Cross-layer cognitive optimization tools & methods for the lifecycle support of dependable CPSoS

Project Overview and Embedded AI Related Activities

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Principal Researcher,
Head of MIPS Group,
CPSoSAware Coordinator

Multimedia Information Processing Systems Group

The Multimedia Information Processing Systems Group was established in 2019 as a part of the Industrial Systems Institute of Athena Research Center.

The group has active presence in

- signal processing and learning (adaptive filtering, numerical linear algebra in signal processing, sparse modeling and optimization, signal processing on graphs),
- multimedia analysis/ understanding and multimedia communications (3D/4D compression, denoising, completion, saliency map extraction, scalable Rendering, , accelerated deep learning),
- interactive media & AR/VR Applications (gesture identification, interaction in virtual environments, multimodal interaction).

Members: 1 Principal Researcher, 2 Collaborative Faculty Members, 4 PhD, 2 Post Doc, 4 Engineers

Active Projects:

Industrial Projects: CAVSense, ENVISION Panasonic Automotive Europe

CPSoSAware Consortium

Participant No.	Participant organization name	Short Name	Country
1 (Project Coordinator)	Industrial Systems Institute, Athena Research Center	ISI	GR
2	Fundació Privada I2cat Internet I Innovacio Digital A Catalunya	I2CAT	ES
3	IBM Research Center	IBM	IS
4	Atos Spain S.A.	ATOS	ES
5	Panasonic Automotive	PASEU	DE
6	Eight Bells Ltd.	8BELLS	CY
7	Università della Svizzera italiana	USI	CH
8	Tampere university	TAU	FI
9	University of Peloponnesse	UOP	GR
10	Catalink Limited	CTL	CY
11	ROBOTEC	RTC	PL
12	Centro Ricerche FIAT - C.R.F. S.C.p.A	CRF	IT
13	University of Patras	UPAT	GR

CPSoSAware Breakthrough

ICT-01-2019– Topic : Computing technologies and engineering methods for cyber-physical systems of systems

- **Models and software tools** to describe a CPSoS in a holistic and abstract way and **to allocate computational power/resources to the CPS end devices of the System** by determining and generating autonomously the cyber-physical processes that will be handled by a device's each heterogenous component (processor cores, GPUs, FPGA fabric) and software components (software stacks).
- **Artificial Intelligence solutions that** support in order **to strengthen reliability, fault tolerance and security at system level** but also will be able **to lead to CPS designs that work in a decentralized way, collaboratively, in an equilibrium, by sharing tasks and data with minimal central intervention**
- CPSoSaware system will interact with the CPS/CPSoS human users/operators through extended reality modules (AR glasses, haptics interfaces) to **increase human situational awareness but also to include human behavior in the CPSoS design and operation phase**

CPSoSaware pillars and Architecture

Artificial Intelligence

CPS Level: Dstirubute, adaptive Cooperative, algorithms, Accelerated Multimodal Fusioning,

Cooperative computation: Distributed detection, Classification, Estimation, topology inference and Cooperation Strategies

System Level: AI based Intelligent Decision making

Model based Design/Computing

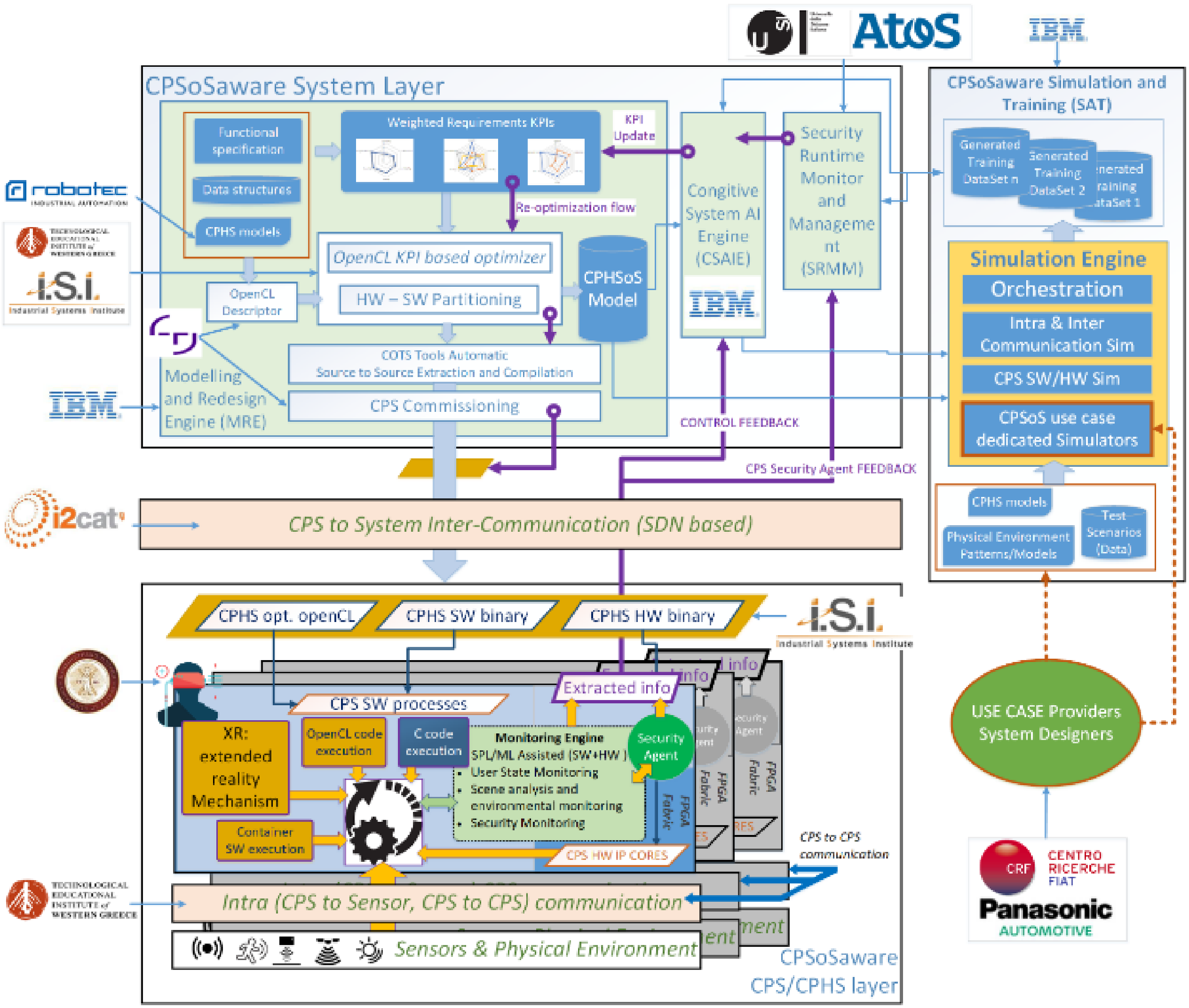
- OpenCL Optimization
- Hardware/Software Partitioning
- Digital Twin like based simulation
- CPS Models
- Use Case models
- Environment models
- Reliability
- Efficiency

