Virtual Final Event

interACT

Designing cooperative interaction of automated vehicles with other road users in mixed traffic environments

From situation awareness to cooperation and communication planning of automated vehicles for their safer integration in mixed traffic: a modular approach

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Institute of Communication and Computer Systems

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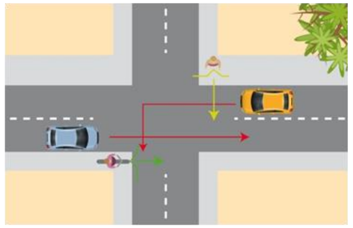
The challenge

5th Objective
Methodology for assessing the quality of interaction

1st Objective
Psychological models

4th Objective
Novel HMI elements



2nd Objective
Intention recognition & behavioural predictions

3rd Objective
CCPU & safety layer

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Contents

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CCPU in interACT

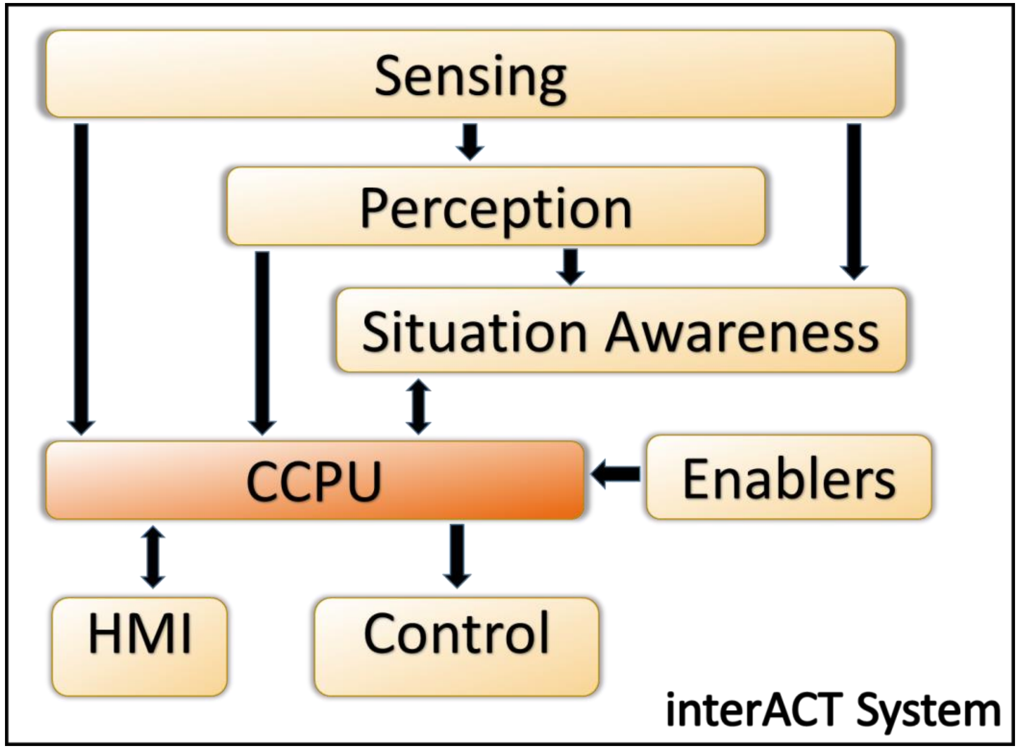
Cooperation and Communication Planning Unit (CCPU) handles the central intelligence of the interACT system

Orchestrates the interaction between all actors

- AV (Sensing, Control)
- On-board user (Situation Awareness)
- Other traffic participants (Perception, HMI)

Integrated Holistic approach

- Expectation conforming approach
- Time-critical applications
- Fault-tolerance by fallback safety maneuver



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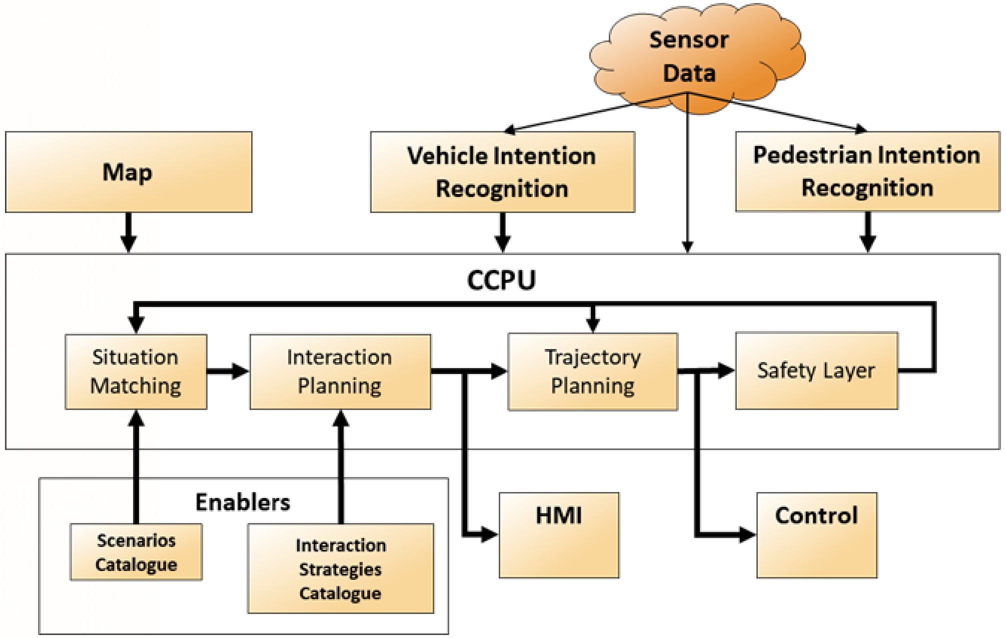
CCPU - modular architecture

CCPU, a modular approach

- Enablers & Support modules
- Core modules
  - Situation Matching
  - Interaction Planning
  - Trajectory Planning
  - Safety Layer



Main tasks

- Gather traffic **environment information** and predicted behaviors
- **Identify** current traffic situation
- Develop a **future safe plan** for the AV
- **Communicate the plan** to all involved traffic actors

Advantages of modular design

- Compartmentalization of tasks via virtualization technology (Docker)
- Robustness – minimal dependencies
- Inter-component communication as a service (via ROS framework)

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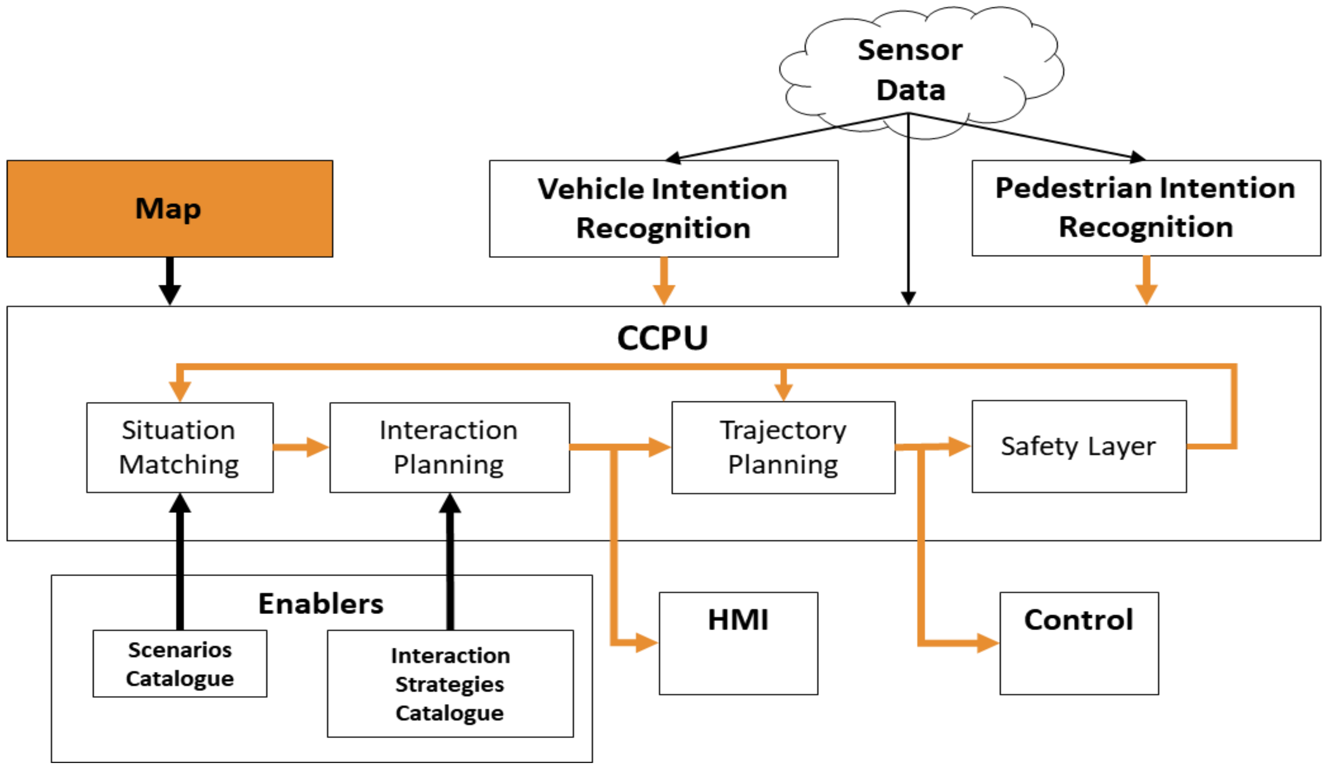
Map & Communication



