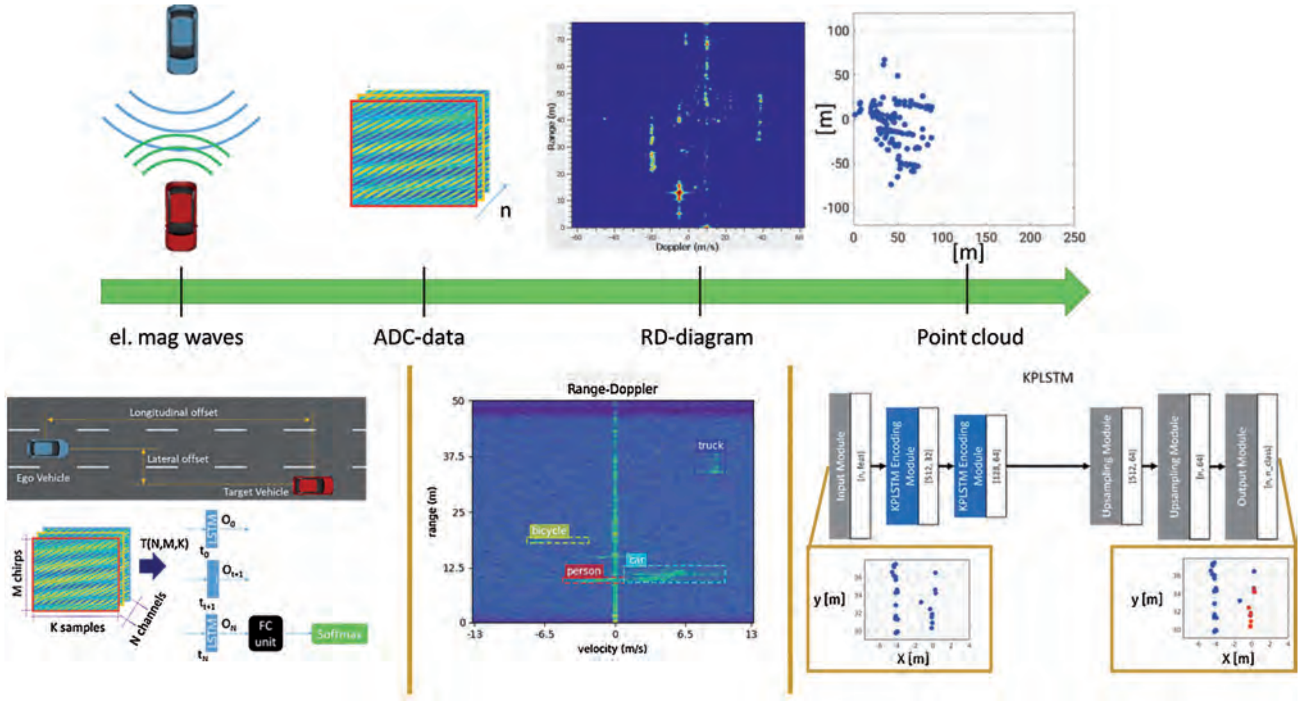


Pathtracer hitmap and radar detections in an urban intersection scene. (© BIT Technology Solution)

AI Use Cases with Radar Data: An Overview

Lukas Lang, Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

In automotive applications with radar sensors, the Machine Learning (ML) approaches highly depend on the used data. However, the type of radar data also highly depends on the used signal processing pipeline. Types can be raw ADC-Data, Range-Doppler diagrams (RD) or point clouds. Evident is, that some approaches are more suitable than others. For example, ADC-Data recurrent neural networks (RNNs) and variational autoencoders (VAEs) are very effective for object range detection. They are suitable because of their complex valued and matrix shaped data structure. For RD YOLO approaches can be used for object detection and localization. And last but not least point clouds can be segmented with approaches like pointnet(++).

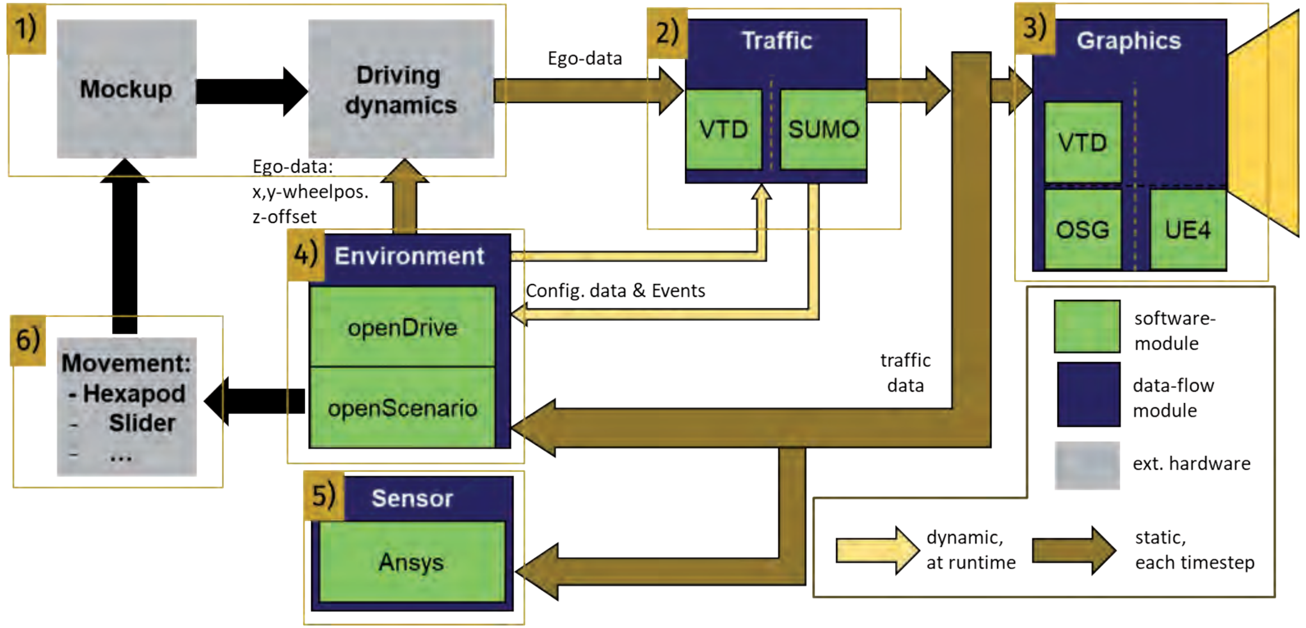


Overview of AI usecases with different radar data. | Ref.: [1] Lang, L.; Saad, K.; Salles, D.; Reuss, H.-C., „Automotive Radar Antenna Configurations and their Impact on Machine Learning Approaches: A Case Study", Driving Simulation Converence (DSC22), Straßburg | [2] Zhang, A.; Nowruzi, F. E.; Laganière, R., "RADDet: Range-Azimuth-Doppler based Radar Object Detection for Dynamic Road Users." 2021 18th Conference on Robots and Vision (CRV) (2021): 95-102. | [3] Nobis, F.; Fent, F.; Betz, J.; Lienkamp, M.; „Kernel Point Convolution LSTM Networks for Radar Point Cloud Segmentation", Applied Sciences 11 (2021), no. 6: 2599. https://doi.org/10.3390/app11062599

The Stuttgart Driving Simulator for Driver-in-the-Loop Simulation Tests

Lukas Lang, Christian Holzapfel, Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart
Günther Hasna, Mohammed Saif, Ansys Germany GmbH

The Stuttgart Driving Simulator is used for testing of ADAS/AD functions with driver in the loop. The simulation framework has been expanded to a highly realistic real-time capable radar simulation by integrating the Ansys radar sensor simulation. This allows to include sensor effects in the behavior of a driver-assistance system or to generate corner cases by manual driving while keeping the flexibility and variability of a simulation. By combining SUMO with the traffic simulation, the variability of realistic traffic scenarios has been extended. Standards like OpenDRIVE, OpenSCENARIO, and OSI ensure transportability and exact reproduction of scenarios.



Driving simulation framework for syntetic data generation.

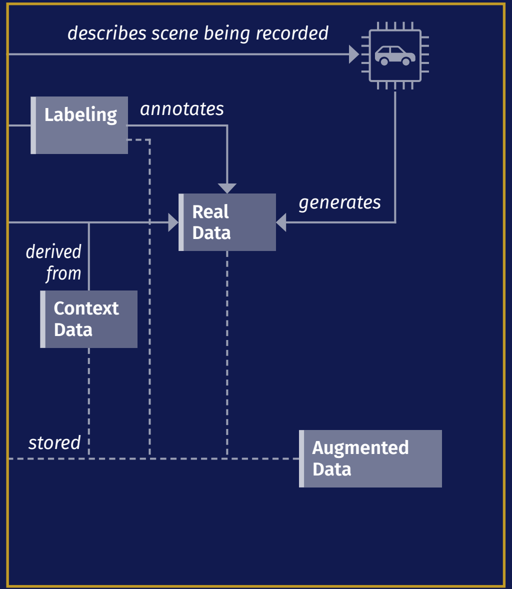
CARLA-Wildlife: A Synthetic Video Data Set for Tracking and Retrieval of Out of Distribution Objects

Svenja Uhlemeyer, **Kamil Kowol**, Bergische Universität Wuppertal
Kira Maag, Robin Chan, Hanno Gottschalk, Technische Universität Berlin

Out of Distribution (OOD) objects are objects with a semantic class outside the semantic space of an underlying image segmentation algorithm, or a semantic space instance that looks significantly different from instances in the training data. OOD objects occurring on video sequences should be detected on single frames as early as possible and tracked over their time of appearance as long as possible. We present the synthetic CARLA-Wildlife data set that consists of 26 video sequences containing up to four OOD objects on a single frame. We propose metrics to measure the success of OOD tracking and develop a baseline algorithm that efficiently tracks the OOD objects.

Exemplary OOD objects from the CARLA-Wildlife data set.
Ref: Maag, Kira, et al. „Two Video Data Sets for Tracking and Retrieval of Out of Distribution Objects." Proceedings of the Asian Conference on Computer Vision. 2022.

2 Acquisition, Curation & Refinement of Real Data



Acquisition, Curation & Refinement of Real Data

The category #2 of the KI Data Tooling architecture called “Acquisition, curation and refinement of real data” provides all elements regarding to real data recording, labeling, pre-paration, context generation and data augmentation for the data life-cycle workflow model.

Goals

The main goal of this category was to provide labeled multi-modal real data recordings containing different views from vehicle and infrastructure perspective to all project partners and the specification of a common data exchange format in conjunction with establishing methods for data preparation. Another important topic was identification, formalization, preparation and extraction of context data from the recorded real data and specification of suitable data structures. Further goals were the development of methods and tools for automatic and semi-automatic annotation of real data, for modifying and enhancing existing scenes for a predefined purpose, e.g. corner cases, and finally for augmenting existing real data.

Achievements

Four test campaigns on two different research crossings were held. These data was processed by creating a multimodal sensor data set combining real and meta data and incorporating labeling. One of the project’s novelties were the “AIM Research intersections”, providing additional highly valuable data like obscured objects, weather and real-world traffic insights. For context generation, all possible sources were used, ranging from images and structured data sources using cameras, sensors, 3D renderers, and open data. Context data was also used to increase ML detection performance of corner case situations and to create a digital twin by using a context aware infrastructure recording with multiple trajectories. For the area of autolabeling, an automated pipeline was invented to apply active learning via neural network uncertainty modeling. Additionally, a pipeline to automatically generate textual scene descriptions was developed. In data augmentation, a method for anonymization of pedestrian faces with generative networks using off-the-shelf general-purpose diffusion models was created. The ambiguity of data augmentation for 3D Object Detection on lidar point clouds was investigated in-depth and finally, virtual humans in 3D environments were synthesized and used by a procedural 3D human generation rendering pipeline.

Context Information for Corner Case Detection in Highly Automated Driving

Florian Heidecker, Bernhard Sick, Universität Kassel | **Tobias Susetzky, Erich Fuchs**, Universität Passau

An essential task of machine learning models for highly automated driving is to reliably detect and interpret unusual, new, and potentially dangerous situations. In this work, additional context annotations for the BDD100k image data set have been labeled and explored with respect to their impact on model performance. We further provide explanations to the initially counter-intuitive results and correct the performance evaluations, showcasing that an understanding of how performance measures are evaluated is important to correctly interpret model performance comparisons.

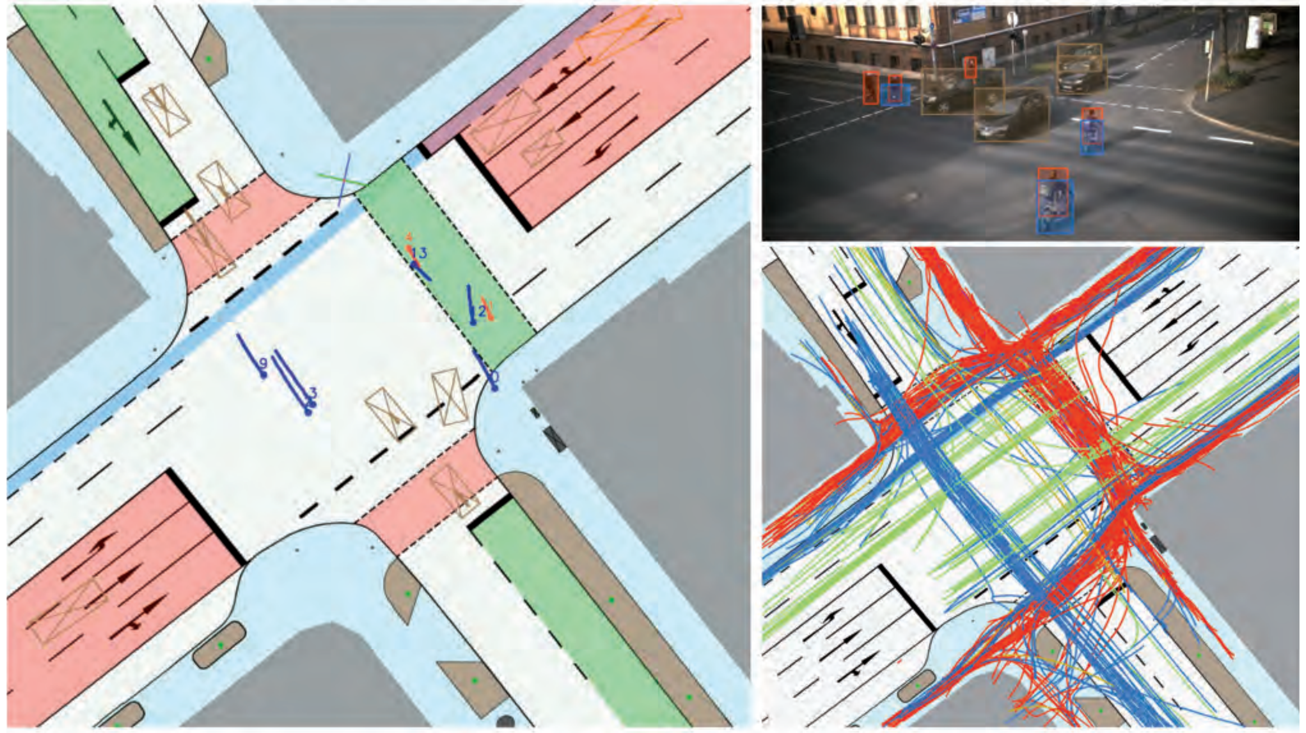
A small overview of example images from BDD100K [1] with different context attributes. The most outstanding context attribute is mentioned by name under each image.

[1] F. Yu, H. Chen, X. Wang, W. Xian, Y. Chen, F. Liu, V. Madhavan, and T. Darrell, "BDD100K: A Diverse Driving Dataset for Heterogeneous Multitask Learning," in Proc. of CVPR, Seattle, WA, USA, 2020, pp. 2636–2645.

