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2025 *Activity Report*

RESEARCH CENTRE: **Inria Paris Centre**

IN PARTNERSHIP WITH: **Valeo**

Project-Team

ASTRA

Automated and Safe TRAnsportation systems

Project-Team ASTRA

Creation of the Project-Team: 2022 July 01

Each year, Inria research teams publish an Activity Report presenting their work and results over the reporting period. These reports follow a common structure, with some optional sections depending on the specific team. They typically begin by outlining the overall objectives and research programme, including the main research themes, goals, and methodological approaches. They also describe the application domains targeted by the team, highlighting the scientific or societal contexts in which their work is situated. The reports then present the highlights of the year, covering major scientific achievements, software developments, or teaching contributions. When relevant, they include sections on software, platforms, and open data, detailing the tools developed and how they are shared. A substantial part is dedicated to new results, where scientific contributions are described in detail, often with subsections specifying participants and associated keywords. Finally, the Activity Report addresses funding, contracts, partnerships, and collaborations at various levels, from industrial agreements to international cooperations. It also covers dissemination and teaching activities, such as participation in scientific events, outreach, and supervision. The document concludes with a presentation of scientific production, including major publications and those produced during the year.

Keywords

Computer sciences and digital sciences

A1.5. – Complex systems

A1.5.1. – Systems of systems

A1.5.2. – Communicating systems

A2.3. – Embedded and cyber-physical systems

A3.4. – Machine learning and statistics

A5.3. – Image processing and analysis

A5.3.3. – Pattern recognition

A5.3.4. – Registration

A5.5.1. – Geometrical modeling

A5.9. – Signal processing

A5.10. – Robotics

A5.10.2. – Perception

A5.10.3. – Planning

A5.10.4. – Robot control

A5.10.5. – Robot interaction (with the environment, humans, other robots)

A5.10.6. – Swarm robotics

A6. – Modeling, simulation and control

A6.1. – Methods in mathematical modeling

A6.2.3. – Probabilistic methods

A6.2.6. – Optimization

A6.4.1. – Deterministic control

A6.4.3. – Observability and Controlability

A6.4.4. – Stability and Stabilization

A6.4.5. – Control of distributed parameter systems

A8.6. – Information theory

A8.9. – Performance evaluation

A9.2. – Machine learning

A9.2.1. – Supervised learning

A9.2.2. – Unsupervised learning

A9.2.3. – Reinforcement learning

A9.2.5. – Bayesian methods

A9.2.6. – Neural networks

A9.2.8. – Deep learning

A9.3. – Signal processing

A9.5. – Robotics and AI

A9.6. – Decision support

A9.7. – AI algorithmics

A9.12. – Computer vision

A9.12.1. – Object recognition

A9.12.2. – Activity recognition

A9.12.4. – 3D and spatio-temporal reconstruction

A9.12.5. – Object tracking and motion analysis

A9.12.6. – Object localization

Other research topics and application domains

B5.2.1. – Road vehicles

B5.6. – Robotic systems

B6.6. – Embedded systems

B7.1.2. – Road traffic

B7.2. – Smart travel

B7.2.1. – Smart vehicles

B7.2.2. – Smart road

B9.5.6. – Data science

Contents

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2 Overall objectives

Context

SAE International[1] established a visual chart [97] that is designed to define the six levels of driving automation, from SAE Level 0 (no automation) to SAE Level 5 (full vehicle autonomy). It serves as the industry's most-cited reference for automated-vehicle (AV) capabilities.

Fully autonomous cars (Level 5 of automation according to SAE J3016), which can work everywhere in all conditions, are not yet on the roads. Nevertheless, major advances are making vehicle automation a reality. Systems exist on serial vehicles with Level 2/2+ (assisted driving) and even Level 3 (high automation, driving only upon system request) since 2021 on privately owned vehicles as well as on public transport driverless vehicles are offered to passengers and goods around the world. Recent demonstrators (automated shuttles and robotaxis) have the merit of proving the feasibility of automated driving as a solution for improving mobility, comfort, safety and energy efficiency.

Current regulation (UN 157 – adopted in June 2020 and voted by 60 countries) allows today vehicles to drive in L3 up to 60 km/h on carriageway roads. Original Equipment Manufacturers (OEMs) are pushing for the extension of this regulation up to 130 km/h including automated lane changes. To allow that (L3/L4 on the highway), many challenges are still to be taken up; technical challenges of course, but also non-technical challenges which are not the easiest to deal with (legal, liability, ethical, monopoly, acceptance, economical. . .) and that are not in the scope of this document even though some intersect with some technical considerations [86, 106, 133].

[1]The Society of Automotive Engineers (SAE) : www.sae.org

For public transportation, on-road experiments are conducted around the world in specific Operational Design Domains (ODDs) and first commercial services are being deployed. For example, in Russia, Yandex has launched the first commercial service in Europe in 2019 in the city of Innopolis and Waymo is currently operating 800 SUV RoboTaxis in the city of San Francisco since August 2023 and one ride-hailing service using highly automated vehicles in the Phoenix metropolitan area (US) in 2020. These systems are operating in geofenced controlled environments due to the lack of technology maturity that are able to deal with all road types (missing lines, construction areas, reckless road users behaviour like scooters, etc.).

Therefore, the development of alternative solutions at a large scale needs other scientific foundations and technological breakthroughs. Car makers, suppliers, infrastructure operators and academics across the world are working today on ways to make driving safer, more comfortable, more efficient and more inclusive through automation, and the race is on to bring the technology to the mass market.

In this context Inria and Valeo are internationally distinguished players especially thanks to their R&D activities on automated unmanned vehicles, Cybercars and more generally on the development of advanced intelligent sensors-based decision systems.

Motivation

Partners in numerous collaborative research projects and bilateral projects, Inria and Valeo have also collaborated in the supervision of doctoral and post-doctoral students. Many Inria researchers have also joined Valeo's R&D teams for several years. Finally, numerous technology transfer actions and joint patent applications have taken place. Motivated by this very strong collaboration for over 15 years, Inria and Valeo wanted to formalize this synergy by strengthening their links, both in the fields of research and technology transfer.

What could be better than to create a joint research team to share the same visions on mobility and transport automation? And what could be better than working together upstream on breakthrough research topics? This naturally resulted in the creation of a joint research team: the ASTRA team. This team brings together talents from three entities: the former RITS team at Inria (Paris), members of the anSWer team at Valeo (Créteil) and members at Valeo.ai (Paris). Beyond the strategic vision assumed by the management of these three entities, the *France Relance* national plan was an important incentive for the creation of this unusual joint entity.

3 Research program

Today, there are still many challenges facing the development and deployment of autonomous vehicles to reach an exploitable and commercially viable solution. This is due equally to technical and non-technical challenges. In particular, the challenges include aspects related to the performance of the systems, their efficiency, their integrability and their costs, not to mention the legal, social and ethical aspects.

A classic robust autonomous navigation architecture should take into account additional aspects related to real-time implementation, functional redundancy, durability, certification and purely technical aspects related to the design and development of functional bricks as well.

As part of this project-team we focus mainly on developments related to automated sensor-based navigation. The other aspects are be dealt with in the framework of collaborations and exchanges with other academic, industrial and institutional partners. Therefore, we focus on four research topics that are central to autonomous navigation and a major focus point for the scientific and technical communities. These components are: perception and understanding of the scene, decision systems and vehicle control, cooperative driving and system modeling. These components are linked one another through a complex but straightforward architecture depicted in Fig. 1.

Obviously, the ability to *perceive and understand the scene* is the starting point of any navigation architecture since it represents the first step of processing sensory data, capturing the world state, and creating the internal digital representations of the decision system. The latter relies on these representations, on the ego vehicle *localization* and the positions of other road users and on contextual data to build *decision* schemes which include maneuvers *planning* and trajectory generation. The *control-command* loop is then responsible of the execution of the trajectories by the generation of control laws that control the vehicle's actuators.

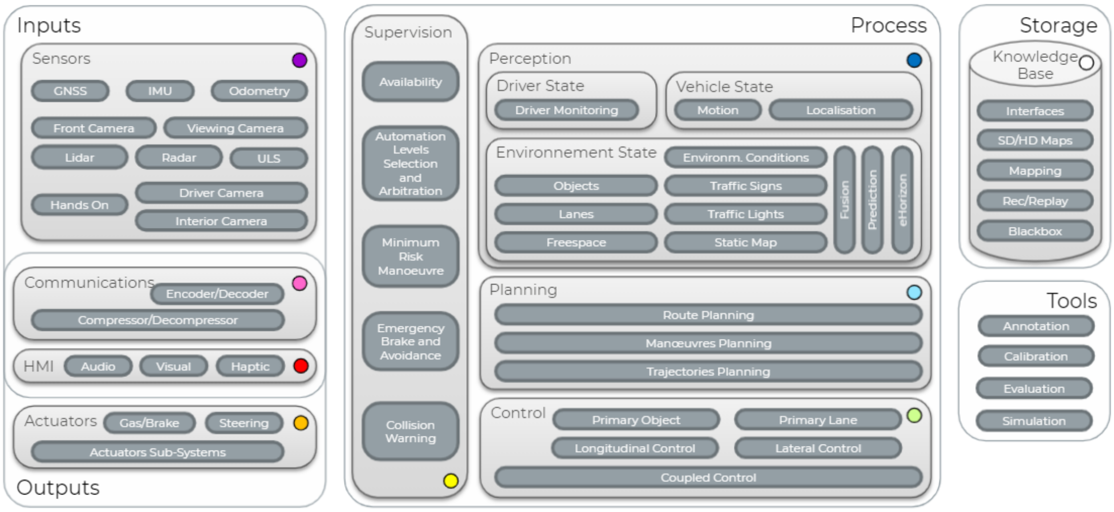

Figure 1: Automated Driving Functional Architecture

All these modules interact as shown in Fig. 1 and ensure an autonomous but individual navigation of a vehicle. However, it is important to study the behavior of these vehicles and their performance when the penetration rate (i.e., their ratio to total traffic) of these vehicles becomes critical. It is also very interesting to study the interactions between these vehicles and their potential cooperation. This is called cooperative driving; it can only take place in the presence of *connectivity*. The latter also ensures interaction and cooperation between autonomous vehicles and infrastructure. The benefits of this type of cooperation are significant, both in terms of the individual performance of each vehicle but also of the overall performance of the vehicle fleet and traffic in general.

3.1 Research Axis 1: Vision and 3D Perception for Scene Understanding

Navigation for mobile robotics requires a robust understanding of the environment from 2D or 3D sensors. Recent learning-based vision algorithms are now able to operate in highly cluttered environments, and tasks which were considered challenging — such as semantic segmentation or object detection — are soon to be solved to a certain extent. Still, the classical supervision paradigm, which relies on large annotated datasets, cannot encompass in practice all outdoor conditions and scenarios. There is therefore a need both to relax the requirement of massive annotations and to extend the perception capability to situations unseen or rarely seen in the training data.

To that aim, in this research axis, we investigate several broad topics. First, we transversely investigate learning with less supervision with applications to various perception tasks. Focusing on outdoor vision, we conduct research relying on data-driven or physics-guided paradigms to hallucinate complex lighting/weather conditions and compensate for missing data in the training sets. Because mobile robots evolve in the physical world we also investigate how vision algorithms can provide in-depth 3D understanding of the scene from images and/or LiDAR scans.

To evaluate our research as well as to foster reproducibility, we rely on relevant recent public datasets (nuScenes [52], Waymo Open [153], Woodscapes [165], SemanticKITTI [43], CADCD [140], etc.) and intend to openly share our research results.

