Automated and Connected Vehicles – Overview

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DLR

Automated and Connected Vehicles (1/2)

Abbildung: acatech

- The mobility of the future should be
  - safe
  - secure
  - clean and efficient

- In particular, automated and connected vehicles will significantly help to
  - improve traffic flow
  - reduce the occurrence of critical situations
  - optimize the handling of planned and unplanned incidences
  - relieve the pressure on drivers and the environment
  - generate added value and stimulates innovative business models

- As the market penetration, the degree of automation, and the level of interconnection will rise, the benefits that can be derived from these developments will also increase.

(cf. Strategy for Automated and Connected Driving of the Federal Ministry of Transport and Digital Infrastructure (BMVI))

Automated and Connected Vehicles (2/2)

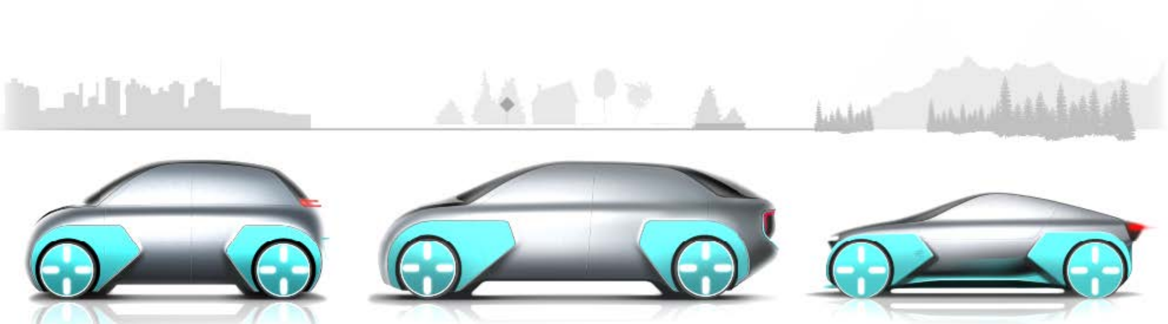


Figure: DLR – Next Generation Car

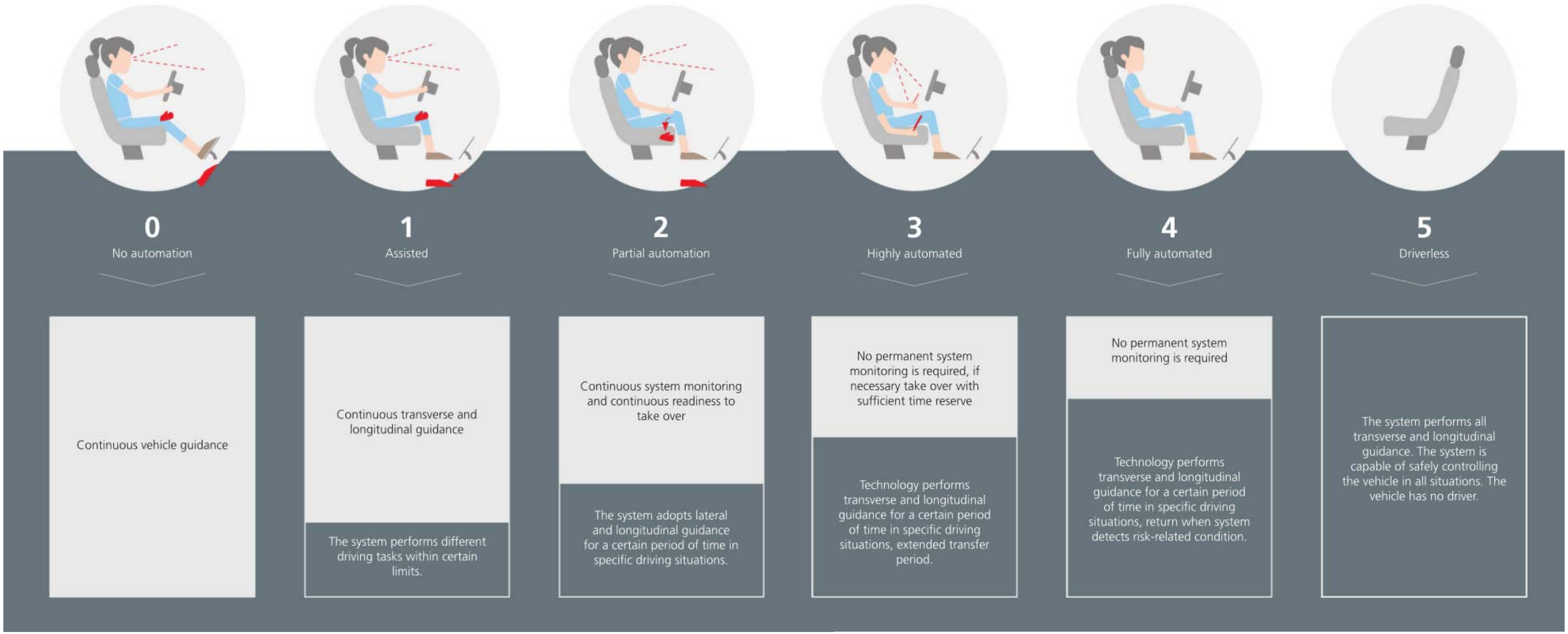
- Beside the action areas
  - *Infrastructure*
  - *Interconnectivity*
  - *Cyber Security* and *Data Protection*
  - *Legislation*

  the action area *Innovation* is currently of high interest in Germany

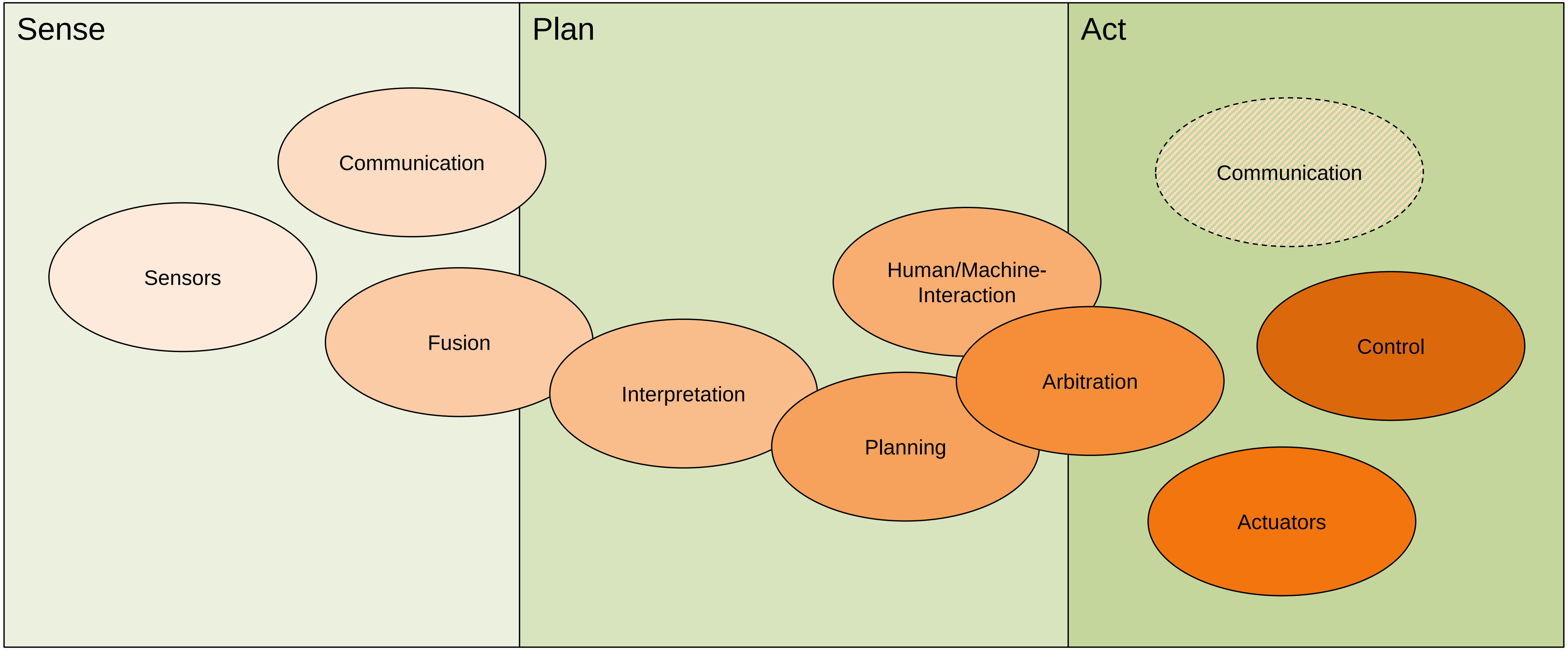
- Within the action area *Innovation* major topics are e.g.
  - automated and connected vehicle functions
  - human/machine interaction
  - intelligent traffic-infrastructure
  - the social dimension of automated and connected vehicles/traffic-systems
  - methodologies and tools/toolchains for verification and validation
  - facilities and test beds for development and test

(cf. Strategy for Automated and Connected Driving of the Federal Ministry of Transport and Digital Infrastructure (BMVI))

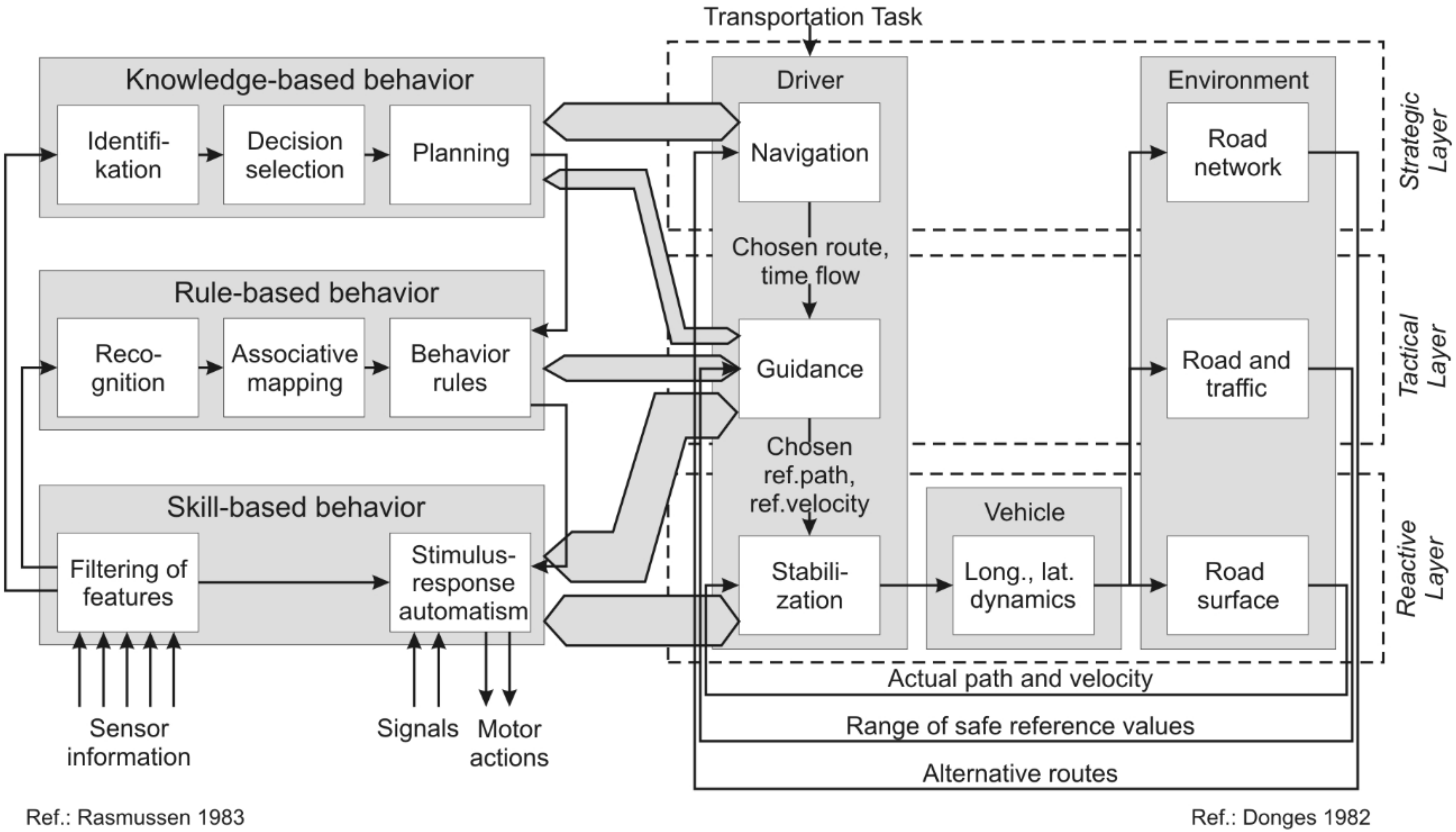
Automated and Connected Vehicles – Levels of Automation (1/2)