Multi Trajectory and Context Recording

Manuel Hetzel, Hannes Reichert, Konrad Doll, Technische Hochschule Aschaffenburg

Data is a critical need for AI-based functions. Creating data for large-scale problems is time-consuming and expensive. Synthetic data can help to tackle these topics. We propose the public research intersection in Aschaffenburg [1] for large-scale data creation using multiple sensors to classify and track all road users. Additional context data like traffic light signal status and weather data is also included. The data is critical to auto-create precise digital clone scenarios for synthetic data creation and quality evaluations. The trajectory and metadata are part of the KI Data Tooling Data Kit and The IMPTC Dataset: An Infrastructural Multi-Person Trajectory and Context Dataset [2].



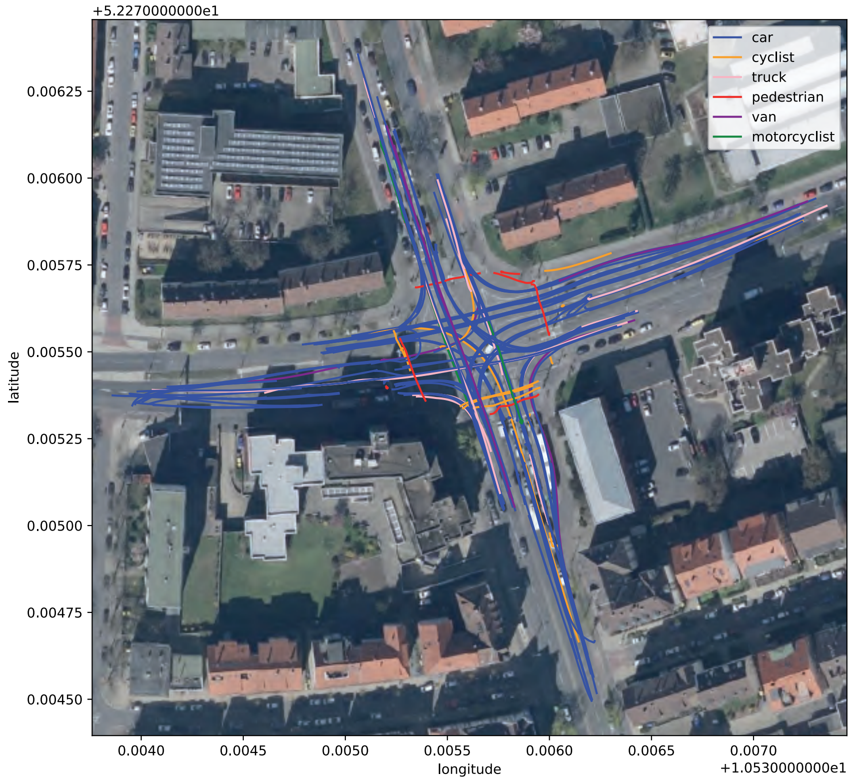
(Left) High-level trajectory and context data visualization, (Right) summary of all VRU tracks. (© University of Applied Sciences Aschaffenburg)

Ref.: [1] M. Hetzel, H. Reichert, K. Doll and B. Sick, „Smart Infrastructure: A Research Junction," 2021 IEEE International Smart Cities Conference (ISC2), Manchester, United Kingdom, 2021, pp. 1-4, doi: 10.1109/ISC253183.2021.9562809. | [2] M. Hetzel, H. Reichert, G. Reitberger, E. Fuchs, K. Doll and B. Sick, „The IMPTC Dataset: An Infrastructural Multi-Person Trajectory and Context Dataset," 2023 IEEE Intelligent Vehicles Symposium (IV), Anchorage, AK, USA, 2023, pp. 1-7, doi: 10.1109/IV55152.2023.10186776.

Benefits of the “AIM Research Intersection” for KI Data Tooling

Clemens Schicktanz, Kay Gimm, Karsten Liesner, Deutsches Zentrum für Luft- und Raumfahrt

The “AIM Research Intersection” from DLR was employed in measurement campaigns involving recording vehicles from project partners to generate a collective trajectory data set. This data set contains information about the traffic conditions across the entire intersection, encompassing regions and road users that might be obscured from a vehicle‘s perspective but are on a potential collision path with the vehicle. Context data was extracted to enhance the recorded trajectory data set. Moreover, the research intersection facilitates the categorization of traffic situations into typical and atypical scenarios, offering valuable insights into real-world traffic behavior.

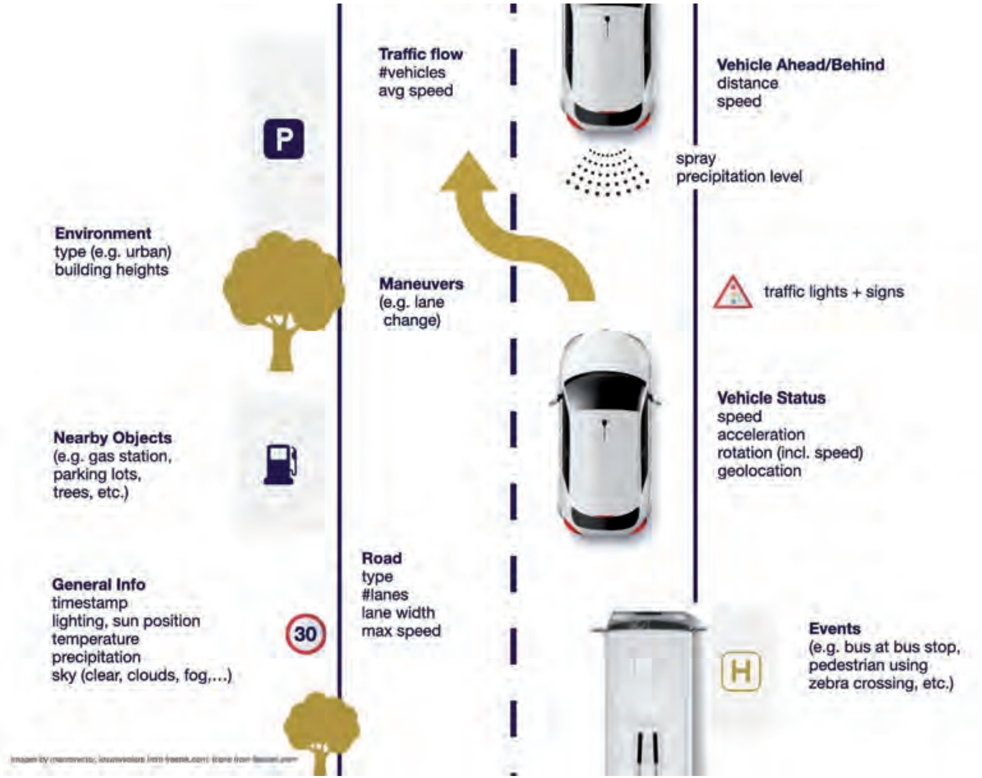


Trajectories of traffic participants at the „AIM Research Intersection“. (© DLR)

Context Generation from Images and Structured Data

Tobias Knerr, Tobias Susetzky, Erich Fuchs, Universität Passau

We gathered context (metadata about a recording in the KI-DT data set) from various sources. Notably, we classified weather and road properties by applying CNNs to RGB images. However, we also used data sources which already provided information in a machine-readable format. For real-world data, this included CAN bus data originating from vehicle sensors as well as data recorded by stationary sensors. For synthetic data, this included knowledge exported by the tools which generate the 3D-rendered scenes. Using the time and location coordinates from CAN bus data, we additionally tapped into third party databases such as OpenStreetMap.

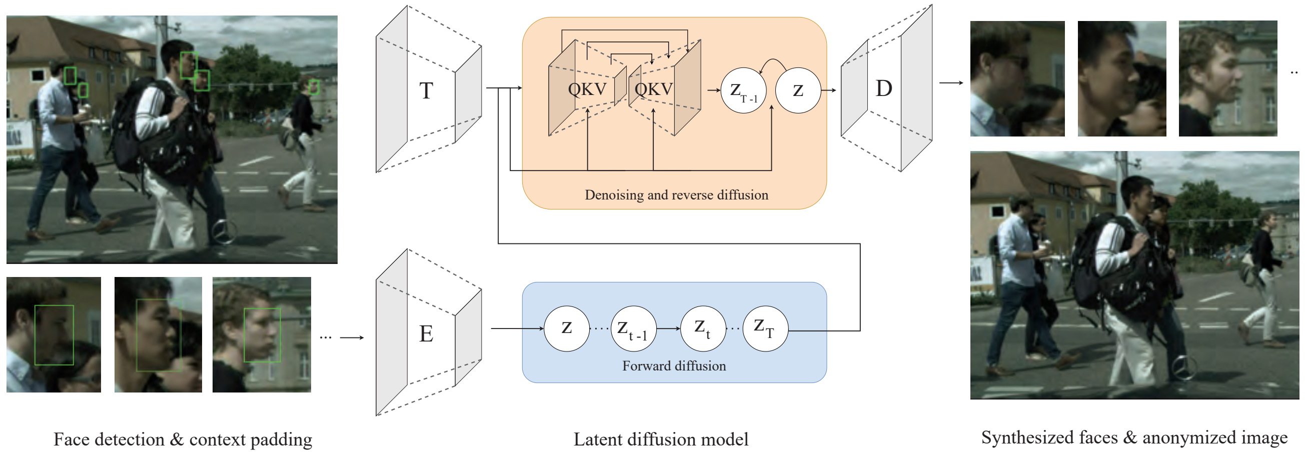


Examples of context generated by KI Data Tooling partners.

Latent Diffusion Face Anonymization

Kevin Rösch, FZI Forschungszentrum Informatik

In order to protect vulnerable road users (VRUs) it is essential that intelligent transportation systems (ITS) accurately identify them. However, data protection regulations require that individuals are anonymized in such data sets. In this work, we introduced a deep learning-based pipeline for face anonymization in the context of ITS. Our two-stage approach contains a face detection model followed by a diffusion model to generate realistic face in-paintings. To demonstrate the versatility of anonymized images, we trained segmentation methods on anonymized data and evaluated them on non-anonymized data.



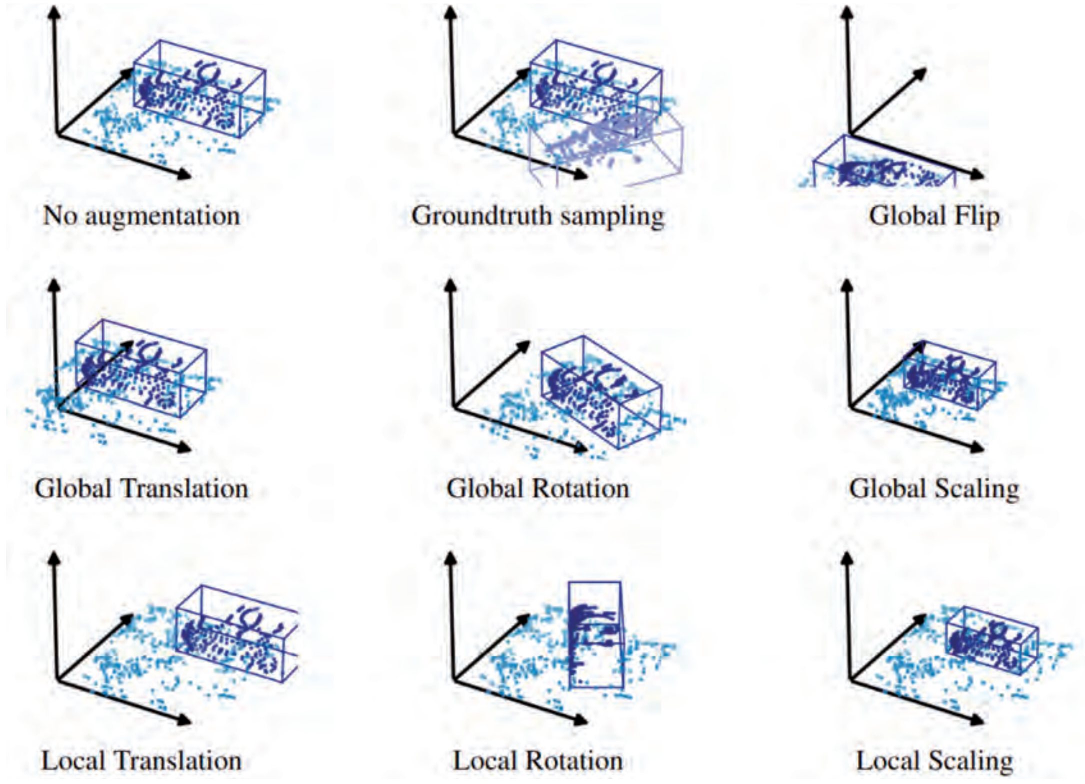
Anonymization pipeline with example images from Cityscapes [1].

[1] Marius Cordts, et al., „The Cityscapes Dataset for Semantic Urban Scene Understanding." In Proc. Of CVPR

About the Ambiguity of Data Augmentation for 3D Object Detection

Matthias Reuse, Valeo Schalter und Sensoren GmbH

Data augmentation is considered an important step in the training strategy of 3D object detectors on point clouds to increase the overall performance and robustness. There exist various augmentation methods for point clouds for the task of 3D object detection with hyperparameters each. The question arises as to the impact as well as the transferability of different augmentation policies. By a variety of experiments it was revealed that there is no general optimal augmentation policy, but instead the optimal policy depends on the network as well as the data set at hand.

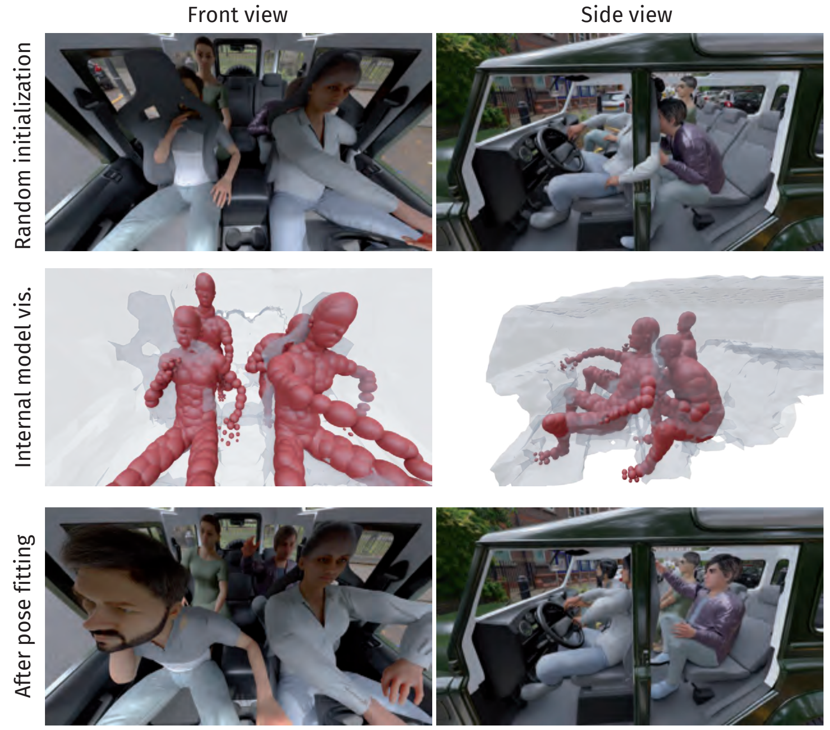


Sketch for most commonly used augmentation methods for 3D object detection on point clouds.

Synthesizing and Adapting Virtual Humans in 3D Environments

Paul Robert Herzog, Robert Bosch GmbH

In the realm of synthetic data generation, creating lifelike virtual humans has seen remarkable advancements enabling the power of infinite labeled data generation. Our key ingredients in this context are procedurally generated 3D humans with encoding of geometry suited for gradient based intersection minimization, realistically posing humans obeying intricate 3D environments modelled as a signed-distance-field, and an automated image rendering pipeline based on Blender. Using this approach, a synthetic image data set has been generated and used for training a human pose estimator, which after being finetuned on ca. 4000 real images, outperformed the pose estimator trained only on real data by more than 30%.