3.1.1 Learning with less supervision

It is now widely accepted that supervised learning is a long-term dead end for computer vision. It relies on costly human- biased annotations, which will soon be unbearable with regard to the ever-increasing size of datasets, trying to cover data diversity. To circumvent the need for labels, strategies have been developed where a trained model is either (almost) directly applicable to unseen conditions (i.e., zero-/few-shot learning) or finetuned on a target domain (i.e., domain adaptation). On the need of data, we investigate automatic generation of data with Generative Adversarial Networks (GANs). Following recent work from the group members [101],[9],[157, 158, 143, 142, 163, 132], we contribute to these research directions, investigating the remaining scientific locks that are detailed below.

Regarding zero-shot learning, we observe that current methods are limited by the low amount of geometric information featured in the embeddings that are used as auxiliary information; we therefore boost this geometric information in the embeddings, for example by jointly using text and images. As for few-shot learning, we use high-contrast dictionary-based approaches where generalization is controlled by the level of sparsity. We are also interested in category-agnostic models that can operate on (e.g., detect, segment) arbitrary objects, or that can adapt online to information retrieved from databases of rare objects. We build upon recent progress in representation learning to enforce separable features representations [103] while enforcing orthogonality of features [155]. Besides, we investigate both zero- and few-shot learning in the context of a complete perception pipeline, instead of focusing on individual vision tasks as commonly done. In both cases, we will also investigate the use of multiple views and multiple modalities (using both images and LiDAR scans).

Concerning domain adaptation, common unsupervised strategy exploits resemblance between a source and a target domain using a self-supervised signal (e.g., pseudo labels [113]) to discover statistics in the target domain. However, when the domain gap is too big, the model adaptation leads to sub-optimal minima [166, 55]. To accommodate bigger domain gaps, we investigate the discovery of new statistics with the support of several modalities (e.g., both 2D and 3D), for a variety of tasks (e.g., semantics, depth and normal estimation). Regarding representation learning, we focus on disentangling latent space representations, working towards domain-invariant features by enforcing orthogonality of the domain features while enabling the discovery of exclusive task/domain features. We study bridging zero-/few-shot to the domain adaptation paradigm, investigating the open domain adaptation setting that accounts for novel unseen domains such as [121, 49].

Finally, to relax the need of training data we investigate automatic data generation with image-to-image (i2i) translations and style-transfer techniques, which both can help training in self-supervision settings [44, 142, 112]. We observe that GANs commonly lack diversity and controllability in the generated data. To that aim, we study multi-domain setups [58] and automatic discovery of domain attributes [93] to foster controllable latent representations. We fight the lack of diversity in the generated datasets [44] with continuous [160] and multi-modal [142] strategies. Besides standard metrics, we also evaluate the quality of our generated data by training proxy vision tasks.

3.1.2 Vision in complex conditions

The wide variety and continual physical nature of physics prevent any dataset to encompass all lighting and weather conditions. Most outdoor datasets account exclusively for data recorded in clear weather daytime while only a handful of them include adverse conditions. In fact, regardless of the recording complexity some conditions are unlikely to be included in any dataset due to their inherent rarity (e.g., snow storm at sunset). Because they lead to drastically varying appearances we focus here on changing weathers, seasons and lighting conditions; with the complimentary goals to improve robustness of vision algorithms and to automatically assess failures cases.

Rather than agnostic data-driven models, we study training with a priori knowledge, with the ultimate goal to get representations invariant to these conditions. To compensate for the scarcity of data as well as to generalize training to unseen conditions, we rely on physics-guided learning to ease and accommodate the discovery of statistics. We rely here on physical guidance to discover the continuous underlying manifold where data lives [14]. Using physical models to guide the training helps vision algorithms to accommodate better to partial or imbalanced distribution in the training set, as well as to better extrapolate to unseen conditions. We are focusing on invariant representations that can improve both the image translation setup and proxy vision tasks (segmentation, objects, etc.); relying on prior works from group members [14], [145], [17, 15].

Sometimes, weather conditions go even beyond the sensing capabilities of sensors, e.g., sun glare or very dark scenes can reduce dramatically the perception of standard cameras. In such cases, robustness is difficult to attain and the system should rather trigger an alert or fail gracefully. Unseen weather conditions encountered at runtime can be regarded as a dataset/distribution shift and can be addressed with predictive uncertainty estimation methods [137]. Through a Bayesian lens we study and devise strategies for automatic assessment and detection of dataset drifts by leveraging approximate ensembles [126, 38, 76], observer networks [64, 94], and complementary information from other sensors [45]. We rely on prior findings and works from group members [64, 76, 75],[17], [145].

On application, we evaluate robustness of the proposed methods on core vision tasks of recent adverse weather datasets [149, 167, 153, 52, 45].

3.1.3 3D scene understanding

Robots still commonly lack the natural ability of humans to estimate the fine-grained geometry of a scene while understanding object interactions and reasoning beyond their field of view. To provide accurate geometry, 3D active sensors such as LiDARs are commonly used in autonomous driving [98], but they only provide a sparse sensing of the scene. In this third topic, we seek a fine-grained geometrical/semantics 3D understanding of the scene with or without 3D sensing, while also relying on frugal supervision. This topic benefits from prior work of group members [144, 47, 46, 101],[16],[99, 164, 107, 53].

Building up on recent methods [47, 46, 154, 119, 88] that efficiently convolve point clouds, we look forward at improving 3D tasks (detection, segmentation, etc.) relying on contextual priors. Furthermore, we address 3D generative tasks like point cloud up-sampling, completion and generation, as well as surface reconstruction, which provides important navigation cues for robotics, and can also assist the human driver in augmented reality scenarios, particularly in adverse conditions. Temporally consecutive point clouds will also be leveraged to disambiguate occlusions and provide denser scene sensing [144, 53]. Regarding richer scene representations, we study the intertwined relation of geometry and semantics [151] through the semantic scene completion task [16],[147, 146], which gained growing interest lately [43].

Another line of study is the interaction between modalities of different nature like for scene understanding, in particular the complementarity of 2D images and 3D scans. We study how multi-modal features can jointly improve performance of core tasks, but also how it can lead to improving the performance of single modalities by exploiting cross-modal features as self-supervision [101],[9].

Besides the use of 3D devices, we also investigate 3D understanding from 2D images. As they originate from passive sensors, images carry less obvious geometrical cues but humans are still able to estimate depth and understand 3D from a photograph, heavily reasoning on learned priors. We study here challenging tasks like scene reconstruction or 6-DOF localization, which can be conveniently self-supervised from either 3D sensing or sequential data.

3.2 Research Axis 2: Localization & Mapping

Vehicle localization and environmental mapping are pillars of the perception task for an autonomous vehicle. While vehicle localization ensures the global positioning of the vehicle in its environment and local positioning with regard to the road and to the close road features, environment mapping contributes in building a useful internal representation that is exploited by the decision system.

Inria and Valeo teams have been working - separately and jointly - on the localization and mapping solutions for over the past 15 years. Many algorithms have been developed and showed their effectiveness in terms of accuracy, precision and safety expectations for autonomous driving. However, the integrity, safety, data size and costs are still challenging points that ASTRA wants to address while pursuing research on localization and pose registration using single/multisensor approaches.

3.2.1 Localization and Map Integrity

Many localization methods were developed mainly based on Particle Filter and GraphSLAM together with a point cloud representation of the environment. These solutions mainly focus on the accuracy and precision requirements of the pose estimations. Yet, the integrity of localization and integrity of maps used for localization are critical to ensure a safe use of the localization system for autonomous driving. State-of-the-art methods on localization integrity usually proceed by: 1. employing Fault Detection and Isolation algorithms (FDI) to remove outliers from input data. 2. computing Protection Levels (PL) to qualify the integrity zone [110] [92] [111] or by calculating the Protection Levels (without FDI) such as in [116] [40]. Maps integrity is highly related to the feasibility to find a distinctive matching when using the map for localization. Indeed the map can be explored by an algorithm that aims to identify the zones or sections that represent a potential ambiguity for matching algorithms such as in [95].

3.2.2 Online Alignment of Multiple Map Layers

A wide diversity of maps that are dedicated to vehicle's localization are nowadays available. These maps are different from each other regarding different key localization features. The most important aspects may be: the structure of the representation (e.g., grid, graph etc.), the underlying theory to represent the information of the environment (e.g., occupancy probabilities, landmarks, etc), and the sensor used to collect information (LiDAR, camera, etc). Map providers, such as Here and TomTom, usually provide maps with different layers to encode different information that are relevant to ADS features (Road model, lanes, and road features). Valeo, having the advantage of being the leader of automotive LiDAR sensor, wants to enhance his ADS solutions arsenal as a map provider by providing a map service based on the laser point clouds and potentially other information layers that are relevant to ADS. For this purpose it is important to find correspondences and align different map layers with other maps from maps providers. This subject is addressed by considering semantic information that can be extracted from heterogeneous sensors and maps data such as in [9] and [10].

3.2.3 Georeferencing of maps without RTK GNSS and IMU

Highly accurate maps that are used for AD localization are usually built using a very expensive Fusion box that includes a very precise RTK_GPS receiver and a first grade IMU. These solutions for map building are very expensive and require deployment of RTK bases in the environment to receive the corrections which imply extra cost. The idea of this subject is to be able to use available sensors (such as standard GNSS, IMU, CAN, LiDAR, Camera) and possibly maps from other providers to build a highly accurate (in the global reference) map using point clouds. Different inputs from sensors and maps can be considered together with an asynchronous fusion method to build an accurate estimation [11]. The method to achieve this goal constitutes the subject of this study.

3.3 Research Axis 3: Decision making, motion Planning & vehicle Control

Decision-making, maneuver and motion planning, and vehicle control are extremely vital components of the intelligent vehicle. These modules act as a bridge, connecting the perception subsystem of the environment and the bottom-level control subsystem in charge of the execution of the motion. We address these issues covering various strategies of designing the decision-making, trajectory planning, and tracking control, as well as shared driving of the human-automation to adapt to different levels of the automated driving system accounting with the driver profile.

The challenges related to decision making and path planning are mainly related to four distinct elements:

1. Errors and uncertainties introduced by the perception subsystems
2. Environment static and dynamic occlusions
3. Lack of understanding and prediction of other road users behaviors
4. Simultaneous consideration of several constraints related to: vehicles dynamics, energy consumption, passengers comfort, offense to driving rule...

Different approaches are investigated in the state of the art addressing one or several issues but, to our knowledge, none are capable of addressing all of them simultaneously. More specifically in most approaches decision and planning are dealt separately or in a way that favors one of them. Approaches based on Markov decision process (MPD, POMDP,...), path-speed profiles, ontologies, artificial potential fields coupled to MPC controllers are able to show interesting results in dedicated environments or in specific situations, however most of them do not tackle properly specific issues such as intention and behavior predictions, interactions or multi-criteria real time optimal maneuver decision.

While continuing the investigation of end-to-end driving approaches based (inverse-)reinforcement learning decision-making approaches, we keep on improving current path-planning methods already developed by both teams at RITS and DAR: Reachable Interaction Sets [42], Artificial Potentials Fields (coupled to MPC control) which are designed for obstacle avoidance, as well as traditional path planning methods. Optimal methods based on the convex optimization and cubic splines are investigated at DAR to design optimized and robust trajectories. More specifically, we are mainly focusing on the following three scientific topics (detailed in the next sections):

- Maneuvers and trajectories prediction of surrounding road users
- Schemes for ego-vehicle actions and maneuvers decision making and motion planning
- Motion planning and trajectories generation

3.3.1 Maneuver and trajectory prediction

To achieve a safe and comfortable driving, an autonomous driving system must have an accurate knowledge of the future motions of all other traffic agents surrounding the autonomous vehicle, such as cars, pedestrians, cyclists, etc. Motion prediction is thus a key task in autonomous vehicles. Several methods of motion prediction have been studied in the literature. Lefèvre et al [114] propose their classification in three levels with an increasing degree of abstraction: Physics-based models, Maneuver-based models and interaction-based models.