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Map & Communication

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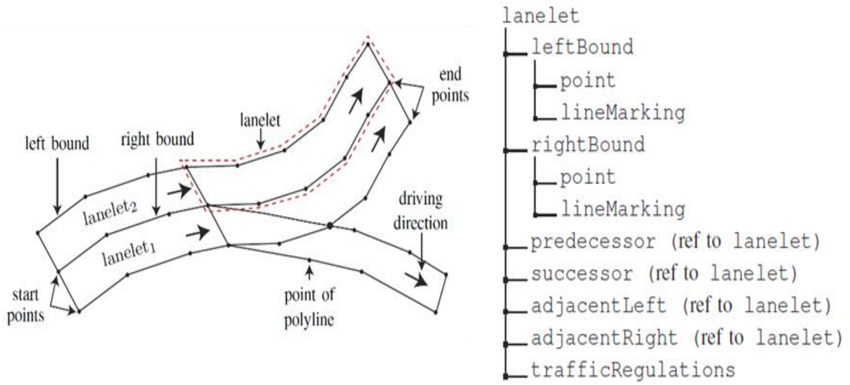
Static map in CommonRoad format

- Toolset developed by TUM
- Road network representation using lanelets
- OpenDRIVE to CommonRoad conversion



Modularity and encapsulation via Virtualization

- Modules as Docker containers
- Internal communication inside the Docker network
- Rapid deployment, zero dependencies, easy updates

ROS Messaging System

- Inter-modular communication via predefined custom ROS messages
- A-priori validation of communication standards – minimization of errors

docker

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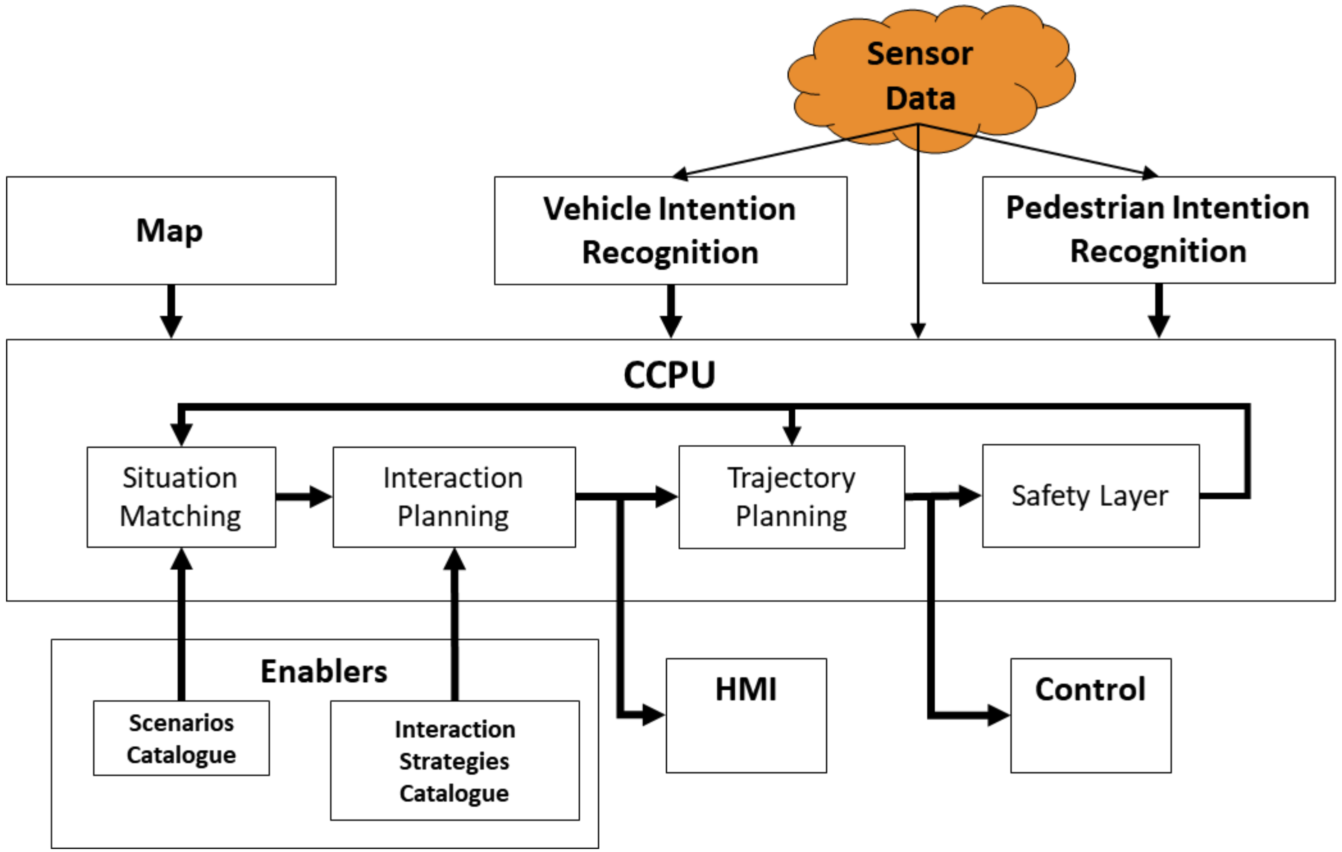
Perception Platform



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Perception Platform

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Sensors & Perception – Basic functionality

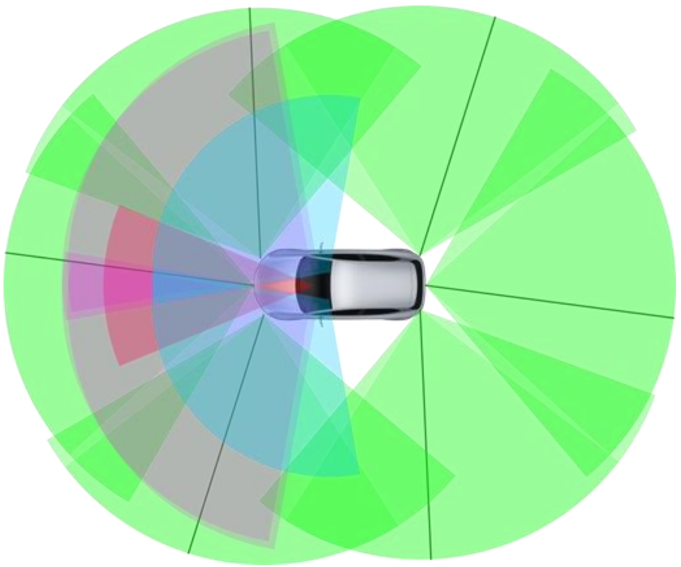
- **Raw data** from the AV and the traffic environment
- Respective **confidence levels** for all measurements
- **Message translators** to formulate raw messages into ROS objects

Main tasks

- Object detection, classification, tracking
- Object intention features
- Localization
- AV state

H/W Equipment

- **Laser scanners** for detection, tracking and classification of static and dynamic objects
- **Stereo video cameras** and **radar sensors** for detection of pedestrian intention and interaction features (head orientation, waving)
- **GNSS INS** system for localization



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Situation Awareness

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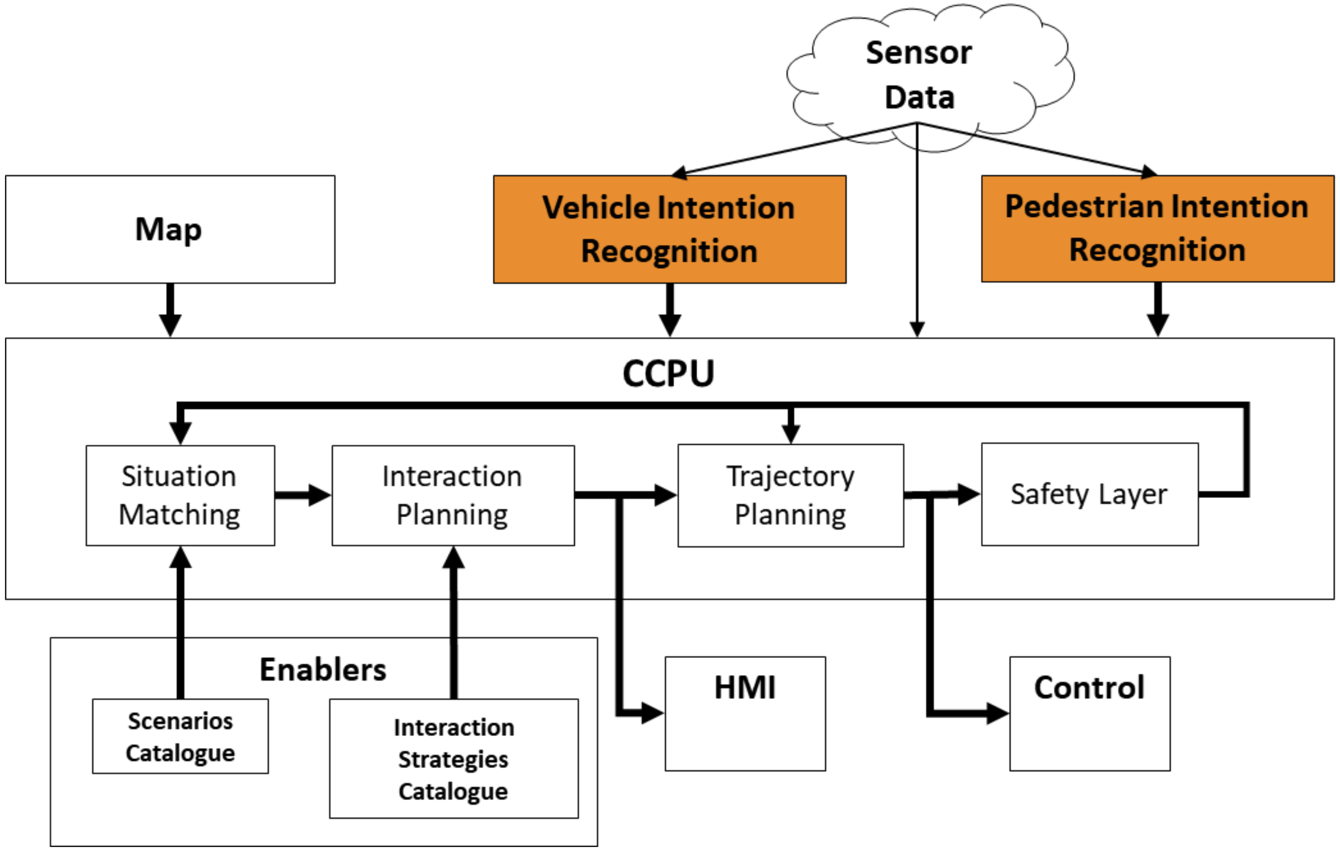

