Challenges in Achieving Explainability for Cooperative Transportation Systems: Perspectives From an Ongoing Research Project

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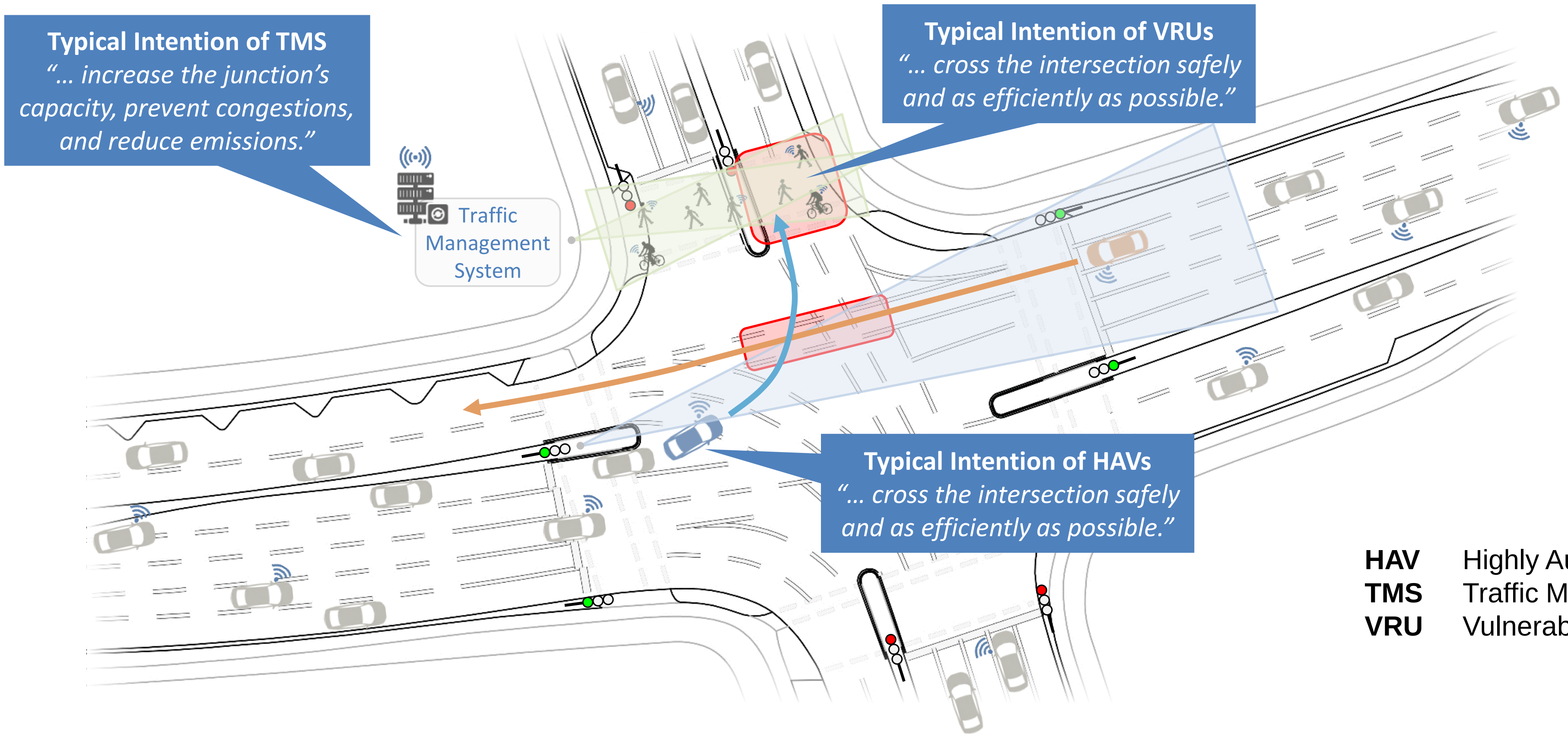
DLR

Cooperative Maneuvers at Urban Intersections

Use of Intelligent Infrastructure Systems to Support Highly Automated Driving



HAV Highly Automated Vehicle
TMS Traffic Management System
VRU Vulnerable Road User

[14] B. Koopmann, S. Puch, G. Ehmen, and M. Fränzle: *Cooperative Maneuvers of Highly Automated Vehicles at Urban Intersections: A Game-theoretic Approach*. In: *Proceedings of the 6th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS'20)*. SciTePress, 2020, pp. 15–26.