- *Physics-based motion models*. They consider that the motion of vehicles only depends on the laws of physics. The future motion is predicted using dynamic and kinematic models linking some control inputs car properties and external conditions. These models are limited to short term prediction and are unable to anticipate any change in the motion of the car caused by the execution of a particular maneuver.
- *Maneuver-based motion models*. They consider that the future motion of a vehicle also depends on the maneuver that the driver intends to perform. The future motion of a vehicle on the road network corresponds to a series of maneuvers executed independently from the other vehicles. These models are Unadaptable to different road layouts.
- *Interaction-aware motion models*. They take into account the inter-dependencies between vehicles' maneuvers. These models require computing all the potential trajectories of the vehicles which is computationally expensive and no compatible with real-time risk assessment. Valeo has filed a patent to overcome this issue [161]. This patented method is being developed in order to be tested in the automated driving prototypes.

Fig. 2 shows a comparison of the different models including their challenges and the used algorithms.

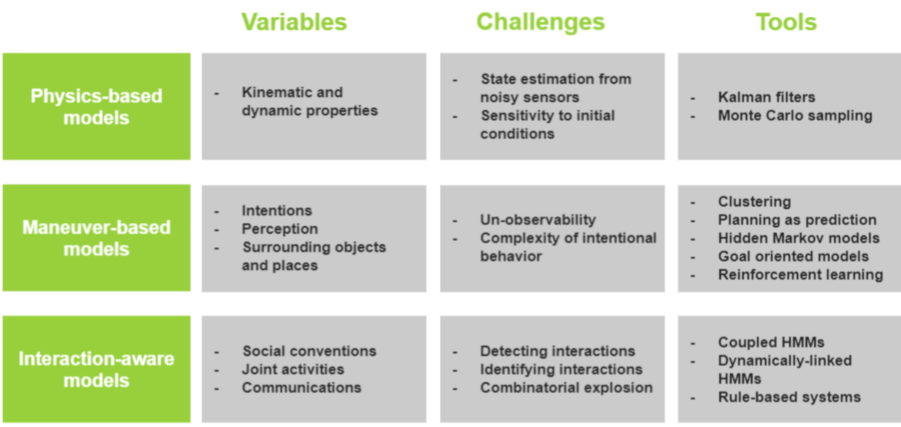

Figure 2: Motion prediction models comparison

Valeo has considered these categories in its development of the automated driving prototypes Cruise4U and Drive4U. The physical-based model is used in situations when their is no knowledge about the route geometry (for example in a big roundabout without lanes), the maneuver-based in highway and urban environment when the road topology is available from HD Map or valeo Drive4U Locate map.

In the few last years, machine learning based algorithms and particularly deep learning are used in order to solve the limits of the current prediction methods. Human motion trajectory prediction has been addressed in the literature [48, 148]. A large amount of naturalistic road user trajectories in different contexts (highways [62, 63, 104] or urban [52, 56]) needed to train and evaluate deep learning methods are now available. Our first works [13],[131],[12],[129], taking as input the track history of a target vehicle and of its surrounding moving road users, obtained accurate prediction results of the target vehicle motion on highways and an extension [130], including the static scene structure, has been proposed for an urban context. Valeo is involved in this research area with activities in prediction of other road users and ego-vehicle trajectory. Different approaches have been implemented and tested in simulation and on test cars [51, 50].

However, work has still to be done in this domain in terms of performance, robustness and generalization before being used in real autonomous driving applications. In fact, the behavior of a human driver depends also on the contextual knowledge of the environment (speed limits, traffic density, day of the week, visibility, road equipment, driver's country, etc.) and on its goal [169]. We plan to include these contextual cues in a prediction method, which should also compute multiple plausible trajectories representing the driver's diverse possible behaviors, give uncertainties estimations on the predictions, carry out multi-agents trajectory forecasts and should be usable in any environment. It will necessitate the use of a more complete dataset [168] composed of various driving scenarios collected from different countries, which may be completed by our own dataset collected with the help of Valeo if necessary. This work will be done in collaboration with Itheri Yahiaoui from Reims University and within the starting PhD thesis of Amina Ghoul funded by the SAMBA project.

3.3.2 Ego-vehicle actions and maneuvers decision making

The most important component of an autonomous vehicle navigation system is the decision system that elaborates the coming tactical actions and maneuvers to be executed. The selection of the optimal maneuver should be the result of relevant and simultaneous consideration of several factors. These factors are mainly: safety and risk assessment, respect of the dynamic constraints of the vehicle and its controllability, uncertainties related to the perception outputs, nearby uncertain interactions with/between close road users, and finally the criterion related to the navigation objectives such as journey duration minimization, driver/passenger comfort, fuel/energy consumption minimization, respect of driving rules, etc. The latter being expressed in terms of kinematics constraints.

In the literature, there are very few approaches describing unified decision architectures capable of taking into account all of the considerations mentioned above. Most approaches are developing planning schemes which separate motion generation and decision making. In these approaches, motion planning (including reactive planning) usually exploits geometry, configuration spaces and other optimization techniques. Decision making schemes rely on AI logic based approaches such as rule based [136], decision trees [60, 117], Finite Set Machines [170], utility-based approaches, Bayesian Networks and Markov Decision Processes like approaches (MDP, POMDP. . .), AI heuristics algorithms (SVM's and evolutionary methods) or AI approximate reasoning methods (fuzzy logic) and Artificial Neural Networks (CNN's, Reinforcement Learning. . .) [118, 159, 57]. In [61] propose an architecture that provides an optimization of the motion generation using the decision making function as the evaluation function, the aggregation of fuzzy logic and belief theory allowing decision making on heterogeneous criteria and uncertain data.

In the coming period we will work on unified architectures, that tackles simultaneously decision making and motion planning. Very likely, one approach will focus on deep learning techniques based on reinforcement learning and inverse reinforcement learning where we deem a (dense) reward function that is suitable for a large class of behavioural planning tasks. More generally, we will investigate model-free and model-based approaches where some interesting approaches have already been initiated and showed interesting results such as in [115]. In particular, in order to better evaluate safety costs, we will take as input the output of the maneuvers and trajectories prediction system described in the previous section, which has the advantage to better estimate the road users trajectories thanks to attention mechanisms that encode interactions and behaviors. This work is done within the PhD of Mr. Islem KOBBI.
Another different approach will still investigate a utility-based approach that is easier to explain. First results were already obtained thanks to the work developed in the framework of the thesis of Mr. Karim ESSALMI; it is based on the Conservation Of Resources theory that we adapted to decision making. In a very new theoretical contribution extending this approach, Quantum Game Theory was investigated to solve the problem of multiple agents interactions in decision making.

3.3.3 Trajectory planning

State of the art on motion planning techniques have been mainly focusing on methods generating the geometric path first, and then applying a speed profile to the generated path. To mention just a few, this approach has been tackled by the following methods (or combinations): interpolating curve-based [85, 84], graph-search based [120], sampling-based [105] and optimization-based [89].

From the motion planning point of view, the inclusion of human factors is a key element for increasing the acceptance of the automated vehicle behavior and for providing a more human-like response. For that purpose, the use of data from real drivers should be envisaged to better define the motion constraints in dynamic environments, allowing to adapt the trajectories to any specific road scenario (intersections, roundabouts, merging, overtaking, lane driving, etc). For instance, motion constraints such as longitudinal and lateral accelerations as well as jerks should be properly taken into account in the generation of a human-like speed-profile, as introduced in [39].

Furthermore, the inclusion of driving factors such as energy consumption or the traffic occupancy should be considered in the multi-criteria optimization for better adapting to any driving situation. This would help to reduce the driving time (such as the commute time) or even reduce the energetic consumption and the stress of both driver and car passengers by reducing the traffic jams and the corresponding repetitive acceleration and braking maneuvers.

Finally, this planning module must fit to the time constraints for its execution in real-time to ensure safety. Thus, a complete and rapid motion planning approach is needed; it should consider the functional safety to generate real-time collision-free trajectories considering the different interactions with the surrounding vehicles to be tracked by the control. For that purpose, works presented at [41] will be extended in order to consider the interaction among the several surrounding road users as one and not as individual interactions, investigating the risk assessment metric that is the most appropriate for each specific scenario.

3.3.4 Robust control of automated vehicles

In order to execute safely a planned trajectory or a reactive maneuver, it is essential that the vehicle executes these trajectories taking into account the vehicle dynamics while ensuring safe, stable and comfortable maneuvers. A tremendous effort was deployed the last 10 years by the team partners in the area of motion planning and intelligent control. Seven PhD thesis were dedicated to the important problem of path and motion planning as well as on corresponding control-command. All are addressing the navigation of autonomous vehicles in structured but complex environments. Harsh configurations such as intersections and roundabouts need specific planning approaches taking into account the geometry and the topology of the places, but also the dynamic and kinematic constraints of each ego-vehicle and as the safety and comfort constraints.

Previously, RITS team (Inria) also implemented specific control algorithms dedicated to specific road maneuvers such as overtaking [138] and parking maneuvers [139]. Control laws were designed with the theoretical proof of stability and optimality. Very interesting results were obtained in two major domains, mainly related to the controllability and stability of dynamic complex systems which are key aspects when it comes to design intelligent control algorithms for vehicles:

- *Plug&Play control for highly non-linear systems: Stability analysis of autonomous vehicles*. The developed Plug&Play control is able to provide stability responses for autonomous vehicles under uncontrolled circumstances, including modifications on the input/output sensors. Former RITS team was among the very first to investigate these theories for automotive applications. They were Investigated in the PhD thesis of Mr. F. Navas [135] and I. Mahtout [125]. The approach deals with: the reconfiguration of existing controllers whenever changes are introduced in the system (gain scheduling), online closed loop identification of the vehicle and its components, and Automatic control reconfiguration to achieve optimal performance [134][11].

- *Fractional Calculus for Cooperative Car Following Control* A Car-Following gap regulation controller using fractional order calculus, has been developed and has been proven to yield a more accurate description of real processes and ensure string stability of the platoons or the vehicles involved in a Cooperative Autonomous Cruise Control [72]. In an effort to combine fractional calculus robust control with plug&play control, a multi-model adaptive control (MMAC) algorithm based on Youla-Kucera

(YK) theory to deal with heterogeneity in cooperative adaptive cruise control (CACC) systems was proposed[73].

ASTRA will evolve by introducing intelligent cooperation between vehicles and, at the same time, autonomously driving the vehicle in a human driver way (increasing driver acceptability) but with the safety and accuracy of optimized control algorithms. To achieve this, we will rely on the existing approaches developed so far but no further research will be conducted in the lifetime of the joint team. This is mainly due to the absence of a senior researcher at ASTRA capable of carrying this topic independently at a high level. This also motivates the team to seek to recruit a new confirmed researcher in the field of the control of dynamic systems, a crucial domain for a team willing to develop and deploy advanced control architectures on real mobile platforms. In the meanwhile it would be very interesting to envisage collaborations with other Inria teams working on similar topics. A perfect example is DISCO team (Inria Saclay Research Center, head: Mrs. Catherine Bonnet). Among others, the research interests of DISCO cover: the realization and reduction of infinite-dimensional systems, Robust H_∞ and BIBO parametrization and stabilization of infinite-dimensional systems, stabilization by finite-dimensional controllers (PID control), delay systems and fractional systems.

This research direction comprises a big interaction with the research axis: *Large scale modeling and deployment of mobility systems in Smart Cities*. The former will be essential when developing control algorithms that rely on a very small communication delay for getting a stable latency, designing stable systems. The latter will serve to analyze the effect over the traffic flow from a developed algorithm, moving from the validation of a proposed controller in a limited number of vehicles to a its study from a macroscopic perspective.