Security

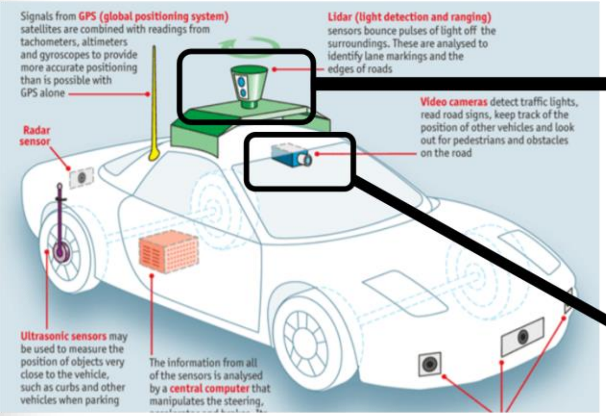
- Run time Security monitoring
- Secure Hardware/Software component design and deployment
- Trusted Security agents/sensors

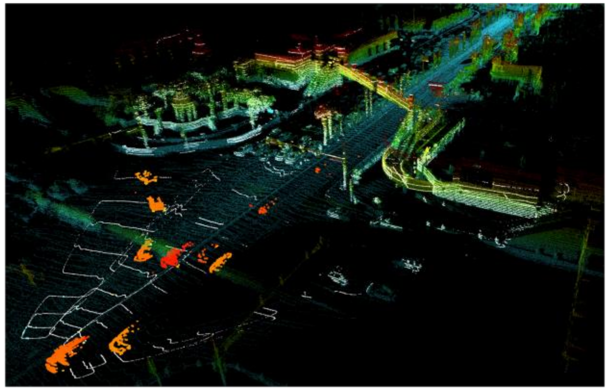
XR UIs

- AR Interventions
- Touchable Holographic Interfaces



Accelerated Multimodal Scene Analysis and understanding





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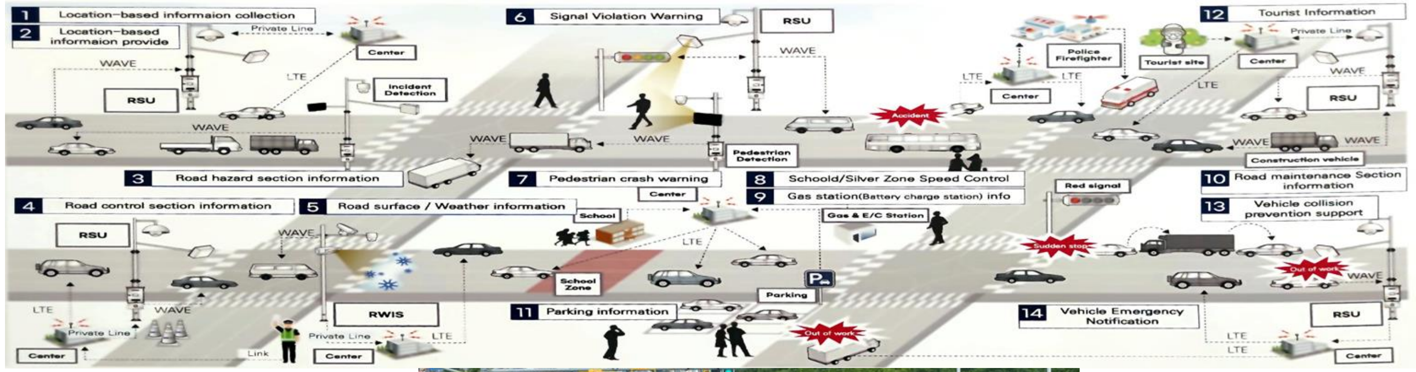
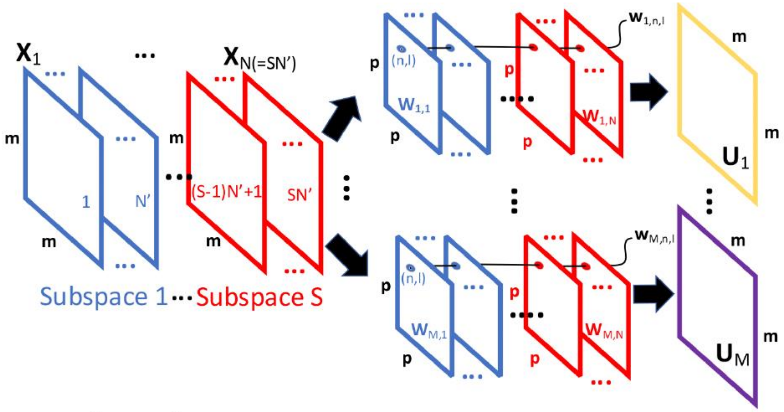
Accelerated Scene analysis – Mission & Vision

- **Accelerated Multimodal Scene Analysis**
  - Improve the performance of transportation systems
  - Enhance travel security
  - Improve fuel efficiency



- **Fast and effective scene understanding solutions for**
  - image classification,
  - object detection,
  - object tracking and
  - semantic segmentation
- **Fast : Fast enough to run on automotive embedded systems , Device specific acceleration**

Model Compression and Acceleration via Product Quantization

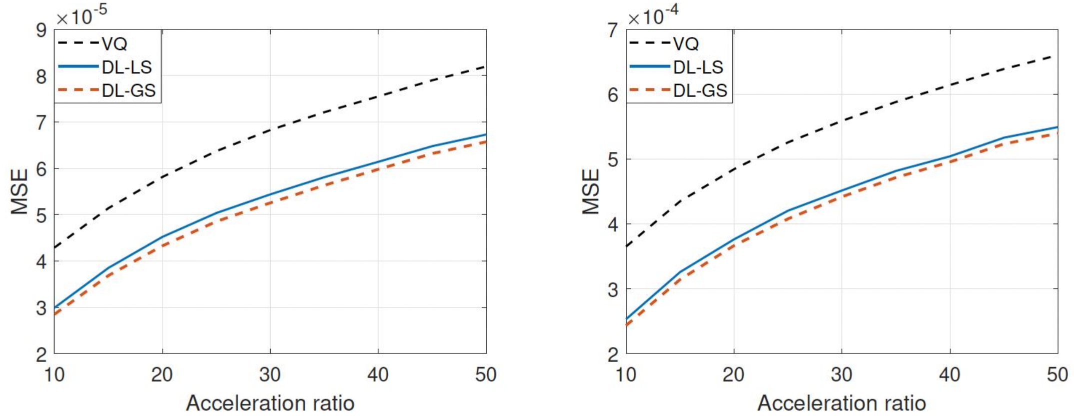


Product Quantization:

1. Partition N-dimensional vector space into S **subspace**
2. perform Vector Quantization (VQ) in each subspace

Vector Quantization:

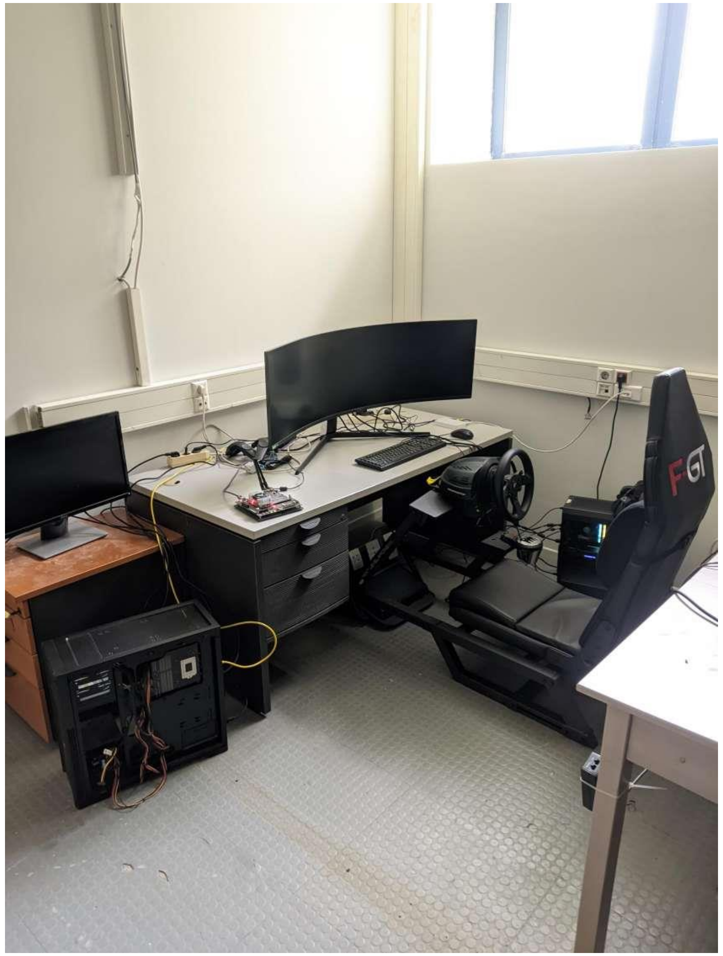
- Represent Mp^2 original sub-vectors using $K \ll Mp^2$ **"codewords"**

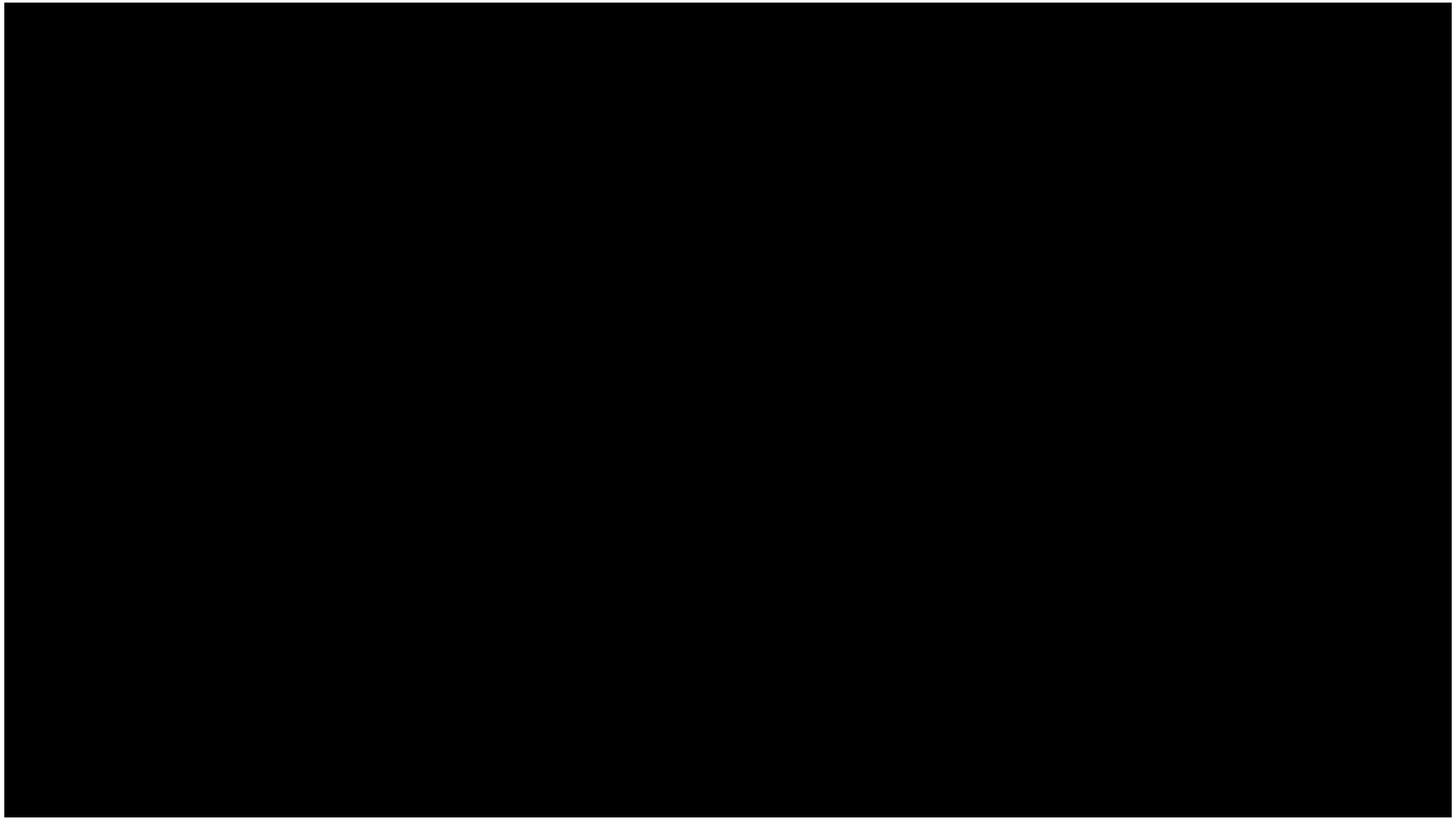


Acceleration Gains for ResNet for Data agnostic and Data aware

- The new matrix factorization $\mathbf{W} \approx \mathbf{D}\Lambda\Gamma$, following a Dictionary Learning (DL) approach, attains improved MCA gains
- Detailed analysis of the acceleration and compression gains achieved
  - Analytical expressions derived that allow the designer to set the involved parameters for targeted MCA gains
- Novel algorithmic approaches to design the factors $\mathbf{D}$, Λ, and Γ
  - The **Data-agnostic** approach aims at minimizing the quantization error between the involved weights and the factors.
  - The **Data-aware** approach aims at the minimization of the representation error at the output of the targeted convolutional layer.

