The IMoST-Vision:
Beschleunigte Entwicklung von Assistenzsystemen unter Einsatz von Computermodellen des Fahrers

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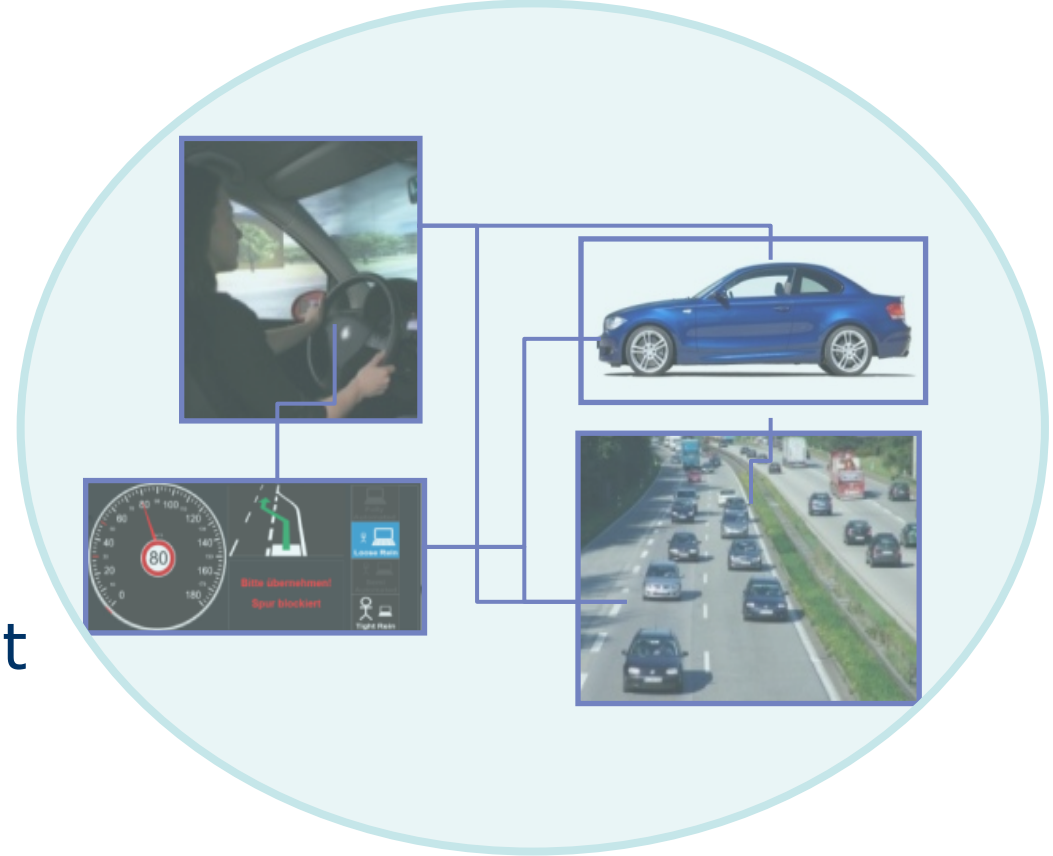
IMoST2: Integrated Modeling for Safe Transportation

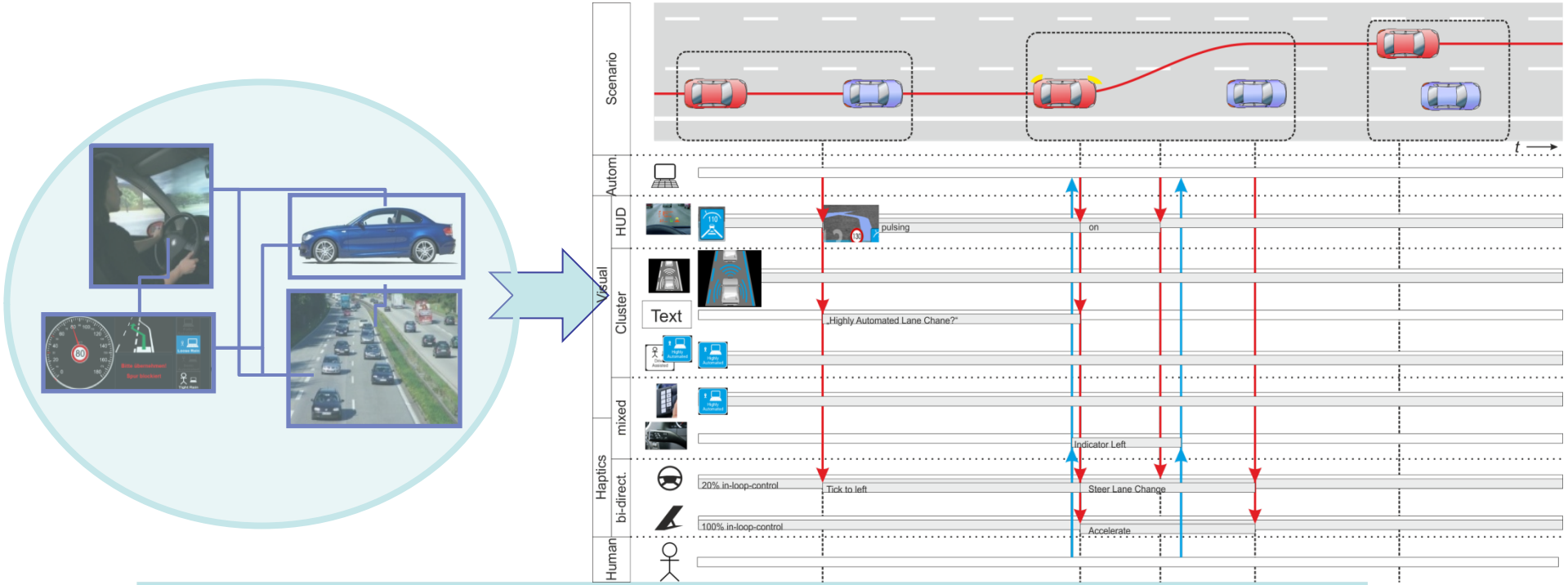
Consideration of interaction between

- **Driver**
- **Assistance** system
  - **A**dvanced
  - **D**river
  - **A**ssistance
  - **S**ystem
- **Vehicle** dynamics
- **Traffic** environment



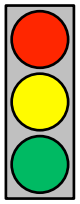
Key aspect: **comprehensive**, **integrated modeling**