Coordinated Cooperative Traffic with Distributed Intelligence (KoKoVI)
Ongoing, Large-scale Endeavor on Future Transportation Systems

- DLR-internal application-oriented research project
- Duration: 01/2022 to 12/2024 (1st phase) | Budget: 16.2 million €

- Main goal: **development**, **testing**, and **demonstration** of building blocks for **future cooperative transportation systems**
    - Idea: lift local coordination approaches to higher levels
    - Support for automated mobility services and remote operation
    - In-process testing in **traffic and driving simulations**
    - Final demonstration with **test vehicles** in real traffic

- Adoption of a **general view on explainability**
    - Results were derived directly from **practical experience**
    - Focus on different aspects of explanations and target groups
    - Identification of **challenges** in achieving explainability along the implementation of the KoKoVI use cases
    - Discussion of **selected approaches** to target these challenges

More information: https://verkehrsforschung.dlr.de/de/projekte/kokovi

Cooperative Transportation Systems

Lifting Local Coordination Approaches to Higher Levels

Users of Automated Mobility Services
- End users with mobile devices
- Logistics company staff

Traffic Participants
- Cyclists and pedestrians (VRUs)
- Human-operated vehicles (Non-HAVs)
- Highly automated vehicles (HAVs)
- Highly automated shuttle vehicles

Intelligent Transportation Infrastructure

Traffic Management Systems (TMS)

Disposition Systems

Remote Operation Center
- Remote operators
- Other technical staff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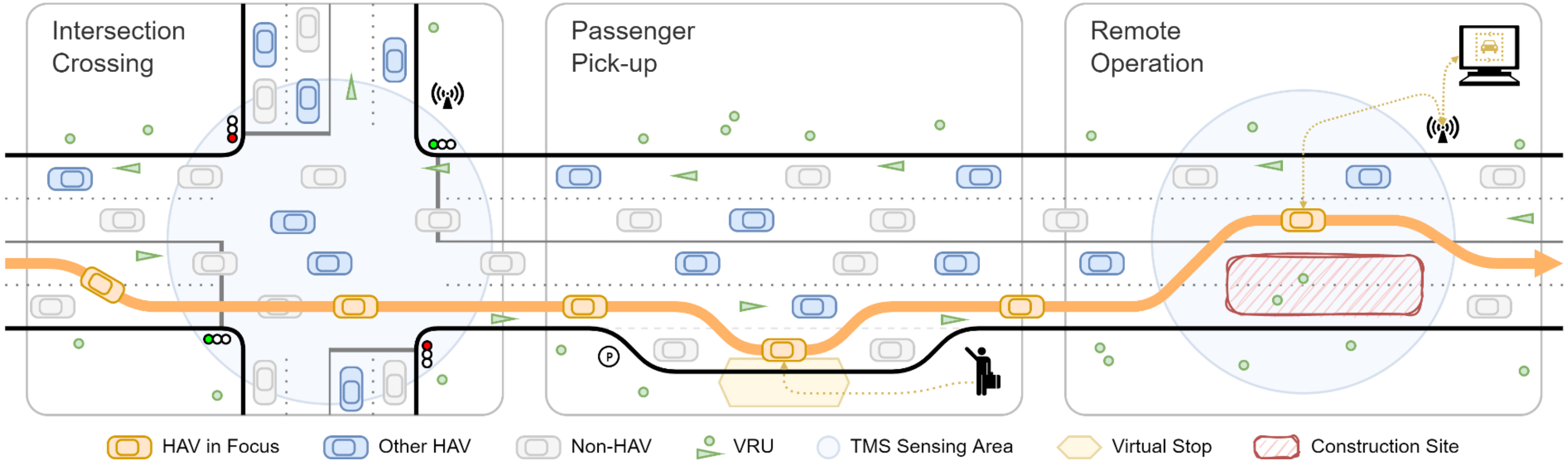
Cooperative Transportation Systems

Example Scenarios Considered in KoKoVI (and Related Projects)



