Model-Based Development and Testing of Automotive Software – Some Experiences and Challenges

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Agenda

Motivation

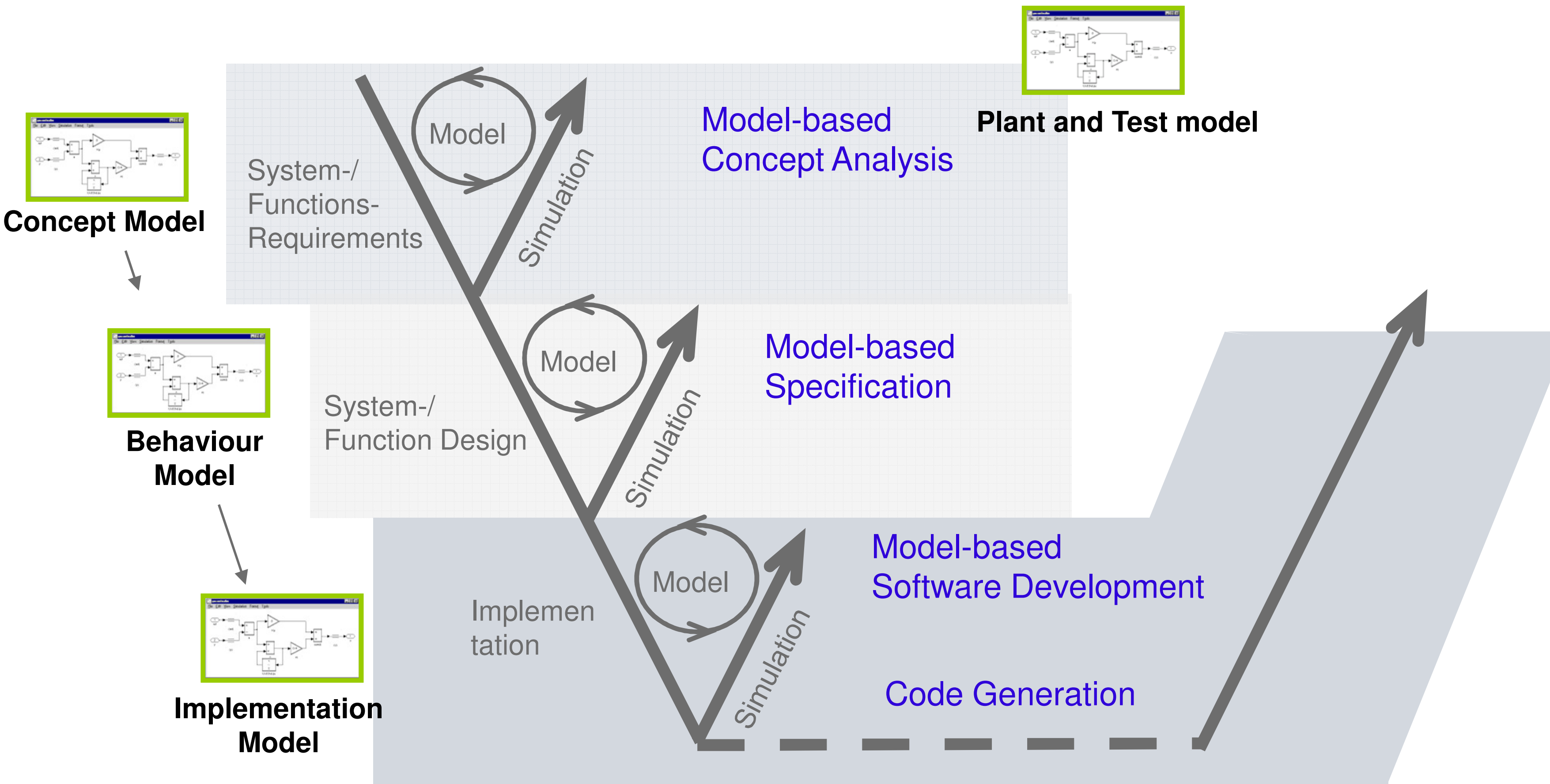
Motivation

- Developing software-based vehicle functions of increasing complexity
- Cost and quality requirements necessitate efficient development methods
- Model-based development methods (since the 90s) using MATLAB/Simulink/Stateflow and code generation