IMoST2: Integrated Modeling for Safe Transportation



Is it always true that

$$\text{TimeToCollision} > 2.6\ \text{sec} \wedge \text{TimeHeadway} > 0.6\ \text{sec}\ ?$$

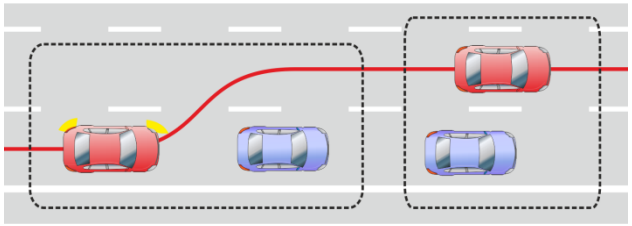


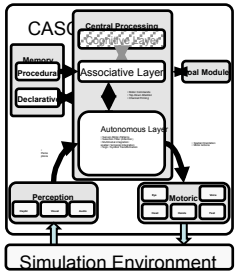
Key aspect: **in-depth analysis of models**

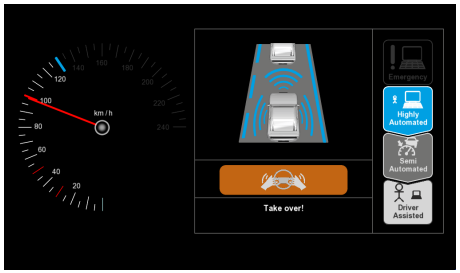
Goals of IMoST2

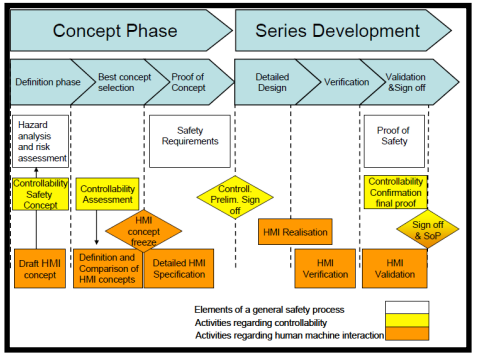
- Demonstrate approach for complex dynamic driving situations
- Driver modeling taking into account
  - Perception
  - Situation awareness
  - Decision making
  - Driving performance
- Empirical validation
- Analysis covering different behaviours
  - Normative
  - Extremes
  - Safety
  - Functionality
- Ensure transferability of results

Lane change & Overtake

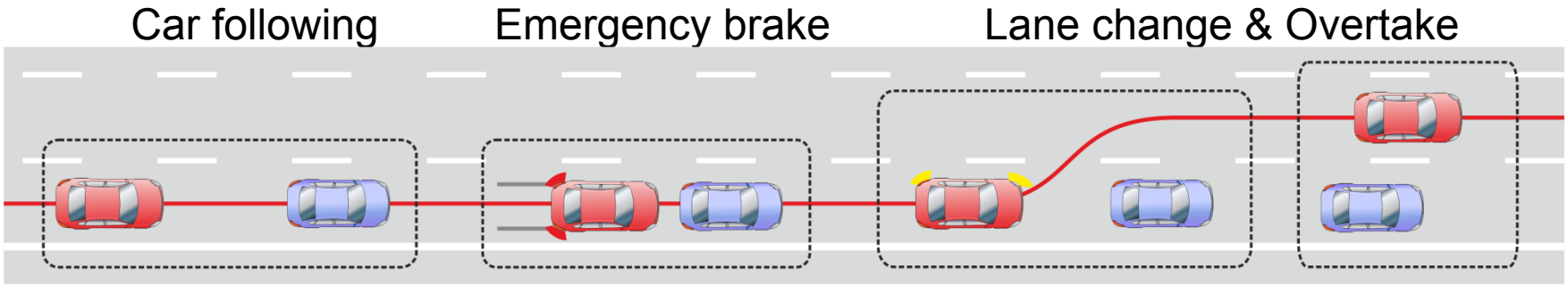




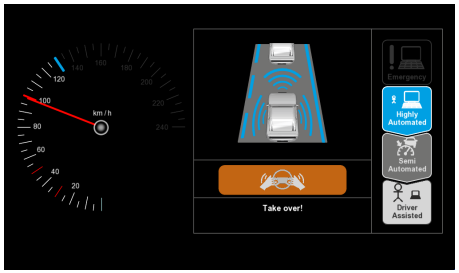




IMoST2 Application Scenario

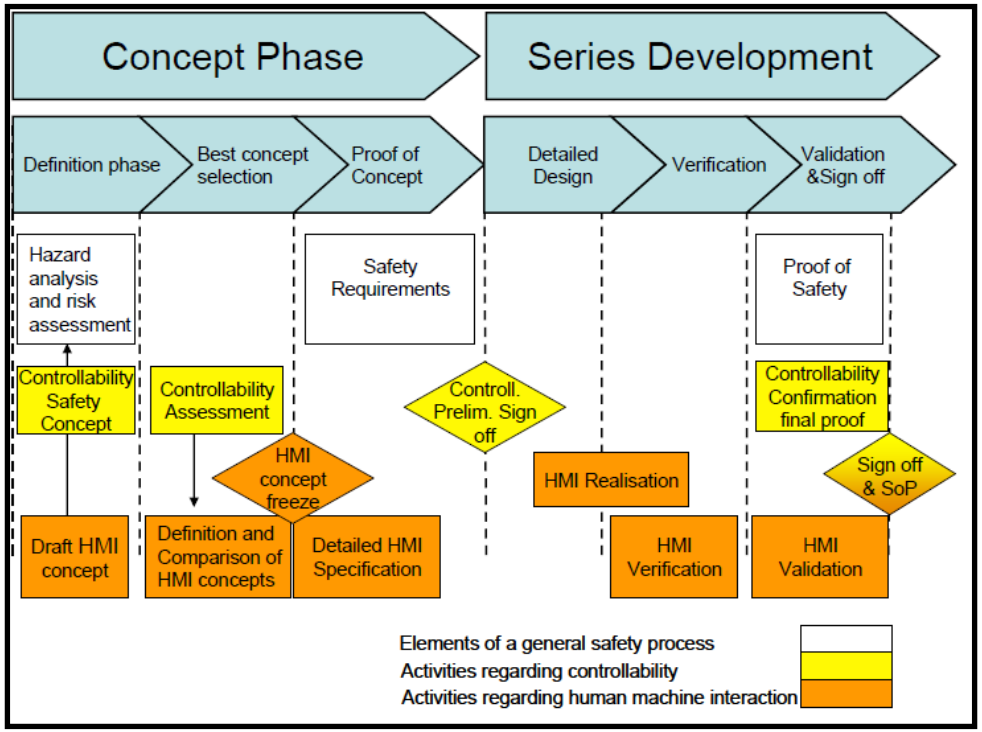


- Driving scenarios on the highway
- Assistance of the driver
- Interaction driver – assistance system