Multimodal Scene Analysis Demo





Relevant publications

[1] G. Arvanitis, S. Nousias, A. Lalos, K. Moustakas, “Deep Saliency Mapping for 3D Meshes and Applications” , ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM), To Appear

[2] S. Nousias, E. V. Pikoulis, C. Mavrokefalidis, and A. S. Lalos, “Accelerating deep neural networks for efficient scene understanding in automotive cyber-physical systems,” in Proceedings - 2021 4th IEEE International Conference on Industrial Cyber-Physical Systems, ICPS 2021, 2021, pp. 63–69.

[3] C. Vitale et al., “CARAMEL: results on a secure architecture for connected and autonomous vehicles detecting GPS spoofing attacks,” Eurasip J. Wirel. Commun. Netw., vol. 2021, no. 1, pp. 1–28, 2021.

[4] A. Papandreou, A. Kloukiniotis, A. Lalos and K. Moustakas, "Deep multi-modal data analysis and fusion for robust scene understanding in CAVs," 2021 IEEE 23rd International Workshop on Multimedia Signal Processing (MMSP), 2021, pp. 1-6, doi: 10.1109/MMSP53017.2021.9733604.

[5] C. Kyrkou et al., “Towards artificial-intelligence-based cybersecurity for robustifying automated driving systems against camera sensor attacks,” in Proceedings of IEEE Computer Society Annual Symposium on VLSI, ISVLSI, 2020, vol. 2020-July, pp. 476–481.

[6] N. Piperigkos, A. S. Lalos, and K. Berberidis, “Graph based Cooperative Localization for Connected and Semi-Autonomous Vehicles,” in IEEE International Workshop on Computer Aided Modeling and Design of Communication Links and Networks, CAMAD, 2020, vol. 2020-Septe, pp. 1–6.

[7] C. Vitale et al., “The CARAMEL Project: A secure architecture for connected and autonomous vehicles,” in 2020 European Conference on Networks and Communications, EuCNC 2020, 2020, pp. 133–138.

[8] N. Piperigkos, A. S. Lalos, K. Berberidis, C. Laoudias, and K. Moustakas, “5G enabled cooperative localization of connected and semi-autonomous vehicles via sparse laplacian processing,” in International Conference on Transparent Optical Networks, 2020, vol. 2020-July.

[9] A. Kloukiniotis, A. Papandreou, A. Lalos, P. Kapsalas, D. . -V. Nguyen and K. Moustakas, "Countering Adversarial Attacks on Autonomous Vehicles Using Denoising Techniques: A Review," in IEEE Open Journal of Intelligent Transportation Systems, vol. 3, pp. 61-80, 2022, doi: 10.1109/OJITS.2022.3142612.

[10] S. Nousias, E. -V. Pikoulis, C. Mavrokefalidis, A. S. Lalos and K. Moustakas, "Accelerating 3D scene analysis for autonomous driving on embedded AI computing platforms," 2021 IFIP/IEEE 29th International Conference on Very Large Scale Integration (VLSI-SoC), 2021, pp. 1-6, doi: 10.1109/VLSI-SoC53125.2021.9606990.

INDUSTRIAL SYSTEMS INSTITUTE

ATHENA Research & Innovation Information Technologies

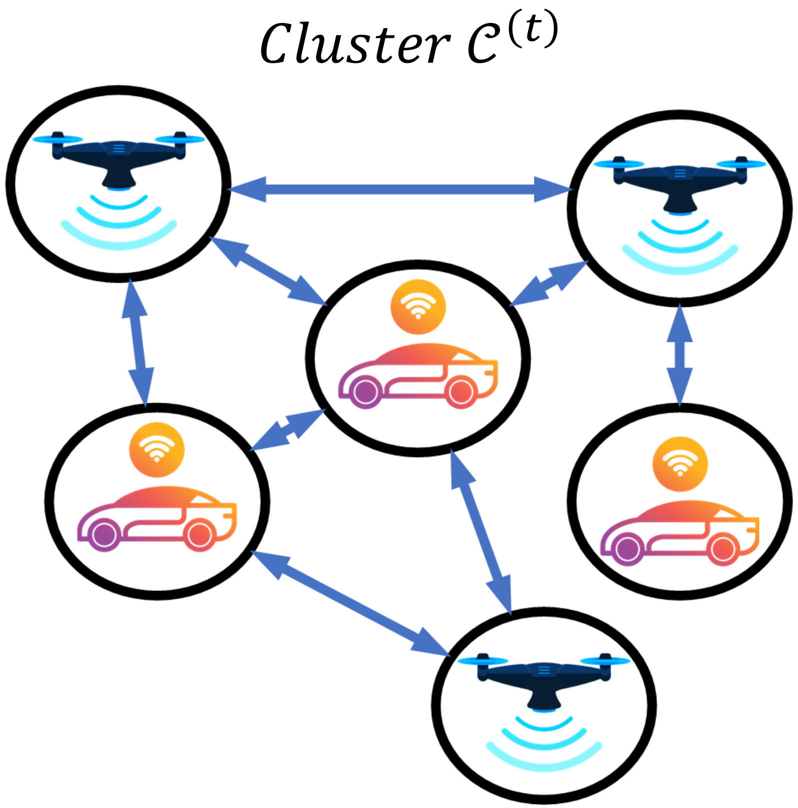
Mission

- Autonomous vehicles, i.e., cars, UAVs, underwater, indoor robots, etc., need to localize themselves and map the surrounding environment highly accurate, in order to optimally plan their future driving actions and maximize safety and efficiency.

- Existing positioning and navigation solutions, e.g., GNSS/IMU, visual and LIDAR based odometry, etc., need to be further improved against occlusion, harsh weather conditions, crowed urban environments, etc.

- Cooperative multimodal fusion as solution: Vehicles exchange and fuse heterogenous measurements coming from multimodal sensors, using V2V communication and advanced processing systems.

- 4D situational awareness task: Vehicle tracks 3D positions of nearby vehicles over time, relying only on its own abilities.