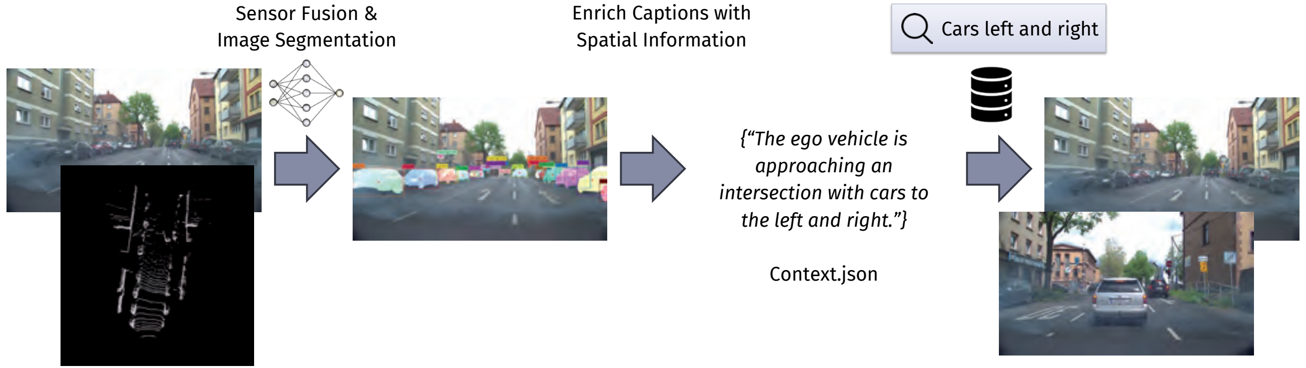
Result of virtual human creation and pose adaptation in a 3D vehicle

Virtual human creation and pose adaptation in a 3D vehicle environment.

From Sensors to Scene Understanding via Auto-Labeling

Stephan Rappensperger, Carlos Valle, fortiss GmbH | **Naveen Shankar Nagaraja**, BMW AG

To train supervised machine learning models in the field of autonomous driving on specific situations, large data sets often have to be manually searched for the desired scenes. To aid the search we enriched the captions for scenes by first autolabeling multi-modal data (camera, lidar). We used the generated labels to build a spatial graph among the different objects in the scene. The edges denote the spatial relation, and to capture this textually we defined a set of pre-defined directional operators (strings) like left-of, right-of etc. The captions generated with this spatial awareness led to better indexing for retrieval of the scenes with Large Language Models.



Processing pipeline from the initial sensor data, through image segmentation, to a textual scene description used for scene search.

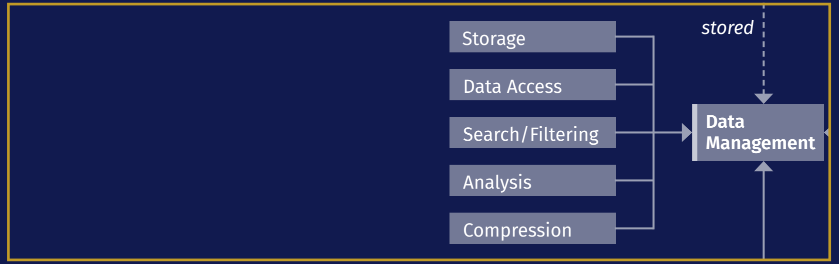
Creating a Multimodal Sensor Data Set

Andrea Kraus, Tobias Wagner, Marcel Matz, Valeo Schalter und Sensoren GmbH

For the development of Deep Neural Networks (DNNs) in the field of autonomous driving, real-world data sets are needed. Creating a multimodal data set involves many steps: Building a recording vehicle, calibrating sensors, defining scenarios. Once the defined scenarios are recorded, metadata and labels are annotated. This process includes challenges, e.g. a consistency of the labeling over the whole data set, that have been addressed in the project.

Example of scala lidar point cloud and camera image from Aschaffenburg recording campaign.

3 Data Storage, Analysis & Discoverability



Data Storage, Analysis & Discoverability

The category #3 of the KI Data Tooling framework architecture called “Data Storage, Analysis & Discoverability” combines those methods in the data lifecycle workflow model that are needed to define a common structure across mixed data types, being synthetic and recorded, to store such data in a explorable and accessible manner, maintain it by improving its discoverability in order to eventually support the data-driven ML development of autonomous driving functions based on mixed data sets.

Goals

Acquired data, whether it be of synthetic, recorded or augmented nature, must be stored and organized in such a manner that the general exploitation of the data is enabled by providing common structures and formats to support the discoverability of the same. The interface to the proceeding category “Acquisition, Curation & Refinement of Real Data” is the storage of the data in the defined common structure such that the discoverability can then serve as an interface to the succeeding category “ML Function Development”. The ML functions can therefore be developed on a well-founded and tailored data set, which contains the necessary information to train the aimed function.

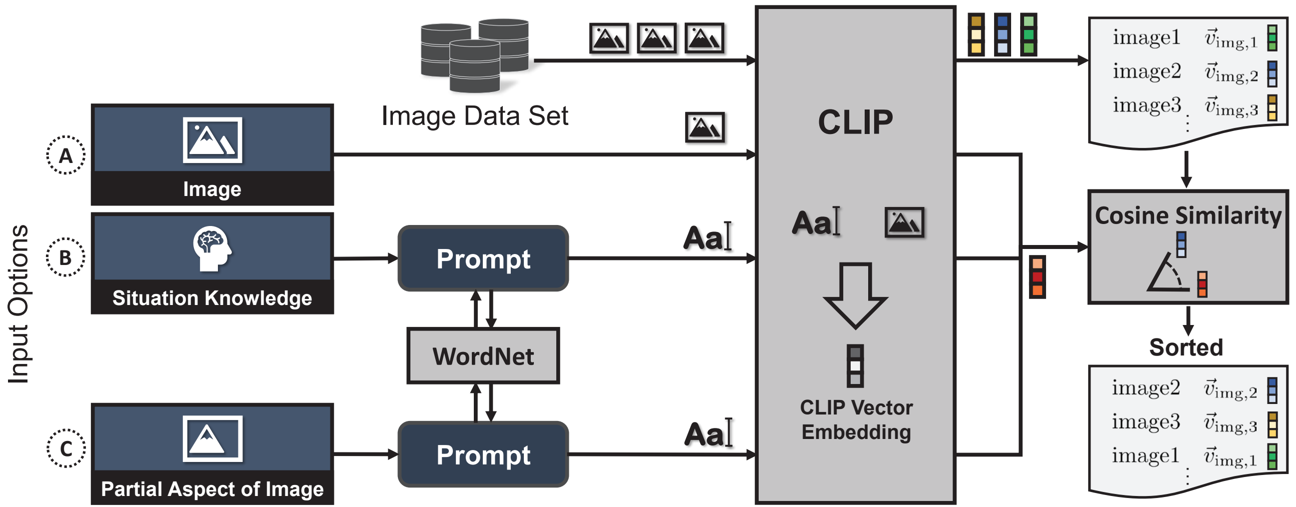
Achievements

Cross project working groups were established to take the responsibility for (1) data structures and formats and (2) toolchain definition of a mixed data-driven machine learning development workflow. In work group (1) a common data structure and formats for synthetic and recorded data has been drafted according to the needs of the main theme of developing ML functions in the field of autonomous driving. The defined structure and formats were brought together and documented in a data specification to provide a blueprint for mixed-data-driven ML projects in the future. As a base for the data specification the input of the sister project KI Absicherung of the VDA Leitinitiative has been taken, which documented its specification of the SynPeDS data set. Furthermore, the cataloging of the collected data and the provisioning of data in a data product as part of a governed and maintained artifact has been proposed to raise the discoverability of the contained data sequences but also to mature data provisioning from basic storage to full productization. The working group (2) focused on the architecture depicting the overall workflow and relation in between the different components of a mixed-data ML lifecycle. The resulting architecture is the fundamental base of the proposed KI Data Tooling framework architecture.

Focus on the Challenges: Analysis of a User-Friendly Data Search Approach with CLIP in the Automotive Domain

Philipp Rigoll, Patrick Petersen, Hanno Stage, Lennart Ries, Eric Sax, FZI Forschungszentrum Informatik

The processing of large image data sets has become a key competence in the development of driver assistance systems. In this context, it is important to have the ability to automate and a versatile approach. We analyzed the use of a state-of-the-art neural network to embed text and images in a vector space. This approach enables semantic searchability with an understandable text-based description. In our experiments, we showed how the method can be used in the development of driver assistance systems. With this method it is possible to search for similar images, situational knowledge or partial aspects of an image by creating a textural prompt.



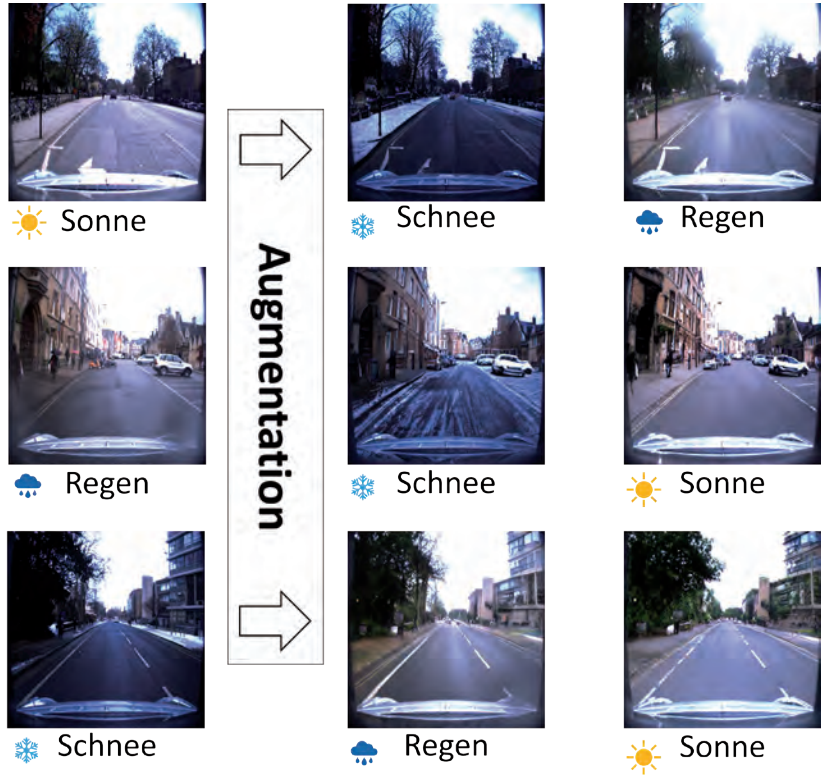
Overview of the proposed method for textual and image-based search of similar images [1].

[1] Rigoll, Philipp, et al. „Focus on the Challenges: Analysis of a User-friendly Data Search Approach with CLIP in the Automotive Domain." arXiv preprint arXiv:2304.10247 (2023).

Augmentation of Images with Generative Networks

Philipp Rigoll, Patrick Petersen, Jacob Langner, Lennart Ries, Eric Sax, FZI Forschungszentrum Informatik

Automated driving functions rely on the diversity of training data. However, it is costly to record various data in real-world test drives. As an alternative to the real-world data recording, we proposed augmentation based on Generative Adversarial Networks. This way, the missing data points can be created synthetically without the need of further real-world data recordings. There are special GAN architectures for image-to-image transformations. These architectures are able to transform images between different domains. Utilizing this, we were able to change the weather in an image. This is especially useful if a weather situation is underrepresented in the initial data set.



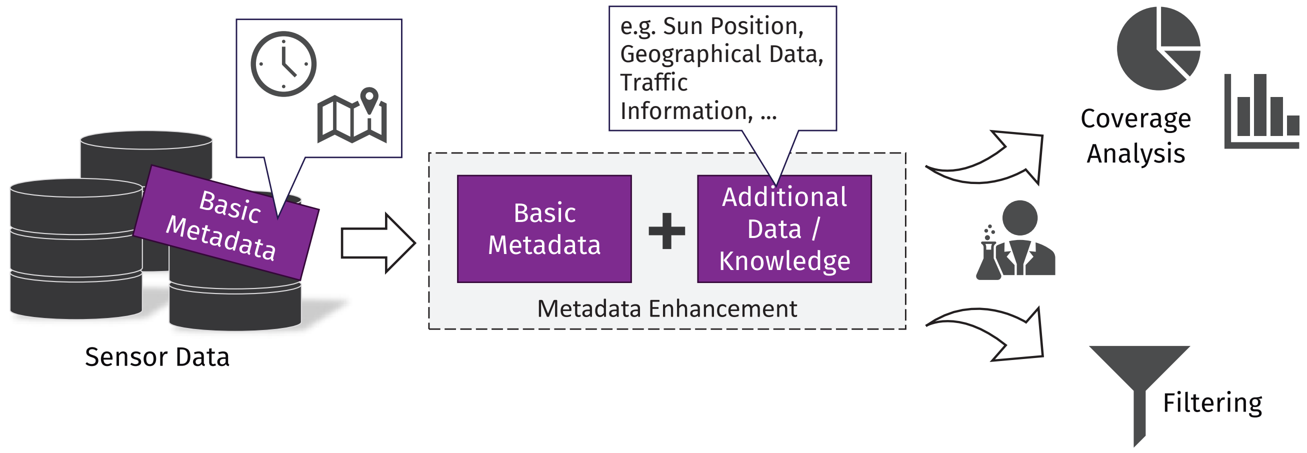
Exemplary augmentations of the Oxford dataset [1] with a image-to-image GAN architecture [2].

[1] Maddern, Will, et al. „1 year, 1000 km: The oxford robotcar dataset." The International Journal of Robotics Research 36.1 (2017): 3-15.
[2] Rigoll, Philipp, et al. „Augmentation von Kameradaten mit Generative Adversarial Networks (GANs) zur Absicherung automatisierter Fahrfunktionen."

Scalable Data Set Distillation

Philipp Rigoll, Patrick Petersen, Jacob Langner, Lennart Ries, Eric Sax, FZI Forschungszentrum Informatik

With large amounts of data, it is necessary to facilitate efficient searchability and filtering. One approach is to rely on context data. This enables easy automation and is efficient due to the simple nature of context data. In addition, it is possible to evaluate the coverage of the data without taking the raw sensor data into account. We enhanced the basic context data (time, position, heading) with additional data from other sources like maps. Based on this advanced context, it is possible to identify special data points such as challenging exposure situations as they occur under bridges. These situations are hard to describe and identify by looking at the sensor data.



Scheme of the context enhancement process [1].

[1] Rigoll, Philipp, Ries, Lennart, and Sax, Eric. „Scalable Data Set Distillation for the Development of Automated Driving Functions." 2022 IEEE 25th International Conference on Intelligent Transportation Systems (ITSC). IEEE, 2022.