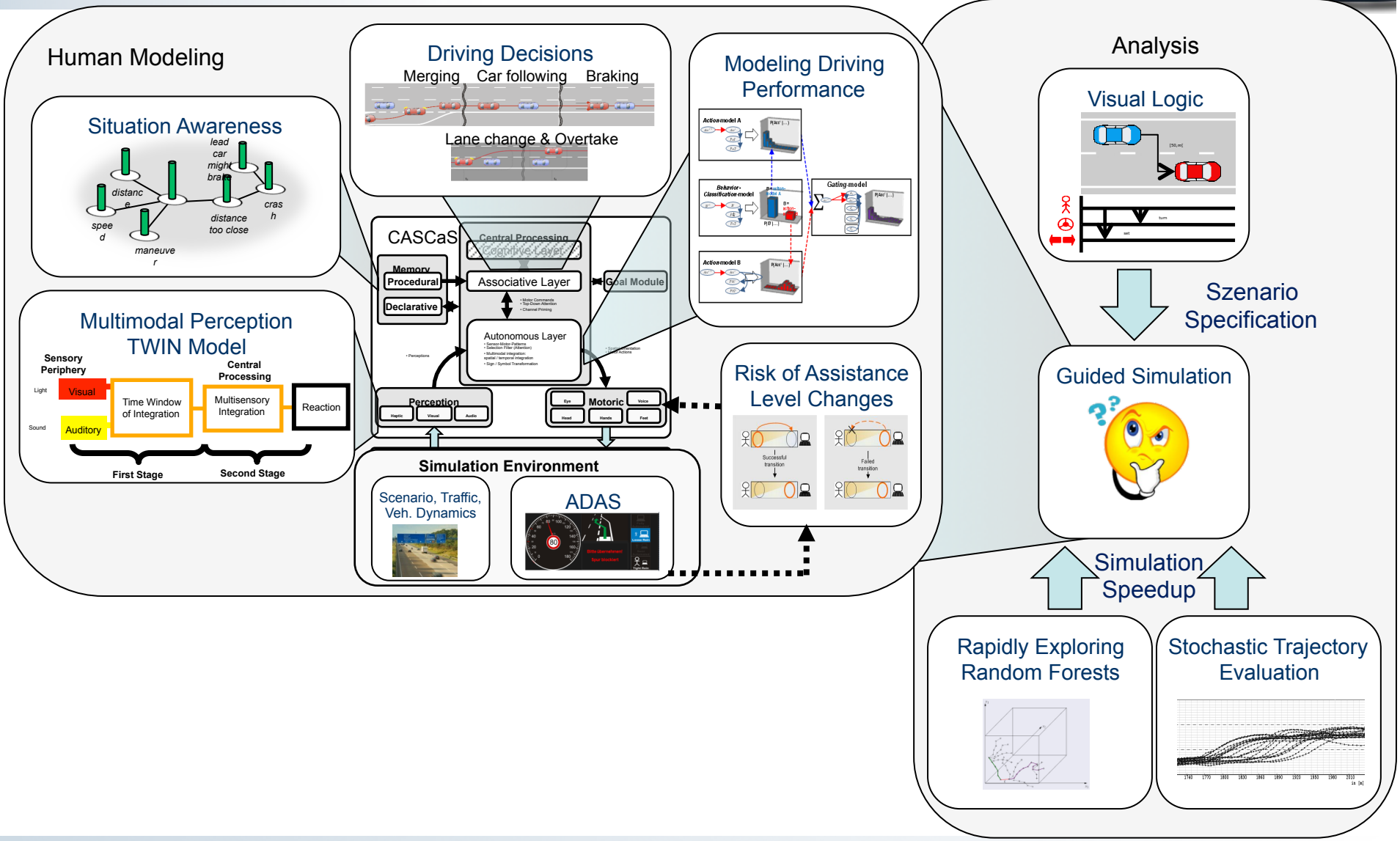


Industrial Relevance

- Improvement of the concept phase
  - Functionality
  - Acceptance
  - Safety
  - Realisability
- Embedding in industrial design process
  - Compliance with norms
    - Safety according to ISO 26262
  - Code of Practice
    - Industrial process guideline



Project Structure IMoST 2



Subproject Human Modeling

- Goal: enhance the IMoST1 cognitive driver model as a tool to model and simulate 1) multimodal Human Machine Interaction, 2) Situation Awareness & Decision Making

→ Basic model capabilities to model & simulate interaction with ADAS

- These fundamental model requirements were motivated by the Response 3 Code of Practice, e.g.:

To enable investigation if driver will ...