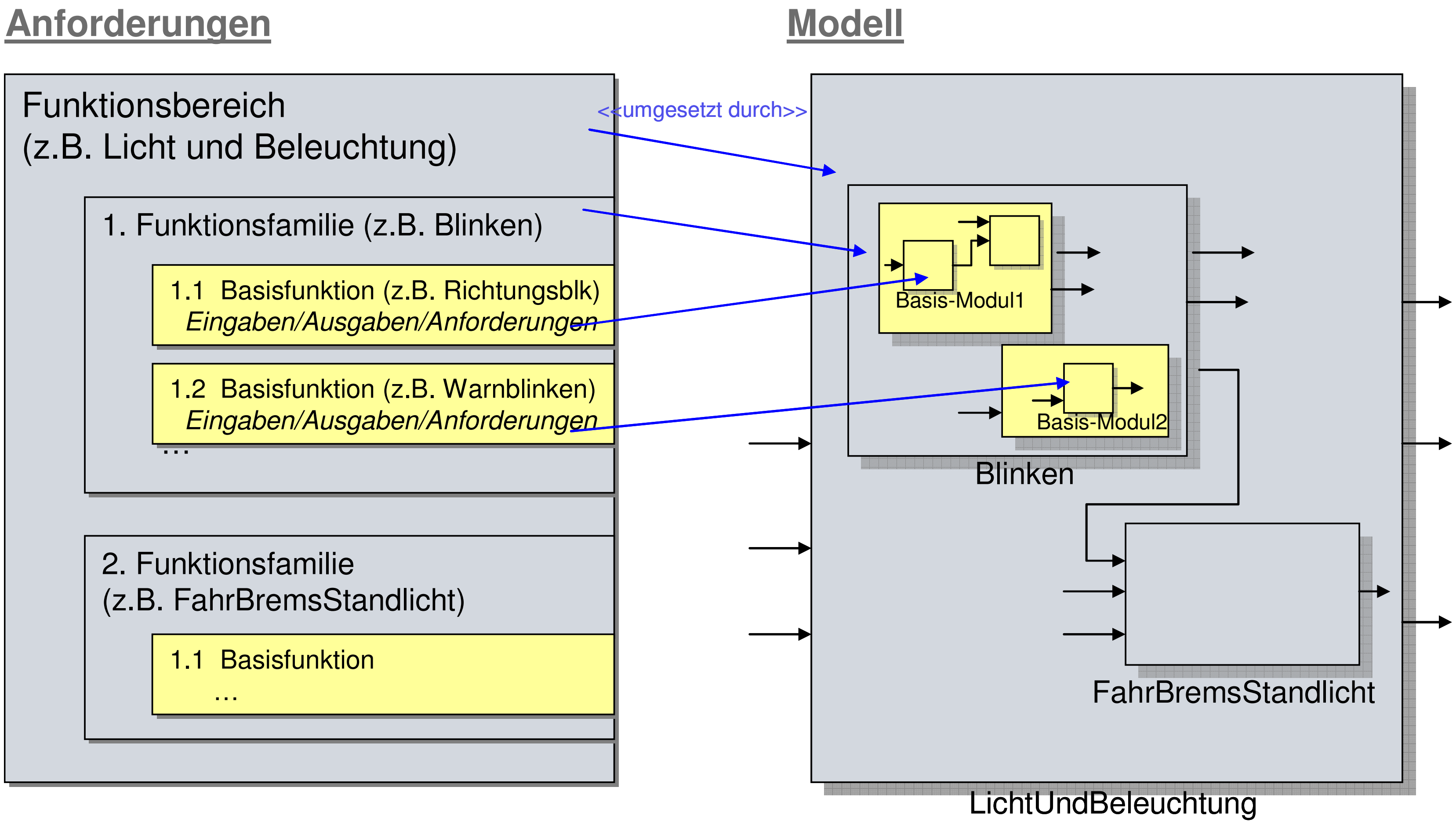
Goal

- Seamless model-based function and software development
- Avoiding ruptures: evolutionary development of models from concept phase to final code generation

Use of Models in the Development Process



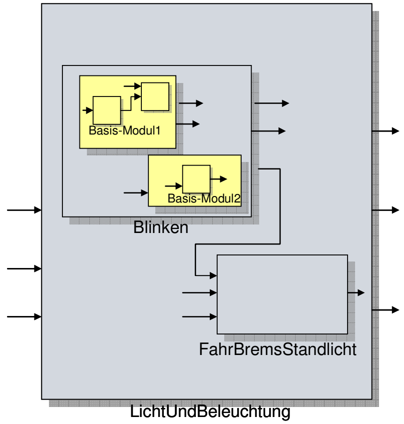
Relation between Model and Requirements – Ideal Case of Function-Oriented Development