A-Eye: Driving with the Eyes of AI for Corner Case Generation

Kamil Kowol, Stefan Bracke, Bergische Universität Wuppertal
Hanno Gottschalk, Technische Universität Berlin

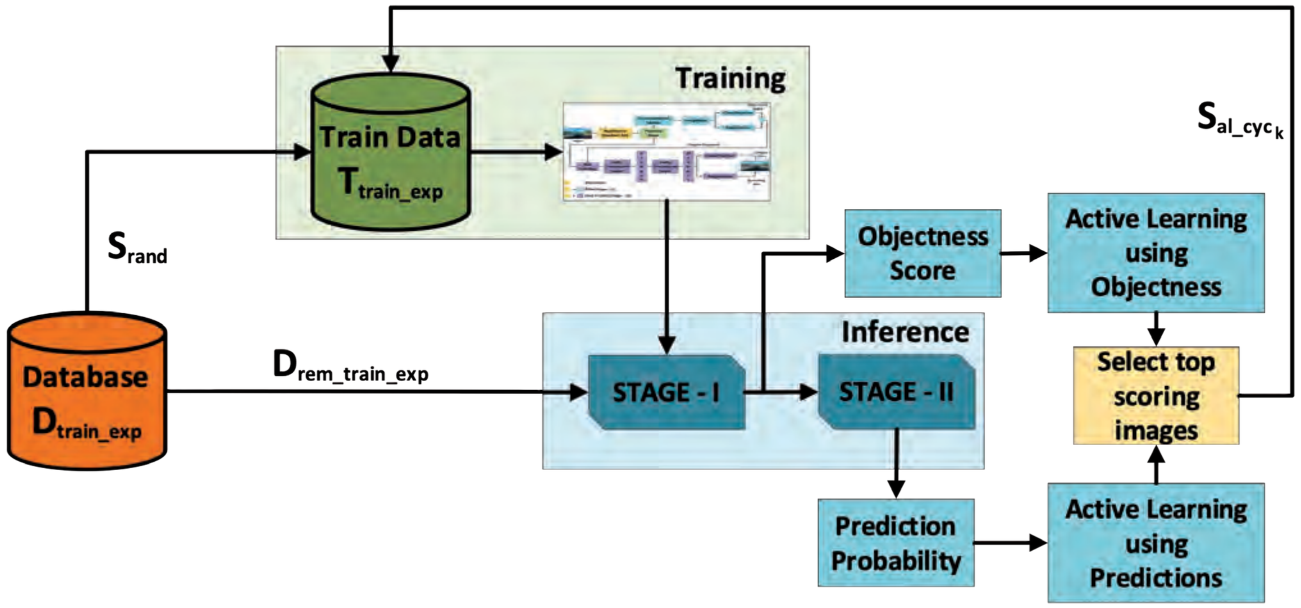
The goal of this work was to enrich training data for automated driving with corner cases, which are critical, rare, and unusual situations in traffic that challenge the perception of AI algorithms. We present a test rig design to generate synthetic corner cases within the driving simulation software CARLA using a human-in-the-loop approach. One person drives based on the prediction of a semantic segmentation network, another person monitors the original CARLA output and intervenes when the semantic driver shows dangerous driving behavior. Enrichment of the training data with corner cases leads to improvements in pedestrian detection in safety-relevant traffic episodes.

Figure caption: Test rig including steering wheels, pedals, seats and screens.
Ref: K. Kowol, S. Bracke, and H. Gottschalk. „A-Eye: Driving with the Eyes of AI for Corner Case Generation." in Proceedings of the 6th International Conference on Computer-Human Interaction Research and Applications - CHIRA 2022.

Exploring the Unknown: Active Learning via Neural Network Uncertainty Modeling

Aditya Agarwal, Christian Falkenberg, AVL Software and Functions GmbH

AI models trained via supervised learning rely on a pre-defined/limited labeling budget. This gives rise to a need to intelligently select and label data such that an optimal model performance could be reached. Active Learning is a promising paradigm that assists in minimizing redundancies by selecting the most useful data to be labeled by querying through an unlabeled data pool. Using different acquisition functions, a pipeline exploits the model's uncertainty to choose iteratively the most informative data from an unlabeled data pool for labelling against a random selection. The approach was found effective for training Faster-RCNN on the BDD100K data set.

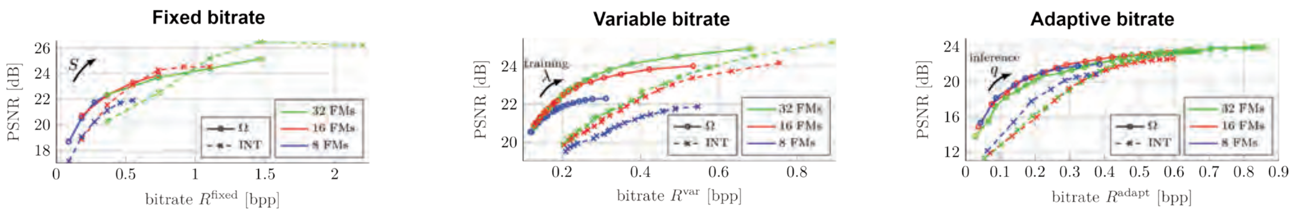


Neural Network Training Pipeline for Active Learning.

Adaptive Bitrate Quantization Scheme Without Codebook for Learned Image Compression

Jonas Löhdefink, Jonas Sitzmann, Andreas Bär, Tim Fingscheidt, Technische Universität Braunschweig

We propose a new learnable quantizer without a codebook and without a training/inference mismatch. This new one-hot max quantizer includes an adaptive bitrate compression system during inference via feature map masking. This way, the bitrate can be controlled using an input parameter. Results on the MNIST data set show that the one-hot max quantizer exceeds the wide-spread integer rounding quantization method in almost every condition. On the Kodak data set, the new quantizer exceeds integer rounding quantization in a variable and adaptive bitrate control mode for the important low bitrates.



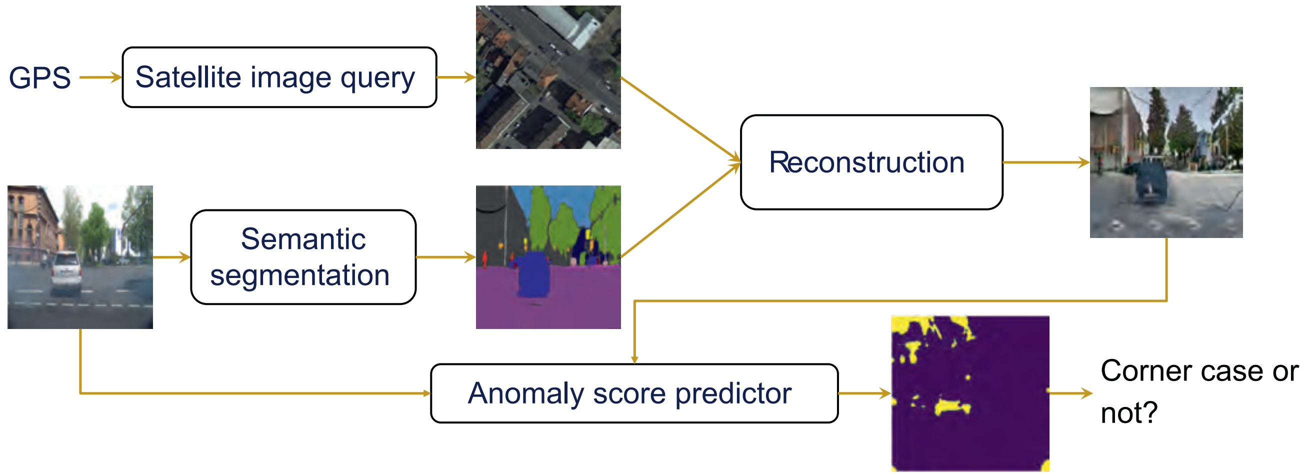
Evaluation on MNIST: For the fixed bitrate scheme, the one-hot max quantizer is better at a low bitrate, integer rounding quantization is better at higher bitrates. For the variable bitrate scheme, one-hot max quantization is better at all bitrates. For adaptive bitrates, one-hot max quantization is better at all bitrates as it is better suited to learn a hierarchical structured feature space. (© Technische Universität Braunschweig)

Ref.: J. Löhdefink, J. Sitzmann, A. Bär, T. Fingscheidt: "Adaptive Bitrate Quantization Scheme Without Codebook for Learned Image Compression", in Proc. of CVPR-Workshops 2022

Corner Case Identification Using Cameras and GPS

Thomas Stone, BMW AG | **Tianming Qiu**, fortiss GmbH

Corner case identification is crucial in autonomous driving, especially in terms of safety and active learning. Existing mainstream detection methods primarily focus on pure image input. This work introduces bird's-eye-view satellite images that are linked to the input image's GPS. By combining the geographical information with semantic segmentation of the input images, we implemented ground-view image reconstruction. The performance of reconstruction reveals how rare a data sample is compared with the majority samples in a training set. The effectiveness of these methods has been demonstrated using real-world images from the KI-DT data set.

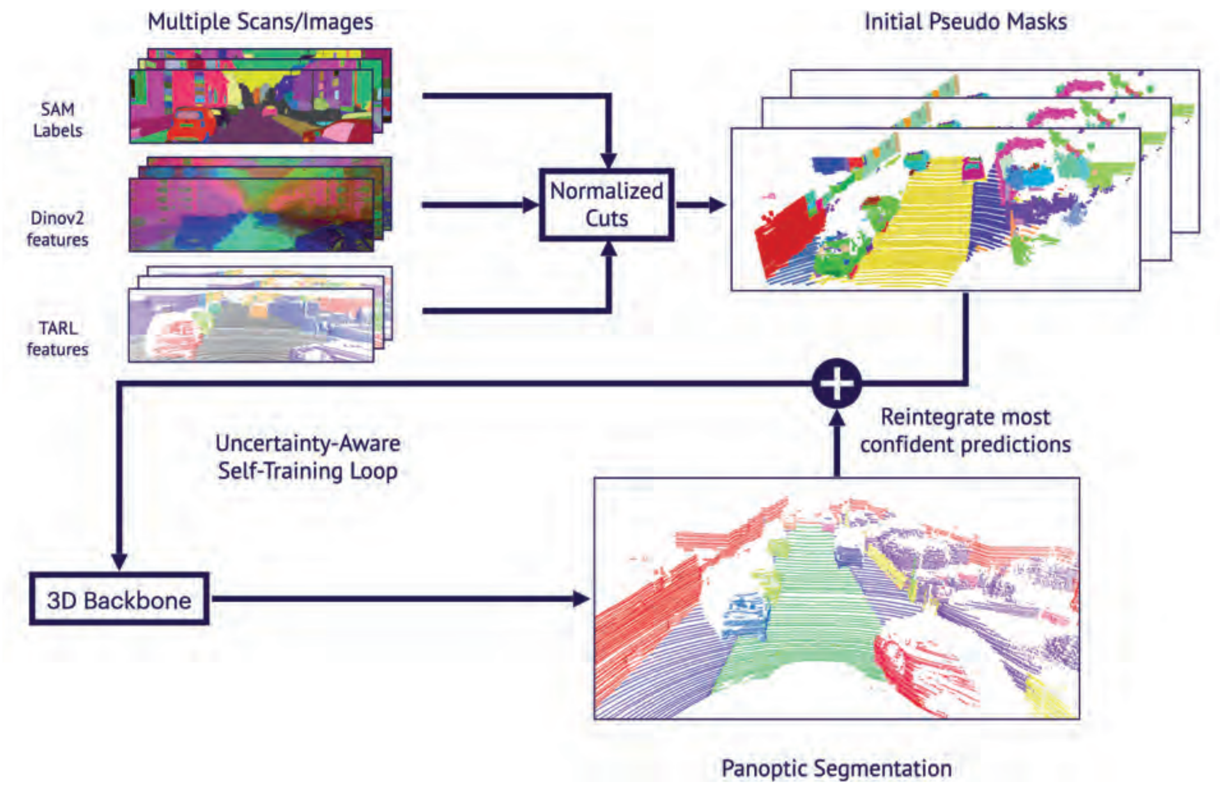


Proposed unsupervised corner case detector pipeline. (© BMW AG)

Self-Annotated Discovery of 3D Instances in Outdoor Scenes

Laurenz Heidrich, Haifan Zhang, Cedric Perauer, Georgi Georgiev, Alexey Artemov, Matthias Nießner, Technische Universität München

Recent advancements in LiDAR sensors have advanced 3D outdoor environment sensing. However, achieving detailed 3D scene understanding often requires neural networks trained on expensive annotated data sets. To tackle this, we propose unsupervised panoptic 3D scene segmentation. Our framework comprises two parts: (1) a pseudo-annotation scheme for generating initial labels from multi-modal self-supervised features and (2) a self-training algorithm for instance segmentation, gradually improving network accuracy. Experiments on challenging LiDAR data sets showcase the potential of our approach for scene understanding.



We design an unsupervised learning-based pipeline for point cloud instance segmentation that integrates pre-trained features and a self-training loop for improved segmentation performance.

4 ML Function Development

ML Function Development

The category #4 of the KI Data Tooling framework architecture called “ML Function Development” combines the AI perception tasks, methods and tools for optimal data use. These methods include data analyses methods, mixed training strategies and results evaluation methods for AI perception tasks with multi-domain data sets.

Goals

The autonomous driving (AD) perception AI development and the processes around it had to be established for the project to show the effectiveness and efficiency of the developed methods and tools. These were methods for abstractions, data analyses and training with mixed domain data sets along with the ML functions. Additionally, the goal was to establish tools that can generate and adapt data requirements for Data Engineers. The overall objective of this category’s work was to simplify the data-driven development process for AD perception AI, allowing for valuable insights to be extracted from any available data domain and constitute requirements for data production.

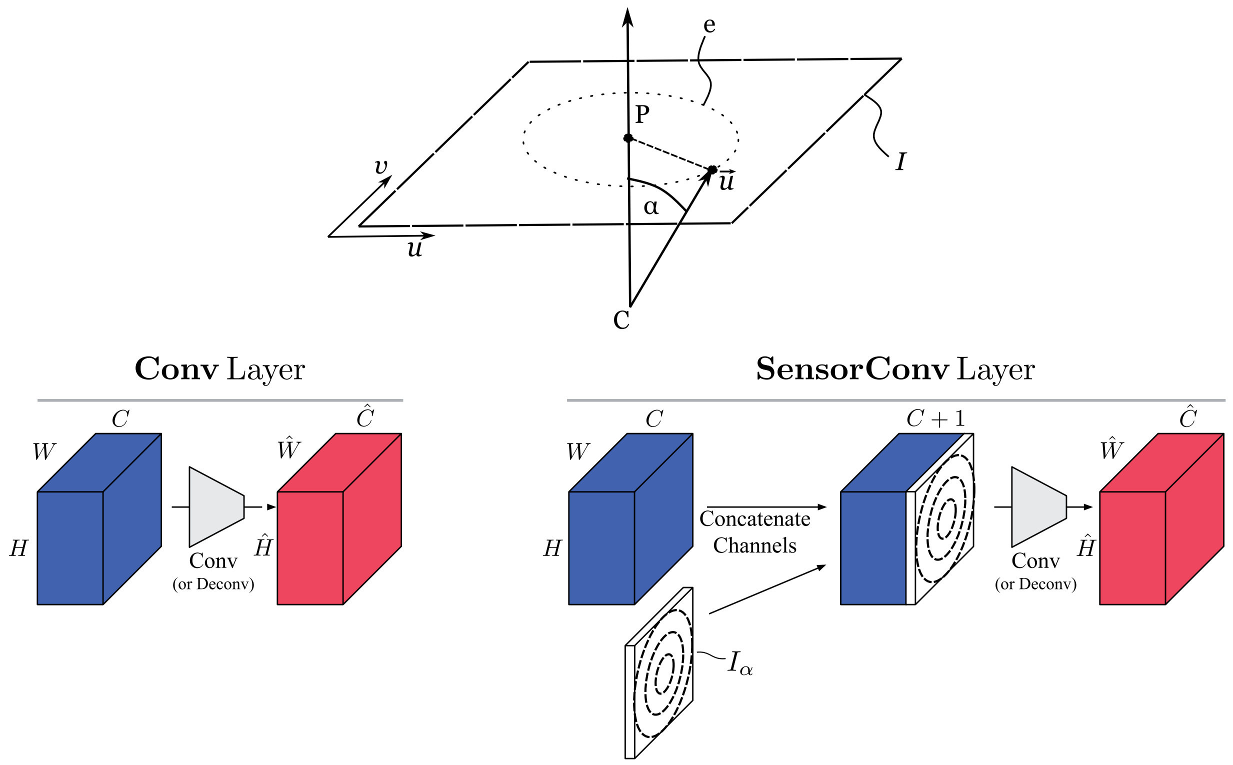
Achievements

The partners in this category have developed advanced perception AI functions for different AD tasks and sensor modalities, including semantic segmentation in camera images and multi-modal object detection. For a better understanding of the recorded data sets and developed ML models, concepts for corner cases and accompanying selection methods have been researched. By accurately and precisely defining corner cases and developing selection methods, gaps in our data sets could be found and filled. For training with the available real and synthetic data, Mixed Domain Training Strategies for perception AI have been implemented. Training the models on mixed data sets improved the generalizability of the perception models. Additionally, abstracted representations for sensor data have been developed, along with methods to use and analyze the data. Abstracting sensor data led to flexible solutions regarding sensor setups. Finally, we have developed domain transfer methods to move synthetic camera images even closer to real recordings than the simulations themselves made possible. These methods include transferring an image into another domain, generating photo-realistic images, and maintaining label consistency during the transfer. By improving the realism of synthetic data, it can be used to fill holes in recorded real data.