3.4 Research Axis 4: Large scale modeling and deployment of mobility systems in Smart Cities

While axes 1 to 3 deal with subjects related to the on-board intelligence of an "individual" intelligent vehicle and its autonomous navigation, axis 4 intervenes when it comes to many communicating, autonomous or automated vehicles but also when it comes to the cooperation with the static environment (infrastructure). The latter may contain and integrate: roadside and monitoring sensors (Cooperative Perception Services), signaling, communication infrastructures, cloud... The research concerns in particular the deployment of equipped vehicles on a large scale in a road or urban environment.

The research objectives are twofold.

- First, the focus is on the modeling of systems comprising a large number of vehicles, often seen as random entities.
  The methodology is mainly to explore the links between large random systems and statistical physics. This approach proves very powerful, both for macroscopic (fleet management [70]) and microscopic (car-level description of traffic, formation of jams [78, 150, 83, 82]) analysis. The general setting is mathematical modelling of large systems (typically in the so-called thermodynamical limit), without any *a priori* restriction: networks, random graphs, etc. One often aims at establishing a classification based on criteria of a twofold nature: quantitative (performance, throughput, etc) and qualitative (stability, asymptotic behavior, phase transition, complexity).
- The second objective concerns the cooperation of these communicating entities in order to address the efficiency and safety of mobility. This cooperation takes several forms. Direct or indirect communications (V2X) are dedicated to maneuver coordination, taming and improving traffic efficiency (cf. section 4.4.2), platooning, safety critical distributed coordination (cf. 4.4.3)... Crowdsourcing is another aspect that could be used for traffic modeling and prediction (cf. 4.4.1), environment augmented mapping, or global vehicles localization. A Phd student will be hired this year to work on this precise subject (cf. 4.5).

Beside this core methodology, other past activities of interest include discrete event simulation [59, 109] and resource allocation for ITS [108, 90, 91].

Finally, axis 4 does not represent a structural unit like the other axes. Its objective is to deal with the problem of scaling, deployment and multi-vehicle cooperation in a global and systemic way. On the substance, methods and theories of modeling will be investigated and the design of secure telecommunication systems will be elaborated. These models and systems are intended to be implemented in more global systems and architectures. They will interact with the other axes through these architectures and will respond in a targeted way to needs; for example, whenever a need for probabilistic modeling is expressed (e.g. section 4.5).

3.4.1 Traffic prediction in urban settings: detecting extreme events

A probabilistic forecasting method that can provide predictions of urban traffic at city level, accurate at short term and meaningful for a horizon of up to several hours, has been devised in the team [81, 77, 80, 127, 128, 79][6], in collaboration with C. Furtlehner (TAU, Inria Saclay). It is designed to leverage spatial and temporal dependency and can deal with missing data, both for training and running the model. The method consists in learning a sparse Gaussian copula of traffic variables, compatible with the Gaussian belief propagation algorithm. Results of tests performed on three urban datasets show a very good ability to predict flow variables and reasonably good performances on speed variables.

When investigating the output of the model, some rare but large errors are noticeable. It turns out that this corresponds to detectors which, for a long period, send values completely at odds with the ones observed during training. These badly behaving detectors may either correspond to corrupted ones, or to drastic changes of the traffic conditions on the corresponding segment, because of road work or accidents for instance.

One way of examining these events has been proposed in [96], and we plan to investigate whether it can be used to improve models. Separating sensor failure from extremal events is even more important, and this is what we plan to investigate in a PhD thesis, by careful analysis of the correlation structure of the model.

3.4.2 Taming highway traffic using cooperative automated vehicles

Several authors [74, 65, 162, 87] have suggested that it is possible to use a small proportion of automated vehicles to regulate highway traffic. These studies are set in a traffic regime which exhibits string instability, which means in terms of transfer function that any excitation of a frequency below a certain limit is amplified. We are interested here in a slightly different setting, where reaction time is taken into account for human drivers. We have shown [37] that the introduction of this delay involves a non rational transfer function, implying in particular that the system is not always stable. We have proposed a complete self-contained proof of stability conditions, based on classical complex analysis. Moreover, we bring to light a phase transition with a new propagation regime, named *partial string stability*, situated between string stability and string instability.

With these foundations established, the next steps are to devise a traffic stabilization scheme by means of a fleet of cooperative automated vehicles. However, contrary to the work in [74], our approach is based on a car-following model with reaction-time delay, rather than on a first order fluid model. The continuation of these studies will concern shock wave analysis and adequate traffic-stabilizing control strategies.

3.4.3 Crowdsourced mapping

The deployment of intelligent and connected vehicles, equipped with increasingly sophisticated equipment, and capable of sharing accurate positions and trajectories, is expected to lead to a substantial improvement of road safety and traffic efficiency. Nevertheless, in order to guarantee accurate positioning in all conditions, including in dense zones where GNSS signals can get degraded by multi-path effects, it is expected that sensory equipped vehicles will need to use precise maps of the environment to support their localization algorithms. Crowdsourced mapping represents a cost-effective solution to this problem, consisting in making use of measurements retrieved by multiple production vehicles equipped with standard sensors in order to build an accurate map of landmarks and maintain it up-to-date in realistic, long-term scenarios. Existing SoA crowdsourced mapping solutions rely on triangulation optimization or graph-based optimization where trade-offs between the map quality and computational scalability are still to be investigated. We propose to extend the work of [152] to improve scalability. One possible approach is to rely on a Gaussian Belief algorithm to estimate and update the position of landmarks and of the the vehicles, along with their corresponding uncertainties.

Figure 3: Valeo Automated Driving roadmap

3.4.4 Cooperative automated driving involving V2X communications

Automated driving in a complex shared road requires cooperation among road entities in terms of cooperative control, cooperative perception, and cooperative path planning. This poses new research challenges that did not exist in the domain of vehicular communications e.g., communications for cooperative automated driving and intention-aware communications. Based on our experiences and know-how on mobile telecommunications, networking, and robotics domains, the ASTRA team will conduct research activities within the following domains:

- Safety critical V2V communications.
- Safety critical distributed coordination.
- Safety and performance guided V2X communication and data processing
- Vehicles' behaviors and intention-aware communications

4 Application domains

The aim of the project team is to tackle the challenges and provide breakthrough solutions for the autonomous and connected mobility. It covers the improvement of the safety, the availability and the performances of ADAS "Advanced Driver Assistance Systems" and the L3 automated systems (Traffic Jam Pilot and Highway Pilot) for privately owned vehicles as well as L4 automated systems including Robotaxi and automated transportation systems like autonomous shuttles. Enabled by 5G and the V2X connectivity in general, the extension to cooperative Automated driving and the Smart city will also be considered. There are more and more cities and highways equipping their infrastructures with sensors that can enable extended and shared perception. During the project, the developed solutions are tested for these applications. Valeo Automated Driving roadmap is addressing them through 3 programs. Cruise4U Program for multiple carriageway/highways, Drive4U for Urban environment including autonomous shuttles and eDeliver4U for last mile delivery as shown in Fig. 3.

The Cruise4U and Drive4U programs allowed to Valeo to perform open roads experiments around the world with more than 200,000 km accumulated in real conditions with plenty of use cases.

Fig. 4 shows a part of the Cruise4U experiments, while Fig. 5 shows world premieres: Drive4U open road experiments with only Valeo serial production sensors operating in Paris, Las Vegas and Tokyo.

A dedicated Automated Driving platform for the project team is under discussion in order to allow quick and easy integration, tests and validations of the Joint team developments.

Figure 4: Cruise4U Program field testings

Figure 5: Drive4U Urban Pilot Program

5 Highlights of the year

5.1 Organisation & Chairing of conferences/workshops:

- Fawzi Nashashibi was the Program Chair of the main conference on intelligent transportation: 36th IEEE Intelligent Vehicles Symposium 2025, 22–25 June 2025, Cluj-Napoca, Romania.
- Raoul de Charette is co-founder and General Chair of ACVSS (African Computer Vision Summer School). The 2nd edition was organised in July 2025 in Kigali, Rwanda. The international summer school welcomes around thirty African students, thanks to the support of Inria, DeepMind, Google, Inria, IEEE, among others.
- Conference "A quarter century for a quarter plane" (15 to 17 April 2025 in Marseille). This conference honoured Guy Fayolle (Emeritus Researcher at ASTRA) and celebrated the 25th anniversary of the publication of his famous book "Random Walks in the Quarter Plane"' (G. Fayolle, R. Iasnogorodski, V. Malyshev), and its many applications in combinatorics and reflected diffusion.

5.2 Awards

- Best Honorable Paper Award at EGSR 2025: Lopes, I., Deschaintre, V., Hold-Geoffroy, Y., & de Charette, R. (2025). MatSwap: Light-aware material transfers in images. CGF (EGSR proceedings).
- Iyad Abuhadrous is recipient of the PAUSE Programme for 2025 and 2026. Special mention goes to Inria, which has shown its solidarity in this programme coordinated by the Collège de France.
- Raoul de Charette was awarded a PRAIRIE PhD grant to work on "Physics-grounded Vision Foundation Models"
- Around 13 outstanding reviewers awards were received by various Astra members in 2025. These selective awards reward from 2% to ≈5% (depending on the venue) of the reviewers for their scientific contributions to the review process. Reviewers awards in alphabetical order: Yasser Benigmim (CVPR 25), Alexandre Boulch (CVPR 25, BMVC 25), Andrei Bursuc (ICCV 25, NeurIPS 25), Anh-Quan Cao (CVPR 25, WACV 25), Raoul de Charette (ICCV 25), Mohammad Fahes (CVPR 25), Ivan Lopes (CVPR 25), Renaud Marlet (ICCV 25), Gilles Puy (CVPR 25, BMVC 25).

6 Latest software developments, platforms, open data

RUBI

- Web site: –
  - Software Family
    1. Research: used internally as a knowledge brick
    2. Transfer: possible transfer to Valeo
  - Audience:
    1. ASTRA team
    2. Partner: Valeo
  - Evolution and maintenance:
    1. nofuture: if transferred to Valeo
  - Duration of the Development (Duration): 18 months
  - Free Description: RUBI (Road Users Behavior Identification) is dedicated to the Identification of existing manoeuvres in a dataset, followed by extraction of the various longitudinal behaviours of road users.

6.1 Latest software developments

6.2 New platforms

Participants: Paul Roger-Dauvergne.

In December 2025, ASTRA has regained possession of its Renault Zoé platform vehicle. This platform has been robotised in direct collaboration with the french company Ex9 and is equipped with perception and localisation capabilities. Initial tests to evaluate the automated system were conducted at the Rocquencourt site.

7 New results

7.1 Multimodal vision

Participants: Yasser Benigmim, Andrei Bursuc, Raoul de Charette, Mohammad Fahes, Tuan-Hung Vu.

Recent progress in multimodal and foundation models has significantly impacted visual representation learning, enabling joint reasoning over images, language, and other sensory modalities. Vision–language models such as CLIP provide powerful shared latent spaces for zero-shot and open-vocabulary perception; however, effectively adapting these models to downstream tasks, domain shifts, and deployment constraints remains challenging, particularly when supervision or target-domain data is limited.

We specifically investigated how vision–language representations can be efficiently adapted and exploited without relying on additional annotations or costly retraining. Following our series of work on adaptation [4, 100, 9, 141] and generalization [68] of Vision-Language Models (VLMs) for dense predictive tasks, in [18] we propose using our prompt instance normalization (PIN) to adapt VLMs to new domains using simple language prompts or unlabeled images. The findings highlight that such PIN is robust to the adaptation prior and can effectively serve as a base to adapt VLMs to rare unseen conditions such adverse weathers or dangerous scenarios. Within the PhD visit of Yasser Benigmim, we further studied VLMs for Open-Vocabulary Semantic Segmentation (OVSS). Challenging the conventional practice of multiple text template, we discovered that some unique template outperform others on specific semantic classes, which we refer as "expert template". In FLOSS [22] we showed that, without any label nor training, performance can be improved using a simple scheme that identifies expert templates.