Properties of Functional Model vs. Implementation Model

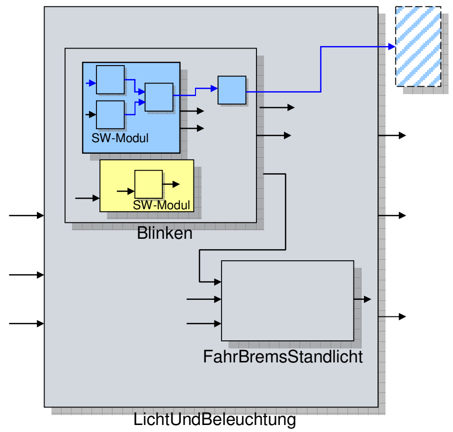
Functional Model:

- Focus on functional system requirements
- Not all aspects modeled (signal preprocessing, diagnosis,...)
- Structuring according to requirements structure
- Hardware independent
- Data not scaled



Implementation Model:

- Functional and non-functional SW-Requirements
- Usage of resources (time, storage)
- Complete functionality incl. of error handling, signal pre-processing etc. modelled
- Interface to basic software
- Typing and scaling of Data
- largely hardware-independent
- Criteria: Maintainability, Extensibility, Testability, „Separation of Concerns“



Transition from a Functional Model to an Implementation Model

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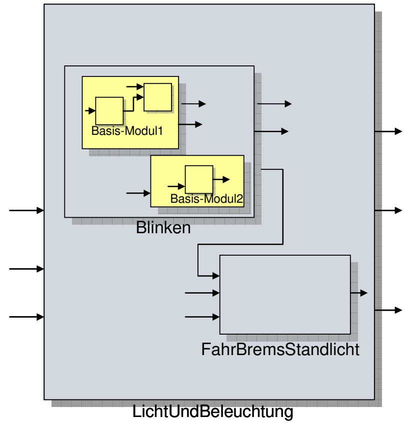
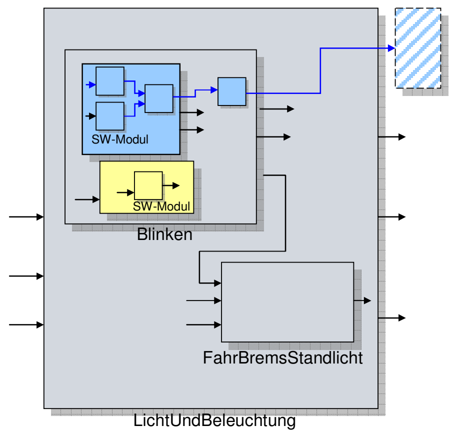
Problematic Changes:

- Change of model architecture for satisfaction of non-functional requirements
- Structural changes to satisfy resource requirements
- Functional extensions, concerning the inner Model structure such as z.B. error treatment, initialisation.



Evolutionary (unproblematic) Changes:

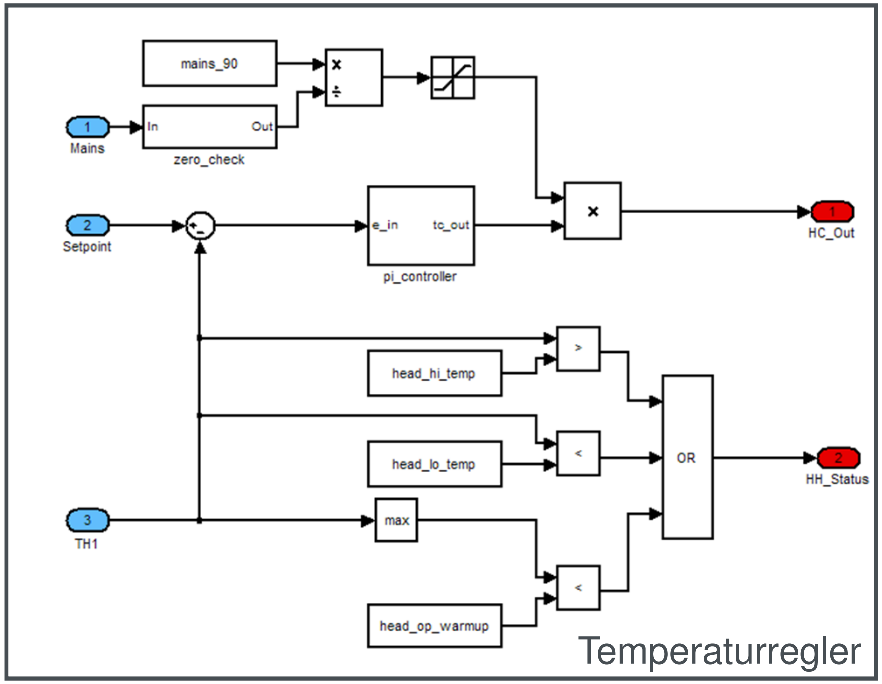
- Functional extensions such as z.B. signal pre-processing, plausibility checking etc.
- Interface to basic software of the ECU
- Scaling of Data
- Local optimisations to lower resource consumption