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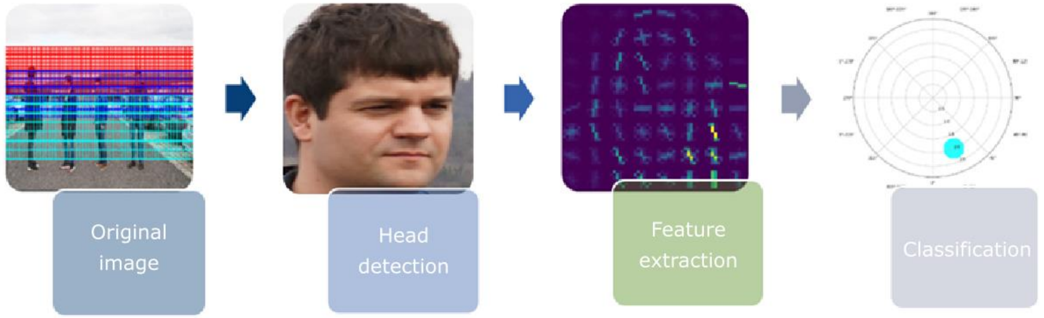
Situation Awareness

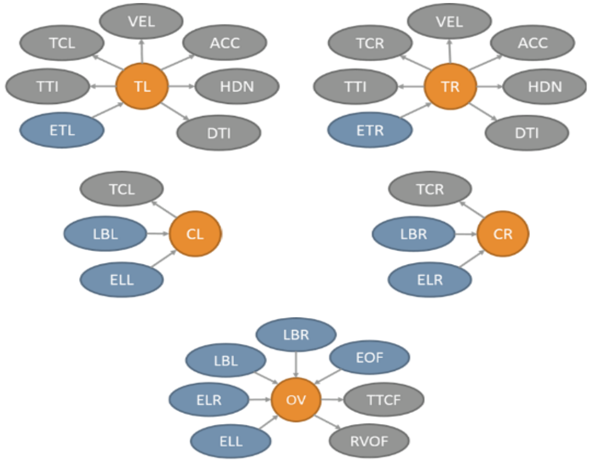
Pedestrian Intention Recognition

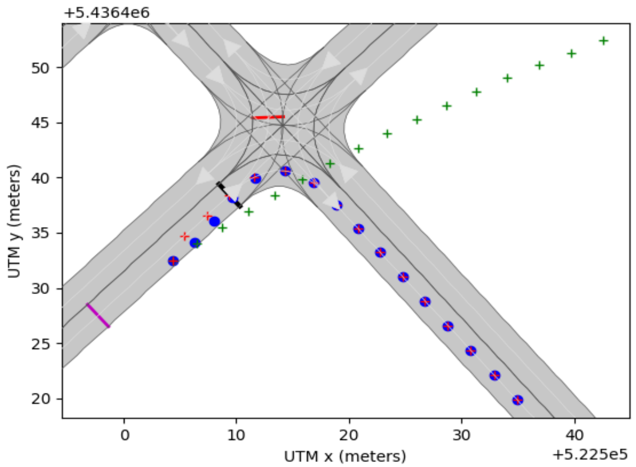
- General mathematical framework to predict pedestrian long-term intention, using **pedestrian motion models** & the semantic map
- **Machine learning algorithms** to enhance precision by accounting for head orientation & hand waving classification



Vehicle Intention Recognition

- Hidden Markov model for **probabilistic recognition** of vehicle's maneuvers and generation of intention-aware map-conforming trajectory
- **Fusion** of vehicle's intention-based trajectory with typical motion-based (short-term) trajectory to extend the prediction time horizon





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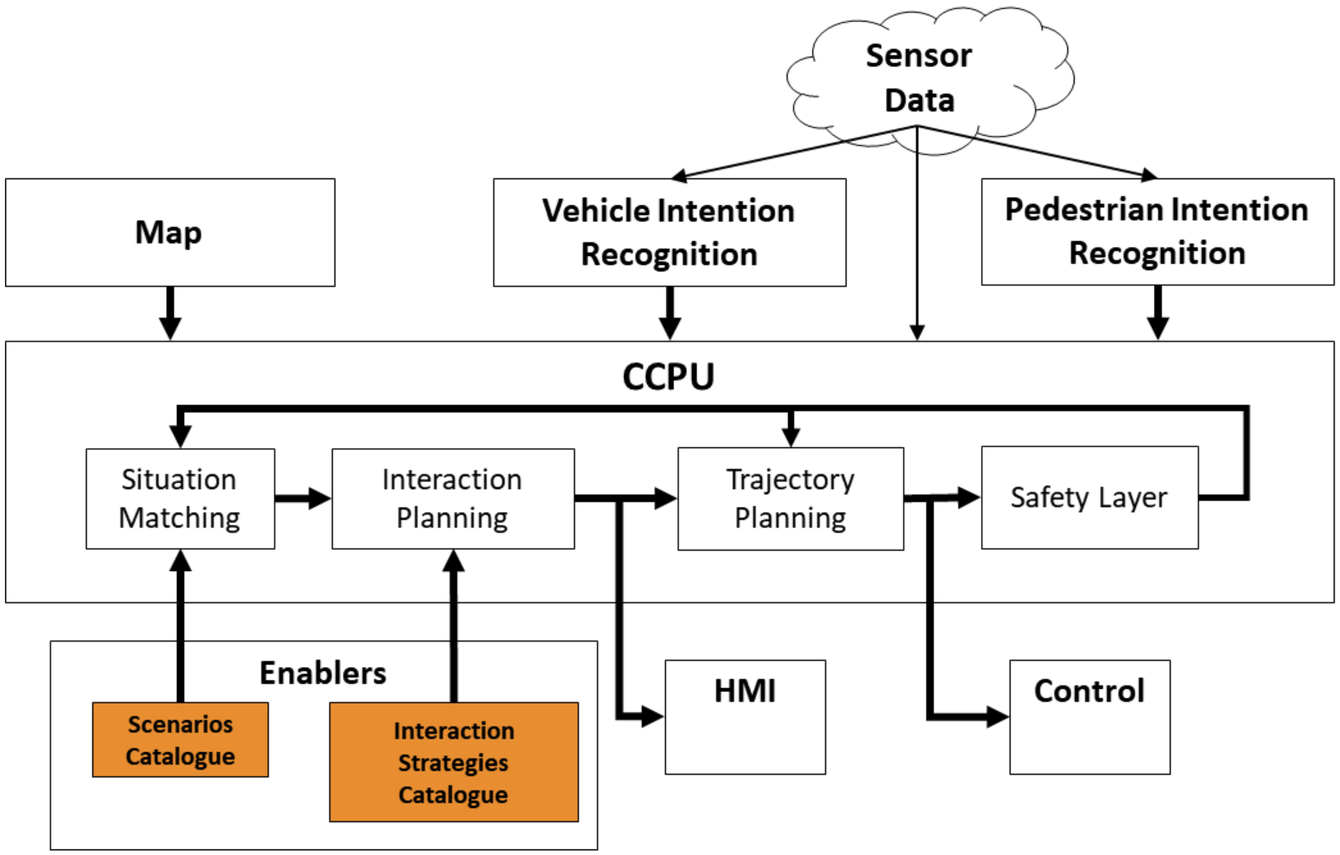
Enablers



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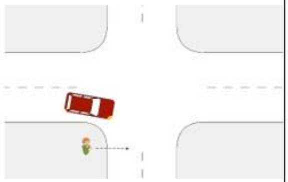
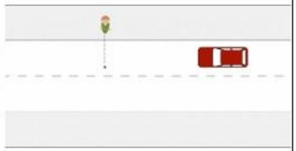
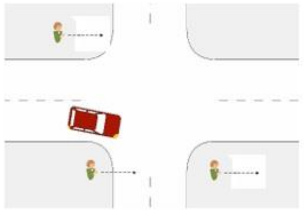
Digitalizing interACT’s scenarios

Use case	Priority
React to crossing non-motorised TP at crossings without traffic lights	Must-have

Based on interACT’s 6 must-have and 2 optional use-cases

Use case Environment	☒ Intersection	☐ Parking space	☒ On the road
Graphical representation and short verbal description			
	We distinguish between different pedestrian behaviors, leading to: **Scenario 1:** Pedestrian waiting for the	We distinguish between different pedestrian behaviors, leading to: **Scenario 4:** Pedestrian waiting for the	**[NEW] Scenarios 7, 8 and 9:** Same as the first but now more complex as the CCPU has to detect other pedestrians too and ignore them

Generated 25 scenarios (variations) for all cases

Traffic conflict scenario	Digital scenario (Horn Clause)	Digital scenario ID
Possible collision between AV and moving pedestrian(s) in urban area.	areaUrban(av) ∧ detected(_TP) ∧ nonMotorised(_TP) ∧ isToCollideWithAv(_TP) → encountered(scenario1)	Scenario 1