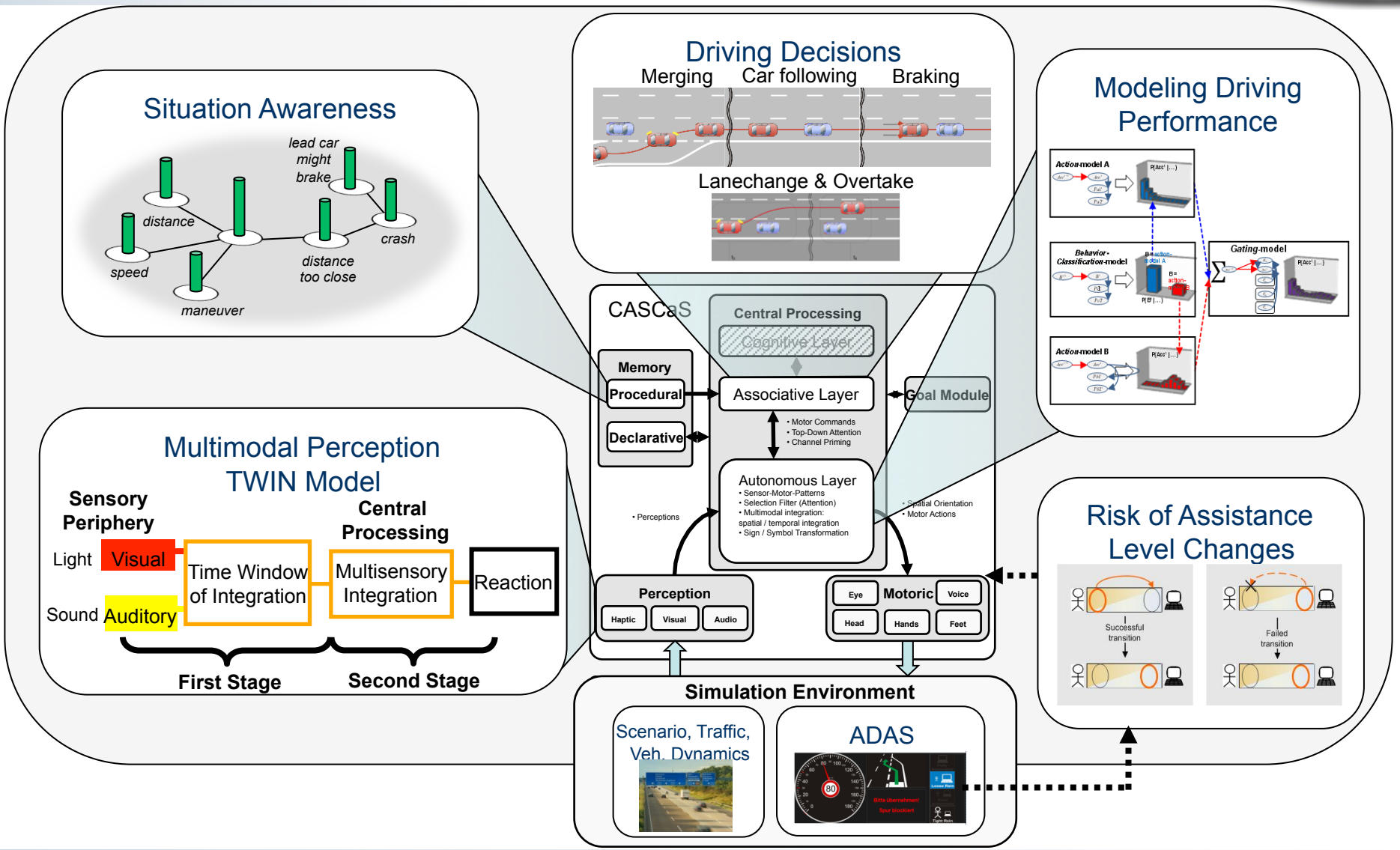
... perceive system (multimodal) signals quickly: "Can system outputs and information be **perceived** by the driver **quickly enough** to enable them to **react appropriately** (e.g. take over request from adaptive cruise control)?"
Multimodal perception

... understand what the system is doing: "Does the human-machine interaction of the system **prevent the driver from losing situational awareness** (e.g. keeping the driver in the loop, providing a consistent warning strategy)?"
Situation Awareness

... see presentation of subproject HM

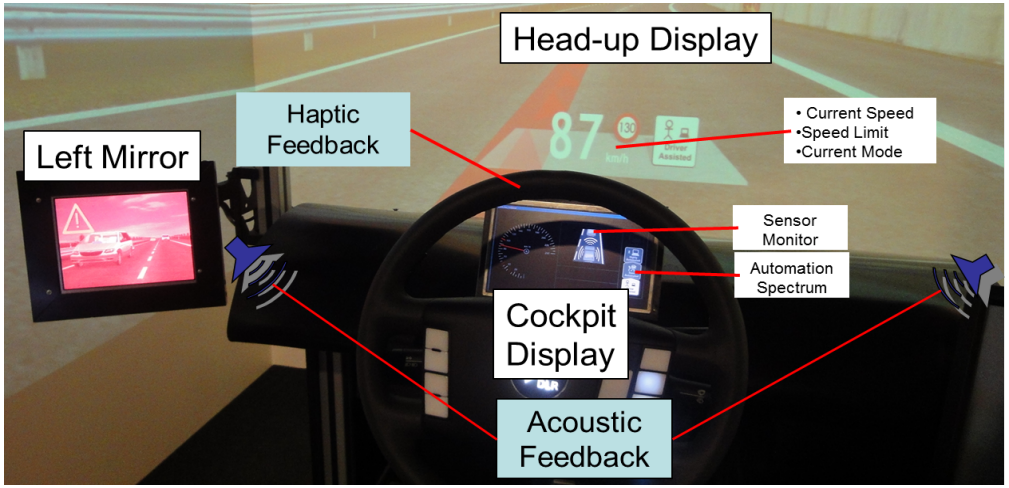
Subproject Human Modeling

IMoST
Integrated Modelling for Safe Transportation



Research Question
Perception of Multimodal Stimuli

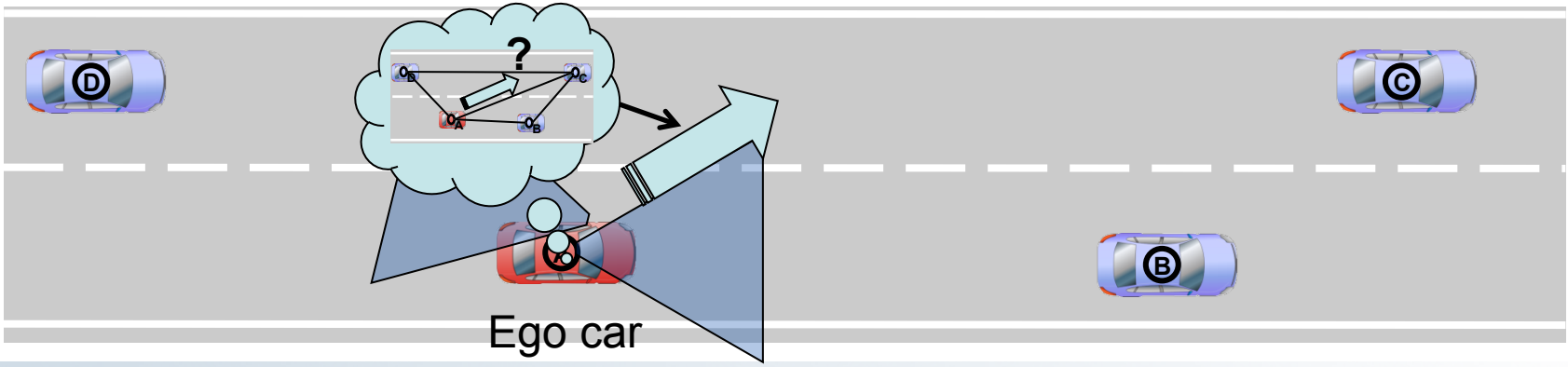
- Goal: Can the TWIN model assumptions about reaction time modeling be transferred into less controlled environment like a driving simulator?
  → Transfer basic research model into application domain
- Stimuli derived from ADAS
  - Modalities: visual, haptic, acoustic
  - Temporal order of stimuli is relevant for reaction time
  - Spatial arrangement impacts reaction time: congruent (same direction) / disparate
- Results: Both spatial and temporal effects could be found
  → TWIN model is a reasonable extension for the driver model