Vision

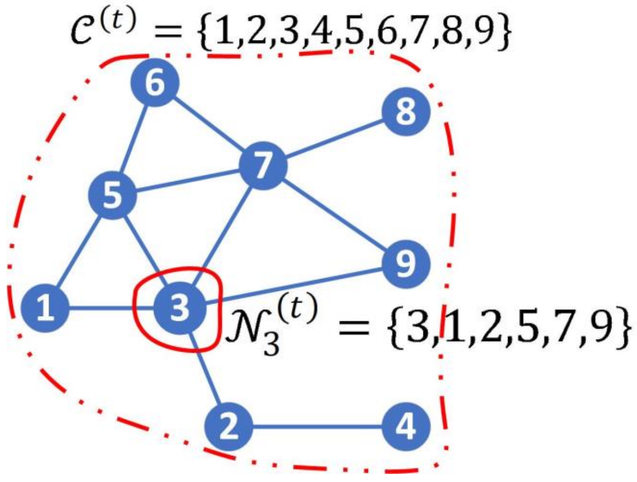
- Vehicle i at time instant t is required to estimate its own position as well as to map the surrounding environment, i.e., to be location-aware of its surrounding connected neighbors.

- Two cases can be identified:

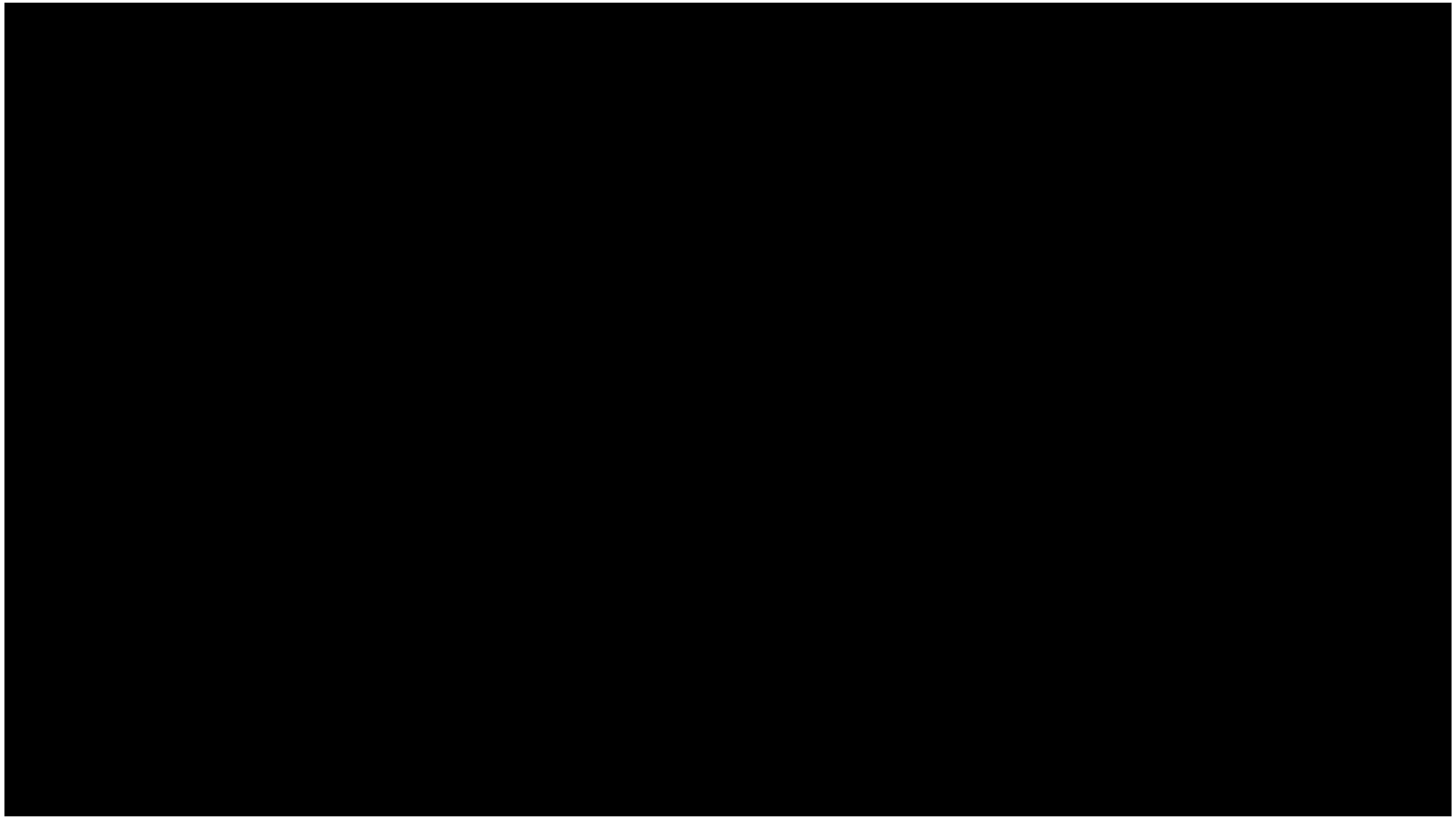
  - Global location awareness (GLA): Target state $\widetilde{\boldsymbol{x}}_{\boldsymbol{i}}^{(\boldsymbol{t})} \in \mathbb{R}^{3|\mathcal{C}^{(t)}|}$ of i comprises of 3D locations of all vehicles belonging to the same cluster $\mathcal{C}^{(t)}$.

  - Local location awareness (LLA): Target state $\widehat{\boldsymbol{x}}_{\boldsymbol{i}}^{(\boldsymbol{t})} \in \mathbb{R}^{3\left|\mathcal{N}_i^{(t)}\right|}$ of i comprises of 3D locations of vehicles belonging to 1-hop and direct neighborhood $\mathcal{N}_i^{(t)}$ of i.

- ***Important***: Target state vector has to be estimated in a distributed manner by vehicle i.