Each scenario formed the base to build the digital catalogues of the CCPU

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Enablers

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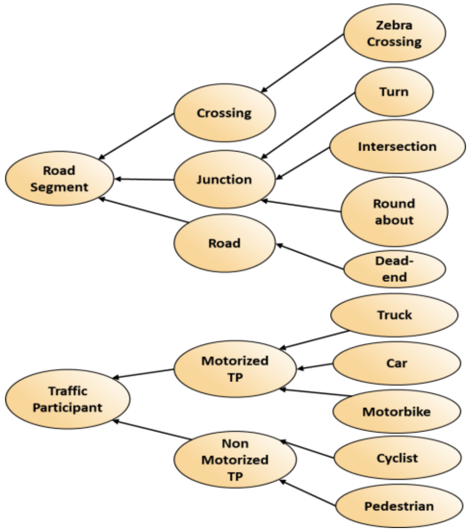
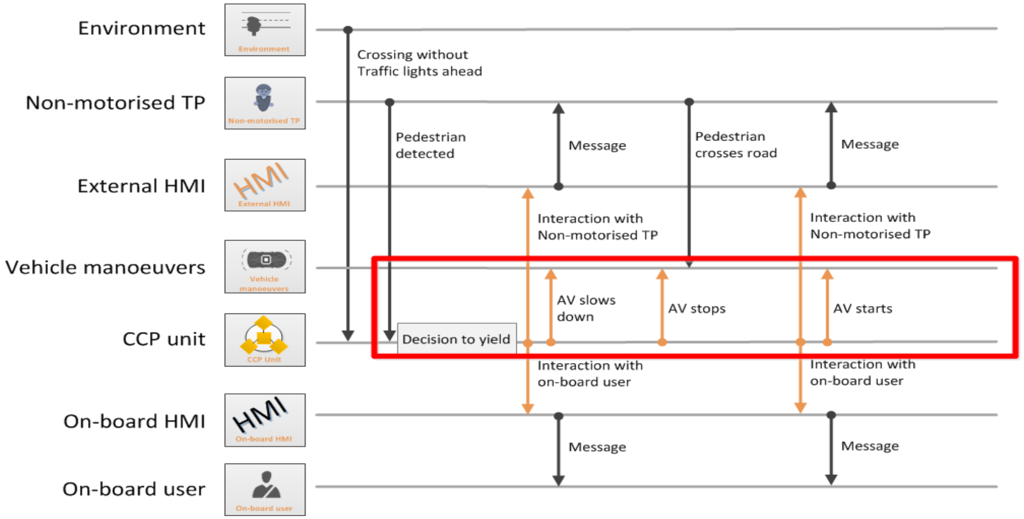


Scenarios Catalogue

- Knowledge representation - **taxonomy**
- Domain definition via a **vocabulary**
- **Relations** between classes and individuals
- Creation of logical rules using **first-order logic syntax**
- Verbal representation of scenarios “translated” into Horn clauses (rules)
- Use of reasoning (inference) to produce **new knowledge**



Strategies Catalogue

- AV goals: Set of allowed actions & constraints
  - **Maneuvers** (ex. Keep speed, slow down, stop)
  - **HMI** output (ex. green light – you may pass)
  - **Constraints** (ex. minDistance=2m)
- TP intentions
  - Define an allowed set of AV goals
  - AV chooses an appropriate goal depending on circumstances
  - Decision making via a **Fuzzy Rule Based system**

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Situation Recognition & Reaction

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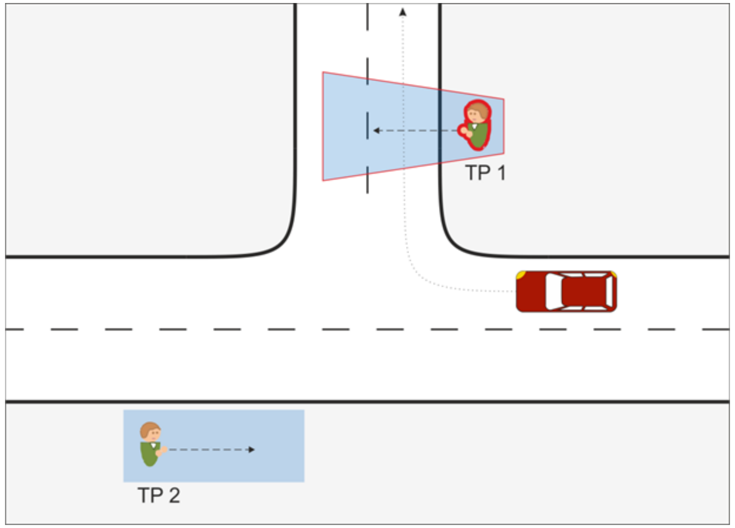
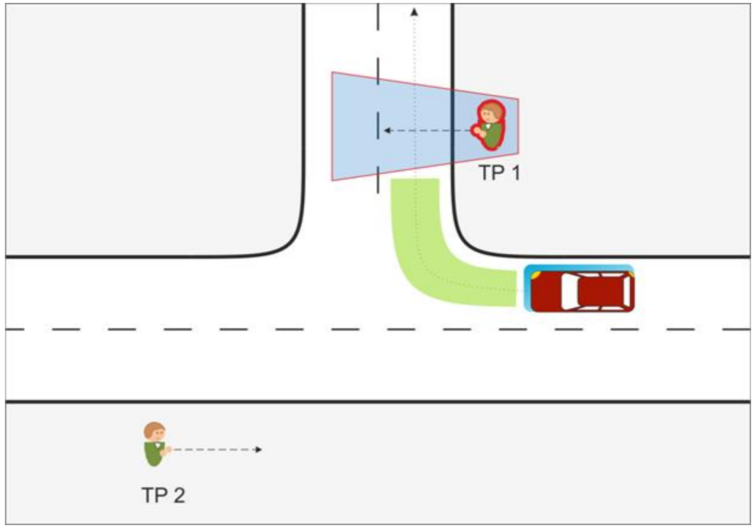
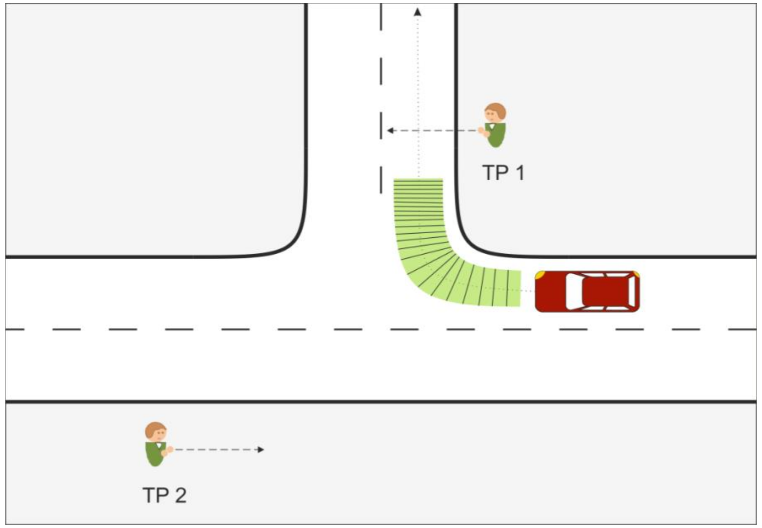


- ✓ Combine map info, sensor data, future intentions and AV's planned trajectory.
- ✓ Detect potential conflicts with other TPs, according to predefined scenarios.
- ✓ Mark relevant scenario (case) and involving actors.



- ✓ Provide a reaction plan according to each scenario and involving actors.
- ✓ Provide technical instructions related to AV's motion.
- ✓ Communicate with other TPs via HMI messages.



- ✓ Translate technical instructions into actual control messages.
- ✓ Manage the controllers to drive the AV into the suggested path.
- ✓ Monitor Safety Layer for emergency situation.

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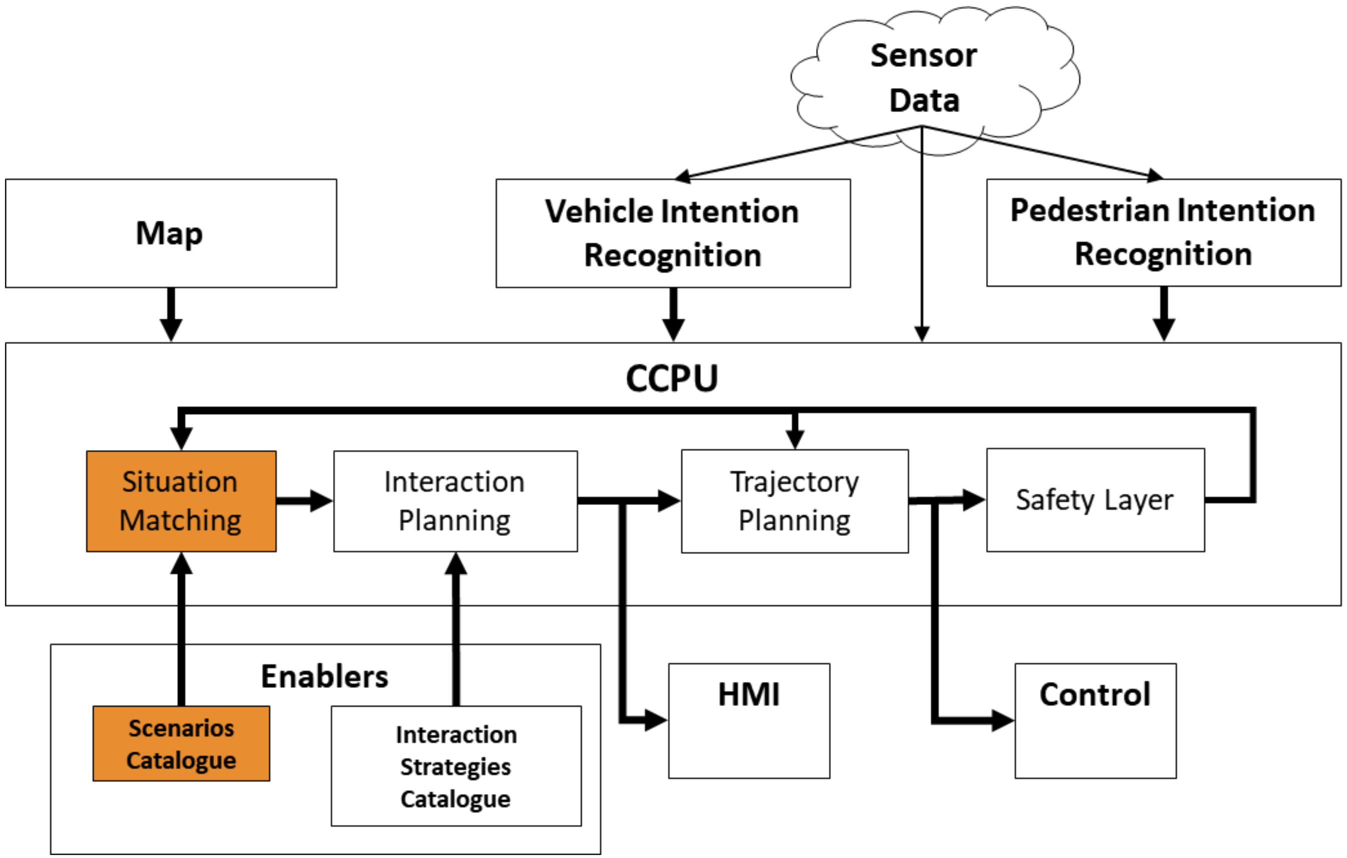
Situation Matching module