Example: Extensions for Error Handling and Diagnosis

Functional Model

- Focus on core algorithm
- Conscious decision not to model diagnosis and error handling



Example: Extensions for Error Handling and Diagnosis

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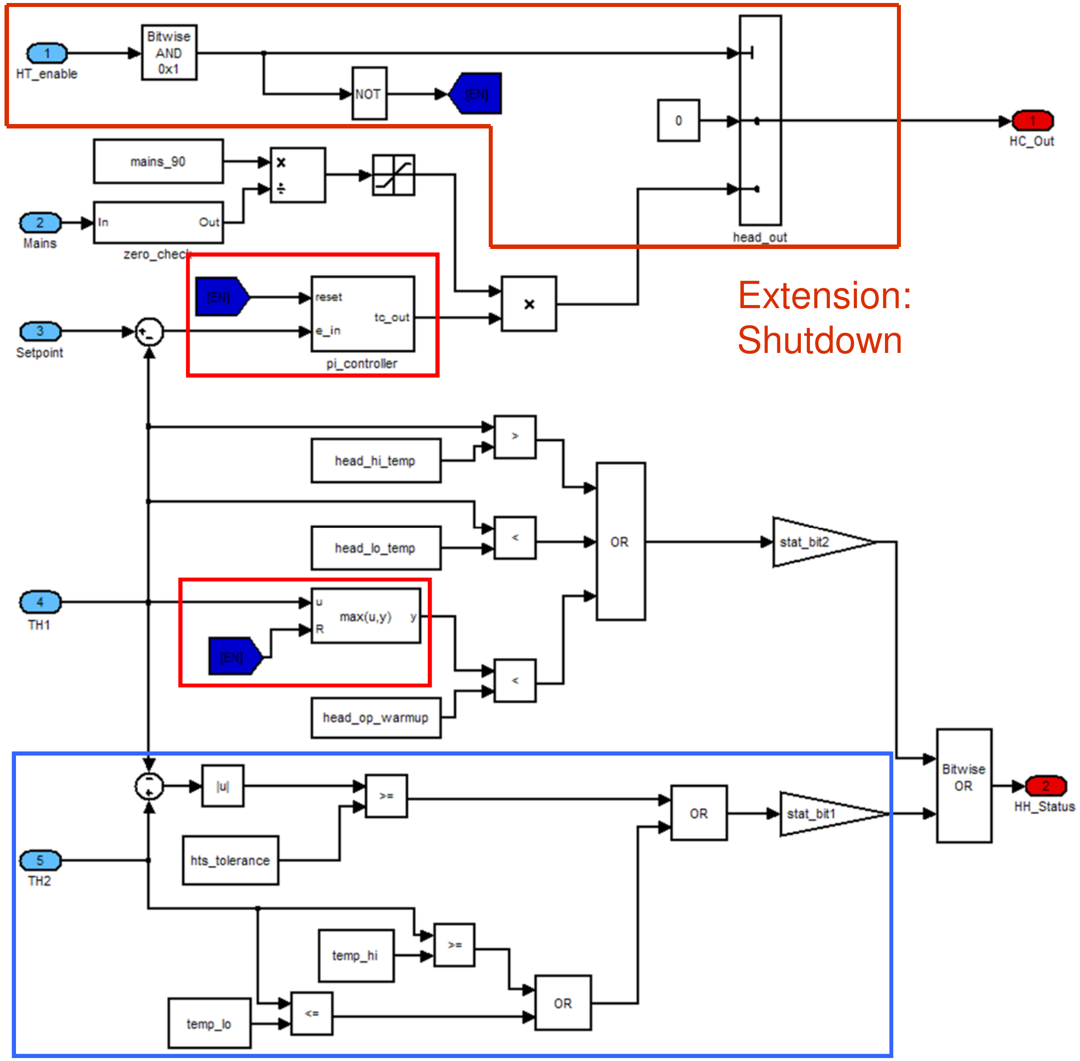
Implementation Model

- Significant adaptations to the core algorithm



Extension: Sensor Watchdog

Lessons Learned

Early validation of model architecture wrt. non-functional requirements

- Early review of functional models by software experts
- Guidelines for model structuration, e.g. using domain specific pattterns (e.g. for error handling)