We also looked at how vision and language models are combined in VLMs. In ProLIP [69], we propose a lightweight alternative to linear probing and adapter-based approaches, proposing a simple scheme to finetune only the linear projection that maps visual features into the shared vision–language space. With only a simple regularization term, and a few seconds of training per model, ProLIP proves extremely efficient, with performance consistently outperforming the literature across a large variety of scenarios.

Beside publications, within Tetania Martynuik's PhD we initiated a collaboration with ENPC on multimodal data generation, with a focus on image, text and 3D data. The results are pending, but observation show that 3D data generation is still a complex endeavour.

This axis of research is still on going and overall, language and other non-visual modalities, are vastly investigated in a number of our research projects. The extension of PODA [18] is planned to appear in IJCV, ProLIP was accepted WACV 2026 and FLOSS in ICCV 2025. All of these are the top-tier venues of computer vision. All works are shared opensource. Finally, Raoul de Charette co-organized a CVPR workshop on pixel-level vision and foundation models (PixFoundation).

7.2 Physics-grounded vision

Participants: Andrei Bursuc, Sebastian Cavada, Raoul de Charette, Tuan-Hung Vu.

The wide variety and continual physical nature of physics prevent any dataset to encompass all lighting and weather conditions. Under that lense, historical works from the group were focusing on vision in degraded weather/lighting conditions [17, 8] where well established physics models allowed investigation of physics guided learning [15]. In the last years, the research topics has continued and enlarged to general physics-grounded vision which became an increasingly central research direction in the Astra-Vision group as robotics applications inherently operate in and interact with the physical world, where perception systems must reason about forces, materials, motion, and physical constraints. As a result, understanding and estimating physical quantities from visual observations is a key requirement for robust and trustworthy perception in real-world robotic scenarios.

In this axis, we investigate how physical principles can be integrated into learning-based vision systems, both as inductive biases and as explicit supervision signals. Some of our prior contributions include physics-guided learning and disentangled representations [15], and places particular emphasis on the estimation of material properties directly from visual data [124, 123]. By grounding visual representations in physical quantities, we aim to improve generalization, interpretability, and robustness under distribution shifts.

A major effort this year has focused on evaluating the ability of modern Vision–Language Models (VLMs) to understand and reason about Newtonian physics. To this end, the team developed a unique simulation framework capable of generating pixel-wise, physically annotated datasets from real-world videos. Our simulator enabled large-scale, controlled evaluation of physical reasoning of VLMs from visual inputs. An extensive study led by R. de Charette, with contributions from S. Paul (intern) and S. Cavada (research visit), is currently unravelling the capacity of VLMs to estimate Newtonian forces at scale, with a publication forthcoming.

Results will be published soon. A PRAIRIE grant was awarded on Physics-grounded Vision to A. Tragoudaras (PhD) under the supervision of Raoul de Charette. Further, several new collaborations are currently being established around physics-grounded vision so the topic is expected to expand further in the coming years, bridging perception, simulation, and physical reasoning.

7.3 Physics-grounded decomposition

Participants: Raoul de Charette, Ivan Lopes.

Beside general physics-grounded vision, we continue to explore image decomposition as a means to access physically meaningful scene representations, with major applications in computer graphics. In previous years, the team proposed a material estimation method operating directly with a single real-world image [124]. Building on this foundation, and in the context of I. Lopes' PhD thesis, a new collaboration was initiated with Adobe on material replacement in images. As part of this effort, we designed and publicly released a new procedural dataset of materials, and proposed a method coined MatSwap [26] that fine-tunes diffusion models to enable controlled transfer of material appearance to real photographs.

Beside edition capabilities, image decomposition may be formulated as a multi task problem. In StableMTL [34] we proposed a method for general multitask learning which adresses, but is not limited to, image decomposition. Leveraging diffusion models, we show that dense task prediction can be addressed with a unified latent loss among tasks, therefore removing cumbersome task balancing typically required by Multi Task Learning (MTL)

MatSwap [26] was accepted at EGSR 2025 and won the *Best Paper Honorable Mention Award*. Ivan Lopes' defended his PhD thesis on October 13th 2025 [122]. StableMTL [34] was submitted to a top tier computer vision venue. All works are shared opensource.

7.4 3D scene reconstruction

Participants: Radu Beche, Alexandre Boulch, Raoul de Charette, Renaud Marlet, Tetiana Martyniuk, Jonathan Seele, Gilles Puy.

3D scene understanding has long been a core research topic within Astra-Vision and naturally aligns with our growing emphasis on physics-grounded perception. Because robots operate, navigate, and interact in a three-dimensional physical world, robust scene understanding requires explicit reasoning about geometry, spatial structure, and semantics. In this sense, advances in 3D perception constitute a fundamental building block for physically grounded and actionable visual representations.

Within this axis, we primarily investigate geometric and semantic reconstruction of complex indoor and outdoor scenes, either from 3D sensory input (LiDAR, depth) or from 2D visual data (images or video). The group has produced major contributions to the field, notably on large-scale scene reconstruction [147, 16, 2, 54, 3]. These works address key challenges such as sparsity, occlusions, and long-range spatial reasoning, and establish strong baselines for both semantic scene completion and neural scene representation.

In the context of T. Martyniuk's PhD thesis, we pursued in-depth research on 3D scene completion. In particular, we proposed a method revisiting point-based diffusion models for scene completion [29]. The resulting framework, LiDPM, demonstrates improved performance on large-scale LiDAR benchmarks while offering increased generative diversity. We also explored joint geometric and semantic reconstruction using triplane-based diffusion models, in the context of the internship of J. Seele. This line of work is currently being consolidated and is under submission to ICIP 2026.

Beyond direct 3D sensory input, we also investigate how rich 3D representations can be inferred from 2D visual data alone. Two new research directions were initiated this year. First, building on Vision Foundation Models (VFMs) trained on internet-scale data, F. Baldé (intern, now PhD student) explores how to distill VFM knowledge into 3D reconstruction pipelines, with first results expected to be published shortly. This work extends prior efforts conducted during A.-Q. Cao's PhD thesis [2, 54, 3]. Second, in the context of the PhD visit of R. Beche, we study how to construct compact and efficient 3D Gaussian Splatting representations [102], targeting improved memory efficiency and scalability without compromising reconstruction quality. This work is also expected to lead to a publication in the coming weeks.

LiDPM [29] was accepted as oral to IV 2025. Other works are soon to be published. All are (will be) shared opensource.

7.5 Learning-Based Online HD Map Construction for Autonomous Driving

Participants: Iyad Abuhadrous, Benazouz Bradai, Fawzi Nashashibi.

Autonomous driving systems require precise, real-time vectorized HD maps to support perception, planning, and safety-critical decision-making, particularly in dense urban environments. Traditional static HD maps are costly to maintain, difficult to scale, and quickly become outdated. This motivates the development of online, end-to-end HD map construction methods that leverage onboard vehicle sensors and operate continuously during driving, enabling applications such as cooperative perception, motion planning, and urban safety.

During Iyad Abuhadrous' work, research focused on learning-based online HD map generation from multi-camera inputs, relying on six RGB cameras (with optional LiDAR) and a Bird's-Eye View (BEV) representation. The MapTR baseline - a transformer-based architecture - was reproduced and analyzed on the nuScenes dataset, following the standard camera-only setup. The model encodes multi-view images into BEV features and directly predicts vectorized map elements, including lane dividers, road boundaries, and pedestrian crossings. Experimental results reached baseline-level performance in extracting these geometric map elements, with ongoing efforts dedicated to improving robustness and generalization across environments.

In parallel, real-time experimentation was initiated using CARLA, enabling synchronized multi-camera streaming aligned with nuScenes-style inputs and metadata. This setup supports the evaluation of online inference behavior under realistic driving conditions. Building on this foundation, current investigations address generalization, uncertainty-aware mapping, and multi-modal fusion, as well as efficiency constraints required for deployment. In addition, this work contributes to a broader analysis of the field through a survey paper on vectorized HD map learning [under review], which positions MapTR and related methods within the evolving landscape of learning-based HD mapping and identifies key open challenges for real-world autonomous driving.

7.6 A Robust Localization System with Real Time Protection Level Calculation and Adaptive Kernel for Enhanced Integrity

Participants: Elias Maharmeh, Zayed Alsayed, Paulo Resende, Fawzi Nashashibi.

Uncertainty in perception tasks, such as localization, is critical for autonomous systems. Many localization systems fail to ensure that their reported uncertainties encompass the true pose. In Elias Maharmeh, we addressed this issue using the integrity framework. We focused on two main aspects. First, fault-tolerant localization through qualitative evaluation. Second, quantitative estimation of error bounds using (horizontal) protection levels. We introduce first PL-RAS (Protection Level-based Robust and Adaptive Solver) [27]. This solver aids robustness in non-linear least squares optimization, including factor graph-based localization systems. PL-RAS improves uncertainty awareness and enhances system integrity. It strengthens both qualitative and quantitative integrity aspects. We tested the approach on urban road data collected using an acquisition vehicle at Valeo's Créteil VMTC site. The results confirmed PL-RAS's effectiveness. In one dataset, the integrity risks are $4.0\ 10^{-4}$ (lateral) and $34.0\ 10^{-3}$ (longitudinal). In a more challenging dataset, the lateral risk becomes $3.0\ 10^{-4}$, while the longitudinal risk increases to $92.3\ 10^{-3}$. These findings demonstrated PL-RAS's robustness in fault tolerance and protection level estimation.

In an improvement of PL-RAS [28], we proposed PL-RAS++, an enhanced approach for solving nonlinear least squares problems in factor-graph-based localization. PL-RAS++ introduces a smoothed residual weighting scheme and a novel PL computation based on Value at Risk (VaR) and Conditional Value at Risk (CVaR) to capture extreme residual variations. We validated PL-RAS++ on real datasets collected at Valeo VMTC site and compared it against a state-of-the-art method. Results demonstrate the clear superiority of PL-RAS++ in achieving zero integrity risk across all tested scenarios while maintaining robustness in challenging environments and under potential faults.

7.7 PathDCM: An interpretable path-based trajectory prediction model

Participants: Amina Ghoul, Fawzi Nashashibi, Itheri Yahiaoui.

To navigate traffic safely while providing passengers with a smooth ride, autonomous vehicles must accurately predict the trajectories of surrounding agents. Predicting future trajectories is inherently uncertain and complex, as agent movements are highly non-linear over longer prediction horizons. Moreover, the distribution of possible future trajectories is multimodal—agents may have several plausible goals and different paths to reach each goal.

Despite these challenges, agent motion is not entirely unconstrained. Vehicles generally follow the direction of their lanes, obey traffic signals, and make legal turns and lane changes. Bicyclists tend to stay in bike lanes, while pedestrians usually walk along sidewalks and crosswalks. High-definition (HD) maps of traffic scenes capture these constraints, making them a critical component of autonomous driving datasets. Many studies have shown that predicting map-compliant trajectories—those that adhere to road boundaries and traffic rules—is essential for real-world autonomous driving systems.

In her thesis [32], Amina Ghoul introduced **PathDCM**, a map-aware path-based model combined with a knowledge-based method, that uses lane centerlines as goal representations, allowing the model to account for road structure and lane restrictions. This map-aware model employs a three-step process—goal prediction, path identification, and trajectory anchoring. This approach combines an interpretable, socially-aware framework with goal representations informed by map-aware road geometry. Unlike traditional methods that primarily condition trajectory predictions on future goals, this approach leverages the paths leading to those goals. This ensures that predictions remain physically plausible and reachable.

In addition, to achieve interpretability, the method integrates a knowledge-based discrete choice model (DCM) with a neural network. The DCM provides interpretable, rule-based patterns that explain high-level decision-making, while the neural network offers flexibility and predictive power. This hybrid approach allows us to validate predictions in safety-critical applications by ensuring that the model's decisions are both accurate and comprehensible.