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Situation Matching module

Flow

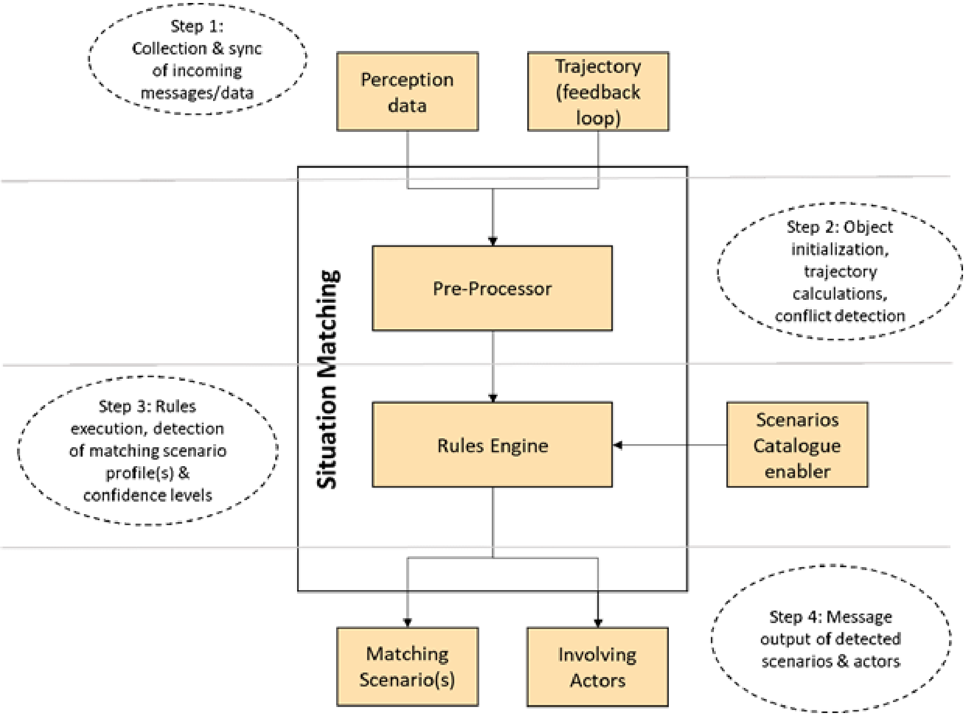
- Collects and synchronizes incoming data.
- Pre-processing mechanism to perform conflict detection calculations.
- Rules Engine to match the traffic scene with a digital scenario from the Scenarios Catalogue.
- Communicate the output and the involving actors to the Interaction Planning module.

Scenario probability estimation

- Accumulates uncertainties from Perception measurements.
- Calculates confidence levels of each provided scenario.

Multiple actors functionality

- Each traffic scenario case is treated individually.
- Separate results for all involved actors.
- In case of mutual conflict, highlight riskier situation.



Recognizes a possible conflict situation between the AV and surrounding TPs

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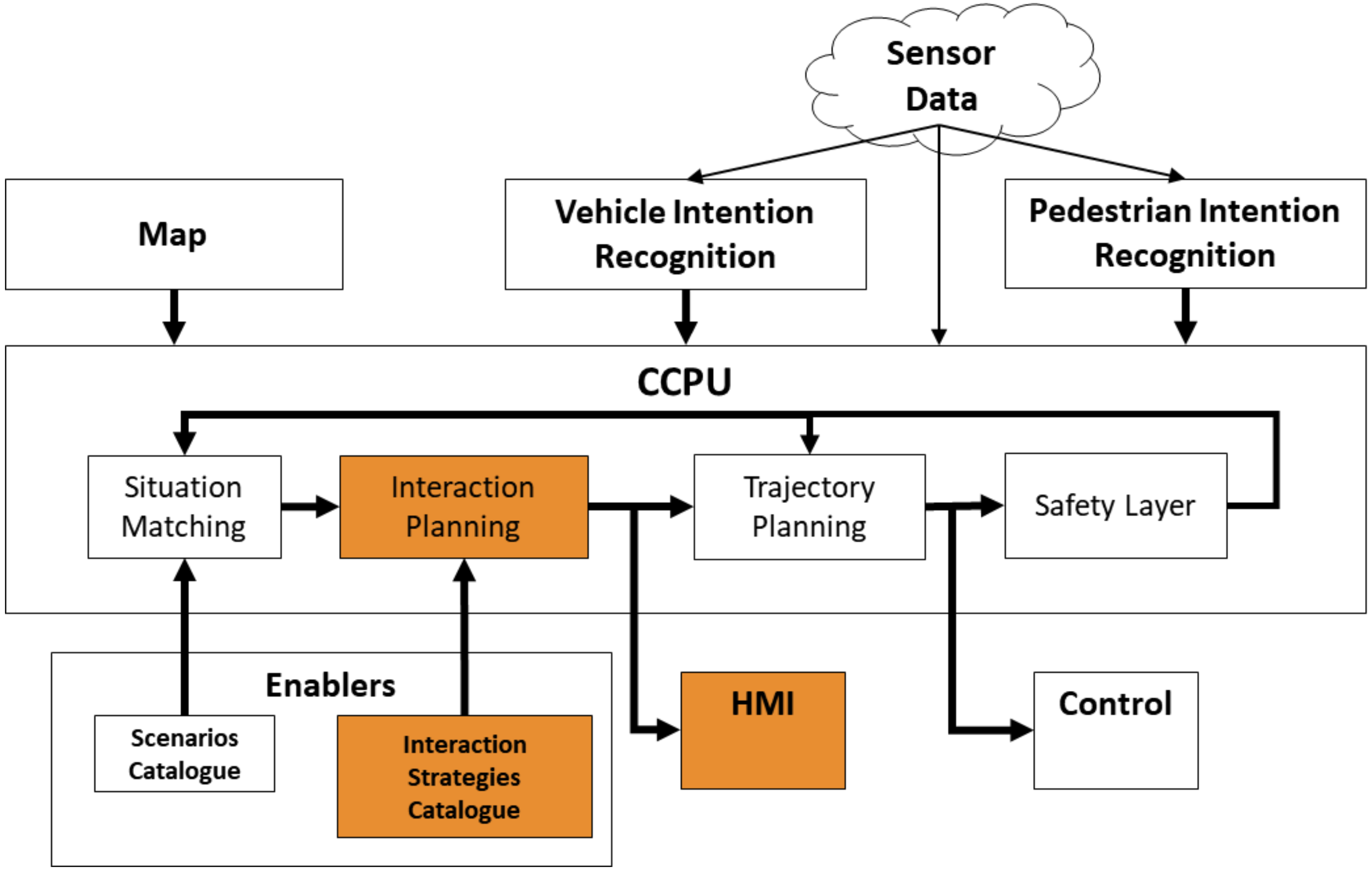
Interaction Planning module



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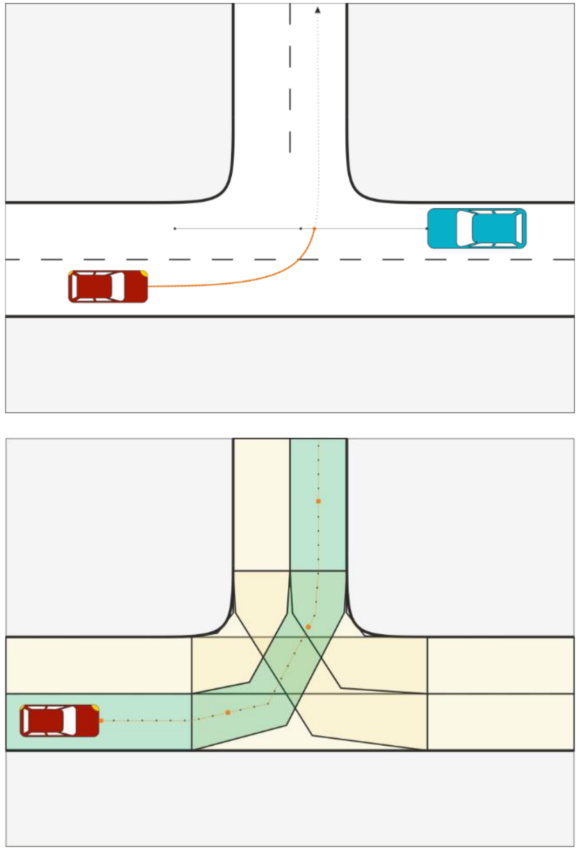
Interaction Planning module

Flow

- Processes incoming information regarding AV state, involved TPs state and triggered scenario.
- **Classifies** the initial scenario into a detailed scenario along with a respective action plan.
- **Communicates** relevant HMI instructions and control constraints.
- In parallel, checks the actual scene to validate the suggested plan is applicable at all times.