Systematic relation between functional model and implementation model

- Functional model not necessarily structured according to requirements structure, use of tool-supported requirements linking, adapted requirements structuring

Many further aspects

- Separation of functionalities according to available computation slots
- Exclusion of modeling constructs (Switch blocks etc.)
- …

Agenda

1 Model-Based Development at Carmeq

2 Stochastic Robustness Testing

3 AUTOSAR

4 The Challenge of Variability

5 The EAST-ADL Architecture Description Language

Motivation and Goals

Background

Growing complexity of ECU functions

- Rear blind
- Central locking
- Braking lights
- Windshield wiper
- …

Properties of classical function testing

- Requirements-based test cases
- Sequential process: function after function
- Focus on positive testing
- Pattern: systematic stimulation – waiting period - measurement

Motivation and Goals

Motivation

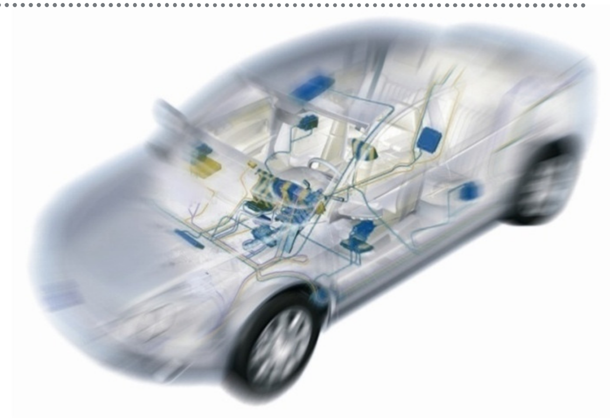
Sporadic misfunctions not detected by a classical functions test , e.g.

- Brake light goes off, due to rear blind being activated
- Brake lights blink asynchronously during wiping and thus acts as a lane changing signal …

These misfunctions often result from unintended dependencies between functions

- Competing access to limited ressources, e.g.
  - Computation time
  - Common SW Services
- Interaction of various individual functions

Lack of predictability which situations and which inputs lead to sporadic misfunctions



Motivation and Goals

Goals

Improvement of Robustness of ECUs based on a new test approach

- Detection of sporadic failures
- Stimulation of ECU with „unusual“ input data

Robustness:

„Property to work - in unusual situations - in a defined manner and to produce meaningful reactions “ (Liggesmeyer)

Extension to classical function test

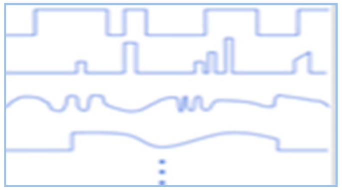
Motivation and Goals

Technical Challenges

Input complexity

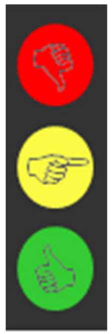
- ignition
- light control
- directional blinking
- warning blinking
- access control
- wiper

n^{200} signal combinations



Evaluation of test runs

- continuous data
- measurement imprecisions
  - value deviation
  - time delays
- missing expected values



New test approach

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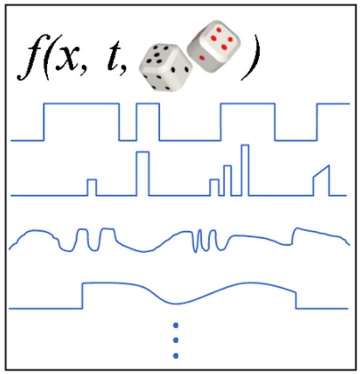
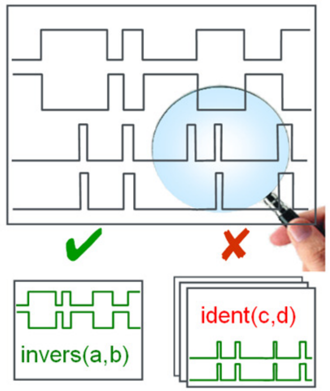
Stochastic rule-based robustness test (SRT)

- *Stochastic test data generation*
  - No individual requirements-based test cases
  - Parallel, stochastic activation of input signals
  - Multiple test scenarios, similar to long-term vehicle tests, but better control and analysis means

- *Rule-based evaluation*
  - General system properties
  - Continuous checking of criteria