Modules for Automated and Connected Driving



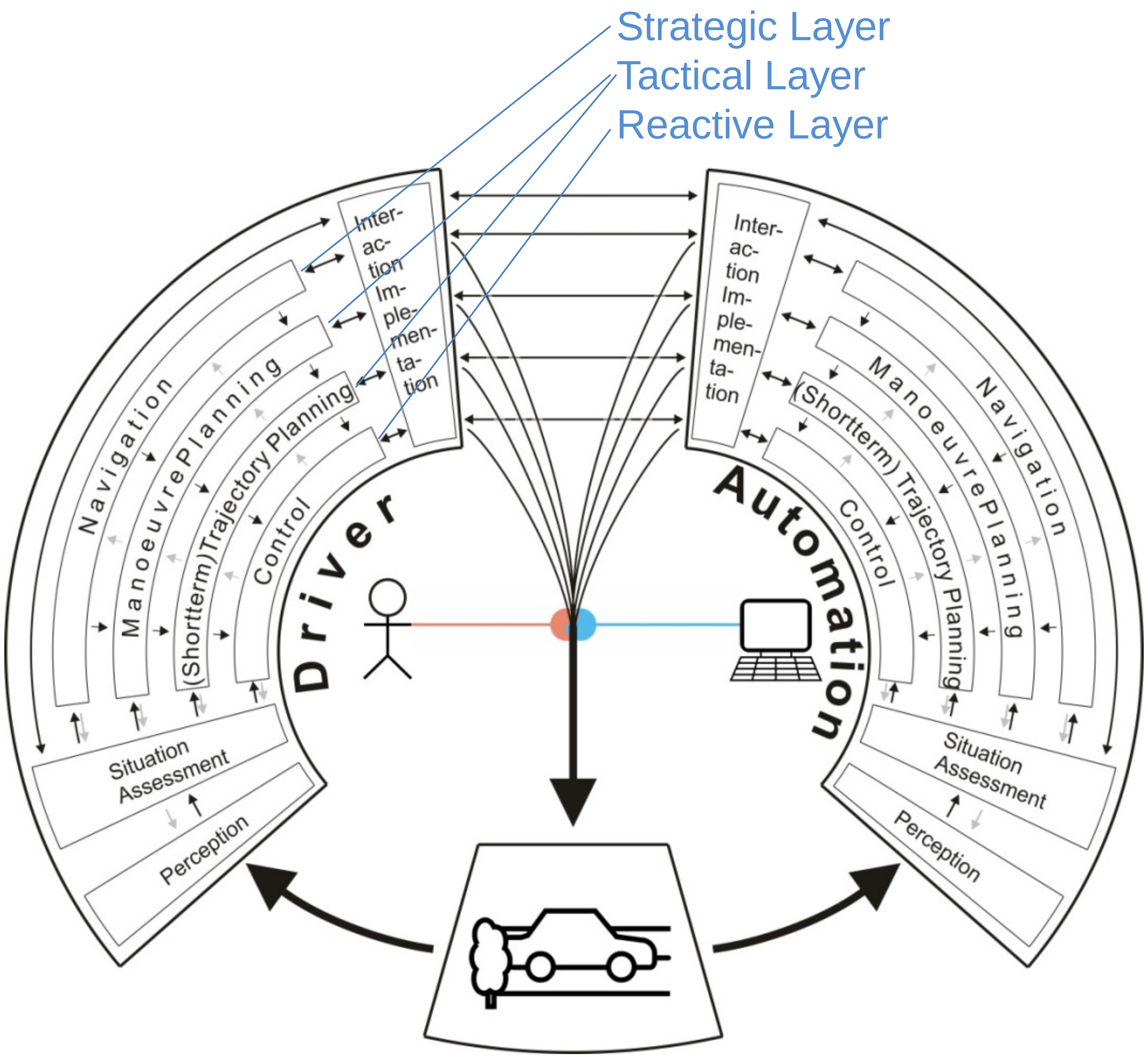
Driving Task



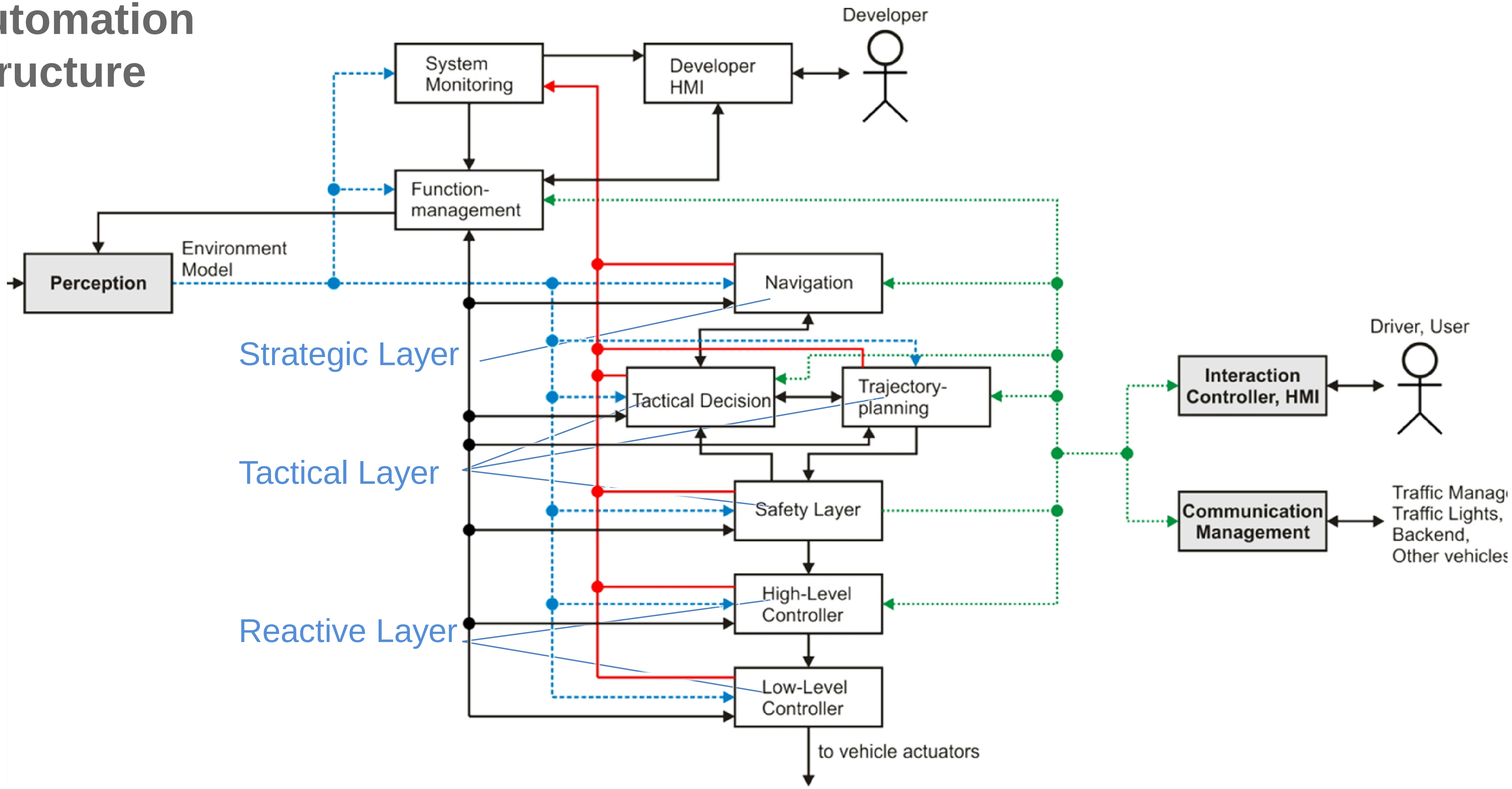
Source: Hesse (2012), Donges (2009)

Driver Compatible Automation

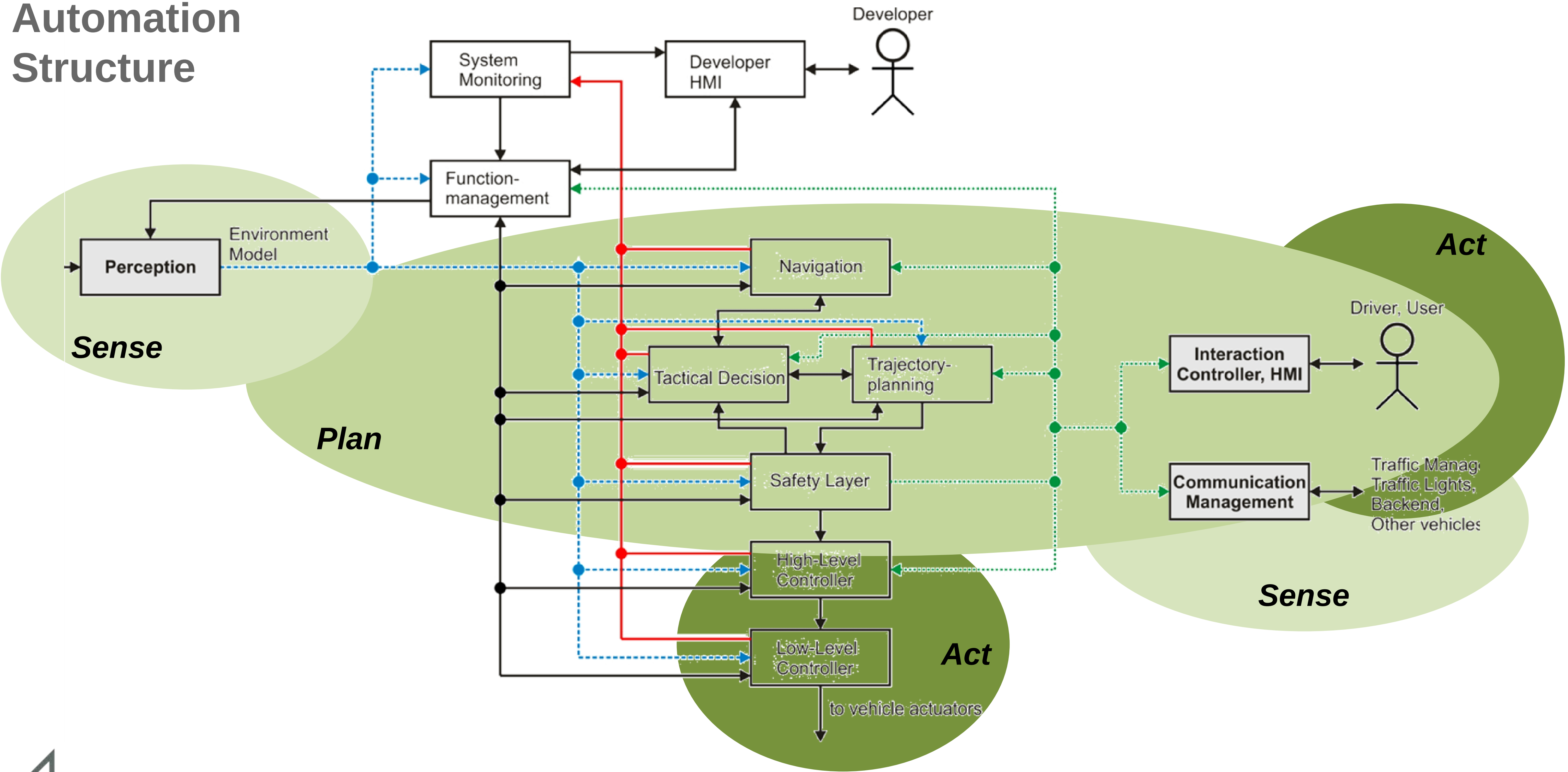
- Driver-compatible automation
- Enable intuitive mental model
- Enable explicit and implicit arbitration with driver
  - Explicit: e.g. Displays, Sounds, haptic patterns
  - Implicit: e.g. Behavior of vehicle