HMI & Constraint Management

- **External HMI** (eHMI) centered around the AV shows the AV's intentions towards other TPs.
- **Internal HMI** (iHMI), implemented in AV's monitor to update information relevant to AV's passengers.
- **Constraints** are generated using the CommonRoad map representation to define important settings for the Trajectory Planning module (stopline, deceleration rate, etc.)



Strategizes a set of actions (plan), according to a given traffic scenario

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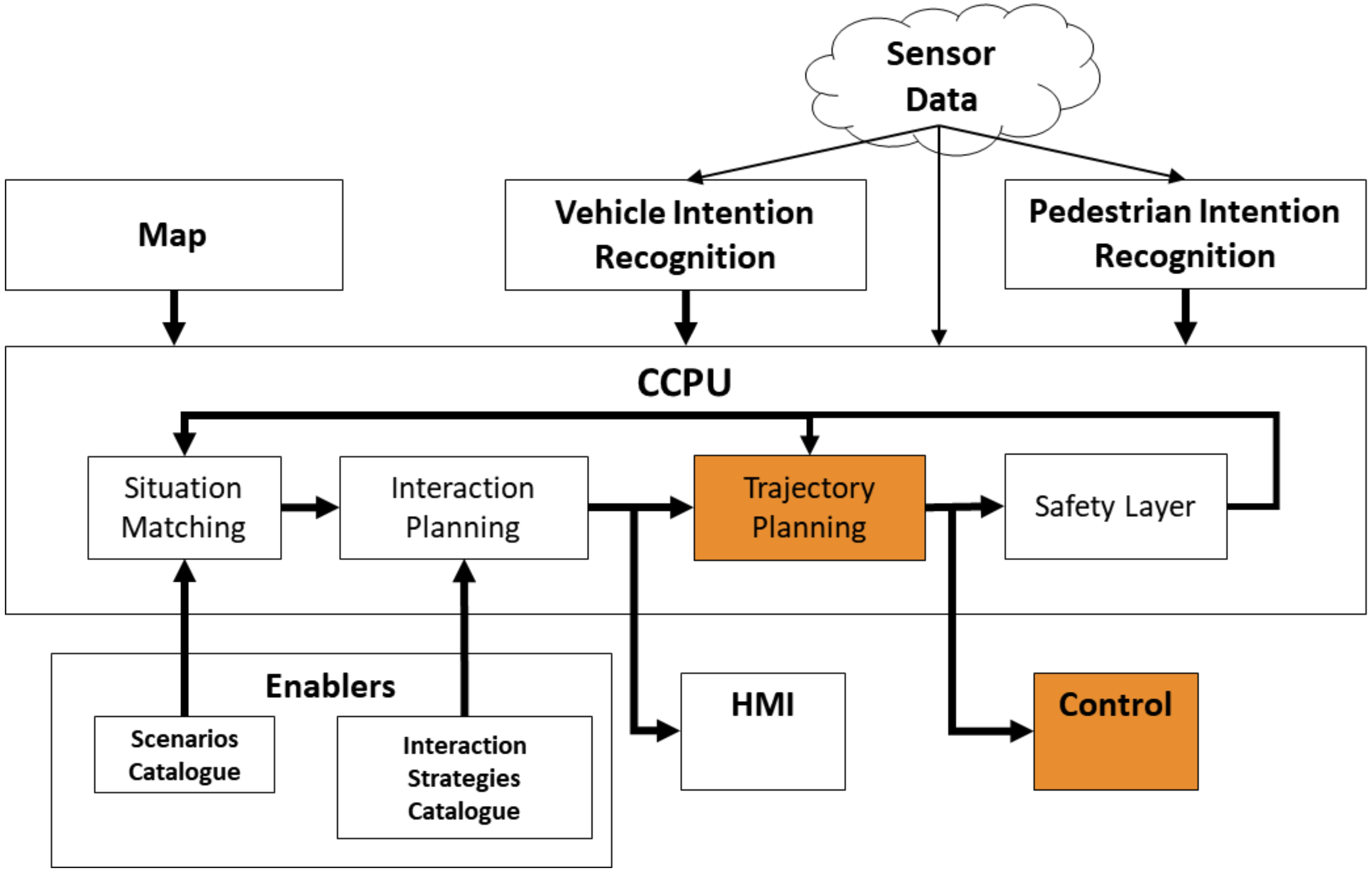
Trajectory Planning module



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Trajectory Planning module

Path planning

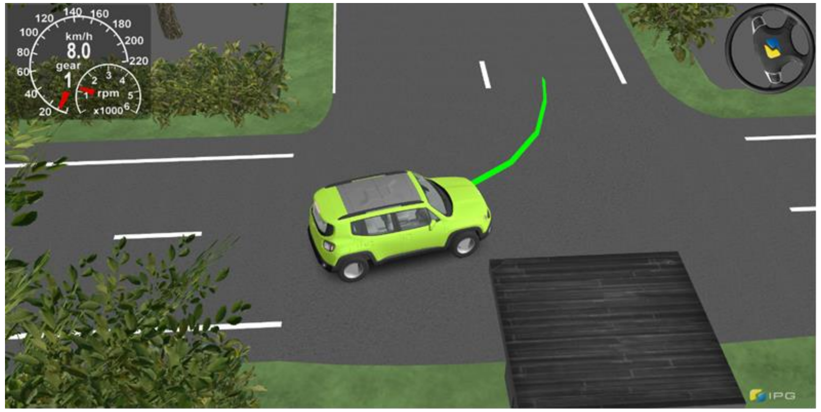
- Determines the vehicle's target route, i.e. a set of points from the **start position** to the **destination**
- Fast and deterministic approach, using Voronoi diagram and A* algorithm

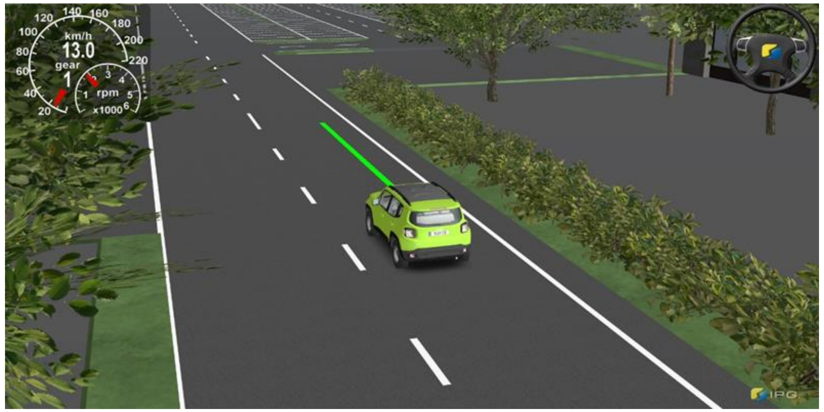
Trajectory planning

- Primarily based on CRF's novel work on **low-speed autonomous driving**
- Model Predictive Control (MPC) strategy
- Lateral and longitudinal MPC implemented in CarMaker toolset.

Control mechanism

- Maximum speed limit at **15 km/hour**
- Trajectory planning module always has control over the actuators
- In case of an emergency (spotted by the Safety Layer) it handles the respective fail-safe maneuver





Generates the a-priory (long-term) path & the dynamic (short-term) trajectory of the AV and handles the vehicle's controllers

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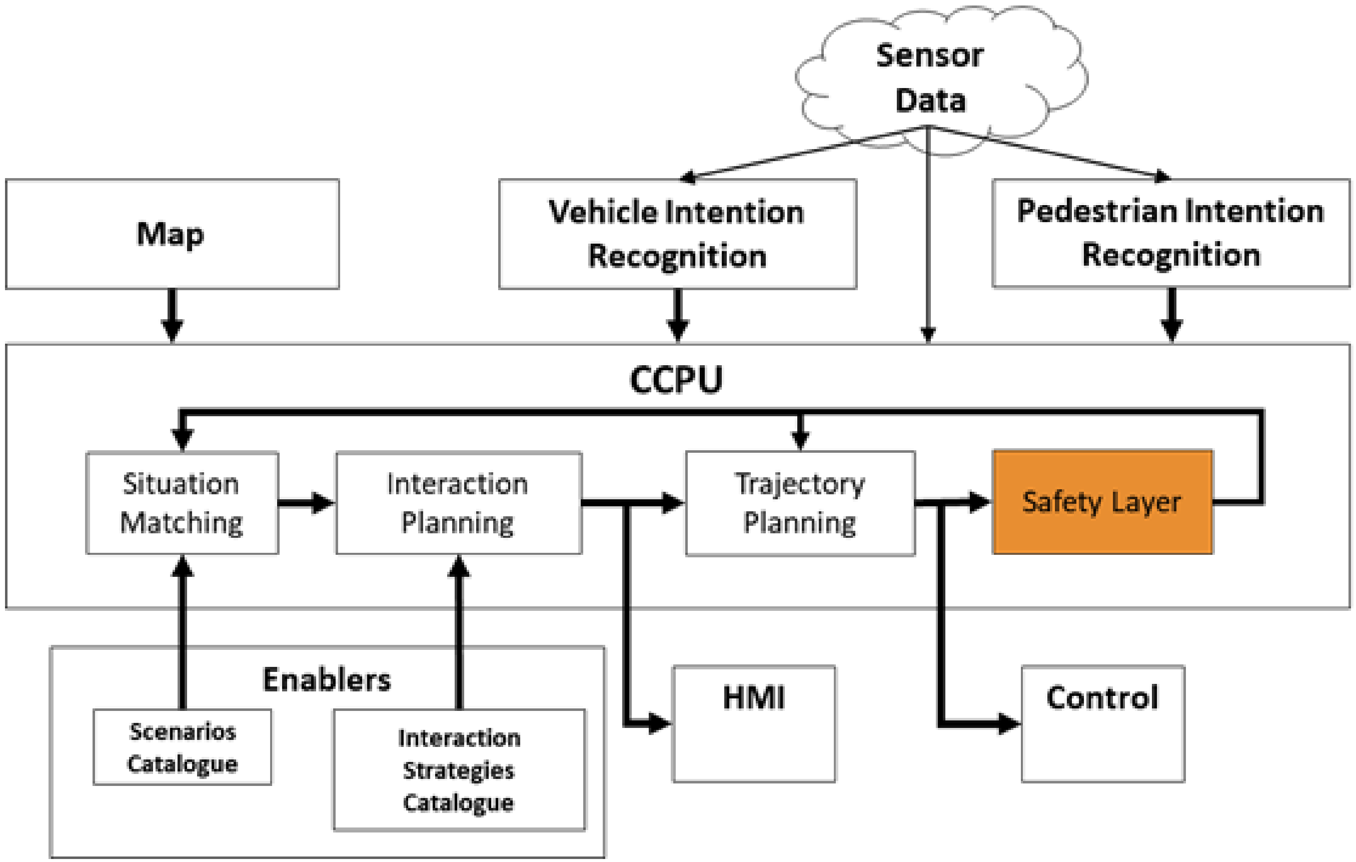
Safety Layer module