PathDCM employs a three-step process: predicting goals using a hybrid approach combining knowledge-based and neural network techniques, identifying feasible paths, and generating trajectories. Experimental evaluations conducted on the nuScenes dataset underscores the accuracy and practical utility of this approach.

7.8 Extended Horizon Planning for Tactical Decision-Making for Automated Driving

Participants: Karim Essalmi, Fernando Garrido, Fawzi Nashashibi.

Traditional decision-making algorithms are often limited by their fixed planning horizons, typically up to 6 seconds for classical approaches and 3 seconds for learning-based methods, which restrict their adaptability in particular dynamic driving scenarios. However, planning needs to be done well in advance in environments such as highways, roundabouts, and exits to ensure safe and efficient maneuvers. To address this challenge, we propose a hybrid method that integrates Monte Carlo Tree Search (MCTS) with our prior utility-based framework, COR-MP (Conservation of Resources Model for Maneuver Planning) [67]. This combination enables long-term, real-time decision-making, significantly improving the ability to plan a sequence of maneuvers over extended horizons while avoiding the 'robot-frozen' phenomenon. Following the work conducted at the end of 2024, the COR-MCTS (Conservation of Resource - Monte Carlo Tree Search) approach [23] has been tested and validated. This method, which combines an optimization-based maneuver planner [67] with Monte Carlo Tree Search, enables the evaluation of sequences of maneuvers rather than independent maneuvers. As a result, short-term decisions are influenced by long-term ones, similarly to human drivers whose decisions are often conditioned by long-term goals.

7.9 Interaction-aware decision-making through quantum game theory

Participants: Karim Essalmi, Fernando Garrido, Fawzi Nashashibi.

Since Automated Vehicles (AVs) inevitably share the road with human drivers, decision-making algorithms must account for human behavior and adapt accordingly. Many state-of-the-art approaches model interactions primarily through safety considerations, typically relying on risk-based criteria to evaluate maneuvers. While effective for ensuring safety, these methods suffer from two important limitations. First, they often lead to overly conservative behaviors [71], potentially resulting in inappropriate outcomes such as the frozen robot phenomenon [156]. Second, they generally neglect interactions between other agents (e.g., between two human drivers) and assume that these agents do not adapt to the ego vehicle's behavior. In real-world environments, however, road users react to the ego vehicle's actions, and their mutual interactions also influence the ego's behavior. In other words, each agent's decisions influence and are influenced by the others. Methods that explicitly model these interactions in the decision-making process are known as *interaction-aware* approaches.

To address these limitations, we investigated the integration of quantum game theory into a maneuver planning framework, leading to the Quantum Game Decision-Making (QGDM) model. Based on the Eisert-Wilkens-Lewenstein (EWL) formalism [66], QGDM achieves interaction-awareness through classical game-theoretic modeling and captures uncertainty and potentially irrational behaviors through quantum principles. The approach was evaluated in several highly interactive scenarios, including roundabouts, merging, and highway. Comparisons with state-of-the-art methods demonstrate that (a) QGDM better adapts to uncertain behavior and (b) it performs comparably when surrounding agents behave more rationally.

This work resulted in two publications [24], one presented at the International Conference on Advanced Robotics (ICAR 2025), as well as an additional paper currently under review.

7.10 RL-based mid-to-mid motion planner for autonomous vehicles

Participants: Kobbi Islem, Atoui Hussam, Rocha Goncalves Tiago, Fawzi Nashashibi.

During his PhD thesis, Islem Kobbi is developing a reinforcement learning RL-based mid-to-mid motion planner for autonomous vehicles, in which a learning agent replaces only the motion planning module while preserving the classical perception, routing, and control pipline used in industry. The agent receives a structured 91-dimensional mid-level observation vector encoding ego-vehicle state, surrounding traffic, and lane geometry, and outputs continuous trajectories parameterized as cubic Hermite splines through two control points, enabling smooth, jerk free and interpretable paths suitable for tracking. To bypass the inefficient early exploration phase of RL, the policy is first initialized by imitation learning via behavior cloning from a rule-based motion planner, then further optimized with Proximal Policy Optimization in a customized MetaDrive highway simulator. Experimental results on diverse highway scenarios show that the RL-trained motion planner significantly improves efficiency, smoothness, and safety, and clearly outperforms both the rule-based expert and the BC-only policy. This work was published at IEEE ITSC 2025 [25]. Current efforts focus on extending this mid-to-mid RL planning framework to more complex urban driving environments.

7.11 Communicating Autonomous Intelligent Vehicles

Participants: Gérard Le Lann.

Cyberthreats directed at radio communications cannot be ignored when addressing safety issues arising with risk-prone maneuvers. To be specific, consider unsignalized intersections (UIs) and communicating autonomous vehicles (CAVs). Most published solutions for the problem of how to achieve safe and efficient crossings in the presence of radio cyberattacks rest on assuming that destructions or corruptions of radio messages can be handled appropriately, i.e., correctly and on time.

These are fragile assumptions. Safety is inevitably compromised under cyberattacks aimed at individual messages. Safety in UI scenarios is a particular instance of the well-known global state problem in distributed systems. Safety cannot hold if CAVs in approach do not share the same global state (CAVs located on entrant road arteries and intending to cross). Building distributed global states (as they evolve over time) to be "seen" identically by all CAVs is impossible in the presence of selective destructions or corruptions of messages.

Thus, the problem: how to make use of radio communications without relying on message passing? There is a solution based on a cyber-physical construct that matches the setting (UI crossing by CAVs) for arbitrary intersections (any number of entrant road arteries, and any number of lanes in every road artery).

Another issue of sociological importance has arisen with the emergence of AI and the much-debated singularity postulate. According to supporters of the singularity concept, levels of universal cognition, consciousness, and reasoning capabilities of AI can only get higher over time. To such an extent that humans will inevitably end up being dominated (i.e., enslaved) by perverted AI able to set up offensive, potentially lethal, strategies unbeknown to humans.

One counter-argument to the singularity postulate rests on observing that lives or physical integrity of humans can hardly be threatened by software entities residing in cyberspace. The issue gets more intriguing when considering AI physical agents (AIP agents), i.e., AI agents that can act upon the physical world, such as humanoid robots or androids.

CAVs equipped with AI software are examples of AIP agents. Passengers could be targeted by perverted intelligent CAVs without passengers, insidious members of a swarm that would then face a "singularity scenario". So far, it has been impossible to provide a description of how pernicious intelligent CAVs would communicate and agree on some destructive cyberattack, secretly, i.e., without onboard systems of honest

CAVs being able to notice. Via a secret platform, using some secret language? Unclear. That line of reasoning is by no means an impossibility proof. More work is needed from scientists, who bear and share the responsibility of clarifying the issue.

7.12 Landmark localization for Autonomous Vehicles

Participants: Noël Nadal, Fawzi Nashashibi, Jean-Marc Lasgouttes.

This study introduces a new approach for real-time global positioning of vehicles, leveraging coarse landmark maps with Gaussian position uncertainty. The proposed method addresses the challenge of precise positioning in complex urban environments, where global navigation satellite system (GNSS) signals alone do not provide sufficient accuracy. Our approach is to achieve a fusion of Gaussian estimates of the vehicle's current position and orientation, based on observations of the vehicle, and information from the landmark maps. It exploits the Gaussian nature of our data to achieve robust, reliable and efficient positioning, despite the fact that our knowledge of the landmarks may be imprecise and their distribution on the map uneven. It does not rely on any particular type of sensor or vehicle. We have evaluated our method through our custom simulator and verified its effectiveness in obtaining good real-time positional accuracy of the vehicle, even on a large scale. This work has been presented at VEHITS 2025 [31] and an extended version will appear in Springer's CCIS series [21].

Although prior research has extensively explored the addition or removal of landmarks in maps, improving the positional accuracy of existing landmarks has been less addressed, with existing solutions often limited to validating landmark presence or absence. We propose in [30] an approach to refine the coordinates of existing landmarks using crowdsourced data, collected from sensors that may include potentially low-cost, low-precision devices. Our results demonstrate that even a few crowdsourced updates can significantly enhance landmark accuracy. These findings highlight the scalability and cost-effectiveness of crowdsourcing for map refinement, opening promising perspectives for low-cost, high-precision map updates in autonomous driving and other geospatial applications.

7.13 Time-Scaling of Stop-and-Go Waves in Car-Following Models

Participants: Guy Fayolle, Jean-Marc Lasgouttes.

Waves, known as *stop-and-go waves* or *phantom jams*, can appear spontaneously in dense traffic. This causes a situation where drivers are faced with consecutive phases of acceleration and braking. Although waves are well understood in the setting of macroscopic models, the results for car-following models are not so numerous. Starting from the linearization of these models, and assuming string instability, G. Fayolle and J.M. Lasgouttes (Inria Paris) [36] give asymptotic estimates of the velocity and shape of these waves. It relies on the well-known saddle-point method in order to describe the trajectory of a vehicle caught in such a wave. Numerical experiments show that this method yields remarkably good estimates of the linearized model, even with only 5 vehicles, as well as a good estimate of the wave velocity.

7.14 Stability and renormalization of Jackson networks endowed with a finite pool of greedy mobile servers

Participants: Guy Fayolle.

A tandem of two queues sharing a pool of servers, where users take the time to switch to the second queue, is used to model a typical pathway through an emergency department (ED), where patients undergo two consultations separated by diagnostic tests. In [35], Ch. Fricker (Inria, MathNet) and G. Fayolle give explicit conditions for ergodicity and transience, which are proved via Foster's criterion, by using a linear Lyapunov function. This result is extended to a Jackson network, with the key difference that the nodes share a pool of servers, with a non-idling service policy. Further, the delay times for customers to move from one node to another must be taken into account. This covers some of the main features of models for emergency departments, namely priorities (triage) between patients. In the case of the tandem queue, scaling the arrival rate and the number of servers by N yields a renormalized process that converges to the solution of an ordinary differential equation (ODE) with boundary conditions. In the case of stability, the nature of this ODE as $t \to \infty$ is also discussed.

7.15 Thermodynamical limits for models of car-sharing systems: the Autolib' example

Participants: Guy Fayolle.

Ch. Fricker (Inria, MathNet) and G. Fayolle analyze various mean-field equations obtained for models involving a large station-based car-sharing system in France called Autolib'. The focus is mainly on a version without capacity constraints, where users reserve a parking space when they take a car. The model is carried out in thermodynamical limit, that is when the number N of stations and the fleet size M_N tend to infinity with $U = \lim_{N\to\infty} M_N/N$. This limit is described by Kolmogorov's equations of a two-dimensional time-inhomogeneous Markov process depicting the numbers of reservations and cars at a station. It satisfies a non-linear differential system having a unique solution, which converges, as $t \to \infty$, exponentially fast towards an equilibrium point, which corresponds to the stationary distribution of a two-queue tandem (reservations, cars), that is always ergodic. The intensity factor of each queue has an explicit form obtained from an intrinsic mass conservation relationship. Two related models with capacity constraints are also presented: the simplest one with no reservation leads to a one-dimensional problem; the second one corresponds to our first model with finite total capacity K [19].

8 Bilateral contracts and grants with industry

8.1 Bilateral contracts with industry

Participants: Fawzi Nashashibi, Raoul de Charette, Jean-Marc Lasgouttes, Benazouz Bradai, Paulo Resende, Zayed Alsayed, Fernando Garrido, Axel Jeanne, Nelson de Moura, Noel Nadal, Mohammad Fahes, Karim Essalmi, Tetiana Martyniuk.

Valeo Group: As a result of a long-standing collaboration, the strategic partnership between INRA and VALEO led to the establishment of a joint project team in 2022. Since that date, several bilateral contracts were signed to conduct joint some of which are funded by Valeo.