Research Question
Situation Representation & Decision Making

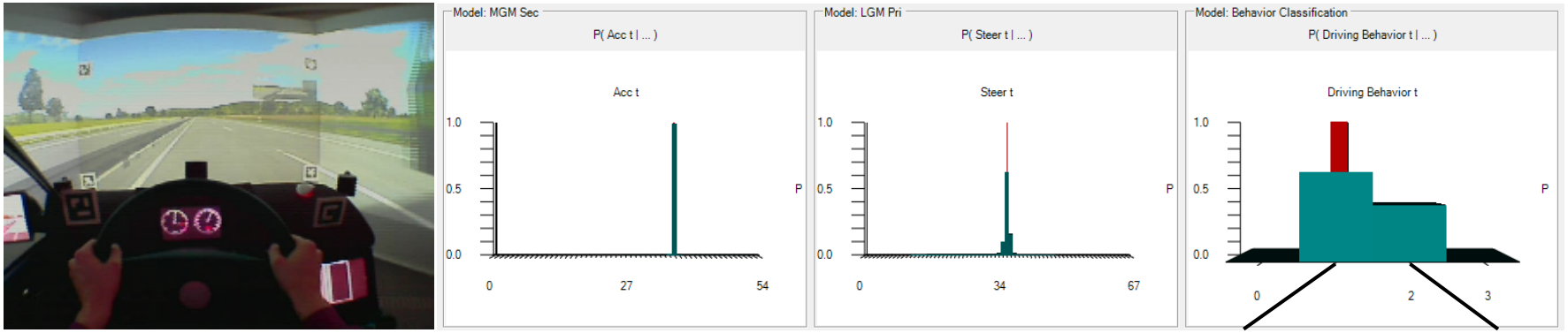
- Goal: Extend the driver model with a mental situation model which is used for manoeuvre decision making.
- Main results: the IMoST2 cognitive driver model instantiates Endsley's model of situation awareness (Endsley, 2000):
  - Perception: gaze behaviour (observe windshield, ext. mirror)
  - Comprehension: create a coherent situation. representation
    - e.g. approaching car D is far away and C is faster
  - Projection: situation assessment + intention of the driver, e.g. lane change → Predict if the gap will be acceptable?

  → Decision Making: Initiate a lane change



Research Question
Driving Performance

- Goal: Build sensory-motor models for the stabilisation and short term planning processes of human drivers on highways.
- Major results: Lateral and longitudinal control by a hierarchical and modular Bayesian Autonomous Driver model (Mixture-of-Behaviors model according to skill hierarchies)
  - Library of sensory-motor processes realized by dynamic Bayesian networks triggered by IMoST2 associative layer of cognitive driver model
  - Pertinent perceptual features derived by machine-learning methods from experimental data obtained in simulator studies
  - Possible assessment of controllability by predicting the context-dependent probability of the driver's lateral and longitudinal actions under the hypothesis of "typical" normative driving behavior

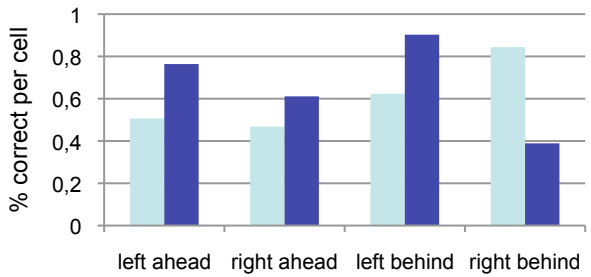


Right Lane Change **Lane Following**

Subproject Experiments and Evaluation

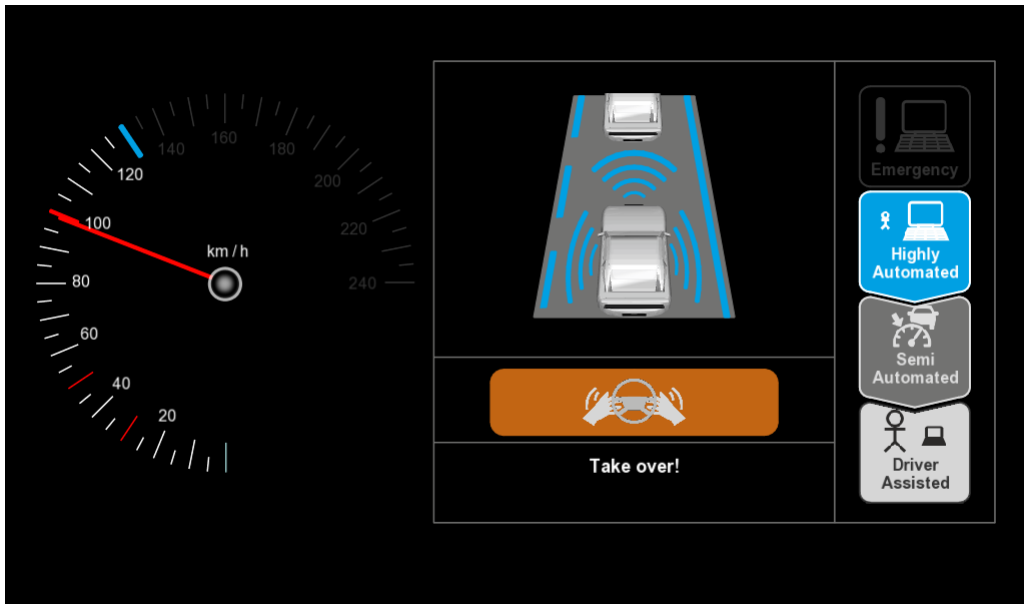
- Goal:
  - Provide the empirical basis for the modelling activities
  - and develop an innovative driver assistance system as counterpart for the modelling activities
- Main results:
  - Goal and task analysis of the relevant driving scenarios
  - Experiments on
    - Multimodal perception
    - Driving performance
    - Situation awareness

Manual



Research Question: Assistance System Development

- Goal: development of an assistance system, with different degrees of automation, supporting manoeuvres on the highway
  - Multimodal interface
  - Expected functionality?
  - Driving beyond system limits
    - Detection?
  - Transitions between degrees of automation
    - Undetected: critical! How to handle?