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Safety Layer module

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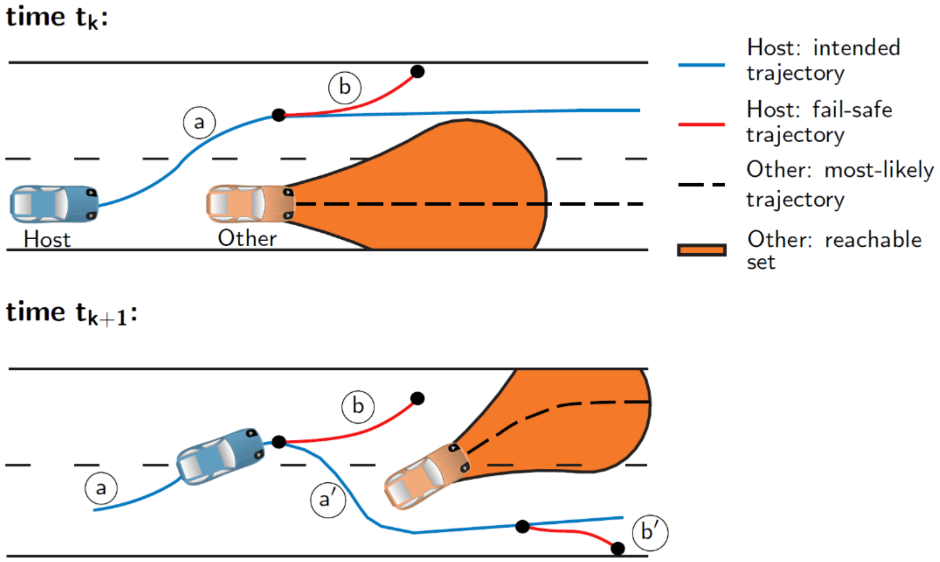
Set-Based Predictions of TPs

- Used as input to compute a fail-safe trajectory at all times
- In parallel, used to check that current AV's trajectory is safe
- Computed using the SPOT tool

Fail-safe Planner

- Computes the **fail-safe trajectory**
- If actual trajectory is checked safe stays inactive, else engages and notifies the Trajectory planner
- Software optimization to minimize computation time and achieve **nearly real-time results**



Monitors CCPU's actions and ensures safety for all vehicle's movements

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Lab proof of concept

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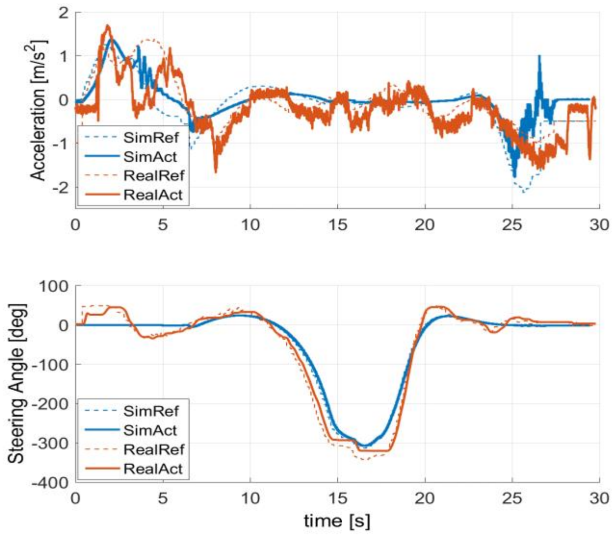
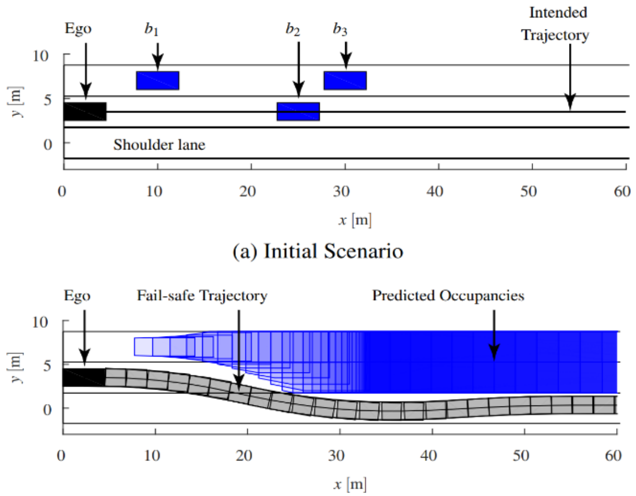
Stage 1: Functional Tests

- Per module unit-tests (validation of native functionality)
- End-to-end tests (data chain, messaging framework)
- Instructions to HMI & Controllers validation





(a) Initial Scenario

(b) Fail-safe trajectory

✓Per component simulation and theoretical analysis

✓Inter-component interfaces (ROS communications) consistency

✓Simulated safety-critical test scenarios generated by a custom tool (TUM) to validate Safety Layer's functionality

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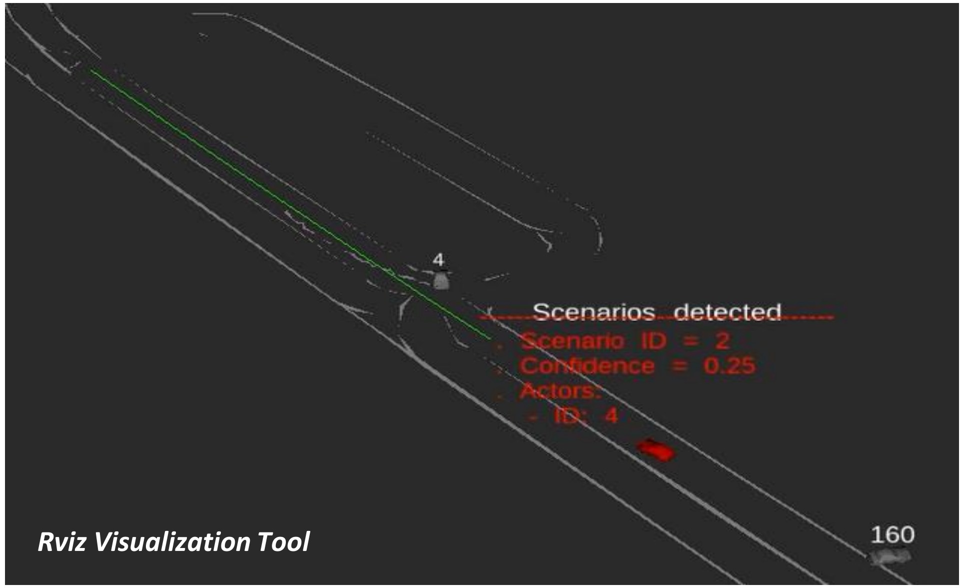
Lab proof of concept #2

Stage 2: Tests against recorded datasets

- *Abstatt, Heilbronn*: 1 dataset of AV free driving for multiple rounds
- *Orbassano, Torino*: 50 datasets with dedicated scenarios (AV-to-vehicle, AV-to-pedestrian, emergency situations)



- ✓ **End-to-end simulation** of actual scenarios, using a customized visualization tool (based on Rviz)
- ✓ **Remote testing** between different components, using ROS library tools and logging scripts
- ✓ **Fine-tuning** of system parameters

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Integration into CRF prototype vehicle

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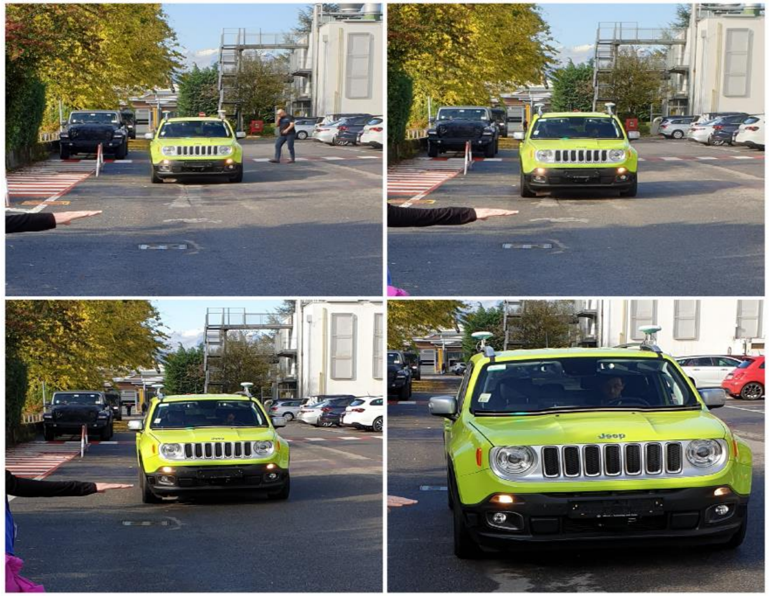
- ✓ A total of 4 Integration Meetings in CRF premises, Orbassano.
- ✓ Full deployment of CCPU inside the in-vehicle PC.