Demo Overview



Relevant Publications

1. N. Piperigkos, A. S. Lalos and K. Berberidis, "Graph Laplacian Diffusion Localization of Connected and Automated Vehicles," in IEEE Transactions on Intelligent Transportation Systems, doi: 10.1109/TITS.2021.3110650.
2. N. Piperigkos, A. S. Lalos, and K. Berberidis, "Graph Laplacian extended Kalman filter for connected and automated vehicles localization," in Proceedings - 2021 4th IEEE International Conference on Industrial Cyber-Physical Systems, ICPS 2021, 2021, pp. 328–333
3. Nikos Piperigkos, Stavros Nousias, Aris S. Lalos, "Robust 4D awareness via diffusion adaptation over Connected and Automated vehicles", *IEEE 14th Image, Video, and Multidimensional Signal Processing Workshop (IVMSP), 2022*.
4. Nikos Piperigkos, Aris S. Lalos, Kostas Berberidis "Robustifying cooperative awareness in autonomous vehicles through local information diffusion", *IEEE 20th International Conference on Industrial Informatics (INDIN), 2022*.
5. Nikos Piperigkos, Aris S. Lalos, Kostas Berberidis "Alternating optimization for multimodal collaborating odometry estimation in CAVs", *IEEE 30th Mediterranean Conference on Control and Automation (MED), 2022*.
6. N. Piperigkos, A. S. Lalos, K. Berberidis, C. Laoudias, and K. Moustakas, "5G enabled cooperative localization of connected and semi-autonomous vehicles via sparse laplacian processing," in International Conference on Transparent Optical Networks, 2020, vol. 2020-July.
7. N. Piperigkos, A. S. Lalos, K. Berberidis, and C. Anagnostopoulos, "Cooperative multi-modal localization in connected and autonomous vehicles," in 2020 IEEE 3rd Connected and Automated Vehicles Symposium, CAVS 2020 - Proceedings, 2020.

Simulation Activities

Mission and Vision

Mission

- **End-to-End quick and effective** testing of algorithmic implementations under various, controllable simulation scenarios
- **Generation of annotated data** from various sensors (e.g., image, lidar, gnss, depth camera, V2X messages etc.).
- Tool for **Visualization and Presentation**
- **Driver-in-the-loop, Model-in-the-loop, Software-in-the-loop and Hardware-in-the-loop** testing.

Vision

- Extend the **End-to-End simulation framework**
- **Integrate** and **test** more algorithms.
- Build an **extendable library of predefined scenarios** describing regular and corner cases.

Why to Simulate?

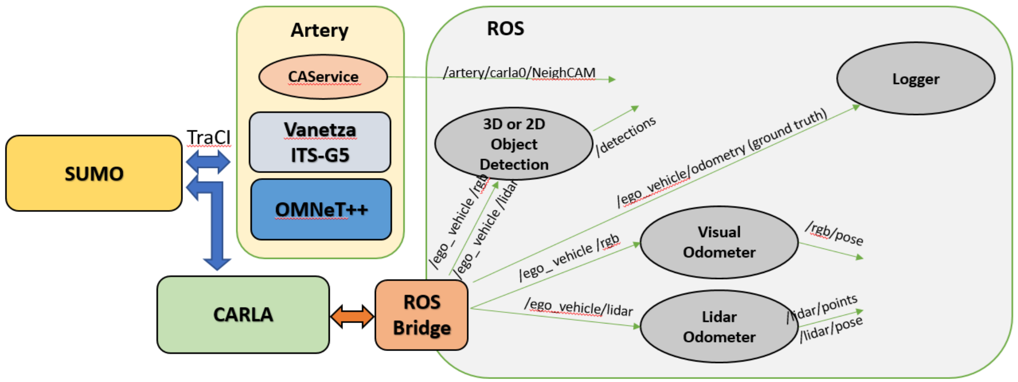
- Self-driving cars would have to be driven millions of miles before reaching a human-level error rate.
- Fewer imposed restrictions in security, costs, and control in environmental conditions.
- Reduced Time to Market

Game engine-based simulator

- A virtual environment based on a game engine offers many comparative advantages over running experiments in the real world
- Key characteristics of a game engine are the rendering system, the physics engine and the scripting engine.
- **CARLA** is probably the most popular game engine-based simulator amongst the research community.
- It implements a scalable client-server architecture
- Simulation-related task are assigned to the server and the clients can control the simulation environment and entities via a Python API

Integrated Solutions

- **Robotic Operating System (ROS**) is an open-source middleware suite.
- It consists of a set of software libraries and tools
- Each algorithm is implemented as a ROS node in C++ or Python.
- Each node can subscribe to one or more topics and consume data, or it can publish produced data under another topic.
- It is a scalable and modular architecture.
- Wide community support.



- Visual Odometers
- Multimodal fusion
- Cooperative localization
- Real time ATE and RPE calculation and visualization
- SLAM backend testing
- 2D and 3D perception algorithms

Christos Anagnostopoulos; Christos Koulamas; Aris S Lalos; Chrysostomos Stylios
Open-Source Integrated Simulation Framework for Cooperative Autonomous Vehicles Inproceedings Forthcoming *11th Mediterranean Conference on Embedded Computing, 2022*

VO Dataset Generation

Mission

- **Detect the limitations of the current SoA Visual Odometry**
- **Decrease the uncertainty of both Deep Learning and Geometric based Visual Odometry methods**
- **Enhance current benchmarks with simulated scenarios on challenging conditions for odometry methods**

Vision

- **Create Visual Odometry system which will be robust under dynamically changing and challenging conditions**

Dataset for Visual Odometry

Scenario: Case Study for Failures

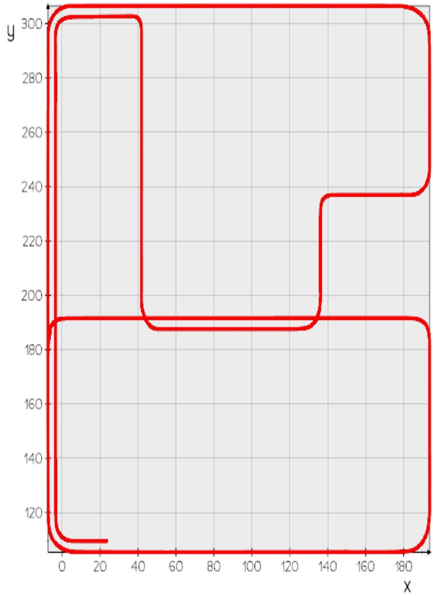
1. **Roads with positive or negative slope :** Algorithms with planarity assumption may fail to detect the road surface.
2. **Rural environment without many buildings and narrow roads:** Check if robust features could be extracted, because rural regions especially in an image are featureless and thus there are far fewer feature points.
3. **Sequence with an infinite loop:** Check loop closure detection accuracy.
4. **Modify weather and lighting conditions:** Check whether multiple weather conditions in images or scattering in points clouds affect trajectory.
5. **Existence of moving objects on the 50%, focus expansion of cameras:** The odometry algorithm may fail to recognize whether the front vehicle is moving or not.
6. **Complex environment in the city:** Check trajectory error in a complex city environment with traffic elements such as multiple intersections, complex lane roundabouts, or tunnels.
7. **Long highways:** Check whether the high speed of the vehicle could affect the estimated odometry. Also, some 3d landmarks at long distances may be detected that have noisy shifts on the image plane and affect negatively the accuracy of the algorithm.