- Several CIFRE theses have been developed throughout the year 2023 between Valeo and Inria : Mr. Karim ESSALMI joined ASTRA in February 2023 as a new PhD student working on Maneuver decision and Motion planning. Mrs Tetiana MARTYNIUK joined the team in June 2023 on a pre-thesis contract with a CIFRE that will start in 2024 and is working on conditioned generation of egocentric 3D driving scenes within the astra vision team.
- Other PhD students and post-docs are jointly funded by Valeo and Inria while Mr. Nelson de Moura is hired as a 2-years post-doc thanks to the national Plan de relance Programme.
- Valeo is currently a major financing partner of the "GAT" international Chaire/JointLab in which Inria is a partner. The other partners are: UC Berkeley, Shanghai Jiao-Tong University, EPFL, IFSTTAR, Stellantis and SAFRAN.

- Technology transfer is also a major collaboration topic between ASTRA and Valeo as well as the development of a road automated prototype.
- Finally, Inria and Valeo are partners of the French project SAMBA (Sécurité Active et MoBilités Autonomes) including SAFRAN Group, Inria Paris, TwinswHeel, Soben, Stanley Robotics and EXPLEO.

The work with Valeo Group is articulated around the collaboration of two Valeo teams:

Valeo DAR works on research and development for Advanced Driving Assistant Systems (ADAS). Starting from July 2022, Zayed Alsayed, Axel Jeanne, Fernando Garrido, and Paulo Resende, employees seconded by Valeo, joined the joint project team to work on the following scientific areas: localization and mapping (Sec. 3.2), decision making, motion planning & vehicle control (Sec. 3.3), and large-scale modeling and deployment of mobility systems in smart cities (Sec. 3.4).

Valeo.AI is the research laboratory of Valeo Group, and follows an academic research line. Valeo.AI collaborates with the vision group (Sec. 3.1). Starting from July 2022, Alexandre Boulch, Andrei Bursuc, Gilles Puy, Patrick Pérez, Renaud Marlet, Tuan-Hung Vu joined as part-time researchers in Astra, with frequent joint group readings, workshops and seminars. Subsequently to his departure from Valeo, in Dec. 2023 Patrick Pérez also left Astra. In 2025 the collaboration led to open source realizations, top-tier publications and the co-supervision of 2 internships and 2 PhDs.

9 Partnerships and cooperations

Participants: Radu Beche, Raoul de Charette, Fawzi Nashashibi, Paul Roger-Dauvergne.

9.1 International initiatives

International visits to the team Radu BECHE, PhD at Universitatea Tehnică din Cluj-Napoca (Romania) started a 6 months visits to ASTRA in the framework of a collaboration program between Inria and the Technical University of Cluj-Napoca, specifically between ASTRA team (Inria) and the Image Processing and Pattern Recognition Research Center (TUCN)

9.2 European initiatives

9.2.1 Horizon Europe

Shift2SDV

Objective: Shift2SDV will develop a common, language-independent middleware framework that delivers microservices for building automotive applications upon abstracting from underlying hardware. It supports stepwise migration, integration of both open-source & proprietary components, and enables safety-critical in-vehicle systems as well as off-vehicle mobility functions.
Coordinator: Virtual Vehicle Research (shift2sdv@v2c2.at)
Partners: non less than 83 entities, 12 from France including Inria and 2 Valeo entities.
ASTRA role: design and development of a Middleware for expressive and predictable embedded Machine Learning.
Scientific output and contribution: ASTRA's contribution is two-fold. First, making sure that the ML runtime and its input formalisms and compilers natively accept complex ML applications involving stateful execution, conditional execution, attention. . . and allow their streaming implementation under resource (e.g. memory and time) constraints. Second, extending ML runtimes with execution mechanisms that facilitate static analysis, and extend ML compilers to allow the generation of such

code.
Participants: Dumitru Potop Butucaru (Inria, AT-Pro), Fawzi Nashashibi (ASTRA), 2 engineers, 1PhD (William Gaudelier).

*The project Shift2SDV (Grant Agreement No. 101194245) is supported by Chips Joint undertaking and its members, including top-up funding by the national authorities of Austria, Denmark, Germany, Greece, Finland, Italy, Netherlands, Poland, Portugal, Spain, Turkey.

9.3 National initiatives

Research projects in the framework of the National Research Agency (ANR)

SIGHT: viSIon throuGH weaTher (ANR JCJC)
Coordinator: Raoul de Charette. **Partners:** Inria Paris, Université Laval, Mines ParisTech. **ASTRA role:** Coordinator. **Scientific output and contribution:** SIGHT addresses vision robustness under adverse weather through physics-guided learning and self-supervision. It directly underpins research reported in Section 3.1.2 and publications in top-tier venues such as CVPR, ICCV, ECCV, PAMI, IJCV.

Other national initiatives

EquipEx+ TIRREX – Autonomous Land Robotics Axis
The TIRREX (Technological Infrastructure for Robotics Research of Excellence) project is the result of ten years of research and reflection in the field of robotics. It aims to develop new flagship robotic platforms and coordinate their access and development at national level (in terms of physical access, digital access, open data and free software). The project brings together all the major players in French public research in robotics (CNRS, INRIA, CEA, INRAe) to develop new flagship shared national platforms.
ASTRA is an active contributor to TIRREX within the *Autonomous Land Robotics* axis. **ASTRA role:** ASTRA is primarily involved in joint efforts to prototype vehicles and functional building blocks for navigation architectures, mainly through its experience in the design and development of highly automated vehicles. **People involved:** Fawzi Nashashibi and Paul Roger-Dauvergne.

Inria initiatives

URBAN-AV – Inria Challenge
Fawzi Nashashibi is co-leader of the Inria URBAN-AV challenge: Human-Aware and Trustworthy Autonomous Driving in Urban Environments, approved in November 2025, duration: 4 years.
Partners: ASTRA, CHROMA, ACENTAURI, CONVECS, STARS and the Valeo group.

9.4 International research collaborations

Université Laval (Canada)

Type: Long-term international research collaboration. **Partners:** Inria ASTRA, Université Laval (Canada), Prof. J.-F. Lalonde. **ASTRA role:** Scientific leadership and co-supervision. **Scientific output and contribution:** Joint work on physics-guided vision and material understanding which resulted in multiple high-impact publications and PhD contributions (Sections 3.1 and 7).

Technical University of Munich (Germany)

Type: Short-term international research collaboration. **Partners:** Inria ASTRA, TUM, Prof. Angela Dai. **ASTRA role:** Scientific collaboration on uncertainty awareness in 3D reconstruction which led to a student visit (A.-Q. Cao in summer 2023) and a publication nominated for an award at CVPR 2024.

Cambridge and UCL (UK)

Type: Mid-term international research collaboration. **Partners:** Inria ASTRA, Cambridge Prof. Cengiz Öztireli and UCL Prof. J-H. Xue. **ASTRA role:** Scientific collaboration on neural decoding with the visit which led to the visit of Weihao Xia and two publications in ECCV and WACV.

University of Hanyang (S. Korea)

Type: Long-term international research & development collaboration. **Partners:** Valeo/Inria ASTRA, University of Hanyang, Prof. Kitchun Jo team (S. Korea). **ASTRA role:** Scientific co-supervision and solutions integration on Valeo prototypes. **Scientific output and contribution:** Joint work on end-to-end perception and localisation including SLAM-based evidential approaches and data fusion.

Technical University of Cluj (Romania)

Type: International research collaboration and scientific events organisation. **Partners:** Inria ASTRA, Technical University of Cluj, Prof. Sergiu Nedevschi (Romania) team (member of the Romanian Academy of Science). **ASTRA role:** Scientific collaboration, conferences and scientific events co-organisation. **Scientific output and contribution:** PhD hosting (Mr. Radu BECHE) and co-supervision, IEEE IV 2025 conference organisation.

Collaborations with Amazon, Adobe

Type: Bilateral academic–industrial research collaborations. **Partners:** Yannick Hold-Geoffroy, Adobe (Canada) ; Valentin Deschaintre, Adobe (UK) ; Maximilian Jaritz and others, Amazon (Germany). **ASTRA role:** Scientific lead or co-lead. **Scientific output and contribution:** Collaborations on material understanding and few-shot learning which led to visits and publications at WACV, EGSR and open-source releases reported in Sections 7.1–7.4.

SystemX Institute collaboration

Type: Academic–industrial research collaboration. **Partners:** Inria ASTRA, IRT SystemX. **ASTRA role:** Co-supervision of PhD research. **Scientific output and contribution:** Joint work on misbehavior detection and collective perception (Sections 7.5), including simulation frameworks and experimental validation.

International PhD visits and long-term exchanges

ASTRA hosted several long-duration PhD visits (e.g., Mohammed-Yasser Benigmim, Weihao Xia) and maintained sustained international exchanges. **ASTRA role:** Host and scientific supervision. **Scientific output and contribution:** These visits contributed directly to publications such as FLOSS, DREAM, and UMBRAE, strengthening ASTRA's international visibility and scientific production.

10 Dissemination

Participants: Zayed Alsayed, Andrei Bursuc, Raoul de Charette, Guy Fayolle, Fernando Garrido, Jean-Marc Lasgouttes, Renaud Marlet, Noël Nadal, Fawzi Nashashibi, Tiago Rocha Gonçalves, Tuan-Hung Vu, Itheri Yahiaoui.

10.1 Promoting scientific activities

10.1.1 Scientific events: organisation

General chair, scientific chair

- Fawzi Nashashibi was the Program Chair of the main conference on intelligent transportation systems: 36th IEEE Intelligent Vehicles Symposium 2025, 22-25 June 2025, Cluj-Napoca, Romania.
- Raoul de Charette is co-founder and General Chair of ACVSS (African Computer Vision Summer School). The 2nd edition was organised in July 2025 in Kigali, Rwanda. The international summer school welcomes around thirty African students, thanks to the support of Inria, DeepMind, Google, Inria, IEEE, among others.

Member of the organizing committees

- Fawzi Nashashibi is member of the organizing program committee of The Fourteenth International Conference on Smart Cities, Systems, Devices and Technologies (SMART 2024), April 06-10, 2025 - Valencia, Spain
- Fawzi Nashashibi is member of the organizing program committee of the 11th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2025), April 02-04, 2025 - Porto, Portugal
- Fawzi Nashashibi was member of the program committee of ICCP 2025 : 2025 IEEE 21st International Conference on Intelligent Computer Communication and Processing, October 16-18, 2024, Cluj-Napoca, Romania.
- Andrei Bursuc co-organized the CVPR 2025 Workshop on Uncertainty Quantification for Computer Vision (website).
- Andrei Bursuc co-organized the CVPR 2025 Workshop on Embodied Intelligence for Autonomous Systems on the Horizon (website).
- Andrei Bursuc co-organized the ICCV 2025 Workshop on Learning to See: Advancing Spatial Understanding for Embodied Intelligence (website).
- Andrei Bursuc co-organized the CVPR 2025 Tutorial on Robotics 101: An Odyssey from A Vision Perspective (website).
- Raoul de Charette co-organized the CVPR 2025 Workshop on Pixel-level Vision Foundation Models (website).
- Raoul de Charette was Area Chair of CVPR 2025 & 2026, WACV 2025 & 2026 and IV 2025.
- Renaud Marlet was Area Chair of CVPR 2025 & 2026, BMVC 2025 and IV 2025.
- Andrei Bursuc was Area Chair of CVPR 2025, NeurIPS 2025 and IV 2025.

10.1.2 Scientific events: selection

Reviewer

- Jean-Marc Lasgouttes was reviewer for IEEE IV and IEEE ITSC.
- Raoul de Charette was reviewer for ICCV, SIGGRAPH.
- Fawzi Nashashibi was reviewer for IROS, IV, ITSC, VEHITS, ROBOVIS
- Renaud Marlet was reviewer for ICCV.
- Andrei Bursuc was reviewer for ICCV, WACV.
- Gilles Puy was reviewer for CVPR, ICCV, BMVC.
- Alexandre Boulch was reviewer for CVPR, BMVC.
- Tuan-Hung Vu was reviewer for CVPR, NeurIPS.