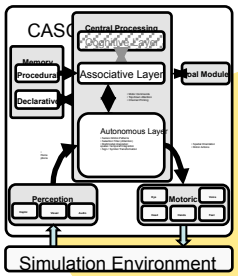


Subproject "Analysis"

- Main goal:
  - Develop specification and analysis methods for safety and functionality of the driver model and the assistance system
- Main results:
  - Techniques for simulation speed-up
  - Model analysis through criticality-driven guided simulation
  - Stochastic driving model
  - Visual logic for description of traffic scenarios

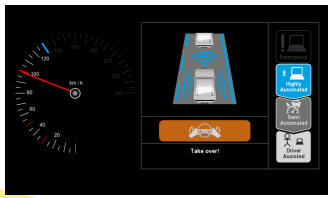
Research Question: Integrated Models

- Goal: integration of heterogeneous models of all constituents
  - Model type
  - Composition
  - Abstraction



Vehicle

Discrete parameters
Continuous parameters
Dense time



Driver

Probability
Dense time

Assistance system

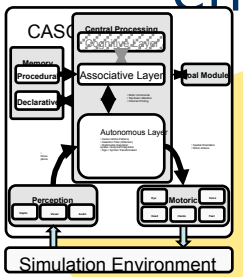
Discretised values
Discrete time

Environment

Discrete paramters
Continuous parameters
Dynamic configuration
Dense time

Research Question: Integrated Models

- Result: integration of i.a.
  - Driver model and assistance system (to be extended)
  - Driver model, assistance system and guided simulation
  - Driving simulator, vehicle dynamics and environment



Vehicle

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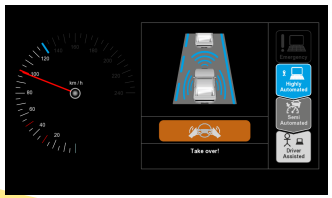