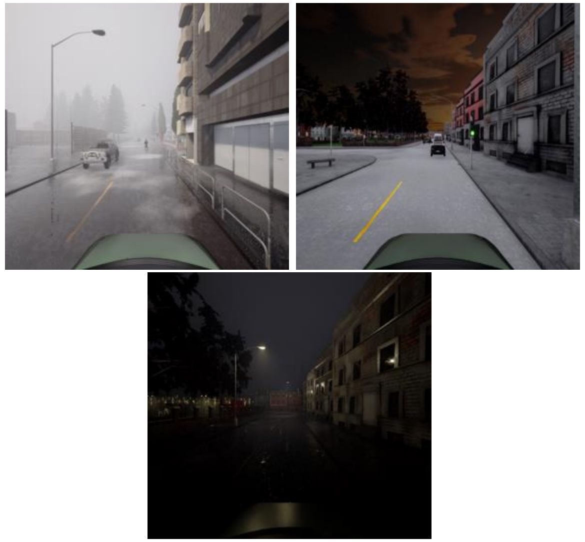
Andreas Kloukiniotis, Andreas Papandreou , Christos Anagnostopoulos, Aris Lalos, Petros Kapsalas , Duongvan Nguyen, Konstantinos Moustakas,"CarlaScenes: A synthetic dataset for odometry in autonomous driving", CVPR 2022 Workshop on Autonomous Driving

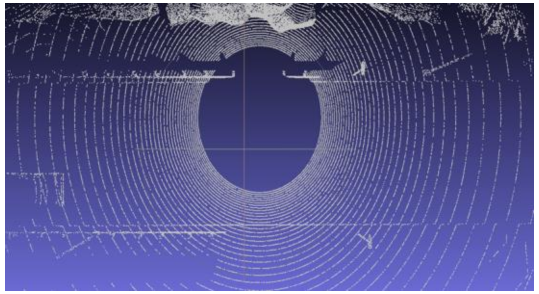
Sc4: Modify weather and lighting conditions

*With scattering in point clouds

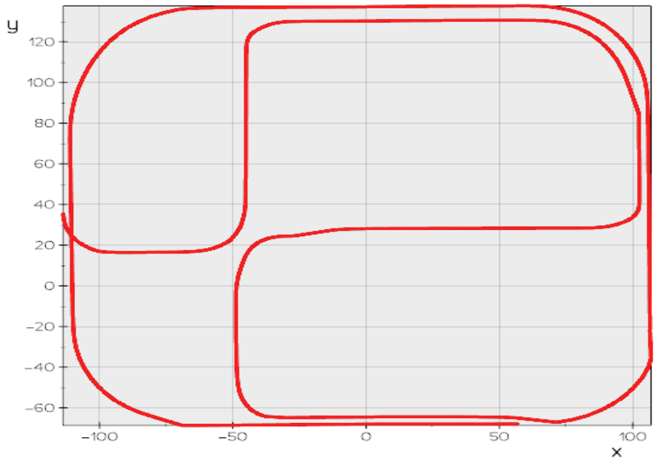
General proportion of points that are randomly dropped