Intersection Crossing

- Support of an HAV by a traffic management system equipped with environmental sensors
  - Real-time information about the traffic situation in remote and poorly visible areas
  - Traffic light phases and future signal courses
  - Behavior and cooperation recommendations to increase traffic efficiency and safety
- Negotiation and execution of cooperative maneuvers such as lane changes and left-turns

Passenger Pick-up

- HAV in focus picks up a passenger at a "virtual stop" located in a parking bay
  - Processing of a trip request sent by the end user by a region-wide disposition system
  - Coordination of the shuttle fleet and selection of a shuttle vehicle to take over the ride
  - Initiation of the user's navigation to the stop
- Interaction with other HAVs, non-HAVs, and VRUs to enable a safe and efficient pick-up

Remote Operation

- Support of the HAV by a human remote operator in unknown or critical situations that cannot be handled by the vehicle's automation
- One of three possible countermeasures:
  1. Execution of minimal risk maneuvers
  2. Transfer of driving tasks to infrastructure
  3. Remote vehicle control by human operators
- Transmission of hazard warnings for oncoming traffic and following vehicles

Challenges in Achieving Explainability

Example Requirements From the Perspective of Four Key Roles

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Passengers of Highly Automated Vehicles

- Handing over control to an automated system requires a high degree of trust in technology
- Understanding the system is key for building trust
- Goal 1: provide passengers with the optimal amount of information about the system‘s behavior and intention
- Goal 2: prevent uncertainties due to deviating driving styles through systematic explanations

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Other Traffic Participants

- Explaining an HAV’s intention to other road users is important for the adoption of the technology
- Missing or incomplete communication can lead to misunderstandings, confusion, and mistakes
- Goal 1: indicate that HAVs are aware of the presence of non-HAVs and VRUs and anticipate their intended behavior
- Goal 2: communicate the HAV’s intention

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Remote Operators

- Monitoring HAVs requires constant vigilance
- Different user conditions such as under- or overload of cognitive demand can lead to vigilance decrements
- Goal: design HMIs such that remote operators are able to reliably detect and respond to critical systems states under various user conditions

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System Developers and Integrators

- Establishing reliable interaction of systems with manufacturer-specific implementations of components and functions is a challenging task
- CTSs are built to provide value to society and should therefore be understandable and usable
- Goal 1: achieve explainability for human users
- Goal 2: provide error analysis and diagnosis, e.g., for legal proceedings after an accident

Challenges in Achieving Explainability

Identified Explainability Challenges and Selected Approaches

- Identification of 13 application-focused explainability challenges during system design
- Six generic challenges are relevant in all scenarios and from the perspective of all roles
- Additional challenges address specific properties of (single) systems and systems of systems

Generic Challenges

System Challenges

System of Systems Challenges

Group	ID	Title
I	**EC-1**	Different domain knowledge
	EC-2	Different levels of abstraction
	EC-3	Different visualizations
	EC-4	Different explanation goals
	EC-5	Different explanation paradigms
	EC-6	Different local goals and needs
II	**EC-7**	Missing explainability of black box components
	EC-8	Missing explainability of system context
III	**EC-9**	Explainability across (sub-)system boundaries
	EC-10	Manufacturer-specific implementations
	EC-11	Incompatible interfaces or communication protocols
	EC-12	Shared responsibility
	EC-13	Distributed decision making