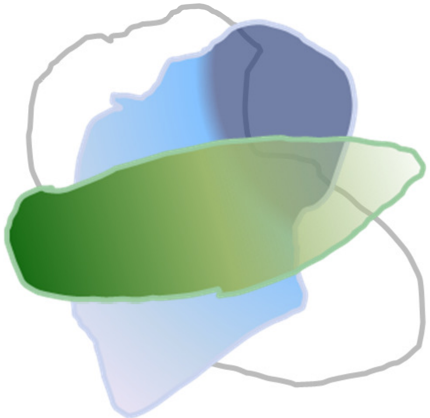
• **all signal combinations allowed**

• **check of selected criteria**

Stochastic rule-based robustness test

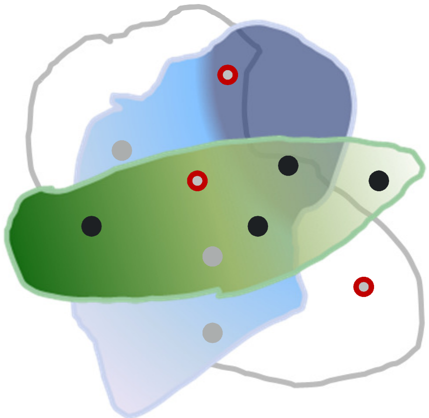
Test data generation

Space of all possible test inputs



Control data for:
- rear blind control
- central locking
- brake light control
- wiper
- …

including timing and interaction



Choose typical use cases for each application

- rear blind control: move up/down
- central locking: unlock/lock
- brake light control: normal/emergency braking
- wiper: fast/medium/slow
- …

Parallel, stochastic activation of the different functions

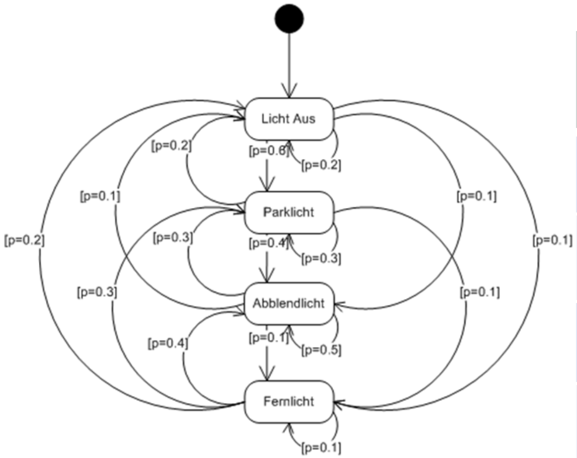
Stochastic rule-based robustness test

Test data generation: example light switch

Light switch positions define „States“

Lichtdrehschalter	Aus	Parklicht	Abblendlicht	Fernlicht
Aus	1	0	0	0
Parklicht	0	1	0	0
Abblendlicht	0	0	1	0
Fernlicht	0	0	0	1