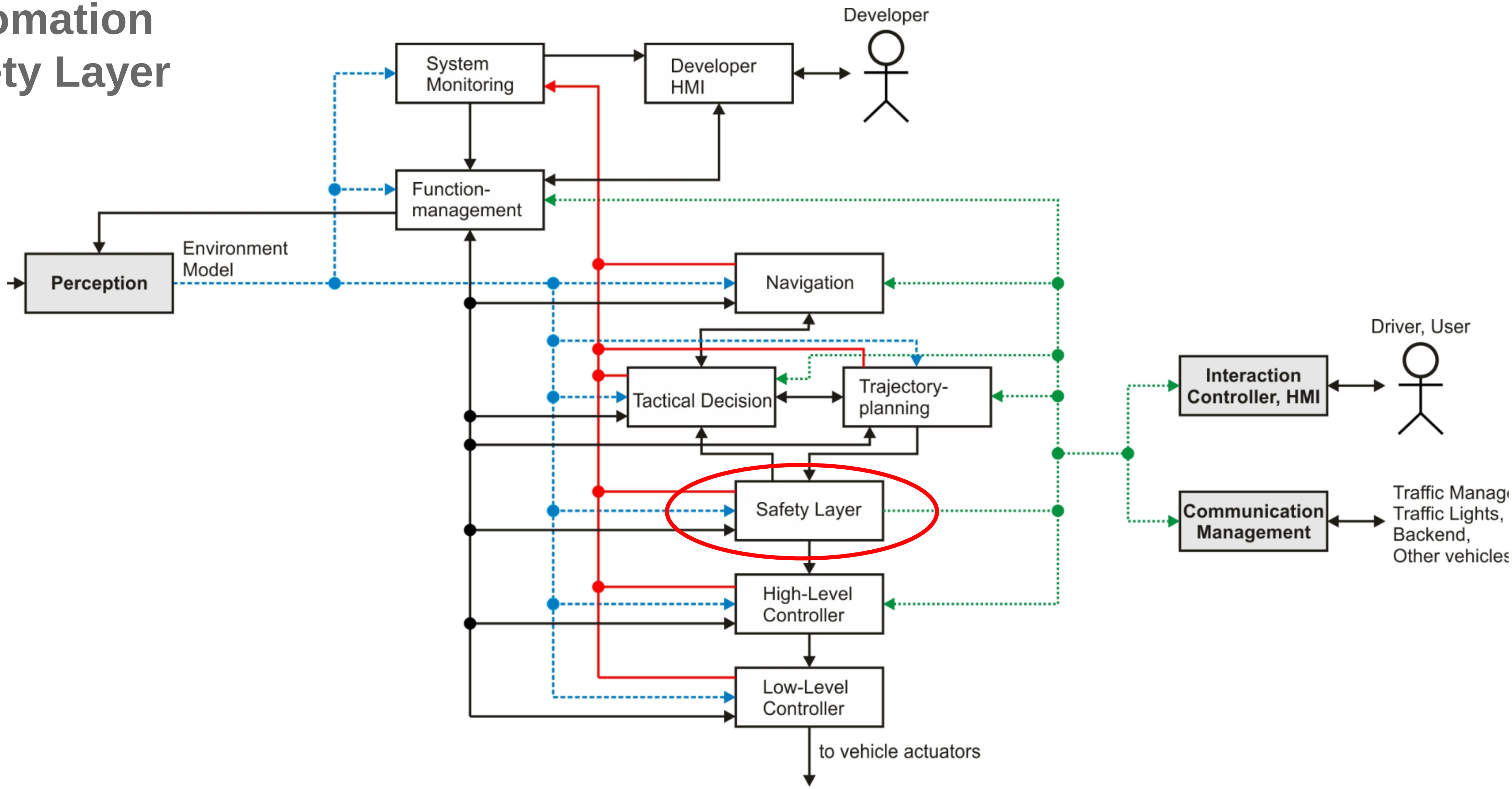
Automation Structure



Automation Structure

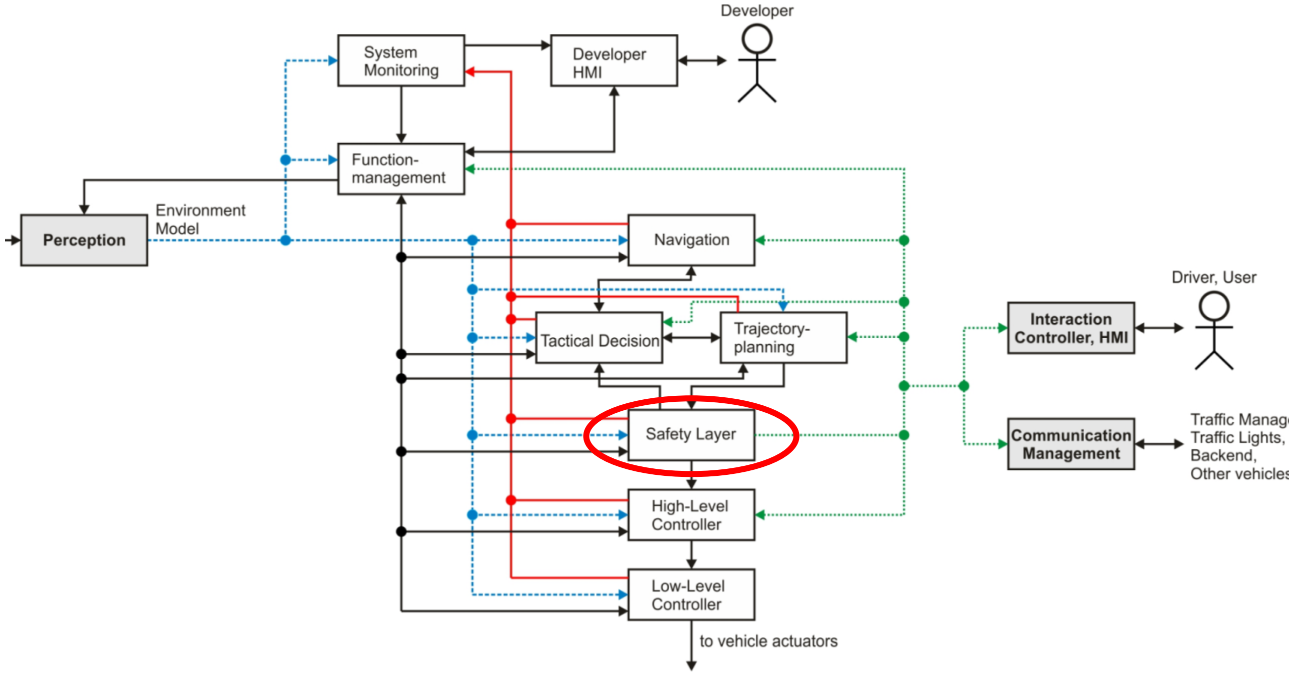


Automation Safety Layer



Automation
Safety Layer

- Safety Layer only allows safe actions by automation (maybe even by driver)
- Must be provably safe
- Allows more freedom in design, used algorithms, updates of other nominal planning algorithms



DLR

Motivation:
Safety and Reliability: Testing at its Limits

- Unexpected,
  non-standardized situations

- Testing at its limit:

  Official press release from Robert Bosch GmbH
  "*If you were to test an automated car like a 'normal' vehicle, you'd have to drive it for several 100,000 years. Therefore, entirely new testing processes need to be developed for automated vehicles and the entire industry is still in the early stages, in this regard.*“ [1]

https://pixabay.com/p-327989/

[1] http://videoportal.bosch-presse.de/en/clip/_/Abt/CC/robert-bosch-gmbh-abstatt-chassis-systems-control-30

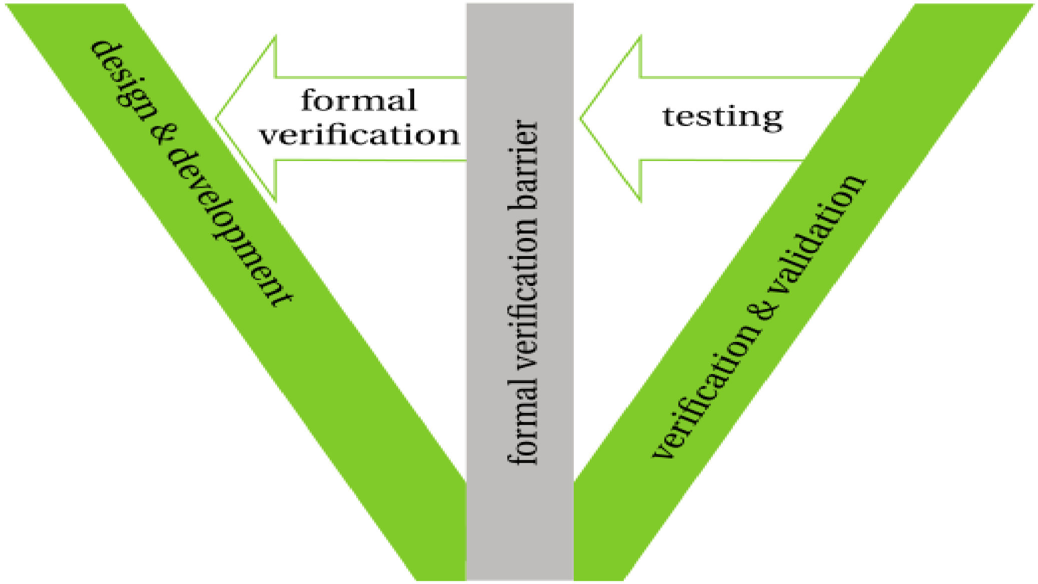
New development techniques vs classical V-diagram

- Classical Verification at its limit („verification barrier“):
  Estimation of the number of variables for classical verification approach [2]:
  - 4 for every surrounding vehicle:
    Position (x,y), velocity, orientation
  - 3 for each lane:
    Width, curvature, change of curvature
  - 8 for Ego-vehicle:
    Position (x,y), velocity, orientation, yaw rate, slip angle, road friction, current loading

  For only 20 values per variables, only 10 surrounding vehicles, only 5 lanes:

  (20^4)^10 * (20^3)^5 * 20^8 ≈ 10^81

  (≈ number of atoms in the observable universe)

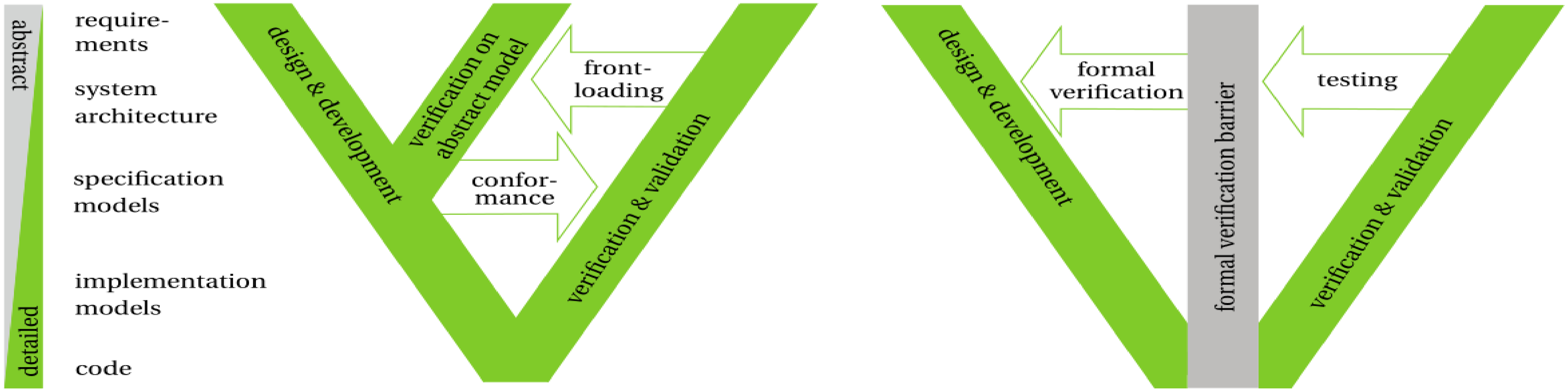


(b) Formal verification barrier.

Pictures: Description of Work UnCoVerCPS

[2] M. Althoff and J. M. Dolan, “Set-based computation of vehicle behaviors for the online verification of autonomous vehicles,” in Proc. of the 14th IEEE Conference on Intelligent Transportation Systems, 2011, pp. 1162–1167.