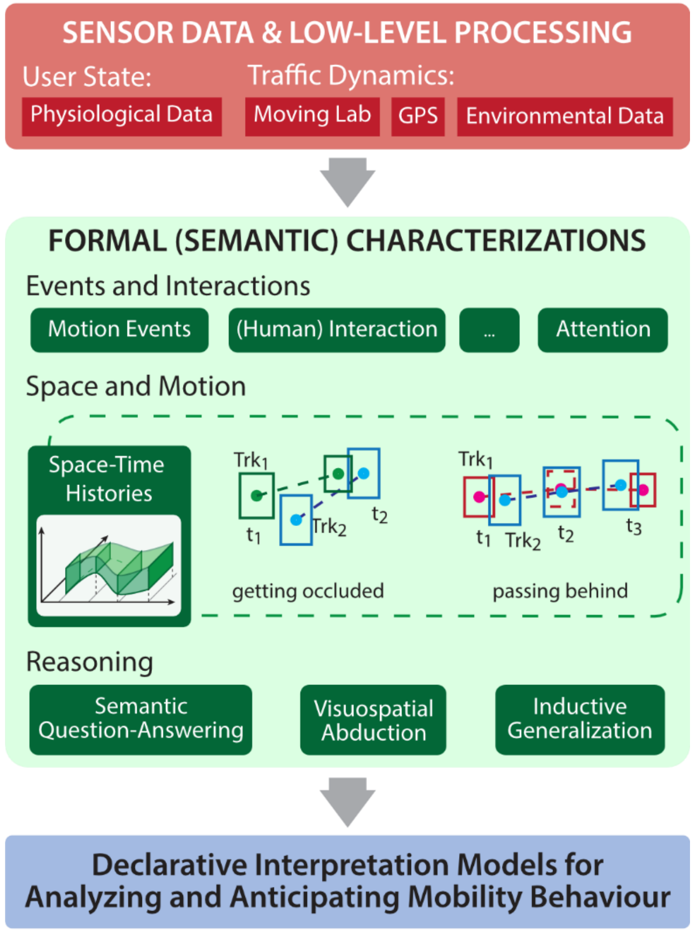
Solution Approaches

- Strategy Evaluation and Synthesis
- Explainability for Trustworthy Highly Automated Vehicles
- Explainable Interpretation Models
- Method for Designing Human-Machine Interfaces
- Architecture Development and Refinement
- Real-Time Handling and Safety Assessment

Developing Explainable Systems: Perspectives From KoKoVI

Explainable Interpretation Models

- Declarative characterizations for analyzing and anticipating mobility behavior
- Queryable relational models for the interpretation and projection of traffic dynamics and mobility behavior, focusing on:
    1. Encoding **high-level human-centered concepts** suitable for reasoning and learning about observed dynamics;
    2. **Grounding human interactions and behavior** with respect to low-level (subsymbolic) sensor data;
    3. Providing **human understandable abstractions** suitable to interface with and externalize inferred interpretations, i.e., for stating high-level **constraints** and **preferences**.
- Based on general and established (declarative) methods, e.g., Answer Set Programming (ASP)



[44] J. Suchan, M. Bhatt, and S. Varadarajan: *Commonsense Visual Sensemaking for Autonomous Driving: On Generalised Neurosymbolic Online Abduction Integrating Vision and Semantics*. In: *Artificial Intelligence*, Vol. 299, 2021.

Developing Explainable Systems: Perspectives From KoKoVI

Method for Designing Human-Machine Interfaces

Application and extension of the KONECT method (Ostendorp et al., 2016)

- Method for the development of safety-critical human-machine interaction interfaces
- Optimized to create visual components for fast and correct detection

- Problem: different user conditions such as under- or overload of cognitive demand can lead to vigilance decrements (Thomson et al., 2015)
  → Response times for critical event detection increase (Helton et al., 2011)

- Planned extension: consider impact of different user states on critical system state representation in the KONECT method to generate suitable HMIs and explanations for human remote operators

[46] M.-C. Ostendorp, T. Friedrichs, and A. Lüdtke: *Supporting Supervisory Control of Safety-critical Systems with Psychologically Well-founded Information Visualizations*. In: *Proceedings of the 9th Nordic Conference on Human-computer Interaction (NordiCHI'16)*. ACM, 2016, pp. 1–10.

Conclusion
Summary and Future Activities

Position Statement
- Achieving explainability in large-scale, cooperative transportation systems is a challenging task.
- The ability to explain processes and decisions is essential for such systems.
- From a systems engineering perspective, it is necessary to …
  - think explainability from the ground up,
  - handle explainability and trustworthiness as core properties of highly automated systems, and
  - carefully design these systems in such a way that the various needs for explanations are taken into account already in early design and engineering phases.

Contributions
- Derivation of 13 explainability challenges from practical experience
- Discussion of selected approaches being worked on in KoKoVI to target these challenges

Future Activities
- Re-evaluation of the identified challenges during system development
- Further reports on the progress in the development of solutions

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Thank you for your attention!

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