Driver

Probability
Dense time

Assistance system

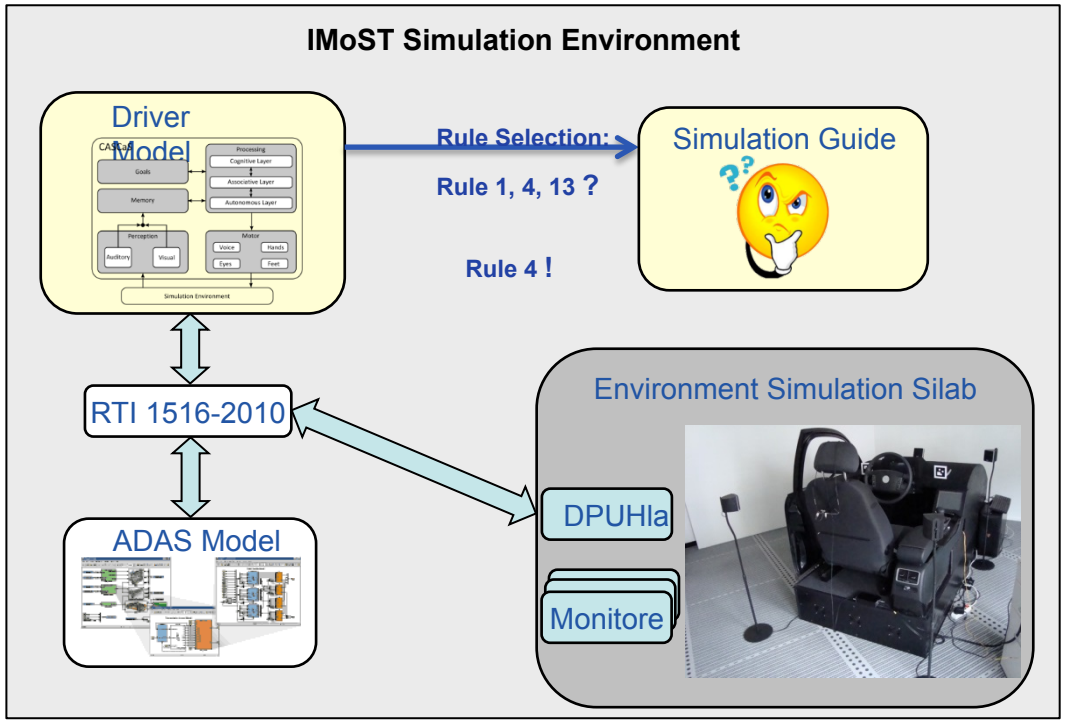
Discretised values
Discrete time

Environment

Discrete paramters
Continuous parameters
Dynamic configuration
Dense time

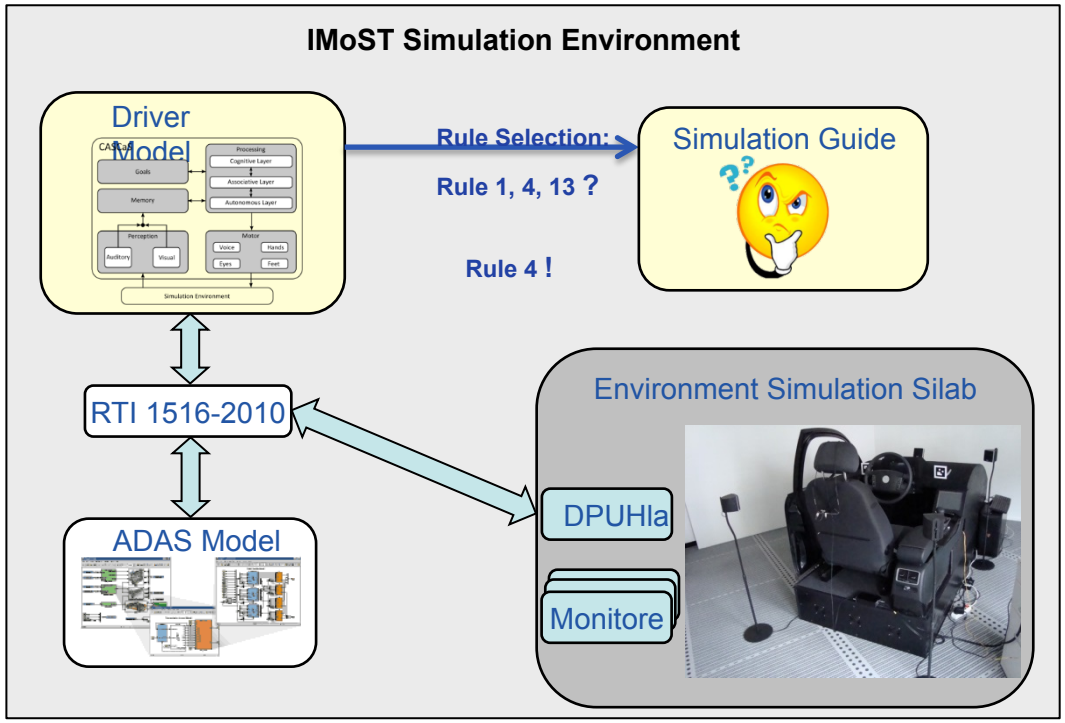
Research Question: Model Analysis

- Goal: in-depth analysis of the behaviour spectrum of the heterogeneous models
  - Functional aspects
  - Safety
- Challenges
  - Model complexity
  - Heterogeneity
    - discrete
    - continous
    - hybrid
    - probabilistic
    - dynamic



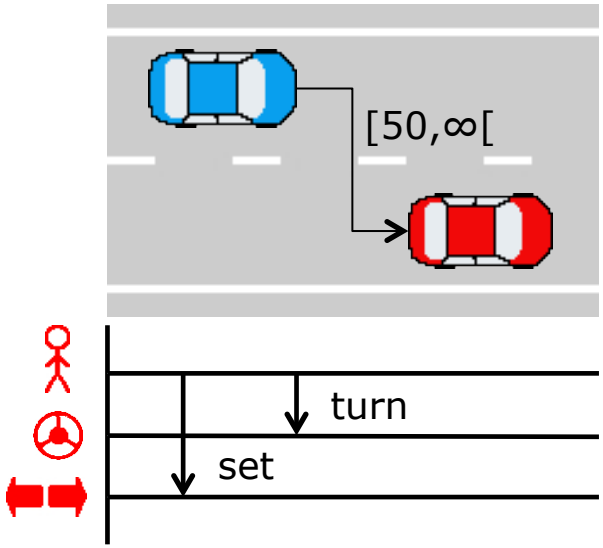
Research Question: Model Analysis

- Result: criticality driven guided simulation
  - Reach specific (rare/borderline) situations in the simulation, based on criticality measure
  - Generation of decision tree
  - In subsequent simulation runs: adapt driver model based on decision tree to reach specific situations even faster



Research Question: Visual Logic

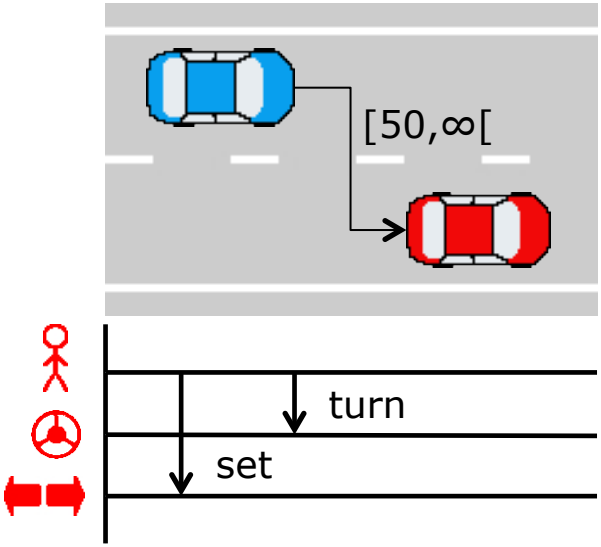
- Goal: Develop a visual description language as interface between system engineers/traffic psychologists and scientists
  - Describe traffic scenarios (movements of vehicles) on the highway

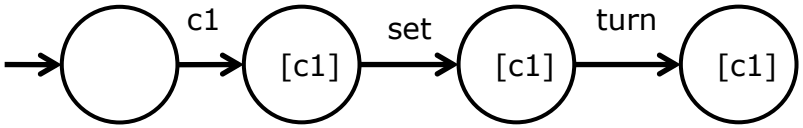


- Intuitive, easy to understand and use
- Formal syntax and semantics

Research Question: Visual Logic

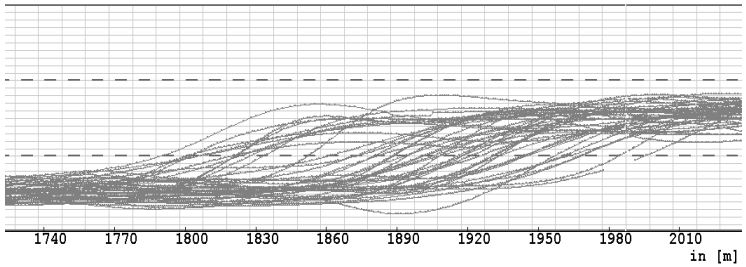
- Result: Visual Logic
  - Two parts
    - "Snapshot" describing spatial situation
    - Communication part describing communications, based on Live Sequence Charts
  - Formal semantics: translation into timed automata





Research Question: Simulation Speed-up

- Goal: Reduce needed simulation time by generating new sample trajectories without having to run the simulation engine (again)
  - Simulation is time-consuming
  - Meaningful statistics need many simulation runs



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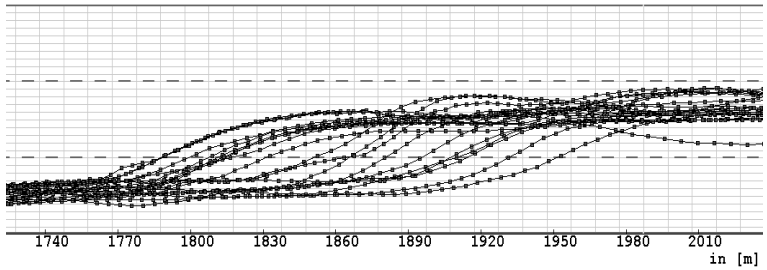