New development techniques vs classical V-diagram



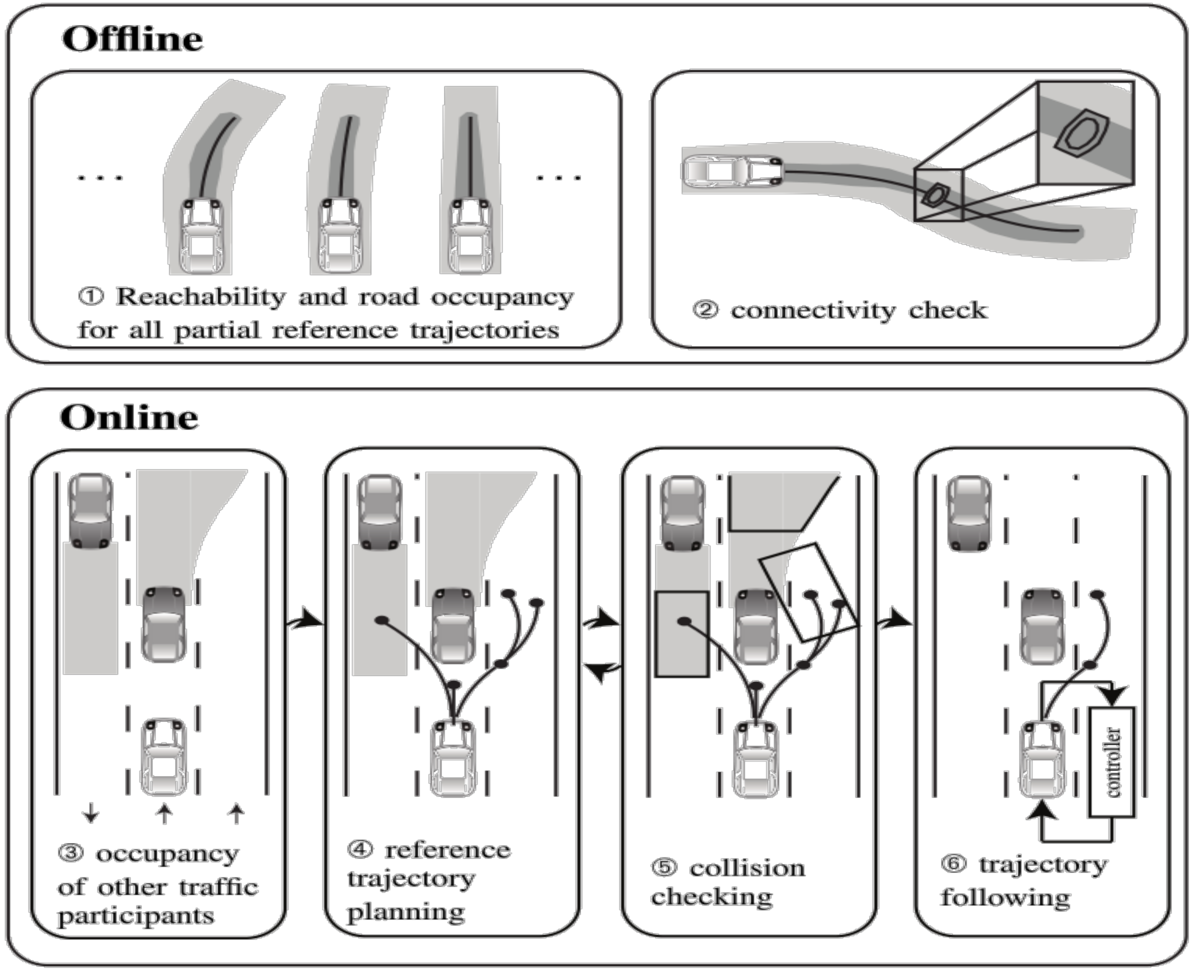
(a) Front loading of verification tasks.

(b) Formal verification barrier.

- Closed loop verification (controller + system)
- Offline pre-verification of behavior components
- Online „on-the-fly“ verification

Pictures: Description of Work UnCoVerCPS

Our Current Approach to Safe Automated Driving



Pictures: Description of Work UnCoVerCPS

1. Verfication of the closed-loop behavior for short maneuver stubs „safe **motion primitives**“

➔Reachable sets of system state

➔Occupancy of x-y-t-space

2. Initialconditions for sequencing of the motion primitives

➔Safe **Maneuver Automaton**

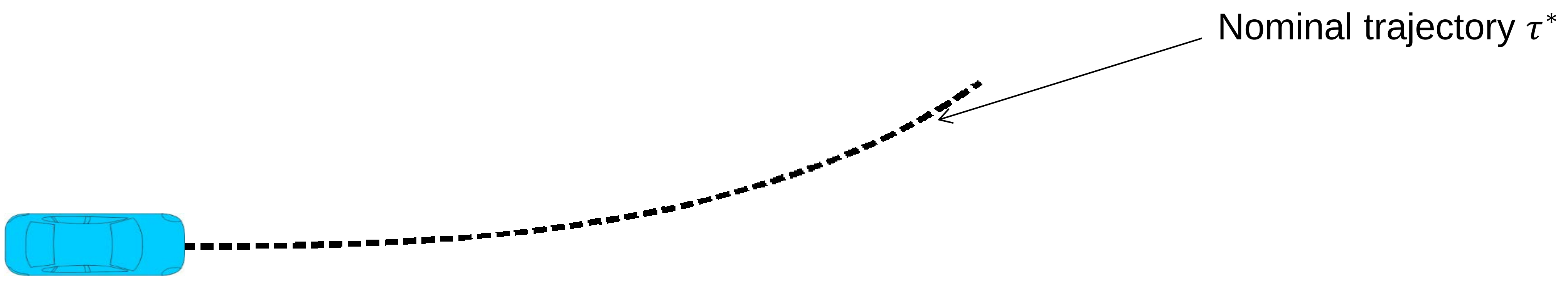
3. Prediction of other participants with formal guarantees

4.-5. Planning of a safe overall maneuver

6. Execution of offline pre-verified behaviors

[3] D. Heß, M. Althoff, T. Sattel. Formal verification of maneuver automata for parameterized motion primitives. In 2014 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2014), , 1474-1481, IEEE 2014.

Pre-computation of a Safe Maneuver Automaton (offline)



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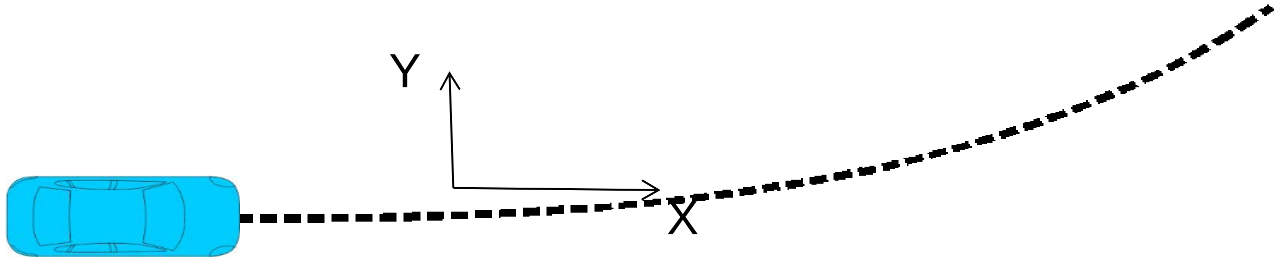

E.g. τ_1^* as an Euler Spiral

$$\dot{X}^* = v^* \cdot \cos(\theta^*)$$
$$\dot{Y}^* = v^* \cdot \sin(\theta^*)$$
$$\dot{\theta}^* = v^* \cdot \kappa^*$$
$$\dot{\kappa}^* = p_{1,1}$$
$$\dot{v}^* = p_{1,2}$$

➔ Two trajectory parameters $p_{1,1}, p_{1,2}$

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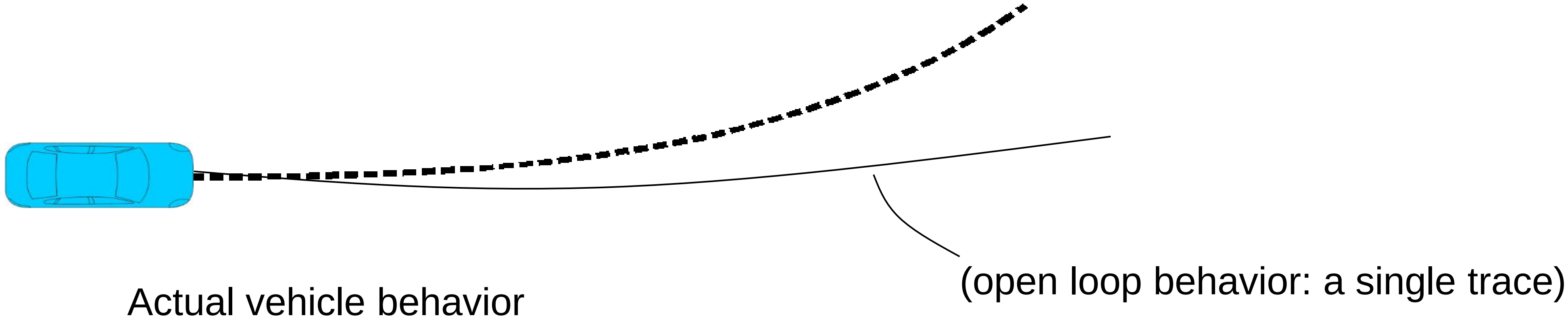
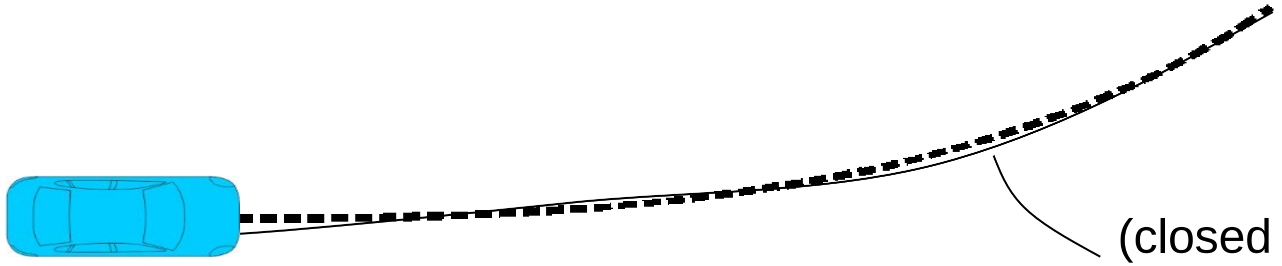


Actual vehicle behavior

$$\dot{X} = v \cdot \cos(\theta)$$
$$\dot{Y} = \mathrm{v} \cdot \sin(\theta)$$
$$\dot{v} = f_1(v, \dot{\theta}, \beta, u) + \xi_1$$
$$\ddot{\theta} = f_2(v, \dot{\theta}, \beta, u) + \xi_2$$
$$\dot{\beta} = f_3(v, \dot{\theta}, \beta, \mathrm{u}) + \xi_3$$

Pre-computation of a Safe Maneuver Automaton (offline)



(closed loop behavior, single trace)

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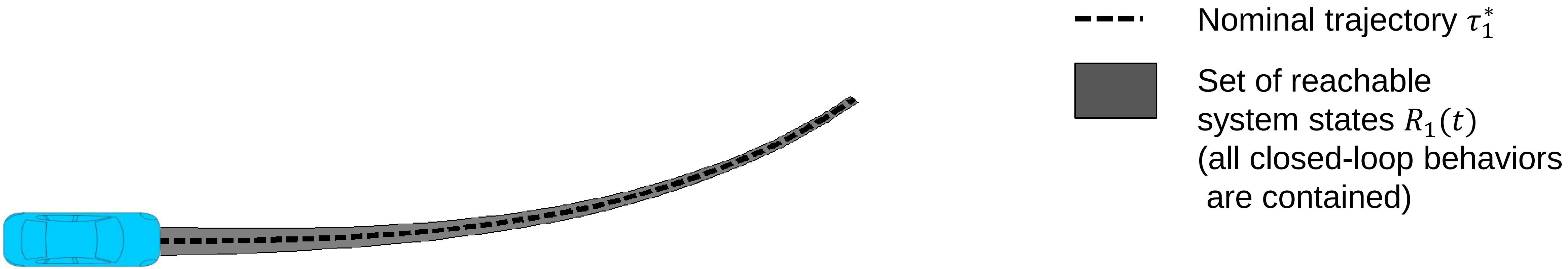
+ controller

$$u \coloneqq c_1(X - X^*, Y - Y^*, \theta - \theta^*, \ldots)$$

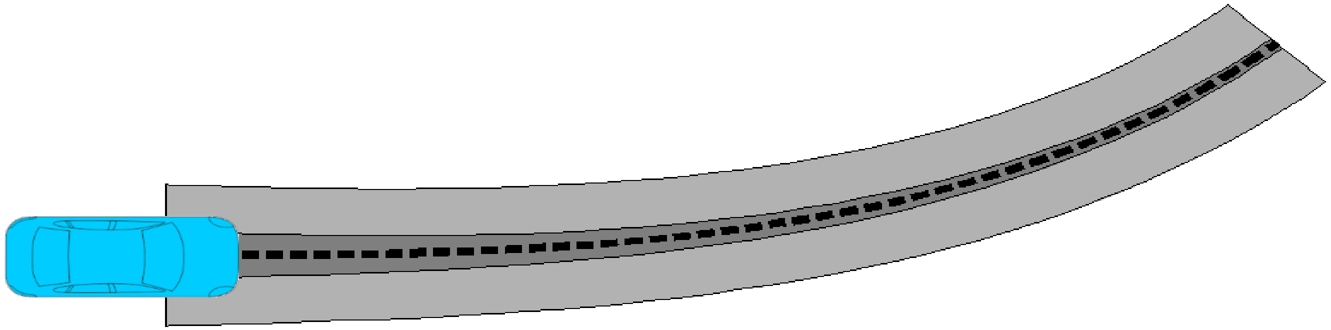
Pre-computation of a Safe Maneuver Automaton (offline)