Sensor Equivariance

Hannes Reichert, Konrad Doll, Technische Hochschule Aschaffenburg

For scalable and robust perception systems in autonomous vehicles, it must be ensured that the perception algorithms are functional independent of the sensor model used during training and inference. The global objective is to reduce the development costs for new systems and to enable flexible and simple adaptation to new sensor models. We propose „sensor equivariance“ as a systematic approach to this topic. With a deflection metric [1] and a SensorConv [2] we propose a simple effective solution to this task towards scaleable perception systems.



Top: Deflection metric: Encoding sensor intrinsics to an image. Bottom: SensorConv-Layer: Convolution layer to process sensor intrinsics.

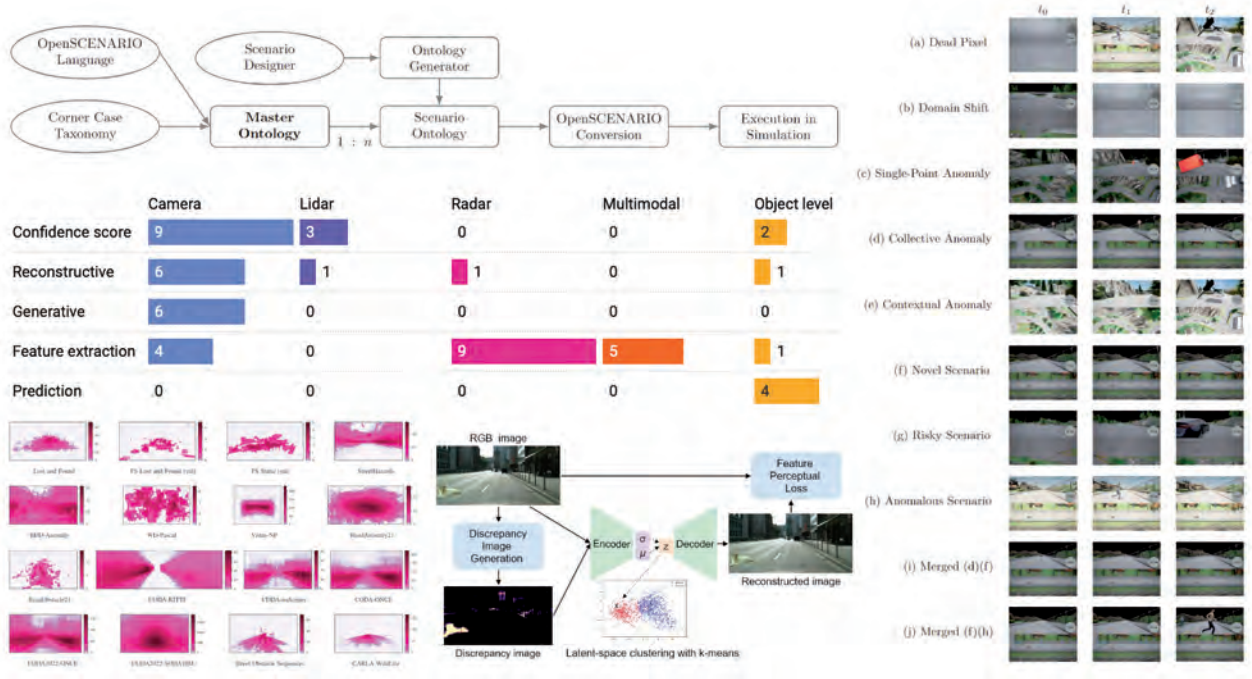
[1] H. Reichert and K. Doll. (2022). An image encoding method for recording projection information of two-dimensional projections (WO2023118163A1). WIPO (PCT).

[2] H. Reichert, M. Hetzel, A. Hubert, K. Doll and B. Sick, „Sensor Equivariance: A Framework for Semantic Segmentation with Diverse Camera Models,“ 2024 CVF CVPR, Seattle USA (submitted)

Generation and Detection of Corner Cases

Daniel Bogdoll, Christian Hubschneider, FZI Forschungszentrum Informatik

In the context of corner cases in autonomous driving, we put an emphasis on both the generation of train and test data as well as methodologies in order to detect such. For the description and generation of corner cases we designed a scalable ontology which describes each corner case in great detail and is actionable, allowing for direct simulation. For the detection of corner cases, we conducted two extensive surveys which describe the categories of current methods in great detail and highlight issues with public data sets in the field. Finally, we developed our own methods for corner case detection, evaluating the potential for autolabeling approaches.



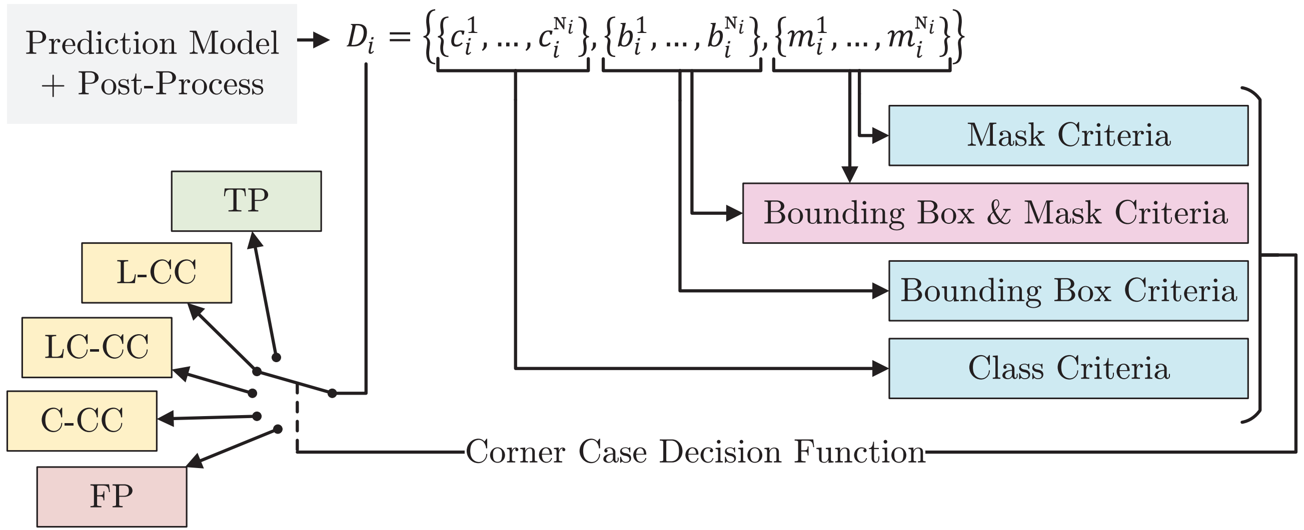
Overview of Methods for the Generation and Detection of Corner Cases ([1], [2], [3], [4]).

[1] Bogdoll, Guneshka, Zöllner: One Ontology to Rule Them All: Corner Case Scenarios for Autonomous Driving, ECCV-W, 2022 | [2] Bogdoll, Nitsche, Zöllner: Anomaly Detection in Autonomous Driving: A Survey, CVPR-W, 2022 | [3] Bogdoll, Uhlemeyer, Kowol, Zöllner: Perception Datasets for Anomaly Detection in Autonomous Driving: A Survey, IV, 2023 | [4] Bogdoll, Pavlitska, Klaus, Zöllner: Conditioning Latent-Space Clusters for Real-World Anomaly Classification, SSCI, 2023

Criteria for Uncertainty-Based Corner Cases Detection in Instance Segmentation

Florian Heidecker, Ahmad El-Khateeb, Bernhard Sick, Universität Kassel
Maarten Bieshaar, Robert Bosch GmbH

Scaling the distribution of automated vehicles requires handling corner cases, which comprise unexpected and possibly dangerous situations. The overall goal of our approach was to identify objects representing a corner case based on the model uncertainty. In this work, we defined 16 uncertainty-based corner case criteria by observing the predictions of machine learning models without using ground-truth labels. We further grouped the objects into corner case categories, which differentiate between localization and classification problems, as well as other types of false predictions.

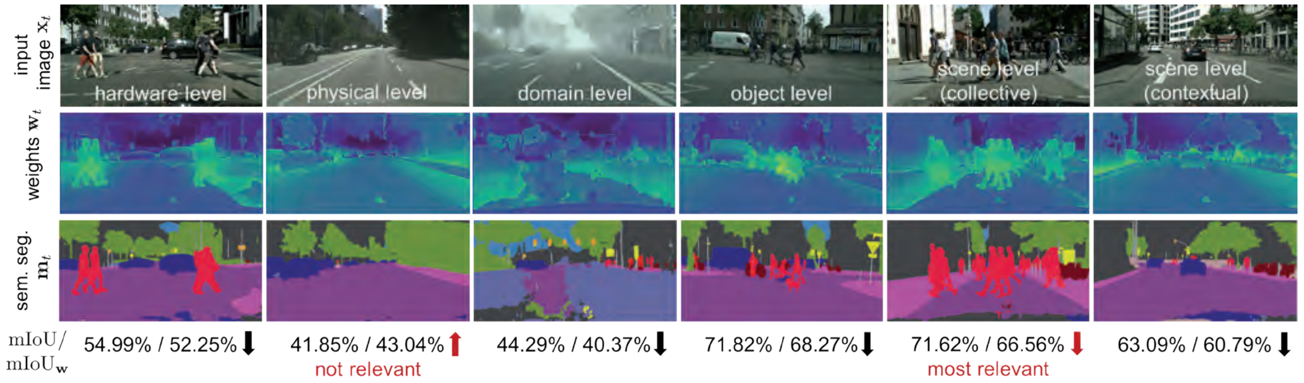


Uncertainty-based corner case detection approach.

Relevance Estimation of Corner Cases for Semantic Segmentation

Jasmin Breitenstein, Tim Fingscheidt, Technische Universität Braunschweig | **Florian Heidecker, Bernhard Sick**, Universität Kassel | **Maria Lyssenko, Maarten Bieshaar**, Robert Bosch GmbH
Daniel Bogdoll, J. Marius Zöllner, FZI Forschungszentrum Informatik

Starting from knowledge-driven definitions of corner cases, we studied their impact on perception methods, in this case on semantic segmentation. Typical metrics such as mIoU are task-agnostic and not affected by the prediction quality for corner cases. We developed a novel relevance-adapted mIoU for the task of corner case identification. This mIoUw metric establishes a link between knowledge-driven corner case types and semantic segmentation methods. In our experiments, we saw that collective anomalies are the most relevant for the investigated OCRNet. We can use mIoUw to estimate the relevance of corner cases for a semantic segmentation method.

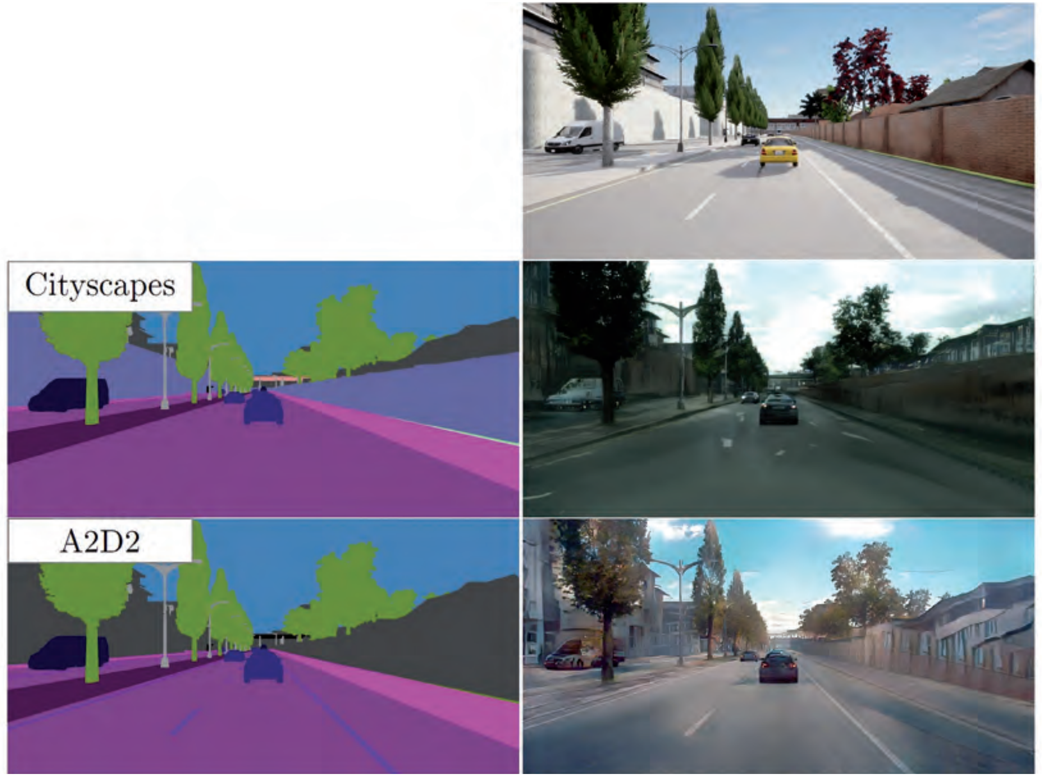


mIoU and mIoUw for example images of corner case types with the corresponding weights for mIoUw calculation. Corner cases have a high relevance when the negative impact on the mIoUw is high compared to mIoU. Collective anomalies have the highest relevance for OCRNet, physical-level corner cases have no relevance for OCRNet. (© Technische Universität Braunschweig)

Domain Adaptation with cDCGAN for Semantic Segmentation

Claudia Drygala, Hanno Gottschalk, Technische Universität Berlin
Matthias Rottmann, Bergische Universität Wuppertal

We investigated the use of conditional deep convolutional generative adversarial networks (cDCGAN) to bridge the domain gap between synthetic and real-world data for the downstream task of semantic segmentation. Annotated and safety-critical driving scenarios can be automatically simulated in the synthetic world in unlimited numbers without endangering humans. With the help of the cDCGAN, these synthetic images can be photorealistically enhanced. This leads to more appropriate training data for the semantic segmentation task and to the generation of photorealistic safety-critical scenes for testing semantic segmentation networks trained on the real-world domain.

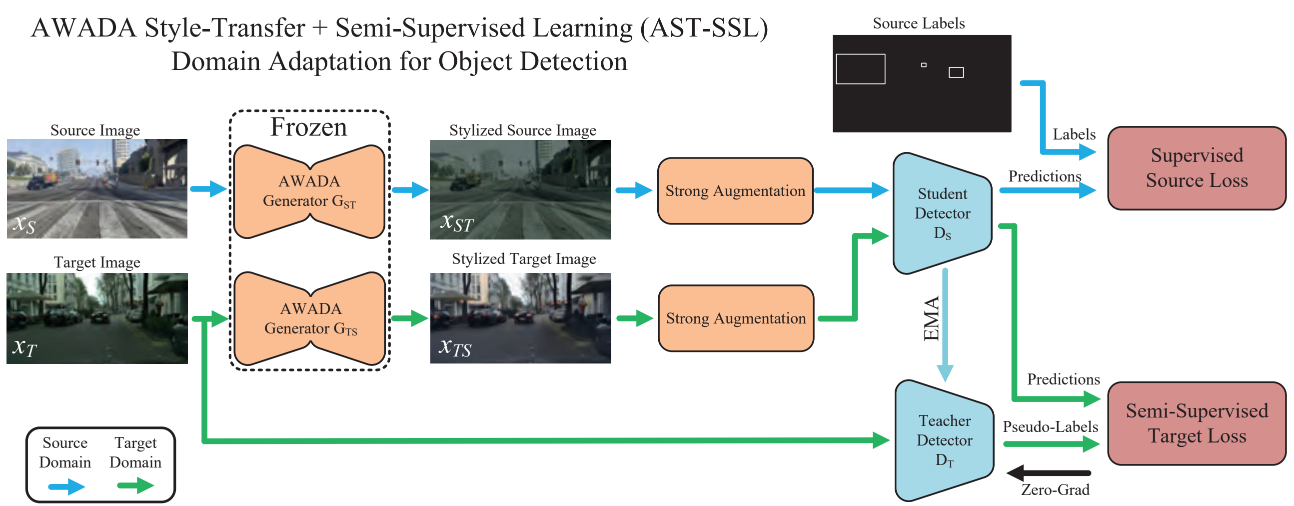


cDCGAN-synthesized images obtained by generators trained on the data sets Cityscapes or A2D2.