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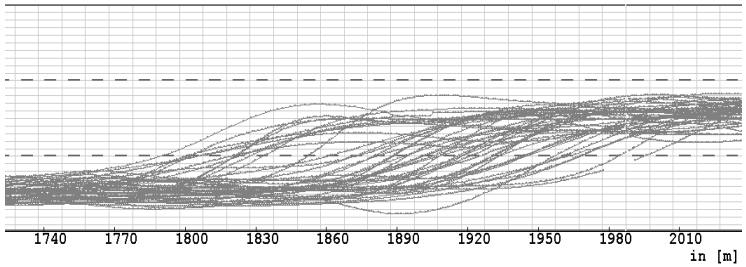
Research Question: Simulation Speed-up

- Results: Generation of new trajectories from existing ones:
  - Recombination of trajectories using sufficiently similar (ε-similar) states
  - Iterative generation of trajectories using stochastic models



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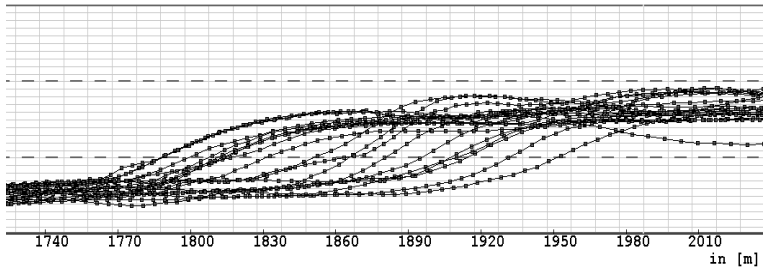


Generated

IMOST Results I

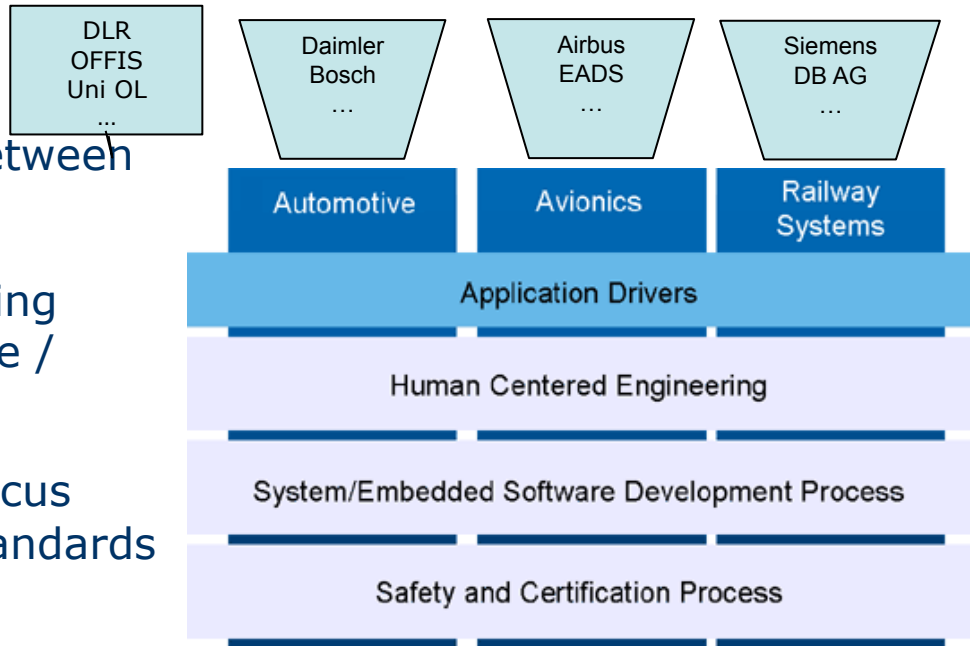
- Virtual test driver
  - Empirically validated model of driver behaviour
    - In complex dynamic situations
    - In interaction with the assistance system (to be extended)
    - Normal behaviour and misbehaviour
  - Theoretical foundations completed, technical integration still to be finished
- Virtual test track
  - Holistic real-time co-simulation of test driver, assistance system, vehicle and traffic
  - On-line predictive assesment with respect to safety and controllability

IMOST Results II

- Driver assistance system
  - Different levels of automation
  - Different types and locations of stimuli, based on (empirically validated) most advantageous combinations
- Analysis techniques
  - Simulation speed-up
  - Criticality-driven guided simulation to reach specific situations
  - Stochastic driving model for efficient modelling of complex behaviours
  - Visual logic for description of traffic scenarios

Strategic context

- SafeTrans e.V.
  - Institutional cooperation between academia and industrie
  - High safety despite increasing traffic volume in automotive / avionics / railway
  - Model-based design with focus on Humans / Systems / Standards for embedded systems
  - Models incorporate all aspects of the system design
  - Development of advanced analysis techniques



Future Work

- Driver model as integral part of the assistance system ("cognitive assistant")
  - Prediction of driver behaviour to improve assistance
- Continuous migration process from verified concepts to realisation, conforming to ISO-26262 and the CoP
- Improvement of analysis techniques
  - Further simulation speed-up
  - A user-friendly tool for visual logic
  - Integration of guided simulation with driver and assistance system

Continuation of IMoST2 Results in other Projects

- CSE (Interdisciplinary Research Center on Critical Systems Engineering for Socio-Technical Systems), Subproject "The car that cares"
  - Car monitors health status of driver
  - Health status critical ➔ take appropriate measures
  - Support especially for elderly people, e.g. automatic driving

- Related IMoST2 results
  - Interactive HMI
  - Findings of experiments related to assistance system
  - "Deceleration to safety" feature of assistance system

Continuation of IMoST2 Results in other Projects

- HoliDes (Holistic Human Factors and System Design of Adaptive Cooperative Human-Machine Systems)
  - Develop and qualify adaptive cooperative human-machine systems

- Employed IMoST2 results
  - IMoST2 driver models are enhanced with respect to interaction with adaptive assistance systems
  - The Bayes model is being integrated into a driver assistance system to serve as driver intension detection

Continuation of IMoST2 Results in other Projects

- D3COS (Designing Dynamic Distributed Cooperative Human-Machine-Systems)
  - Build cooperative driver assistance systems
  - Test them with human drivers

- Employed IMoST2 results
  - Results from subproject "Human Modelling", especially results related to perception
  - Results are adapted to pilot (instead of car driver) behaviour

Thank you!