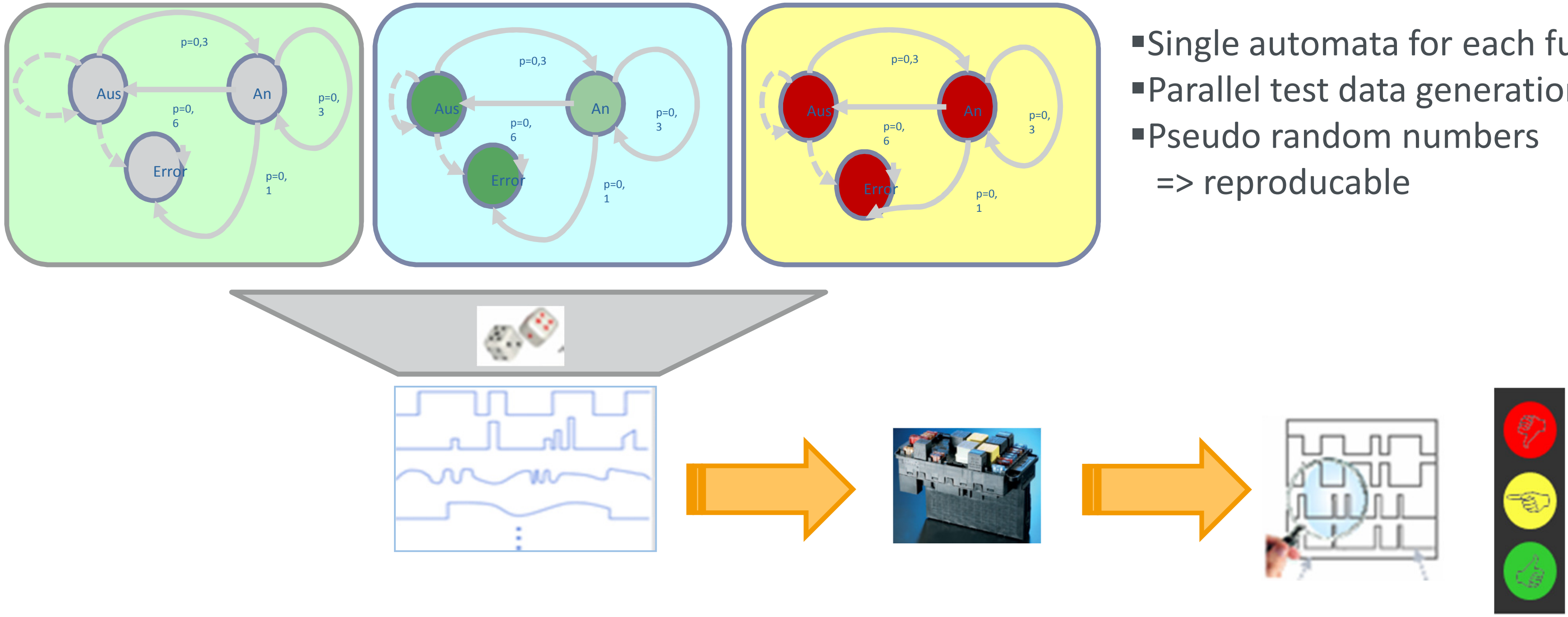
Transition probabilities



Lichtdrehschalter	Aus	Parklicht	Abblendlicht	Fernlicht
Aus	0,2	0,2	0,1	0,2
Parklicht	0,6	0,3	0,3	0,3
Abblendlicht	0,1	0,4	0,5	0,4
Fernlicht	0,1	0,1	0,1	0,1

Stochastic rule-based robustness test

Parallel test execution and evaluation



- Single automata for each function
- Parallel test data generation
- Pseudo random numbers
  => reproducable

Test run evaluation

- Specification of assertions (using simple rules)
  - All assertions are constantly checked during test runs
  - Deviations/problems are detected and stored

Stochastic rule-based robustness test

Rule-based evaluation

Individual functions are usually well-tested, but not the cooperation of functions

Problems are often deviations to general intuitive behavior

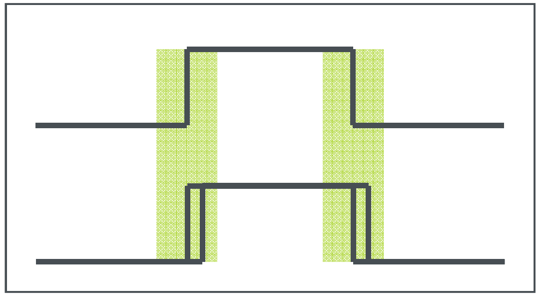
- Left and right braking light are not synchronous???
- Backlight blinks very shortly if the gear switch is used???
- The right back light is blinking too long, if the rear blind is moving???

Problem:
Due to different communication channels of signals, there can be delays

Example: signals, which are cyclically send over the network are eventually received later due to bus load.

Left braking light

Right braking light



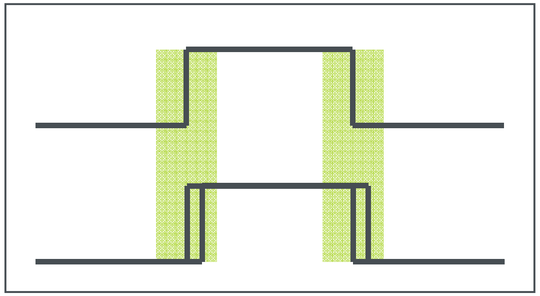
Stochastic rule-based robustness test

Example of evaluation rule

Rule to be checked

Left and right braking lights are simultaneously activated, delays of max. 50 msec are tolerated.

Pattern *SYNCHRON*

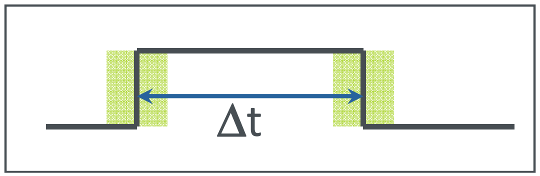


SYNCHRON(Bremslicht_Links, Bremslicht_Rechts, 50ms)

Rule to be checked

Blinker may blink for at most 500 +/- 50 msec .