Unsupervised Domain Adaptation for Object Detection Using Adversarial Style Transfer and Semi-Supervised Learning

Maximilian Menke, Maarten Bieshaar, Robert Bosch GmbH

In object detection, there are several approaches for targeting a domain gap. Techniques based on feature learning, adversarial style-transfer, semi-supervised learning or graph-neural-networks are popular. We recommend to combine style-transfer for input image domain adaptation with semi-supervised learning for object detection network domain adaptation. Our contributions: We propose AWADA, a style-transfer method for domain adaptation for object detection on the input level. In addition, we propose AST-SSL combining Semi-Supervised Domain adaptation with AWADA-based adversarial style-transfer.



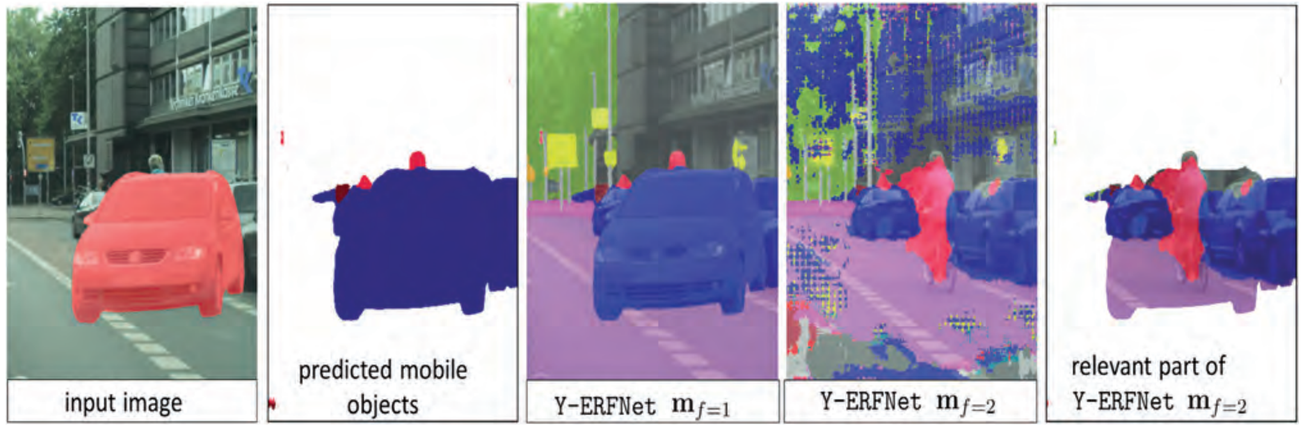
AST-SSL Semi-Supervised Learning Framework combined with [2] AWADA Adversarial Style-Transfer [1].

[1] M. Menke, T. Wenzel and A. Schwung, „Improving Cross-Domain Semi-Supervised Object Detection with Adversarial Domain Adaptation," 2023 IEEE Intelligent Vehicles Symposium (IV), Anchorage, AK, USA, 2023, pp. 1-7, doi: 10.1109/IV55152.2023.10186678. | [2] Menke, Maximilian and Wenzel, Thomas and Schwung, Andreas, Awada: Foreground-Focused Adversarial Learning for Cross-Domain Object Detection. Available at SSRN: https://ssrn.com/abstract=4272713 or http://dx.doi.org/10.2139/ssrn.4272713

Joint Prediction of Amodal and Visible Semantic Segmentation for Automated Driving

Jasmin Breitenstein, Tim Fingscheidt, Technische Universität Braunschweig

Amodal perception describes the human ability to hallucinate the full shape of (partially) occluded objects. In automated driving, this ability is crucial for safe environment perception, since occluded objects, especially pedestrians, can always become a safety hazard. We considered amodal semantic segmentation to segment also the occluded parts of objects, and we proposed to train visible and amodal semantic segmentation jointly. Our methods are evaluated on the Amodal Cityscapes Challenge for amodal semantic segmentation. We showed that the joint training of amodal and visible semantic segmentation leads to a performance improvement in both tasks.

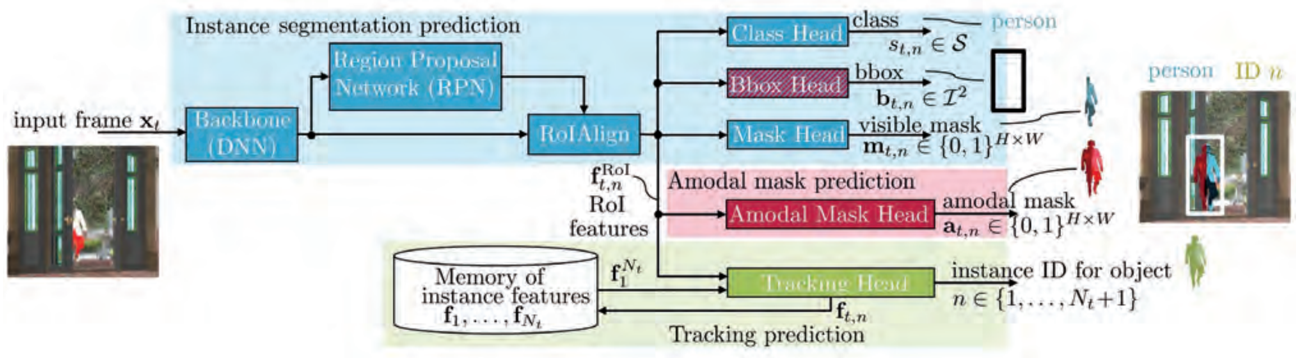


Qualitative predictions for mobile objects of the joint amodal and visible semantic segmentation method. Mobile objects are all objects with the ability to move, e.g., person, rider, car. We especially visualize the relevant parts, i.e., the insertion of the amodal prediction into the predicted mobile objects, showing that the full shape of the person occluded by the car can be recovered. The rider cannot be anticipated from just the head. (© Technische Universität Braunschweig)

Towards an End-to-End Amodal Video Instance Segmentation Challenge

Jasmin Breitenstein, Tim Fingscheidt, Technische Universität Braunschweig

The aim of this work was to develop to our knowledge the first end-to-end trainable method for amodal video instance segmentation. Amodal perception allows humans to perceive what is currently occluded in a scene. This ability is also crucial in automated driving where occluded pedestrians form a potential safety risk. Our end-to-end trainable amodal video instance segmentation showed that exploiting the temporal context of video data leads to better amodal segmentation quality. Using the CARLA simulator, we showed first works to generate synthetic data with amodal ground truth for a challenge on automotive data for amodal video perception methods.

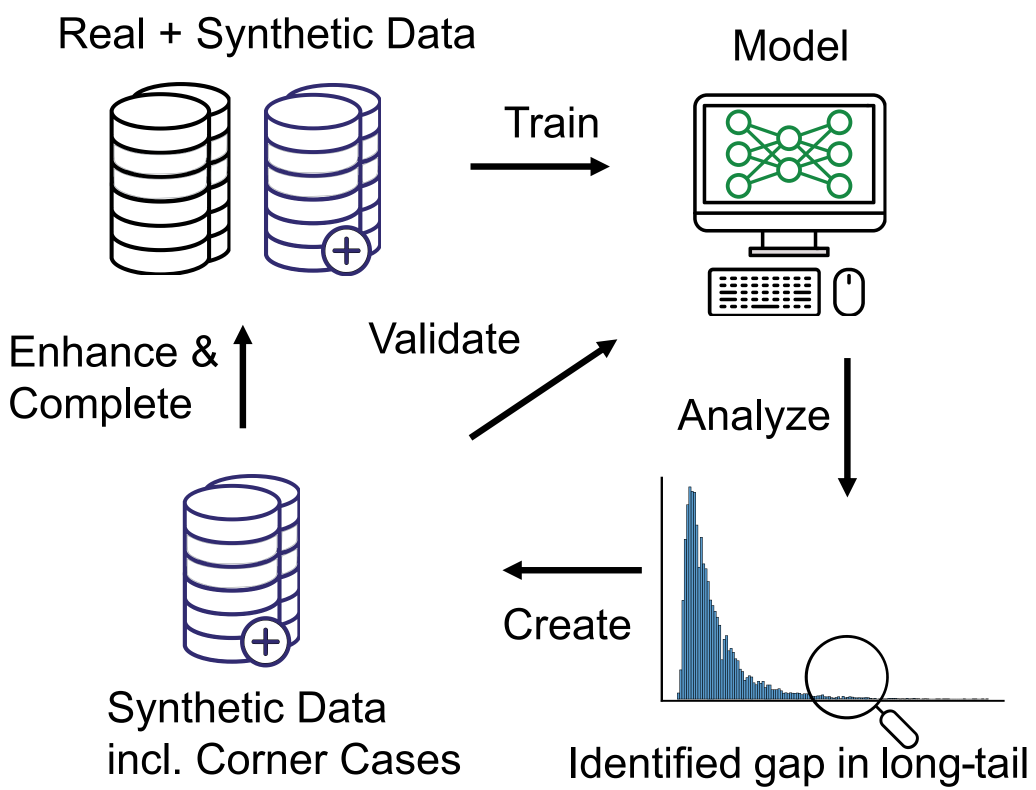


Our proposed VATrack method for end-to-end amodal video instance segmentation can simultaneously predict amodal and visible instance masks, while also tracking the instances throughout the sequence. The instance segmentation is based on Mask R-CNN, the tracking is based on QDTrack and MaskTrack R-CNN. (© Technische Universität Braunschweig) Ref.: J. Breitenstein, K. Jin, A. Hakiri, M. Klingner, T. Fingscheidt, „End-to-end Amodal Video Instance Segmentation", in Proc. of BMVC-Workshops 2023

Mixed Training - Identification and Filling of Data Gaps

Maarten Bieshaar, Maximilian Menke, Robert Bosch GmbH

Synthetic data has tremendous potential when paired with real data. We suggest the following strategy: first, use synthetic data to systematically uncover data gaps and limitations in AI performance; second, fill these gaps using synthetic data in a directed way. Our investigations revealed that although synthetic and real data do not behave identically, we can still use synthetic data to detect performance deficiencies in AI models. Our research indicates that a combination of both synthetic and real data can help mitigate these gaps, but further research and more sophisticated mixed training techniques are necessary.

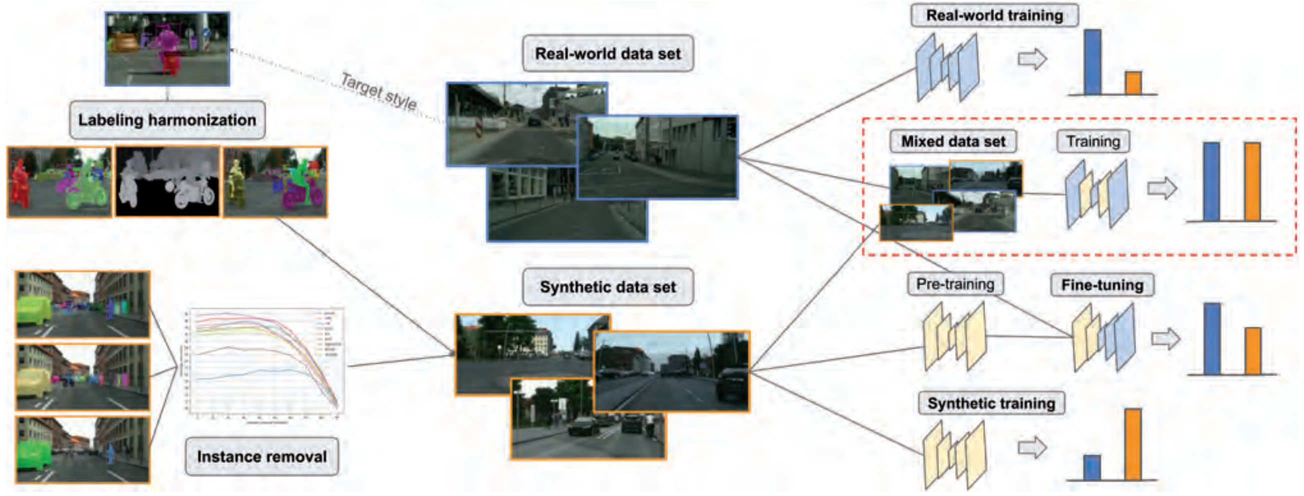


Data-driven engineering process to identify and mitigate gaps in real data sets using synthetic data mixed with real data.

Mixed Data Set Training

Andrea Kraus, Martin Simon, Valeo Schalter und Sensoren GmbH

Deep neural networks (DNNs) need large amounts of training data to ensure good accuracy and robustness. While the synthetic images produced do not seem to require annotation effort, their effectiveness in properly feeding DNNs remains to be proven. Synthetic data shows promising properties to improve the performance of DNNs on real-world image inference. It is realistic, diverse and capable of being learned. In this work, we first highlighted the harmonization requirement before using synthetic and real data together. We explored the issues and benefits of data set mixing strategy. This approach overcomes the current PointRend performance on Cityscapes at efficient costs.

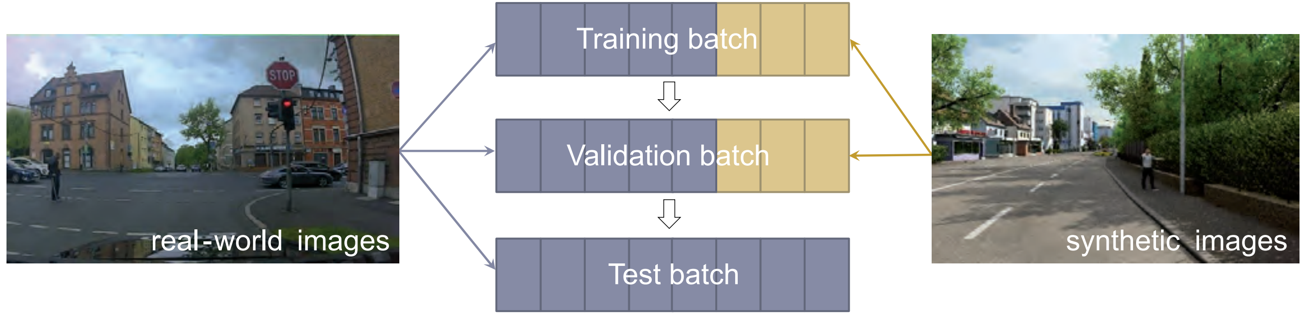


Overview of processing steps for the use of synthetic data. On the left, the pre-processing steps: labeling harmonization regarding class definition and non-valuable synthetic instance removal. On the right, different training approaches (real-world training, mixed data set training, fine-tuning, synthetic training) and their performance obtained on Cityscapes (blue) and Synscapes (orange).

Real-Synthetic Data Mix Training

Thomas Stone, BMW AG | **Tianming Qiu**, fortiss GmbH

In contrast to real-world data, synthetic data is typically more accessible and cost-effective for annotation. Our objective was to investigate various strategies for mixing real data from KI Data Tooling and synthetic data from KI Absicherung. Our work primarily focused on „batch-wise“ mixing, which involved combining real and synthetic images within the same training batch. We had the flexibility to adjust the mixing ratio and weights of the loss function from both data sources. This work presents a complex non-convex optimization challenge in high-dimensional spaces. Even minor adjustments can lead to significant variations in results.