Comput Reachable Set trajectory $R_1(t)$

- For closed loop system
    - with bounded disturbances
    - with parameters of τ_1^*
- For an initial set $R_1(0)$
- With an end set $R_1(t_f)$

Pre-computation of a Safe Maneuver Automaton (offline)



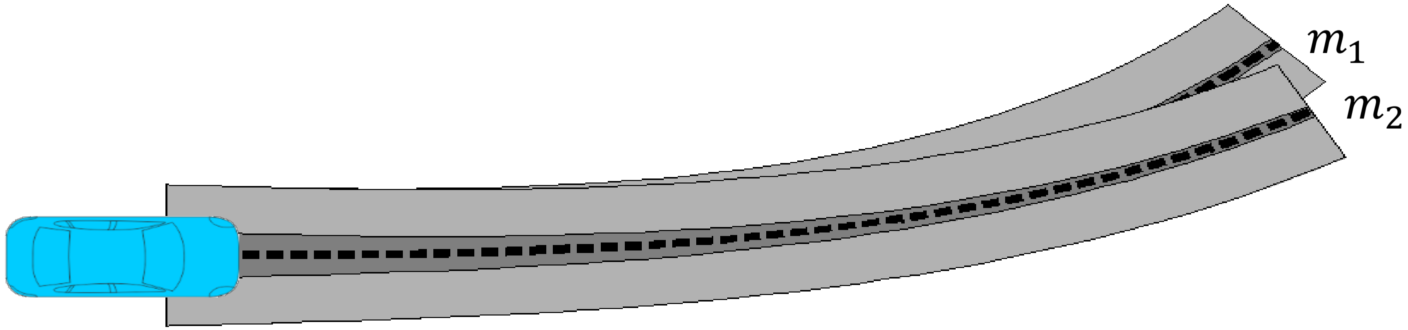
Nominal trajectory τ_1^*

Set of reachable system states $R_1(t)$ (all closed-loop behaviors are contained)

Set of positions possibly covered by vehicle body
➔ Used for collision tests

1. Repeat computation of reachable sets for multiple, short maneuvers

Pre-computation of a Safe Maneuver Automaton (offline)



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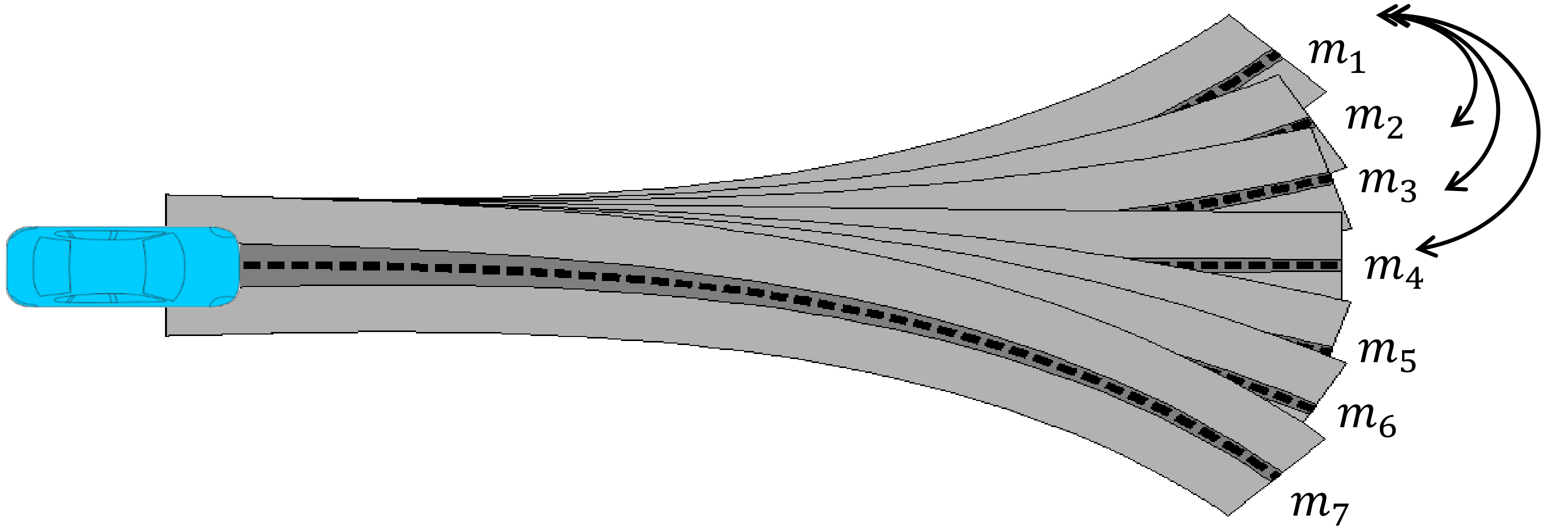

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1. Repeat computation of reachable sets for multiple, short maneuvers
2. Decide which maneuvers can be safely connected $R_i(T_i) \subseteq R_j(0) \Rightarrow connectible(i,j)$

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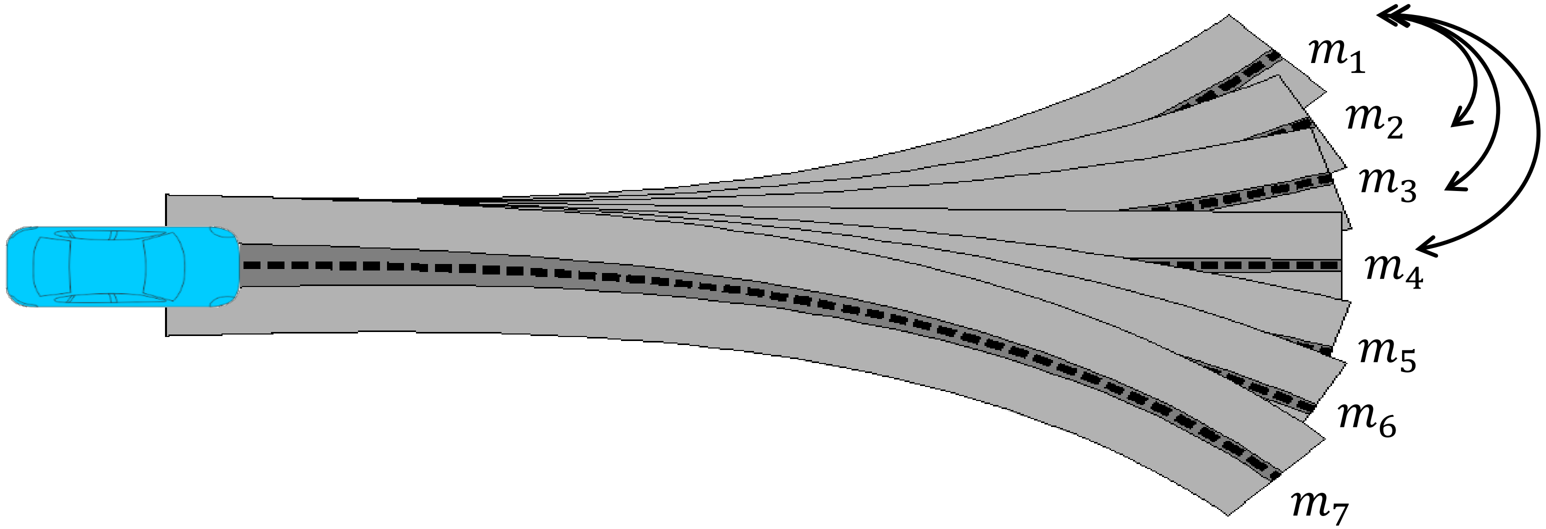

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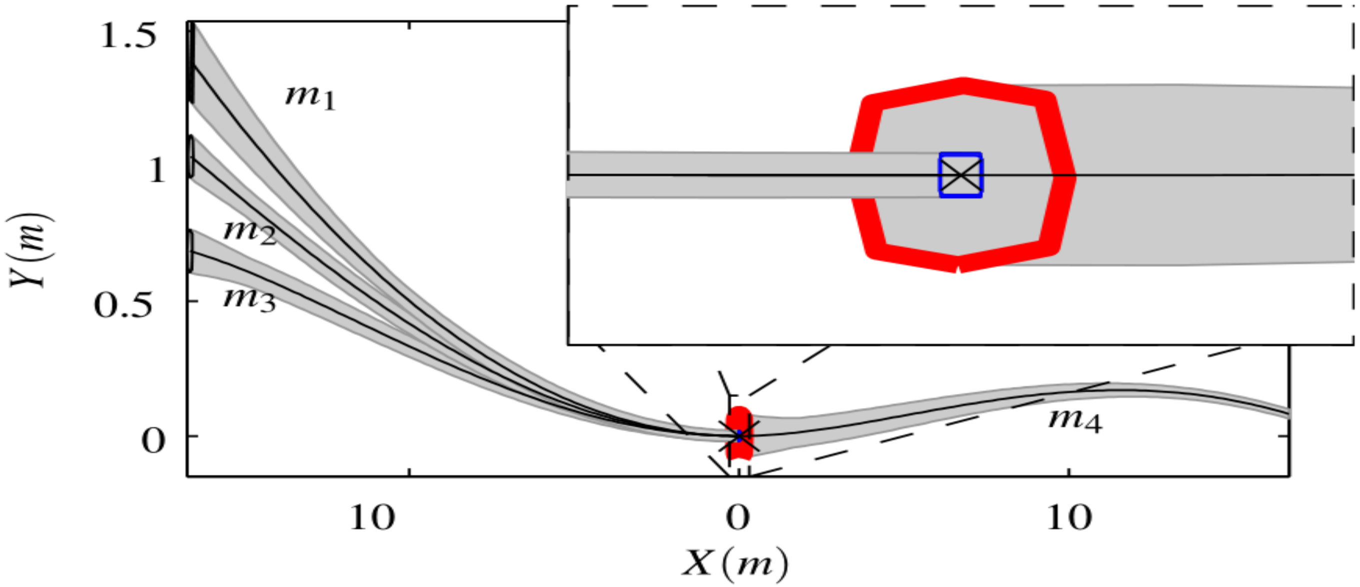
➔ Safe Maneuver automaton
➔ Set of „motion-primitvies", from which complex motions can be assembled