Testing as an agile process

Development (add new features or updates)
Deployment in the car, using Docker
Live testing
Feedback & analysis

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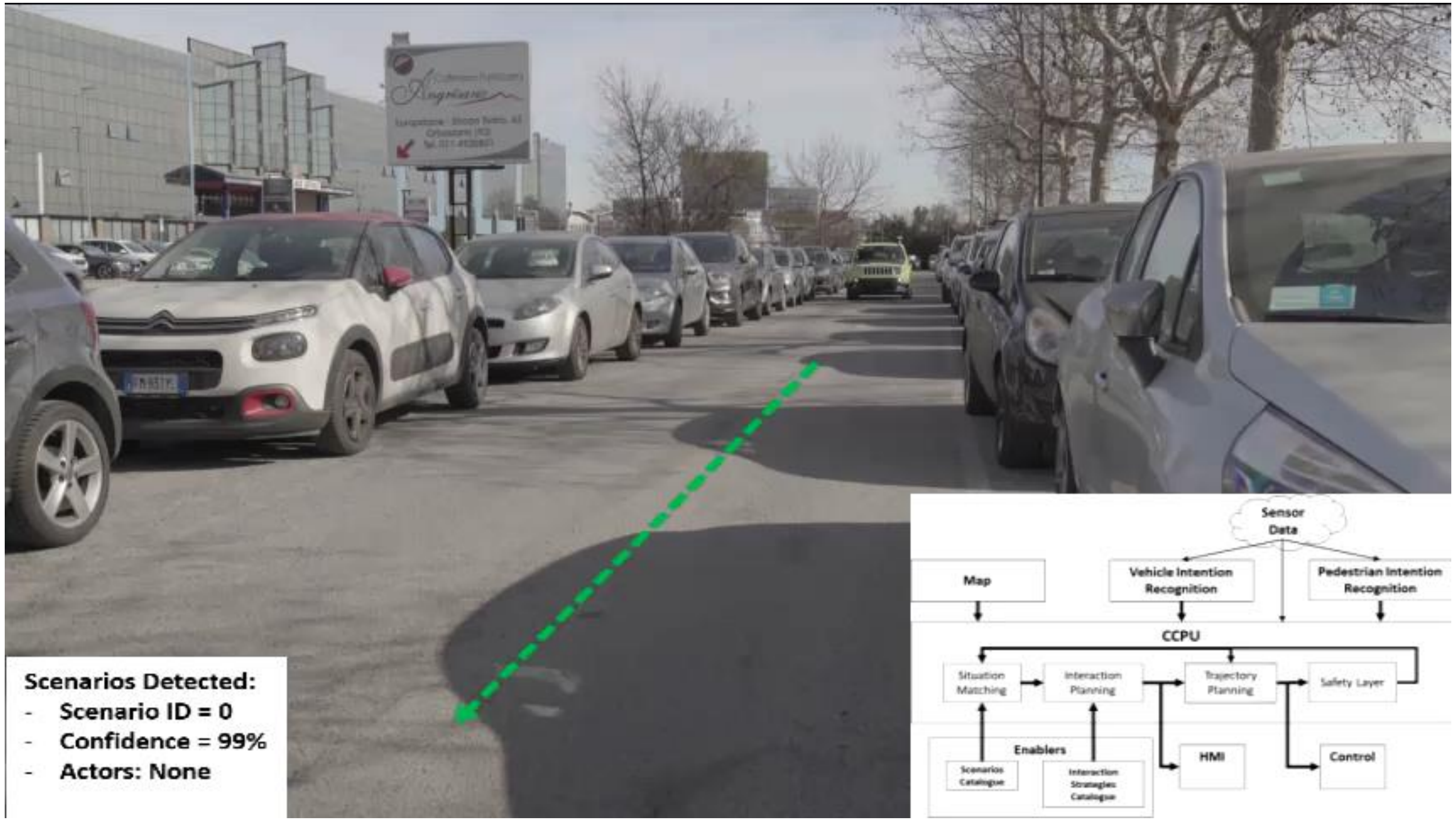
AV-Pedestrian interaction case

www.interact-roadautomation.eu

Replay Speed
= 50%



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interACT
Designing cooperative interaction of automated vehicles with other road users in mixed traffic environments

AV-Vehicle interaction case

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Replay Speed
= 70%

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Conclusions

DESIGN process

- Modules‘ logic and **architecture** built
- **Scenarios** and **Strategies** catalogue defined
- Design and algorithmic logic **development of each CCPU module**
- Common **standardized road format** and **messaging mechanism** (I/O ROS messages)

IMPLEMENTATION into prototype

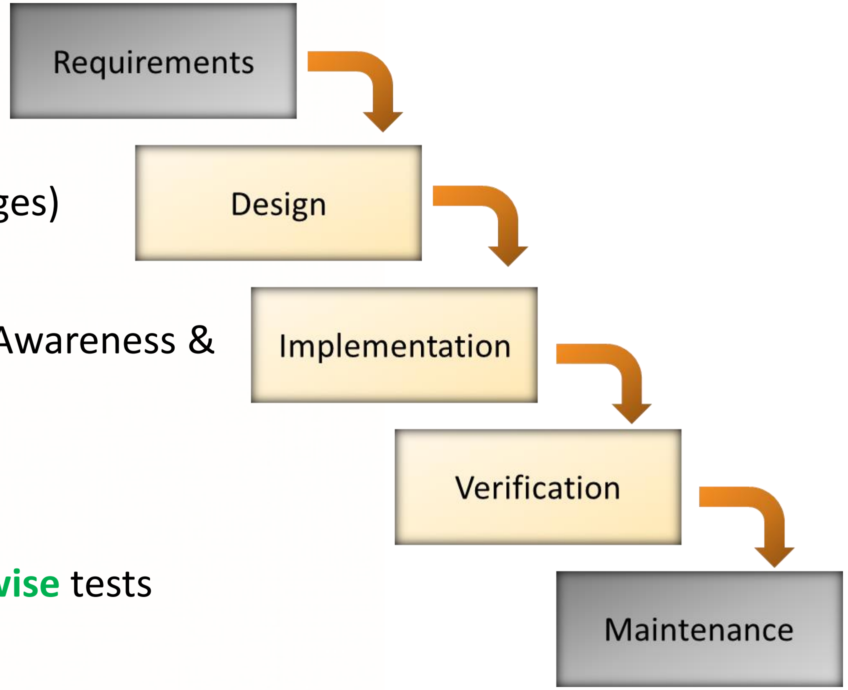
- Development of **CCPU modules**, plus their dependencies (Perception, Situation Awareness & Enablers)
- **Safety of the generated maneuvers** is validated in parallel through Safety Layer

LAB testing

- Testing methodologies: iterative process of **unit-tests**, **functional** tests, **system-wise** tests
- Testing framework: **simulated data** and **real-world datasets**

DEPLOYMENT in CRF demonstrator vehicle

- All modules deployed and **modular functionality** checked during integration & evaluation phase
- Technical tests of selected **AV-to-pedestrian** and **AV-to-vehicle** scenarios in controlled environment (CRF Security Centre)



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Related published work

[1] Althoff, M., & Lutz, S. (2018, June). Automatic generation of safety-critical test scenarios for collision avoidance of road vehicles. In 2018 IEEE Intelligent Vehicles Symposium (IV) (pp. 1326-1333). IEEE.

[2] Zhu, A., Manzinger, S., & Althoff, M. (2018, June). Evaluating location compliance approaches for automated road vehicles. In 2018 IEEE Intelligent Vehicles Symposium (IV) (pp. 642-649). IEEE.

[3] Sontges, S., Koschi, M., & Althoff, M. (2018, June). Worst-case analysis of the time-to-react using reachable sets. In 2018 IEEE Intelligent Vehicles Symposium (IV) (pp. 1891-1897). IEEE.

[4] Wu, J., Ruenz, J., & Althoff, M. (2018, June). Probabilistic map-based pedestrian motion prediction taking traffic participants into consideration. In 2018 IEEE Intelligent Vehicles Symposium (IV) (pp. 1285-1292). IEEE.

[5] Dietrich, A., & Ruenz, J. (2018, August). Observing traffic–utilizing a ground based LiDAR and observation protocols at a T-junction in Germany. In Congress of the International Ergonomics Association (pp. 537-542). Springer, Cham.

[6] Drakoulis, R., Bolovinou, A., Drainakis, G., Amditis, A. Bayesian maneuver recognition for vehicle long-term intention-aware trajectory prediction. (to be submitted)

[7] Drakoulis, R., Drainakis, G., Portouli, E., Althoff, M., Magdici, S., Tango, F., Markowski, R. "interACT D3.1 Cooperation and Communication Planning Unit Concept" (2018)

[8] Markowski, R., Lapoehn, S., Bolovinou, A., Drainakis, G., Drakoulis, R., Althoff, M., Klischat, M., Tango, F., Borello, G. "interACT D3.2 Cooperation and Communication Planning Unit prototype and accompanying report" (2018)

[9] Weber F., Sorokin L., Schmidt E., Schieben A., Wilbrink M., Kettwich C., Dodiya J., Oehl M., Kaup M., Willrodt J., Lee Y., Madigan R., Markkula G., Romano R., Merat N. "interACT D.42 Final interaction strategies for the interACT Automated Vehicles" (2019)

[10] Ruenz, J., Wu, J., Zhang, J., Cao, Y., Schürmann, B., Althoff, M., Drainakis, G., Portouli, E. "interACT D2.3 Sensors and algorithms incorporating the developed models to be integrated into the demonstrator" (2019)

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Thank you!

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