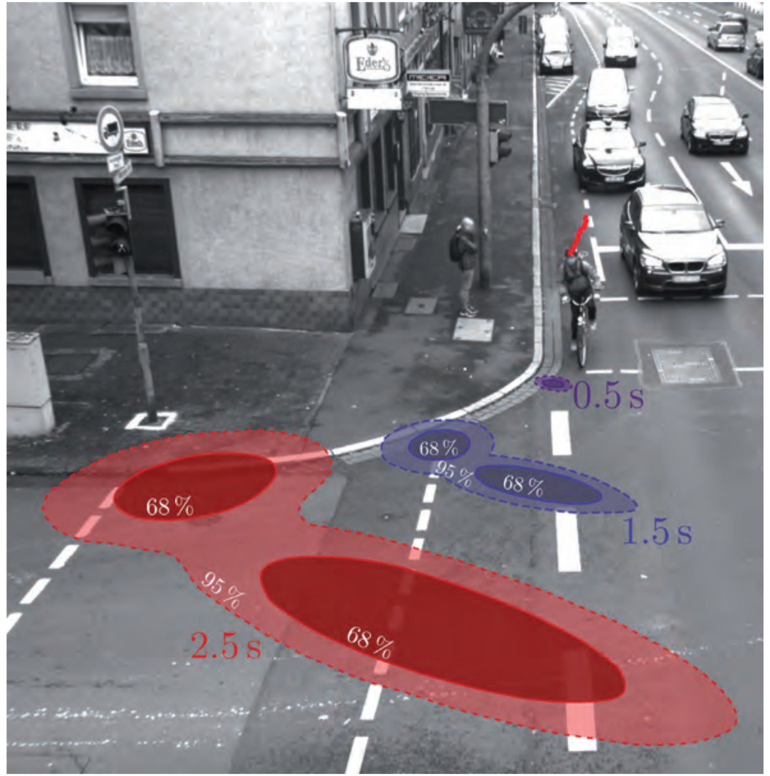


We randomly combine various real-world and synthetic images into each batch during training. The mixing ratio is a hyperparameter that can be adjusted. The validation batch can adhere to the same strategy as the training batch. However, our primary focus is on the test performance with real-world data, so the test batch exclusively contains real-world data. (© BMW)

Probabilistic Trajectory Forecast of VRUs

Hannes Reichert, Manuel Hetzel, Konrad Doll, Technische Hochschule Aschaffenburg

In the context of driver assistance, an accurate and reliable prediction of a VRU trajectory is mandatory to reduce the risk of VRUs in traffic. We propose using probabilistic forecasts to model inherent uncertainties for reliable systems using a semi-supervised approach. A multi-modal ensemble combines distributed forecasts to cover different motion states and behaviors. We further introduce two metrics to measure the quality of the forecasts, called Reliability and Sharpness, to ensure that all trained model forecasts are reliable.



Probilistic forecast of a cyclist's future location with uncertainty. (© University of Applied Sciences Aschaffenburg)
Ref.: S. Zernetsch, H. Reichert, V. Kress, K. Doll and B. Sick, „A Holistic View on Probabilistic Trajectory Forecasting – Case Study. Cyclist Intention Detection," 2022 IEEE Intelligent Vehicles Symposium (IV), Aachen, Germany, 2022, pp. 265-272, doi: 10.1109/IV51971.2022.9827220.

Partner Contributions

BMW AG

BMW GROUP

Company Overview

BMW AG is the parent company of the BMW Group, which is one of the ten largest automotive manufacturers worldwide. One of the central elements of change in the coming years at BMW and in the world is the progressive automation of driving. Driver assistance systems available today in current BMW and MINI models already provide comprehensive support in a wide range of driving situations. Development at BMW continues from highly and fully automated to autonomous driving, in which the task of driving can be completely transferred to the vehicle.

Key Contributions

- Consortium lead and other lead roles
- Validation tools for 3D models and materials in the BMW-lead open-source project OpenMATERIAL
- Lead of digital twin creation and specification of real and synthetic data generation
- Data domain mixing strategy and corner case detection algorithms for efficient data usage and recommendations for data generation
- Autolabeling and context identification methods

Exploitation Story

We plan to implement several strategies from the project to improve the development of AD perception technology. One of these strategies will be to incorporate Mixed Domain Training to close domain gaps and maximize data usage efficiency. Additionally, we plan on utilizing digital twins, to recreate various scenarios of recorded data and investigate the differences between synthetic and real data, ultimately helping us with closing domain gaps and safety argumentations. We also plan on using Auto Labeling to handle real data recordings more efficiently. Finally, we will implement the OpenMATERIAL validation tool in our processes to improve digital asset generation and exchange.

Impact of KI Data Tooling

The project's biggest contribution is a process and tooling framework for generating and working with data, real and synthetic. This framework serves as a template and a benchmark. Next, methods for working with multiple different data domains, especially domain transfer and gap filling methods, can now be researched with a focus on state-of-the-art data generation methods. This will have an impact on several AD topics, such as safety and data retention policing. The project also showed the limits of state-of-the-art digital twin generation methods. This will lead to adoption of neural, volume and light field-based techniques, increasing digital twin generation precision and time-efficiency.

Continental Automotive GmbH

Company Overview

The Continental AG, as the parent company of Continental Automotive Technologies GmbH, develops technologies and services for the sustainable and connected mobility of people and goods. Continental offers secure, efficient, intelligent, and affordable solutions for vehicles, machinery, traffic, and transportation.

Continental Automotive Technologies GmbH focuses on innovative products for a modern automotive future where individual mobility and driving pleasure coexist with driving safety, environmental responsibility, and economic efficiency.

Key Contributions

- Leading roles in subproject and work packages
- Lead of working group on data structures and formats, aiming to establish common interfaces for data sharing and the integration of synthetic and real data
- Data discoverability and management in a mixed data setup to facilitate purpose-oriented training data sets for ML
- Conceptualizing mixed-data machine learning development by defining a process and tooling framework for a data operations solution

Exploitation Story

We are planning to implement the proposed concept of a data mesh as a solution for data management, governance, and discoverability for AD data and beyond. We will incorporate the concepts and the data itself as high value outcomes of KI Data Tooling. Furthermore, the knowledge obtained from mixed data training and the generation of synthetic data is of great interest for future developments in the field of machine learning.

The defined process and tooling framework serves as a valuable foundation to support projects at Continental, which aim to improve AD functions of the future. These projects will benefit from the data, tool landscape, and overall knowledge gained in KI Data Tooling.

Impact of KI Data Tooling

Finding suitable data is of great importance and supports the high value of synthetic data to improve the coverage of corner cases, which would not be possible based on data sets solely based on real data. KI Data Tooling shows that the effort of including synthetic data is not just possible but a great accelerator of AD function development in the future.

The data set and its data management concept, as detailed in KI Data Tooling, will be highly valuable for future collaborations, providing a common foundation for data sharing among partners.

The process and tooling framework will serve as a blueprint to future AD development, leveraging a combination of synthetic and real data.

Robert Bosch GmbH

BOSCH

Company Overview

The Bosch Group is a leading international technology and service company. In the mobility area the Cross-Domain Computing Solutions division bundles software and electronics expertise for vehicle computers, sensors and control units for numerous applications of driver assistance, automated driving and parking as well as infotainment. Methods of AI and data-driven development are strategic focus areas. Bosch has contributed its extensive know-how to all AI projects within the VDA Leitinitiative.

Key Contributions

- Project co-lead and leading the synthetic data topic
- Synthetic data: Bosch brought in the sensor effect and model knowledge for video and radar and evaluated the synthetic data quality of those modalities. In addition, augmentation of virtual persons into real scenes was introduced
- AI methods: Development of methods for GAN-based video domain transfer, semi-supervised learning and mixed training approaches for video data. A multi-modal auto-labeling approach for 3D box radar annotation was applied.
- Set up of a recording vehicle with multimodal sensor-set, GPS and ego motion localization, including calibration and synchronization to the infrastructure system. About half of the real data was recorded with the Bosch vehicle.

Exploitation Story

The created data set will further be used to investigate methods and metrics for synthetic data production, usage in AI training and evaluation. The established AI methods will be further improved since larger parts of the produced data just came at project end. Sensor models, assets, materials and digital clones will be used for future radar and camera development. Finally, the blueprints established for GDPR conform data exchange will be used in further (funded) development cooperations.

Impact of KI Data Tooling

The knowledge gained by own work as well as in cooperation with partners and the data set established will influence our future synthetic data strategy. With all the options ranging from classical physical based rendering towards new AI technologies there are important technical and strategic decisions to be taken. Which are: mapping appropriate solutions to use cases and deciding about make/buy/partnering. The technical results and knowledge gained about the possibilities of standardizing interfaces help to answer these questions.

Valeo Schalter und Sensoren GmbH

Company Overview

Valeo is an automotive supplierand partner to all automakers worldwide. As a technology company, Valeo proposes innovative products and systems that contribute to the reduction of CO2 emissions and to the development of Intuitive Driving. The product group Valeo Driving Assistance is leading innovative solutions in the fields of Advanced Driving Assistance Systems and Automated Driving. It oversees the development of exterior sensors (ultrasonic, cameras, radars, laser scanners, etc.), as well as electronic control units of different levels of complexity.

Key Contributions

- Real Data recorded with its test vehicle equipped with several cameras, lidars and radars in various measurement campaigns at the test intersections, which were then enriched and labelled
- A developed tooling for automatic context generation, methods for lidar augmentation and compression enriched the data set
- Development of a lidar model based on the real sensor to create synthetic twin data

Exploitation Story

Valeo plans to use the results directly in data-driven development in the field of ADAS. Usable synthetic data supports and accelerates the development of AI-based algorithms. The results obtained in KI Data Tooling can be directly used in the pre-development and product development of AI functions for automated driving functions. The insights on building multimodal data sets, enriching those using automatically generated context data, will be used for training and validation of AI functions regardless of sensor type.

Impact of KI Data Tooling

The resulting data set in KI Data Tooling represents a novelty due to the presence of real data from different experimental vehicles together with infrastructure sensors. The varied scenarios at the research intersections including specific corner cases, along with the synthetic replicas of specific sequences, form a tool for exploring the utility of synthetic data in AI algorithm development. The methods developed to build this data set add value to research and industrialization of AI algorithms in autonomous driving.

ZF Friedrichshafen AG

Company Overview

ZF is a global technology company supplying systems for passenger cars, commercial vehicles, and industrial technology, enabling the next generation of mobility for self-drivers and movers. ZF allows vehicles to see, think and act. In the four technology domains of Vehicle Motion Control, Integrated Safety, Automated Driving, and Electric Mobility, ZF offers comprehensive product and software solutions for established vehicle manufacturers. ZF is shaping the future of mobility: with zero emissions and zero accidents. No matter how you move, ZF is there.

Key Contributions

- Generation of realistic, artificial radar sensor-signals, including providing corresponding sensor models and synthetic data streams
- Assessment and evaluation of synthetic radar data quality, verification by comparing real world and simulated data sets
- Validation of corner case detection and analysis of corresponding data sets, including providing a semi-automated corner case detection pipeline

Exploitation Story

The results the project KI Data Tooling is providing will either support the V&V campaigns or it will contribute to the improvement and acceleration of development processes of AI-based functions in AD and ADAS applications. In this context the generation of appropriate synthetic learning- and testing-data sets for machine-learning applications is essential and will be one of the major future key technologies KI Data Tooling is support-ing. Furthermore, the achievements in data analytics methods and test space exploitation and coverage are quite promising, results will enter several development projects in ZF.

Impact of KI Data Tooling

The progression and further development of realistic physical environment- and sensor-models, and the various new approaches and methods of using those in KI Data Tooling project will push forward the research and development projects for AI-based functions development within ZF significantly. The results of KI Data Tooling will close some of the remaining gaps in the development processes and tool- and methods building kit. They will boost the transformation towards more virtual development and testing processes in ZF.

ANSYS Germany GmbH

Company Overview

Ansys is a leader in engineering simulation. Ansys AVxcelerate, provides accurate sensor simulation enabling engineers to test and validate autonomous vehicles. Ansys solutions include sensor simulation for LiDAR, radar, and camera with an open architecture connecting to customer tools to facilitate seamless workflows. Ansys provides tools to manage scenarios, configure simulations and explore validation domains. Key analysis can be used for validation and safety traceability as well as optimization which can be deployed in HPC/Cloud.

Key Contributions

- Support in creating a demonstrator for physics-based radar sensor simulation in combination with FKFS's driving simulator
- Reviewing existing materials, such as 3D models for rendering with support in the analysis of measured radar materials roughness
- Regular collaboration and discussion with BIT and other partners on the simulation of radar systems using results from Ansys HFSS
- Supporting the implementation of ASAM OpenX standards

Exploitation Story

Ansys's collaboration with FKFS resulted in the development of a demonstrator for radar sensor simulation. This innovative solution combines FKFS's driver simulator with Ansys's physics-based radar sensor simulation, allowing for realistic sensor outputs. The demonstrator showcases the seamless integration of the two systems, enabling engineers to test and analyze radar sensor performance in various scenarios. The experience gained by this project will help Ansys to continue to enhance its physics based sensor system simulation capabilities and to integrate with various other driving simulators.

Impact of KI Data Tooling

The impact of KI Data Tooling is significant in the field of engineering simulation. By leveraging advanced physics-based simulation techniques, high-quality synthetic data can be created for machine learning (ML). Through the experience gained, simulation processes can be optimised to develop safe AD functions for inner-city traffic situations. Further activities will be executed in getting more physics based measured materials and create even larger digital twins to optimize future sustainable mobility solutions.

AVL Software and Functions GmbH

AVL

Company Overview

AVL Software and Functions in Regensburg pioneers future mobility technology, offering eco-friendly and secure solutions. Specializing in software, hardware, and system development, AVL leads climate-neutral mobility. Their global offerings include software, ADAS/AD, and e-mobility components, merging tech with expertise in Cybersecurity, Big Data, Digitalization, and Embedded Systems. AVL excels in safe, comfortable driving and automation.

Key Contributions

- Deriving and developing evaluation metrics for comparing digital twins (Camera and Lidar)
- GAN based models developed for converting synthetic data to real data
- AVL was one of the partners in data collection campaign at Braunschweig
- Post processing of raw sensor data from camera and lidar into synchronized frames
- Implemented an Intelligent data selection strategy via active learning

Exploitation Story

The KI Data Tooling project will have a significant impact on perception algorithm development at AVL. Most significant, the application of active learning will maximize the efficiency of labelling budget, which directly will lead to higher performance of the trained neural networks (NNs). Understanding the mechanisms of active learning enables the tuning of these methods to different needs and data sets. The application of an active learning tool chain will reduce development time and allows more agile development cycles. In combination with closing domain gaps via application of GAN and synthetic data, the training of NNs for the detection of road users and related objects will be greatly enhanced.

Impact of KI Data Tooling

The influence of KI Data Tooling is multifaceted, ranging from metrics for data set comparison, data post-processing, further enhancement of synthetic data with DNN and a novel method for critical data selection. By leveraging AI tools, engineers can select important unlabeled data which reduces redundancy and significantly improves training time. These tools also allow for quantifying the quality of synthetic data and comparing raw data from different sensors. AVL's contribution assists ADAS engineers at each step, from data post-processing to quality check followed by data selection and bridging the domain gap with synthetic data.

dSPACE GmbH

Company Overview

dSPACE is one of the leading providers of solutions for the development of autonomous driving vehicles. With its end-to-end solution portfolio, automotive manufacturers and their suppliers develop and test software and hardware components of their new vehicles. The portfolio ranges from integrated solutions for simulation and validation, to engineering and consulting services. With more than 2200 employees worldwide, dSPACE is represented at its headquarters in Paderborn, with project centers in Germany, and by subsidiaries worldwide.

Key Contributions

- dSPACE established an “efficient path” to generate synthetic data, as alternative to the “performance path” also pursued in the project, thus allowing for a direct comparison between both approaches.
- For this purpose, dSPACE developed tooling to automate 3d-geometry and scenario reconstruction and applied the tooling to create virtual twin data.
- dSPACE contributed to the quantification of the quality of synthetic sensor data for AI use-cases.