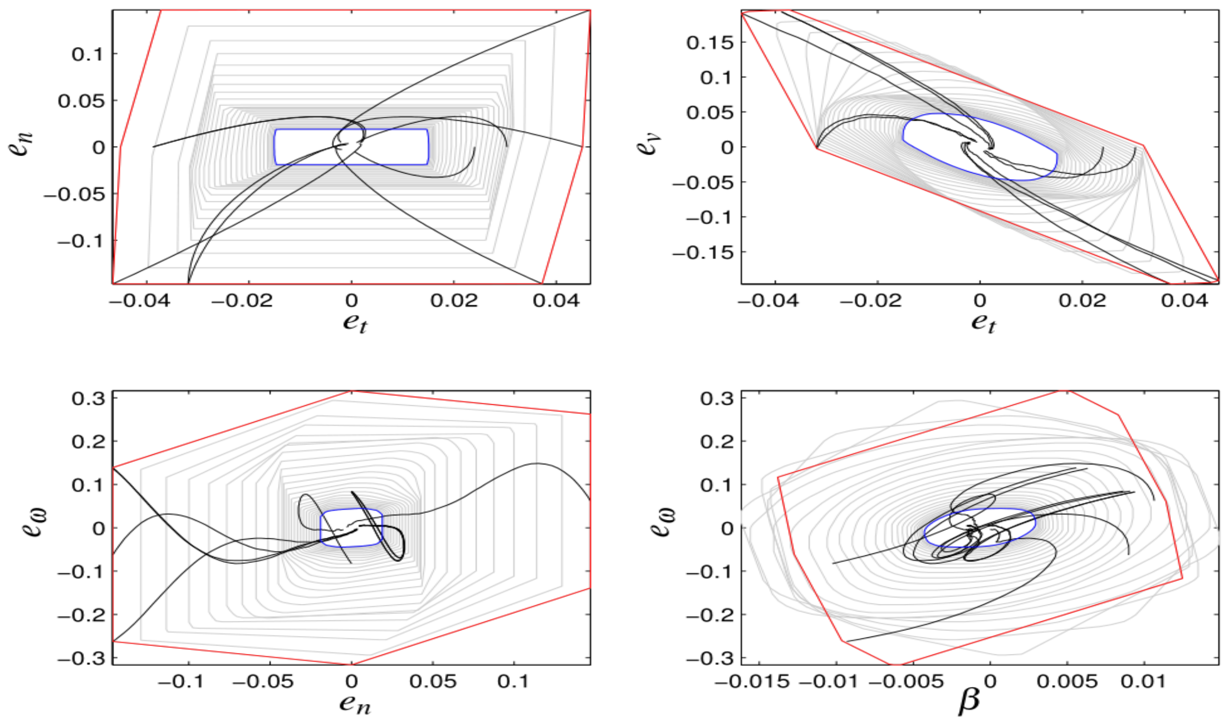
Pre-computation of a Safe Maneuver Automaton (offline)

Safe Maneuver Sequences:



- $R_i(t), t \in [0, T_i]$: Reachable set of motion primitive i.
- System state x is guaranteed to be in Reachable set $x(t) \in R_i(t),\ t \in [0, T_i]$, when executing maneuver i
- $R_i(T_i) \subseteq R_j(0) \Rightarrow$ Maneuver j may be safely executed after maneuver i

Example for Reachable Sets

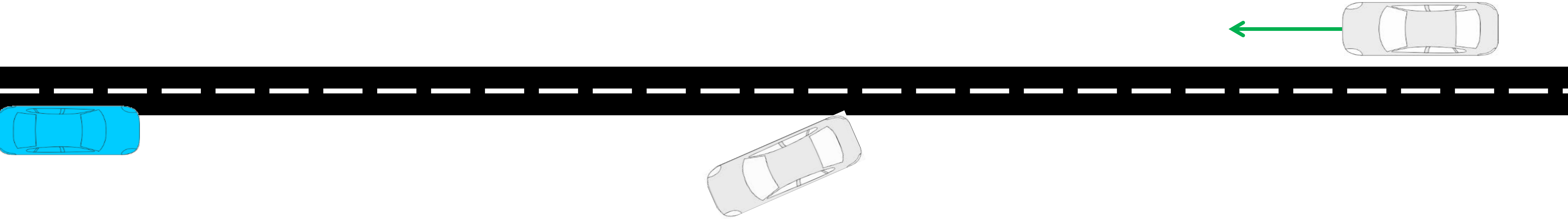


- System state: Tracking error
  - e_t longitudinal deviation
  - e_n lateral deviation
  - e_v velocity error
  - e_ω yaw rate error
  - β slip angle

- **Red:** $\boldsymbol{R_i(0)}$ initial set, before maneuver i
- **Blue:** $\boldsymbol{R_i(T_i)}$ final set, after maneuver i
- Gray: Intermediate sets
- Black: Example traces

$R_i(T_i) \subseteq R_i(0) \Rightarrow$ Maneuver i may be executed after itself (infinitely often)

Combinatorial Planning
with Pre-computed Safe Maneuver Automaton



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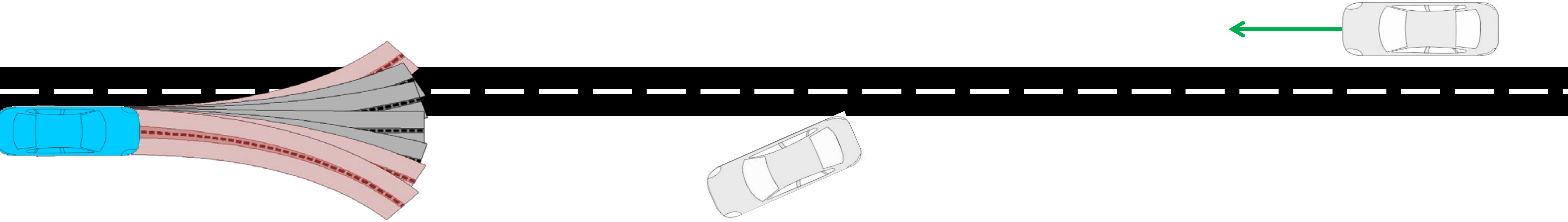

Combinatorial Planning
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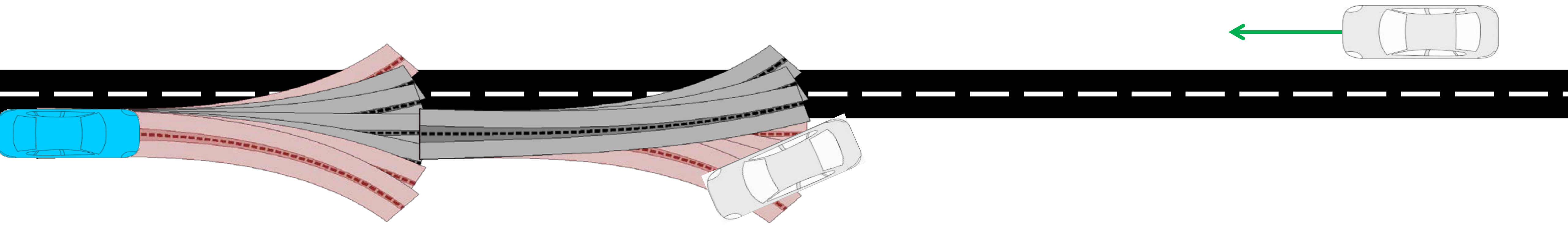

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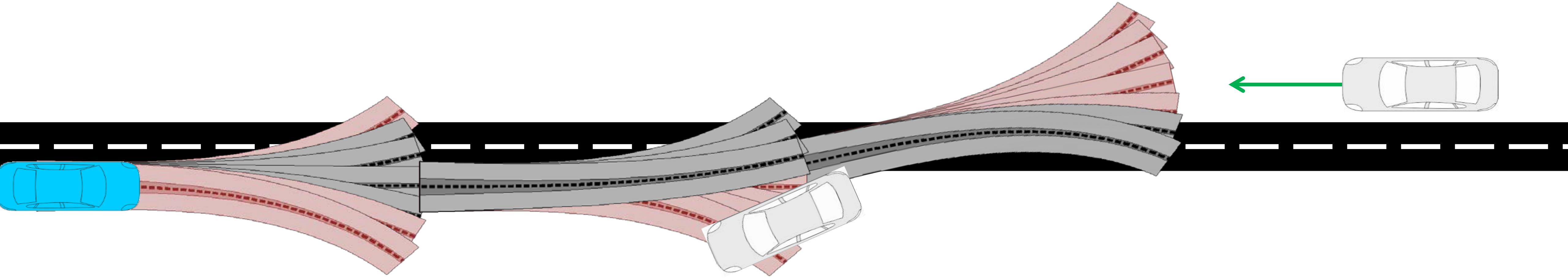

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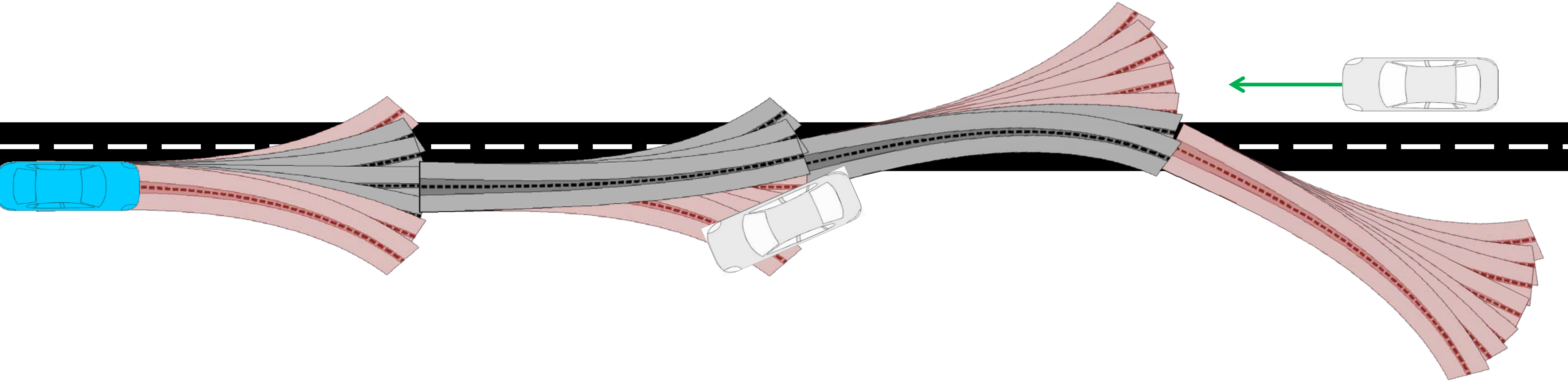

Combinatorial Planning
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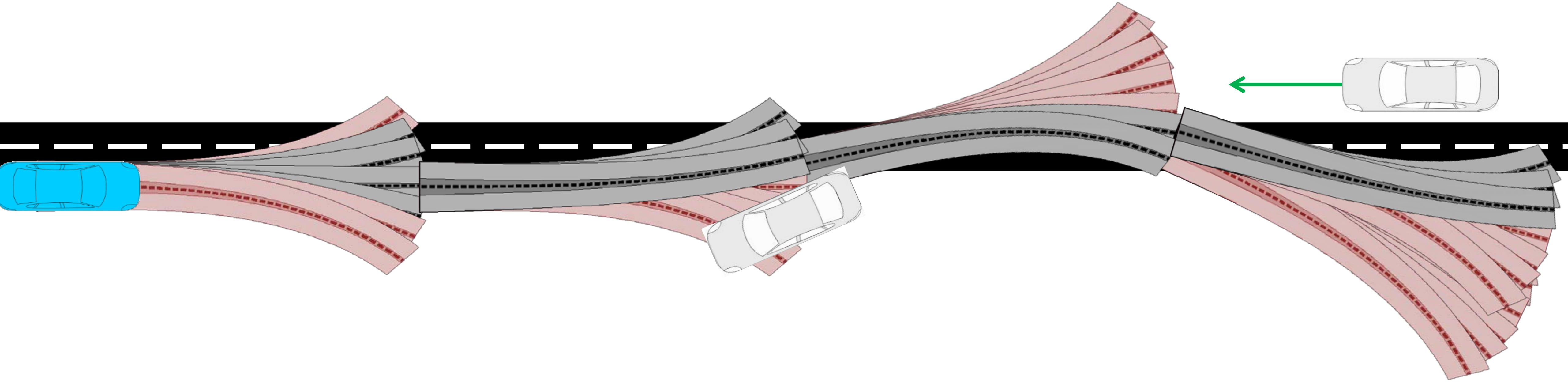
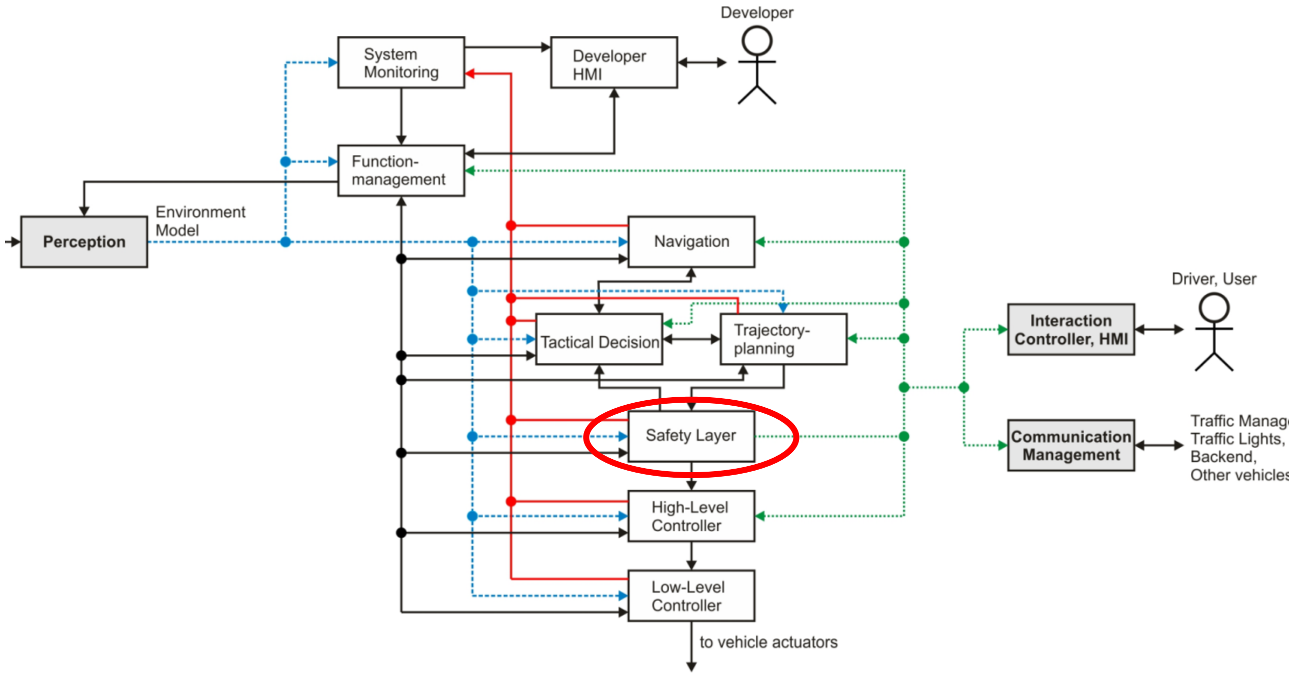