Sc6: Complex city environment



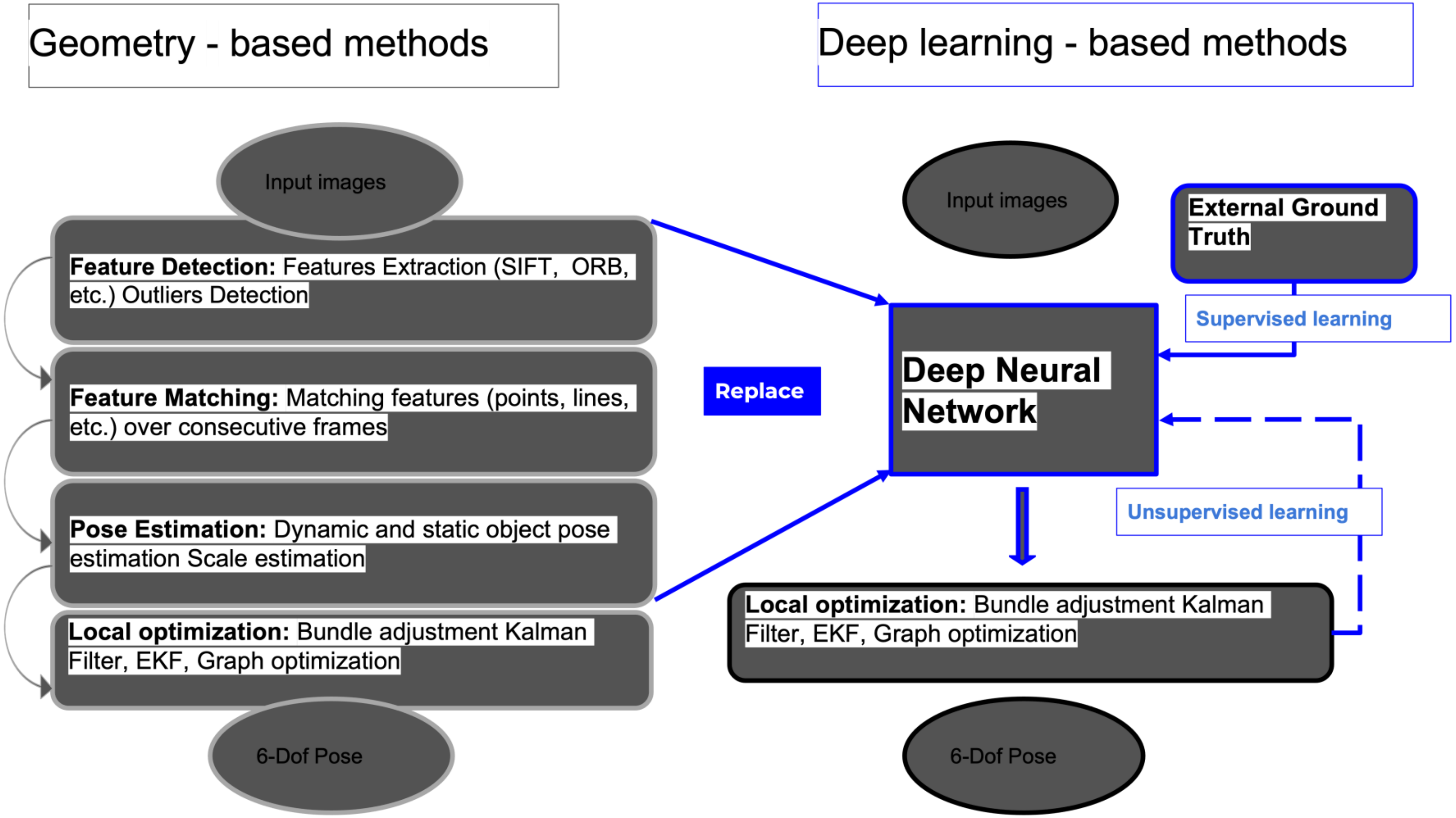
Deep SLAM Mission & Vision

Mission

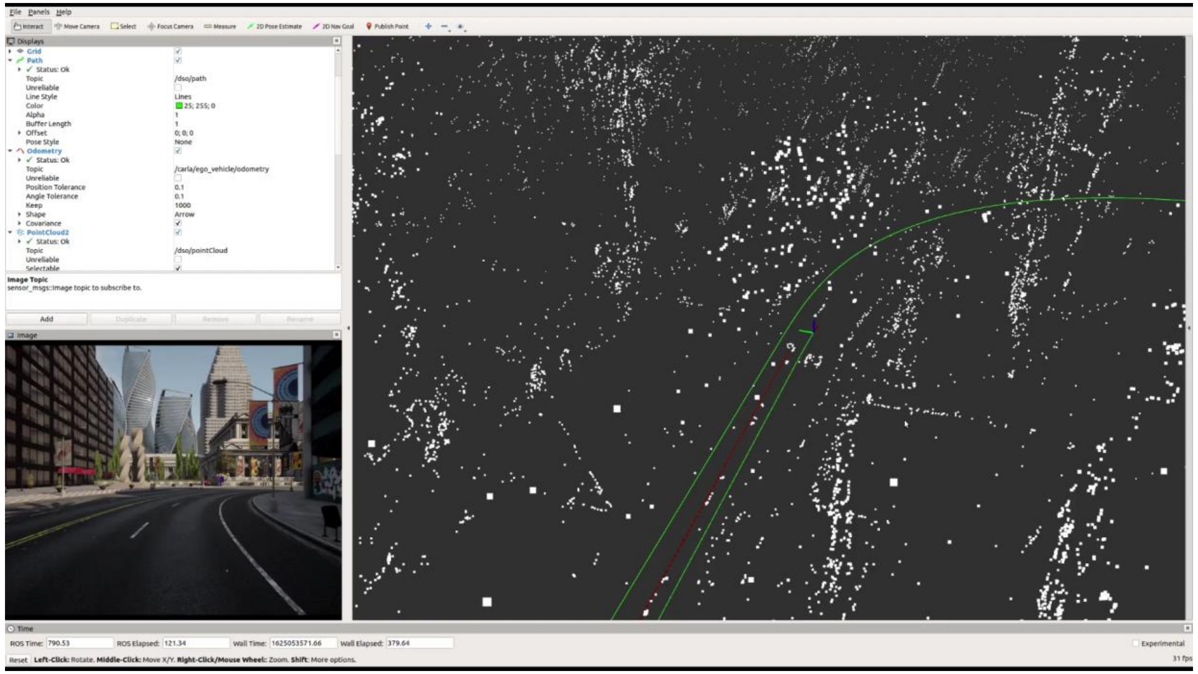
- **Investigate how deep embedded learning can profit and optimize the VO systems.**
- **Detach the training process from human annotated data**

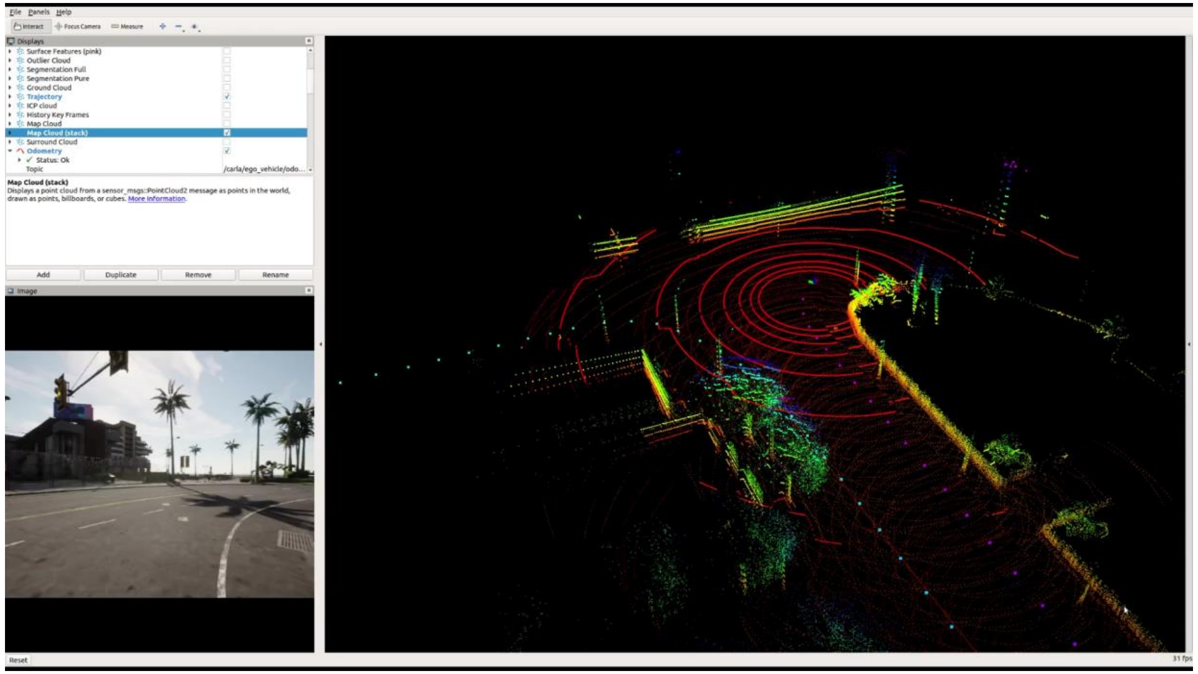
Vision

- **Train Deep Learning matching module will be robust under dynamically changing and challenging conditions**



Visual Deep SLAM Demo on CARLA





Future Directions

- Realistic Cooperative Awareness simulation in CARLA simulator environment, using:
  - Scene analysis and understanding modules based on Convolutional Neural Network -> Aim: Evaluate performance against missing detections, occlusion, variety of weather conditions, processing time, etc.
  - V2V network communication using SUMO and VANETZA -> Aim: Study the effect of network delay during the exchange of measurements phase.
- Acceleration/Compression of NNs used for LiDAR and Image Analysis
  - Miniaturized versions with increased accuracy
  - Deploy in Heterogeneous Embedded devices within a CPSoS of autonomous vehicles
- Automotive Simulation Activities
  - Extend the **End-to-End simulation framework**
  - **Integrate** and **test** more Cooperative Awareness algorithms.
  - Build an **extendable library of predefined scenarios** describing regular and corner cases.
- Extension of Embedded Vision solutions in other areas, such as
  - Precision Agriculture
  - Human Robot Collaboration in Industrial Environments

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