Exploitation Story

dSPACE plans to build on the learnings and results from the project to further improve its simulation products also for AI use-cases. The efficient creation of synthetic data sets for training and testing of AI-based functions requires efficient and highly automated tools. dSPACE will continue to develop its tools to support its customers with the creation of highly realistic simulation scenarios and data-sets with high variety. Insights on mixed (real/ synthetic) training strategies will be used in AI-model development at dSPACE for closing domain gaps and improving model performance in a data-efficient way.

Impact of KI Data Tooling

The KI Data Tooling project went to great lengths to create a unique data set of real and synthetic sensor data as one of the main results of the project. This data set will enable a host of research to further the understanding of strategies for using synthetic data for AI model training and testing. Not only did the project demonstrate that synthetic data can play an important role in the development of AI, but it also revealed many challenges that still exist in the creation of high-quality synthetic data sets. The project contributes to an understanding of how synthetic data should be used and what kind of synthetic data is best suited.

Deutsches Zentrum für Luft- und Raumfahrt

Company Overview
DLR is the national aeronautics and space research center of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport and security is integrated into national and international cooperative ventures. Around 250 scientific employees work at the Institute of Transportation Systems. They carry out research and development for automotive and rail systems and for traffic management. And in doing so, they contribute to increasing the safety and efficiency of traffic on roads and railways.

Key Contributions
- Data Generation: creating a mixed real data set from infrastructural and vehicle perspective at AIM Research Intersection in Brunswick
- Trajectory Auto Labeling: development of a toolchain for the automated extraction of critical and atypical traffic scenarios based on trajectory data
- Coordination of TPX activities fostering communication and information exchange within the related projects of the family
- Extensive GUA and contract management

Exploitation Story
The developed data processing toolchain for scenario mining, will be applied and adapted in future research to derive safety critical events in scenarios aside urban intersections. DLR's large-scale facilities have been enhanced in the project. A modern weather station was installed at AIM Research Intersection allowing trajectory data to be recorded, evaluated and processed for learning purposes depending on specific weather, visibility or road conditions. New high resolution 3D models of real intersections, developed algorithms and large-scale facilities enable us to join future collaborative research projects. By this we will also transfer our gained expert knowledge into the industry.

Impact of KI Data Tooling
Data Tooling lives for the creation of unique data sets for testing and enriching AI-Methods for image processing purposes in the context of developing autonomous driving functions. Infrastructurally perceived trajectory data serves as ground truth for the evaluation of on-board sensor functions (especially environment detection). It helps to create further realistic synthetic data. The KI Data Tooling twin data set provides high precision real data and synthetic data for equal scenarios and therefore allows domain adaptations easily. The TPX initiative showed that it is possible to promote collaboration throughout the industry and shape the future of autonomous driving together in Germany.

Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart

FKFS
RESEARCH IN MOTION.

Company Overview

The Research Institute for Automotive Engineering and Powertrain Systems Stuttgart (FKFS) is an independent research institute, founded in 1930 as a foundation under civil law. Around 180 highly qualified and motivated employees undertake research and development projects in the fields of Automotive Powertrain Systems, Automotive Engineering and Automotive Mechatronics. In close cooperation with the University of Stuttgart engineering students are educated.

Key Contributions

- Specification and development of the KI Data Tooling toolchain architecture for the creation of synthetic scenes
- Development of a modular co-simulation framework based on open-source software and automotive simulation standards to create synthetic scenes
- Conversion of real-world measurements into scenario-based simulations
- Validation of synthetic sensor data
- Research on machine-learning usage on and abstraction of radar-senor data

Exploitation Story

KI Data Tooling enabled us to investigate and develop a set of new tools regarding the creation and real-time simulation of sensor data. Alongside the integration of Ansys physics-based radar sensor simulation into the Stuttgart Driving Simulator, we also developed a middleware for the combination of various simulation programs. A measurement-conversion tool complements our work. Our new tools expand our capabilities in the area of real-time sensor simulation and synthetic data creation. The knowledge in machine-learning approaches for sensor-data abstraction gives us the opportunity to develop new strategies for creating efficient and more training data with real-time simulation.

Impact of KI Data Tooling

The Data Kit of the project will have a major impact on the application of synthetic sensor data. Not only did we create synthetic data based on a high amount of scene variations, we also produced a synthetic image of a multimodal data set resulting from real-world measurements. This will show limits of current simulation models and accelerate further development. The extension of standards for the specification of data ensures exchangeability of data as well as performant simulations with high technical detail.

FZI Forschungszentrum Informatik

Company Overview

The FZI Forschungszentrum Informatik is an independent and non-profit foundation for applied cutting-edge research and technology transfer. For over 35 years, the FZI has been researching and developing innovations for the benefit of society and bringing the latest scientific findings in information technology as practical solutions to companies and public institutions. In doing so, the FZI qualifies people for an academic career, a professional start in business or even the leap into self-employment.

Key Contributions

- Scene and object based augmentation of camera images
- Method for improved object placement in augmented images using generative AI
- Toolset to enable the searchability of automotive image data sets
- Contextual enrichment of driving data based on IMU and location data
- Structuring and detection of corner cases in driving data
- Material measurements of common materials in automotive scenarios regarding radar and lidar reflections

Exploitation Story

KI Data Tooling was the cornerstone for follow-up projects regarding the use of AI in modern vehicles. As a non-profit research institution, it is not possible for the FZI Forschungszentrum Informatik to directly exploit the project results commercially. However, the research findings from KI Data Tooling have been incorporated into the initiation and conceptualization of new industrial projects. In the course of the project, numerous scientific theses were supervised, thereby promoting the next generation of scientists. The scientific findings have been published in nine scientific articles at renowned international conferences and also flow into various PhD projects of the scientific staff.

Impact of KI Data Tooling

KI Data Tooling formed the basis for substantial AI research regarding augmentation of real-world data in an automotive context. In addition, numerous novel methods for contextualization and searchability of unlabeled data sets were explored. Furthermore, insights into corner case structuring and recognition were generated and research on radar models was advanced. Through KI Data Tooling, numerous publications in important automotive and AI conferences could be achieved and thus the standing of the FZI could be improved as well as the dissertations of the scientific staff could be significantly advanced.

Bergische Universität Wuppertal

BERGISCHE UNIVERSITÄT WUPPERTAL

Company Overview

The University of Wuppertal, founded in 1972, is a dynamically growing university. For decades, the Department of Mathematics and Computer Science has been a research-oriented department, ranking in the top third of German mathematics rankings. It is one of the few universities in Germany to have its own department of Security Engineering.

Key Contributions

- Development of a conditional generative learning method for the photorealistic enrichment of synthetic data used for training and testing of semantic segmentation networks.
- Generation and selection of corner cases by a simulator assembled by BUW using a human-in-the-loop approach and the CARLA simulator software.

Exploitation Story

The simulator constructed by BUW can be used for future work to generate synthetic datasets with a variety of ground truth data, such as semantic segmentation masks, lidar point clouds, or depth information. The advantage of synthetic data is that safety critical situations can be simulated without endangering humans. With the help of the developed conditional generative learning method, safety-critical situations created in CARLA can be adapted to the style of the real-world domain. These photorealistically enhanced images can be used to test whether semantic segmentation networks trained on real-world images are able to perform well in safety-critical situations.

Impact of KI Data Tooling

Within KI Data Tooling, BUW introduced a different definition and approach for generating and selecting corner cases based on human-machine interaction using the constructed simulator. The developed conditional generative learning approach helps to bridge the domain gap between synthetic and real-world data. This leads to more appropriate training data for the downstream task of semantic segmentation and to the generation of photorealistic safety-critical scenes for testing semantic segmentation networks trained on the real-world domain.

Technische Hochschule Aschaffenburg

Company Overview
TH AB is a university of applied sciences located in Aschaffenburg; Germany. With 3,400 students in 16 bachelor's and 10 master's programs, several dozen active Ph.D. students, several cooperation partners, research projects, and the right to award doctorates, the TH AB stands for quality in research and education. Konrad Doll's group is working on innovative solutions in the fields of advanced driving assistance systems and autonomous systems, with a key focus on protecting vulnerable road users.

Key Contributions
- The TH AB research intersection, equipped with its unique multi-sensor setup, provides high quality trajectories and meta data of all road users to enable a complete scene understanding of the ongoing traffic situation
- An international patent for building robust perception models, that work with various sensor modalities and types
- Pioneering works in the field of intention detection of VRUs by means of reliable probabilistic trajectory forecast

Exploitation Story
TH AB plans to use the results directly in data-driven ADAS development and research. Usable real and synthetic data supports and accelerates the development of AI-based algorithms. With the available data recording system and toolkit, TH AB can further focus its research on robust and reliable perception systems to protect VRUs in complex urban scenarios while considering cooperative aspects. The data and tooling from KI Data Tooling provide a strong foundation for further applied research and academic training at TH AB.

Impact of KI Data Tooling
The impact of KI Data Tooling is significant in data-driven AI algorithm development and evaluation. With a strong data foundation, a data-toolkit, and various lessons learned in the data generation process, KI Data Tooling contributes to vulnerable road user safety in automated traffic.

Technische Universität Braunschweig

Company Overview

Since 2017, the Signal Processing and Machine Learning group at TUBS has led computer vision research in automated driving. A core area is safe and robust perception based on camera data. In KI Data Tooling, they investigated concepts for corner case detection and developed image compression methods. Their contributions received three CVPR Workshop Best Paper Awards in 2019, 2020, and 2021. Professors Fingscheidt, Gottschalk, and Houben also co-edited the book „Deep Neural Networks and Data for Automated Driving" (Springer, 2022).

Key Contributions

- Definition and description of corner cases
- Relevance estimation of corner cases
- Amodal segmentation on images and videos
- New methods for learned image compression

Exploitation Story

Learned image compression is vital for a data kit in automated driving. With the growing data demands for perception functions, the contributions are a necessary part to optimize data transfer or to process data efficiently. The contributions to corner case definitions and descriptions are a crucial part for understanding detection method requirements, and they provide a foundation to generate specific corner cases. Relevance estimation assesses a perception method's capability to handle certain corner cases. Amodal segmentation addresses corner cases by occlusions by segmenting what is behind them, but also improving visible performance of the segmentation method at the same time.

Impact of KI Data Tooling

The project KI Data Tooling establishes the data kit for automated driving, combining synthetic and real data. The pipelines for data generation and recording not only provide all necessary means for this procedure but have shown their potential for digital twin creation. Additionally, a variety of filtering methods was developed to manage large data volumes. The filtering methods accompanied by the new training strategies of KI Data Tooling will also impact many future applications in the area of automated driving as we are confronted with larger and larger amounts of data and the question is how to intelligently select training, validation, and test data for training perception methods.

Technische Universität München

Company Overview
The Visual Computing & Artificial Intelligence Lab at TUM advances research at the intersection of computer vision, computer graphics, and artificial intelligence. Our research mission is to obtain highly-realistic digital replica of the real world for both static and dynamic scene environments. In our research, we heavily build on advances in modern machine learning, and develop novel methods that enable us to learn strong priors to fuel 3D reconstruction techniques.

Key Contributions
- TUM proposed the first unsupervised method designed specifically for 3D instance segmentation of large, outdoor 3D LiDAR point clouds.
- To build this method, a pseudo-annotation scheme for generating initial unsupervised pseudo-labels using a variety of image- and point-based self-supervised features has been proposed and a self-training algorithm which starts from initial noisy proposals and reintegrates confident predictions in the training loop.

Exploitation Story
The approach can be used at the initial stages of data annotation for generating robust initial instance segmentation masks for 3D LiDAR point clouds. Resulting in a reduction in data annotation costs and improved data quality.

Impact of KI Data Tooling
The resulting algorithm in KI Data Tooling represents a new direction for semantic and instance-based scene understanding due to its capability to leverage generic neural predictors made available recently (e.g. Visual Foundational Models) for integration into a coherent scene understanding model. The capability to use multi-modal, complementary feature predictors (e.g. image-based vs. point cloud-based) also has significant implications for versatility of the approach (e.g. the method can be used without color image input).

Universität Kassel

Company Overview
Kassel University is comprised of over 100 different courses grouped into 13 fields, sporting over 25,000 students. With over 1,000 yearly graduates in mathematics, natural sciences, and engineering it's a motor for quality research, and innovation. Berhard Sick's research group focusses on topics revolving around machine learning, soft computing, pattern recognition, data mining, and embedded and real-time systems. One of the core research directions in recent years has been in the automotive sector.

Key Contributions
- Practical evaluations of active learning and development of autolabeling approaches for object detection
- Definition, description, and taxonomy of corner cases in automotive machine learning
- Extension of deep learning models with uncertainty evaluations, leading to criteria for corner case detection in image data
- Quantitative evaluations of corner case detection methods, comparing different models on a variety of context labels and attributes

Exploitation Story
With projects such as DeCoInt2 and VERANO, Kassel University is building its expertise in the field of automotive research. Our involvement in KI Data Tooling expands this knowledge further with new data and tooling approaches that speed up further applied research, such as the efforts of understanding and identifying context information and corner cases in driving situations, which have been made available to the wider scientific community. Additionally, we plan to use the results directly in future works, which involve our own multi-sensor-enhanced car. The insights gained in KI Data Tooling will impact our approach in recording and annotating our own autonomous driving data set.

Impact of KI Data Tooling
High-quality machine learning models are the most important innovation of the past decade. With a growing demand for their use in public, however, the requirements for their safety also rise. The software tooling approach developed in KI Data Tooling is crucial in enabling and accelerating large-scale development of data-driven AI algorithm development and evaluation, while also addressing crucial considerations, such as critical and dangerous driving situations, protecting vulnerable road users in complex urban scenarios, and providing insight into model behavior.

Universität Passau

Company Overview

The Institute for Software Systems in Technical Applications (FORWISS) at the University of Passau provides a link between academia and industry. Based on our expertise in image and signal processing especially for environ-mental perception, we provide solutions to partner-specific challenges by means of fundamental and cutting-edge research.

Key Contributions

- Compressing LIDAR point clouds for more compact storage of training data
- Annotating sequences in multimodal AI training data sets with context information to enable search, filtering, and statistical evaluation
- Classifying weather and road surface properties by applying CNNs to RGB images from vehicle-mounted cameras and synthetic 3D-rendered scenes
- Extracting context from external data sets, including crowdsourced OpenStreetMap geodata

Exploitation Story

Over the course of several key projects such as Ko-PER, Ko-HAF and @CITY-AF, FORWISS has built considerable expertise in automotive and geospatial software. Our research and development work during KI Data Tooling (KI-DT) adds to that experience and enables us to contribute to future projects in similar domains. Likewise, our work on Convolutional Neural Networks supplements our already strong skill set in AI and synergizes with our decades of experience in classical image processing. Our published work on applying the classification tools developed during KI-DT to third-party data sets makes this expertise accessible to the wider scientific community.

Impact of KI Data Tooling

High-quality data sets with rich metadata are essential to advance automotive AI, but creating and working with these data sets requires a diverse set of software tools. KI-DT has explored many aspects of tooling, ranging from storage to context generation to search and retrieval. The ability to generate synthetic recordings from physically plausible virtual worlds, which was employed and further developed during KI-DT, helps to address rare but critical driving situations which are difficult or dangerous to record in the real world. By working with open stand-ards and leveraging KI-DT's tools to improve publicly available data, we aim to ensure that KI-DT will have a lasting impact.

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Note on the legal form of the cooperation
The cooperation between the partners within the project has no independent legal personality. In fact a scientific exchange is conducted between the research centers, organizations and universities listed as cooperation partners. A legal or similar relationship under company law, an association or similar is not established by the scientific cooperation. No cooperation partner is entitled to represent individual other cooperation partners or all cooperation partners together towards third parties.

Project Consortium

- BMW GROUP
- BOSCH
- Continental
- Valeo
- ZF
- Ansys
- AVL
- dSPACE
- DLR
- FKFS
- FZI
- Bergische Universität Wuppertal
- TH Aschaffenburg
- Technische Universität Braunschweig
- Technische Universität München
- Uni Kassel Versität
- Universität Passau

External Technology Partners

- BIT Technology Solutions
- Mackevision
- eict