Safety Layer - Summary

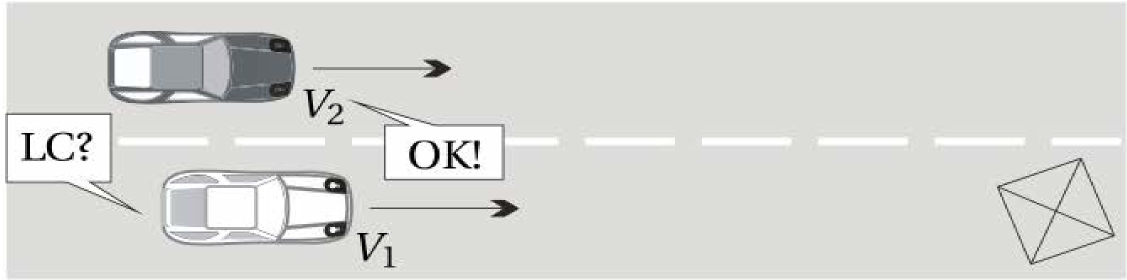
- Planning with online verification
  - uses decomposition of plans into proven motion primitives with reachable sets
  - allows „safety–guarantee“ for unknown and untested scenarios
  - reduces test effort to (mainly) conformance testing, system/model limits and „main scenarios“

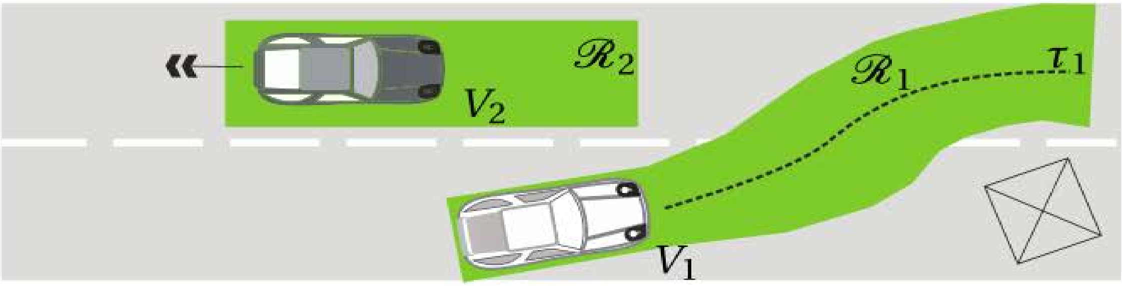


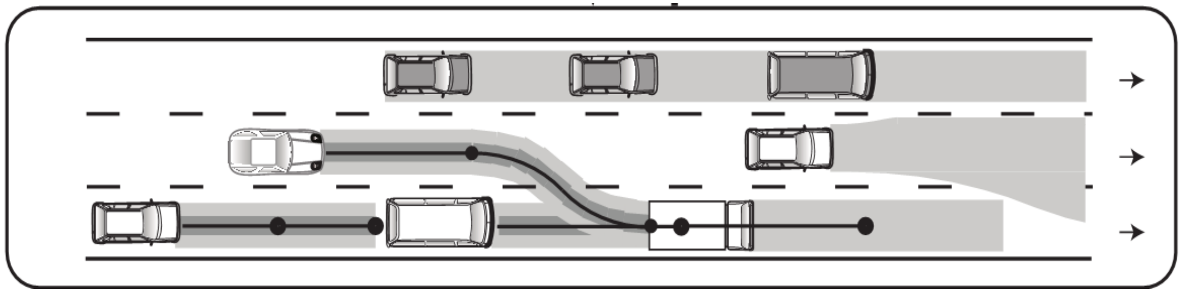
Pictures: Description of Work UnCoVerCPS

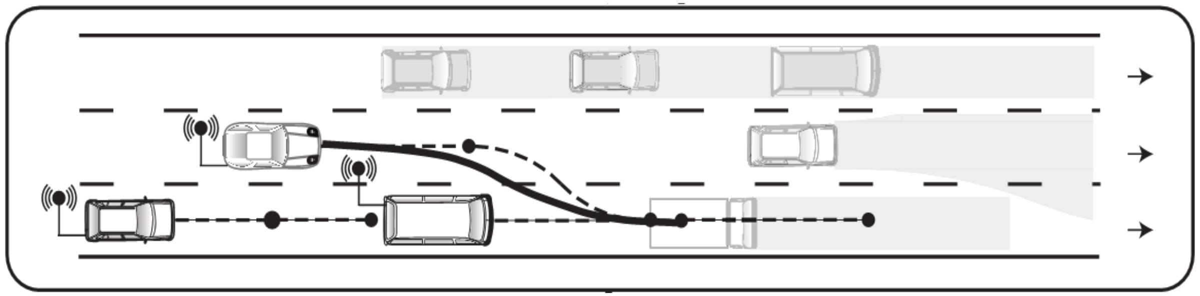
Safety Layer in Cooperative Driving

- Safety Layer concepts can extended from single vehicle to cooperative behavior such as in EU-project UnCoVerCPS (2015-2018) DFG-project CoInCiDE (2016-2018)

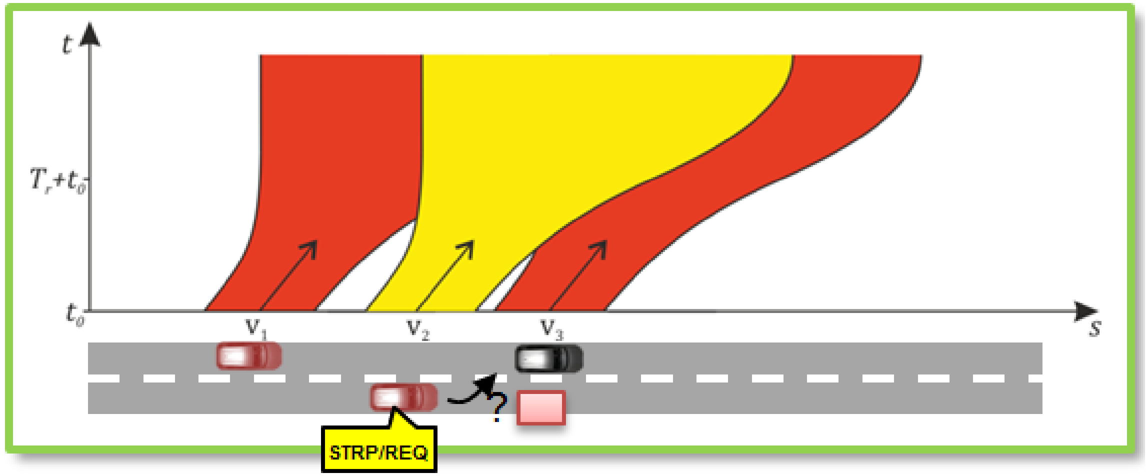


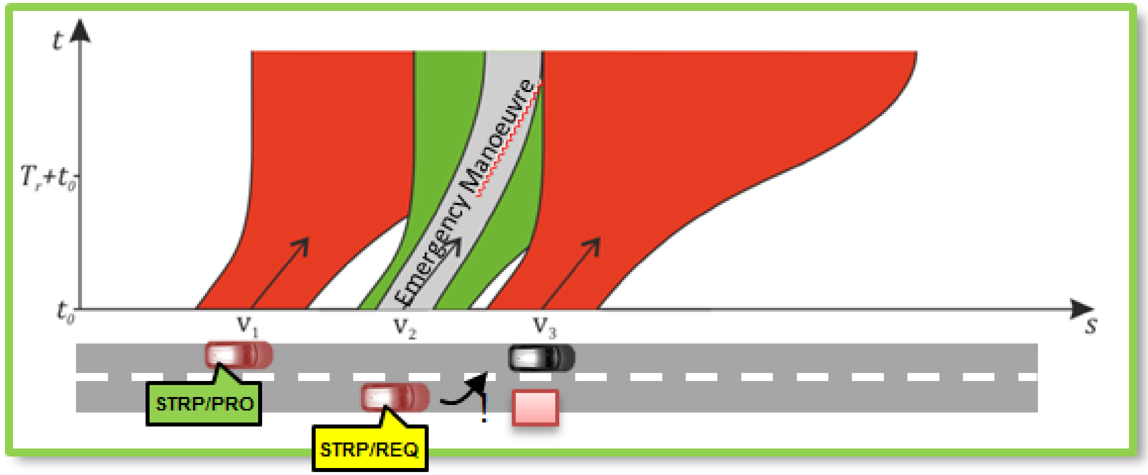






Safety Layer Applied to Cooperative Lane Change






COOPERATIVE AND AUTOMATED
DRIVING
TESTSITE EDEMISSEN

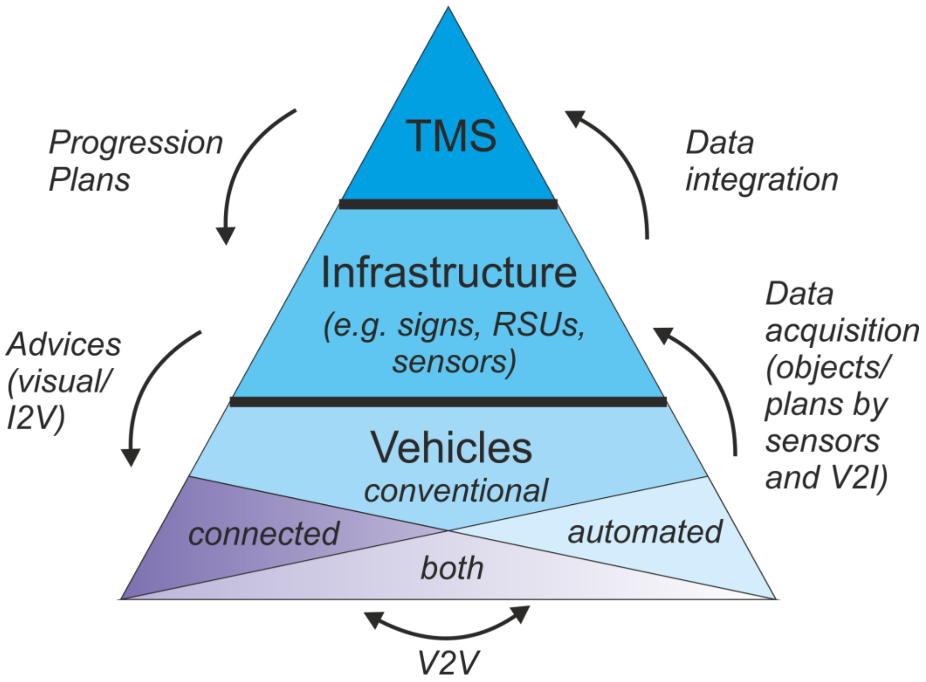
Interaction revisited
Cooperation with other Traffic-Participants