10.1.3 Journal

Member of the editorial boards

- Guy Fayolle is associate editor of the journal *Markov Processes and Related Fields* (MPRF).
- Fawzi Nashashibi is Senior Editor of the journals IEEE Transactions on Intelligent Vehicles (T-IV)
- Fawzi Nashashibi is Senior Editor of the IEEE Sensors journal and Editorial Board Member of the Vehicular Sensing Section
- Fawzi Nashashibi is Associate Editor of the IEEE Transactions on Intelligent Transportation Systems (T-ITS)
- Fawzi Nashashibi is Associate Editor of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)

Reviewer - reviewing activities

- Guy Fayolle reviewed several papers and books submitted for publication in some majors journals, e.g. *Transactions of the American Mathematical Society, Markov Processes and Related Fields, Journal of Statistical Physics, Electronic Communications in Probability, etc*.
- Fawzi Nashashibi was reviewer for IEEE IV, IEEE ITSC, IEEE/RSJ IROS, VEHITS, SMART conferences, and of IEEE Transactions on Intelligent Vehicles, IEEE Transactions on Intelligent Transportation Systems

10.1.4 Scientific expertise

- Raoul de Charette reviewed associate research team for Inria.
- Guy Fayolle is scientific advisor and associate researcher at the *Centre for Robotics of Mines ParisTech*.
- Guy Fayolle is a member of the working group IFIP WG 7.3.
- Fawzi Nashashibi is member and representative of the french academics at Vedecom's Working Group on Vehicle Automation.
- Fawzi Nashashibi is member of the SMIS working group of NextMove cluster

10.1.5 Research administration

- Jean-Marc Lasgouttes is member of the *Conseil d'administration* of Inria.
- Jean-Marc Lasgouttes is member of the *Comité Social d'Administration* of Inria.
- Jean-Marc Lasgouttes is member of the *Formation spécialisée en matière de santé, sécurité et conditions de travail* of Inria.
- Jean-Marc Lasgouttes is member of the *Formation spécialisée de site en matière de santé, sécurité et conditions de travail* of Inria Paris.
- Jean-Marc Lasgouttes is member of the *Comité de centre* of Inria Paris.
- Raoul de Charette is member of the *Comité d'Evaluation Scientifique* of Inria Paris.

10.2 Teaching - Supervision - Juries - Educational and pedagogical outreach

10.2.1 Teaching

- Master: Andrei Bursuc, Self-supervised learning, 2 hours, ENSTA, France.
- Master: Alexandre Boulch, “Machine learning for point cloud”, ENSTA-Telecom, Professional M2
- Seminar: Fernando Garrido, Paulo Resende, “decision-making and planning for automated driving”, 16 hours, Valeo Créteil, France.
- Engineering: Fernando Garrido, Paulo Resende, “decision-making and planning for automated driving”, 24 hours, École d’ingénieurs ESME Sudria, France.
- Engineering: Fernando Garrido, Paulo Resende, “decision-making and planning for autoamted driving”, 24 hours, Institut Supérieur de l’Automobile et des Transports (ISAT) à Nevers, France.
- Engineering, 2nd year: Fawzi Nashashibi, “Image synthesis and 3D Infographics”, 12h, M2, INT Télécom SudParis, IMA4503 “Virtual and augmented reality for autonomy”.
- Master: Fawzi Nashashibi, “Perception and Image processing for Mobile Autonomous Systems”, 12h, M2, University of Evry
- Engineering, 2nd year: Fawzi Nashashibi, “Image synthesis and 3D Infographics”, 12h, M2, INT Télécom SudParis, IMA4503 “Virtual and augmented reality for autonomy”
- Licence, 2nd year: Noël Nadal, “C avancé”, 10.5h, Sorbonne Université, France.
- Licence, 2nd year: Noël Nadal, “Programmation fonctionnelle”, 10.5h, Sorbonne Université, France.
- Licence, 2nd year: Noël Nadal, “Mathématiques discrètes”, 10.5h, Sorbonne Université, France.
- Engineering, 2nd year: Tiago Rocha Gonçalves, “Véhicule intelligent et communicant,”, 6h (TP), CentraleSupélec, France.

10.2.2 Supervision

- PhD in progress: Antonios Tragoudaras, “Physics-Grounded Vision Foundation Models”, november 2025, supervisor Raoul de Charette, co-supervisor: Tuan-Hung Vu
- PhD in progress: Fatima Baldé, “3D scene-level modeling from a single image”, november 2025, supervisor Raoul de Charette, co-supervisor: Alexandre Boulch
- PhD in progress: Karim Essalmi, “Maneuver Planner based on the Conservation of Resources Theory and Quantum Game Theory”, march 2023, supervisor Fawzi Nashashibi, co-supervisor: Fernando Garrido Carpio
- PhD in progress: Mohammad Fahes, Mines-ParisTech, “Crowdsourced Unsupervised Learning in Adverse Conditions”, October 2022, supervisor: Raoul de Charette, co-supervisors: Tuan-Hung Vu, Andrei Bursuc, Patrick Pérez.
- PhD in progress: Amina Ghoul, UPMC Sorbonne University, “Trajectory prediction in an urban environment”, May 2021, supervisor Fawzi Nashashibi, co-supervisors: Anne Verroust-Blondet, Itheri Yahiaoui.
- PhD in progress: Islem Kobbi: UPMC Sorbonne University, “RL-based Decision-Making and Planning for Automated Driving”, October 2024, supervisor Fawzi Nashashibi.
- PhD defended Oct 13th 2025: Ivan Lopes, PSL Research University, “Physic-guided learning for vision in adverse weather conditions”, November 2021, supervisor: Raoul de Charette.

- PhD in progress: Elias Maharmeh, "Integrity and Robustness of Algorithms for Localization and Mapping in Autonomous Driving", March 2024, UPMC Sorbonne University, co-supervisors Fawzi Nashashibi et Zayed Alsayed
- PhD in progress: Tetiana Martyniuk, PSL Research University, "Conditioned generation of egocentric 3D driving scenes", December 2023, supervisor: Raoul de Charette, co-supervisors: Renaud Marlet.
- PhD in progress: Noël Nadal, "Cartographie et localisation crowdsourcées pour la conduite autonome en environnement urbain", October 2022, Supervisor: Fawzi Nashashibi.

10.2.3 Juries

- Jean-Marc Lasgouttes was in the CSI committees of Corentin Gauthier (Inria), Elsa Lopez Perez (Inria) and Julien Moreau (Inria).
- Fawzi Nashashibi was the President of the PhD thesis jury of Mrs. Nihed NAIDJA (Université Paris-Saclay/CentraleSupélec), "A Unified Game-Theoretic and Multi-Criteria Optimization Framework for Autonomous Vehicle Decision-Making and Trajectory", Gif-sur-Yvette, September 22, 2025.
- Fawzi Nashashibi was reviewer of the PhD thesis of Mrs. Rabbia ASHGAR (Université Grenoble-Alpes/Inria), "Uncertainty-Aware Motion Prediction with Dynamic Occupancy Grid Maps Generation", Saint-Ismier, July 10, 2025.
- Fawzi Nashashibi was reviewer of the PhD thesis of Mr. Thibault CHARMET (UTC/HEUDIASYC), "Operational Design Domain Monitoring for Safe Intelligent Vehicle Navigation", Compiègne, October 21, 2025.
- Fawzi Nashashibi was in the CSI committees of: Ayan BARUI (UCA/Inria Sophia Antipolis), Fabian GRAF (Sorbonne Université/Inria Paris), Gustavo SALAZAR-GOMEZ (UGA/Inria Rhône-Alpes), Lingxiang HU (Université Paris-Saclay/Univ. Evry), Tarek TAOUI (INSA Rouen), Yuxuan SONG (Sorbonne Université/Inria Paris).
- Raoul de Charette was reviewer of the PhD thesis of Mr. Corentin SAUTIER (ENPC), "Learning and using actionable Lidar representations without annotations", ENPC, October 7, 2025.
- Raoul de Charette was reviewer of the PhD thesis of Mr. Lous HEMADOU (Uni. Caen), "Généralisation de domaine en vision par ordinateur", Inria, Dec 10, 2025.
- Raoul de Charette was in the committee of the PhD thesis of Mr. Yasser BENIGMIM (Telecom Paris), "Domain Adaptation in the era of Foundation Models", Telecom Paris, Dec 12, 2025.
- Renaud Marlet was in the committee of the PhD thesis of Mr. Adrien Lafage (ENSTA).
- Renaud Marlet was in the committee of the PhD thesis of Mr. Yasser BENIGMIM (Telecom Paris), "Domain Adaptation in the era of Foundation Models", Telecom Paris, Dec 12, 2025.
- Andrei Bursuc was in the committee of the PhD thesis of Mr. Timothée DARCET (Inria Grenoble).
- Andrei Bursuc was in the committee of the PhD thesis of Mr. Marc LAFON (CNAM).
- Alexandre Boulch was in the committee of the PhD thesis of Mr. Maxime MERIZETTE (CNAM).

10.2.4 Educational and pedagogical outreach

- Andrei Bursuc gave a Talk at Société des membres de la Légion d'honneur: "Au-delà de l'effervescence: Où l'Intelligence Artificielle peut-elle nous mener?", Velizy-Villacoublay, France.

10.2.5 Talks

- Renaud Marlet: keynote talk at the Computer Vision workshop, IPP, Paris. January 14, 2025.
- Andrei Bursuc: keynote talk on "Multi-modal foundation models in the automotive industry" at the Multimedia Modeling Conference. Nara, Japan, Januray 2025.
- Andrei Bursuc: keynote talk on "Uncertainty and risks on Reliability in the age of Foundation Models" at the IGN LASTIG seminar, France, September 2025.
- Andrei Bursuc: talk on "Open & Repurposable Foundation Models for the Automotive Industry" at the ai-PULSe. Paris, France, December 2025.
- Alexandre Boulch: talk IOGS - industrial track. Paris, France, December 2025.
- Raoul de Charette: talk on "The tale of understanding images" at the AI program with World Learning Organisation, Algeria (remote). April 14, 2025.
- Raoul de Charette: talk on "Computer Vision" at the Arts et Technologie de l'Image, Saint Denis, France. December 2025.

10.3 Popularization

10.3.1 Specific official responsibilities in science outreach structures

- Raoul de Charette is co-founder of the African Computer Vision Summer School (ACVSS) which is both a scientific and educational event. Cf. Scientific events Sec. 10.1.1.

10.3.2 Participation in Live events

- Raoul de Charette was invited to talk at the Musée d'Histoire Naturelle, Paris, France. October 23rd, 2025.

11 Scientific production

11.1 Major publications

[1] Z. Alsayed, G. Bresson, A. Verroust-Blondet and F. Nashashibi. '2D SLAM Correction Prediction in Large Scale Urban Environments'. In: ICRA 2018 - International Conference on Robotics and Automation 2018. Brisbane, Australia, 21st May 2018. URL: https://hal.inria.fr/hal-01829091.

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11.2 Publications of the year

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[21] N. Nadal, J.-M. Lasgouttes and F. Nashashibi. 'Adapting landmark geopositioning for use with imprecise maps'. In: *Communications in Computer and Information Science* (9th Mar. 2026). URL: https://hal.science/hal-05458898 (cit. on p. 27).

International peer-reviewed conferences

[22] Y. Benigmim, M. Fahes, T.-H. Vu, A. Bursuc and R. de Charette. 'FLOSS: Free Lunch in Open-vocabulary Semantic Segmentation'. In: ICCV 2025 - International Conference on Computer Vision. Honolulu, United States, 19th Oct. 2025. URL: https://inria.hal.science/hal-05201728 (cit. on p. 21).

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Doctoral dissertations and habilitation theses

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Reports & preprints

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