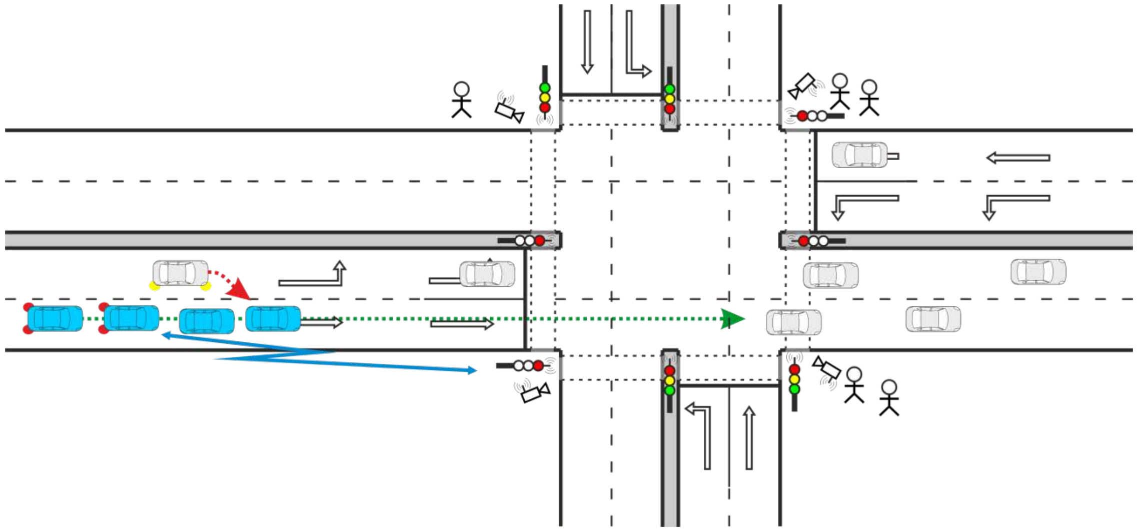
- Explicit and implicit interaction and arbitration between
    - Vehicle automation and driver/user
    - Vehicle automation and other traffic participants
    - Onboard driver/user and other traffic participants
- Technical cooperation (also explicit and implicit) between
    - Vehicle automation and other technical systems

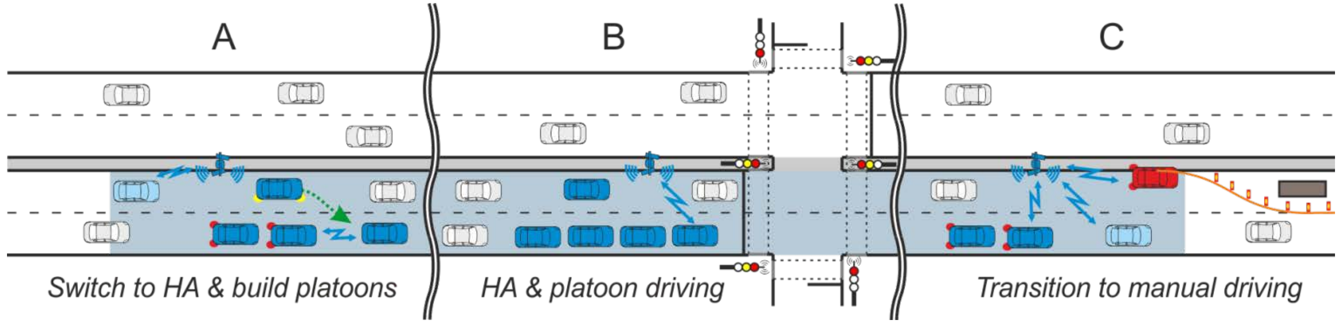
Cooperation with Traffic-Infrastructure, other Vehicles, Traffic-Management and other Traffic-Participants

MAVEN
Managing Automated Vehicles Enhances Network

TransAID







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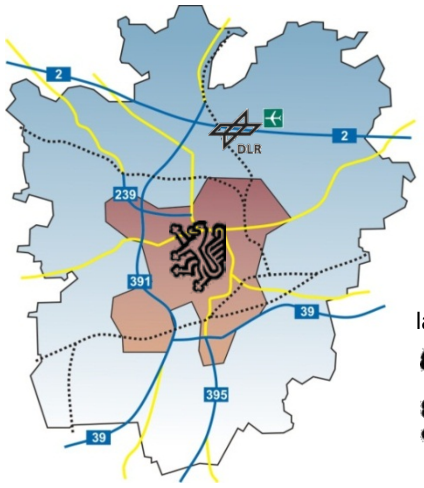
AIM 2009 2014 2024

Application-Platform Intelligent Mobility (AIM) (1/2)

(2009 … 2014 …)

Large-scale research infrastructure in the area of Brunswick (Germany): An entire city serves as a platform for application-oriented research and development-activities in the field of intelligent mobility

- AIM consists of
  - databases, models, simulation toolboxes and simulators
  - dedicated test tracks
  - real urban areas within the city of Brunswick
  - selected surrounding areas around the city of Brunswick
- Besides observation it is possible to influence selected large-scale aspects (e.g. traffic flows) and microscopic aspects of traffic/mobility (e.g. via traffic lights and assistance and automation systems).
- The different building blocks of AIM are represented by a set services / service-clusters.



langfristige Partnerschaft:

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Niedersächsisches Ministerium für Wirtschaft, Arbeit und Verkehr

Niedersächsisches Ministerium für Wissenschaft und Kultur

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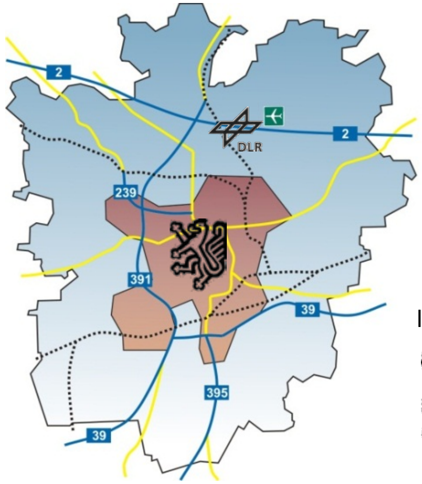
AIM 2009 2014 2024

Application-Platform Intelligent Mobility (AIM) (2/2)

Services / Service-clusters provided by AIM



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– Overview

- Reference trac...
- ...rtual
- ...flow in the BS region
- Traffic flow data in the BS r...
- Modular Mock...
- Modular and S... ...for ITS Components

Databases / Maps / Models → Simulation / Simulators

Laboratories / Test Beds / Driving Simulators

- Test tracks
- Refere...
- ...pace / iLane
- High-precision positioning in the BS urban area
- Virtual traffic management centre

Infrastructure / Proving Grounds / Living Labs – for Development and Test

- ... services
- Traffic management / traffi...
- D...
- ...ger (rail) transport data
- Mobility portal

Vehicles

Data-Platforms / Backend-Systems for Data and Services

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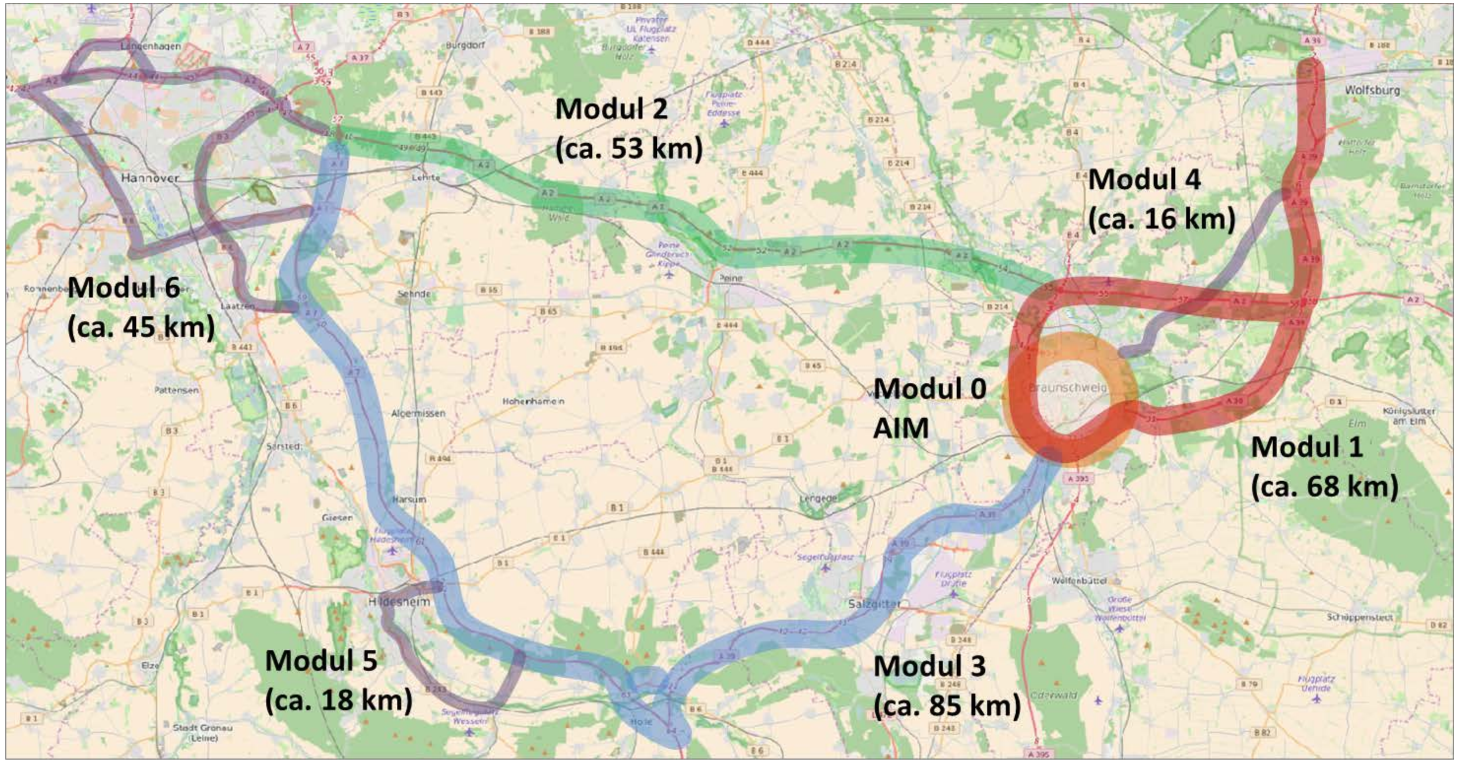
2014
2019 … 2029
TESTFELD NIEDERSACHSEN
Für automatisierte und vernetzte Mobilität

Test Field Lower Saxony

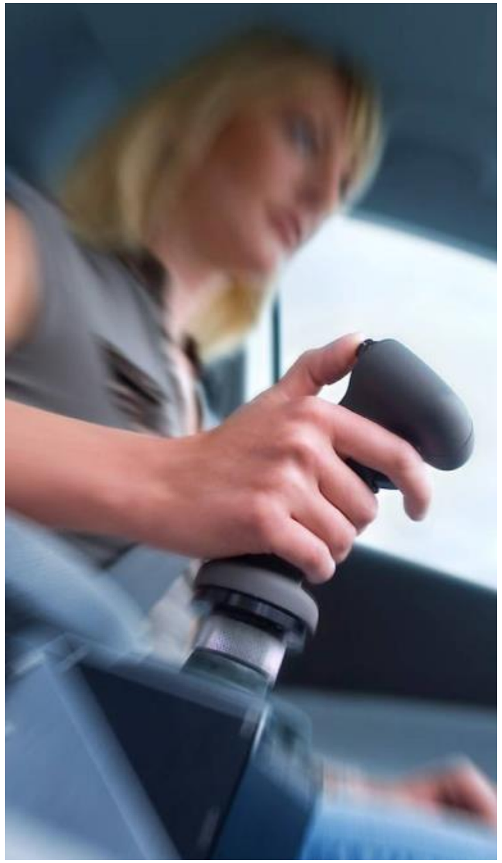
Approximately 280 km of different types of roads will extend AIM – with a focus on highways. Technical components of the Test Field Lower Saxony are based on established AIM-Components. The integrated use of AIM and Test Field Lower Saxony will be possible.



Module 7: Proving ground (with urban appearance) on non-public area.

- **Camera-based Detection** – anonymized detection of traffic objects and their trajectories → ground truth
- **Communication** – Car2X via WiFi 802.11p and Mobile
- **Maps** – highly accurate and up to date maps for vehicles and various simulation-purposes
- **Scenarios and Models** – parametrizations and (sub-) models for the construction of (ecologically) valid simulations
- **Interfaces to Traffic Infrastructure and traffic-related Databases** – e.g. connection to the traffic management
- **Backend-System** – data management and delivery of online services
- **Cadastre** – in particular, documentation of the test field status / quality

Thank you for your Attention!



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