Pattern *HOLDS_AT_MOST*



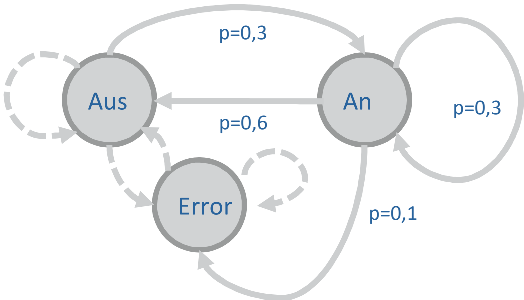
HOLDS_AT_MOST(Blinker_Vorne_Links, 500ms, 50ms)

Implementation

Test environment

Intelligent, random generated test data

→ Parallel Markov Automata

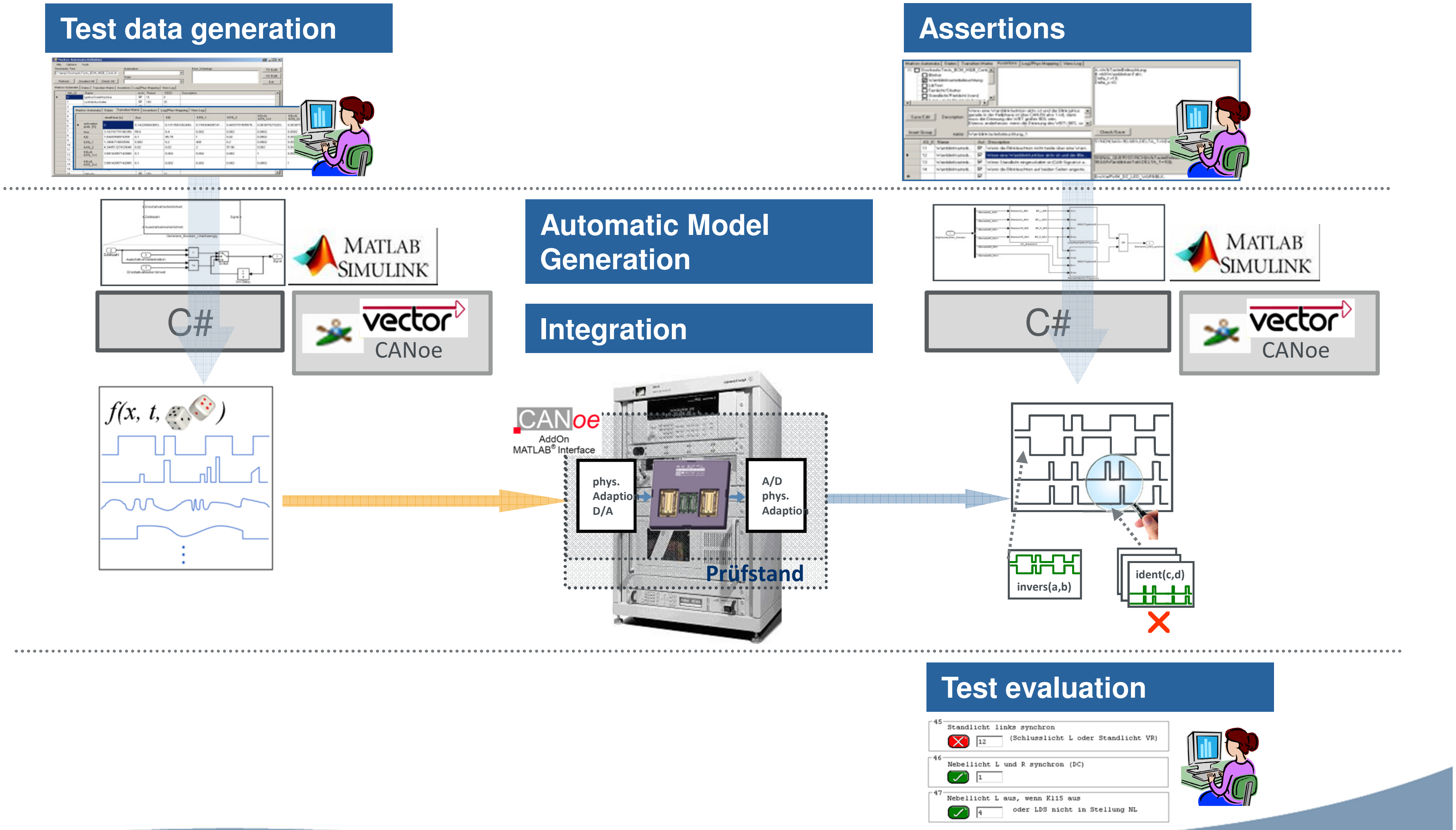


→ Assertion checking

Zusicherung	Formulierung
Blinker synchron	SYNCH(Blinker_Vo_Li, Blinker_Hi_Li, 50ms))
Blinker leuchten maximal 500 ms	HOLDS_AT_MOST(Blinker_Vo_Li,500)
Fernlicht an bei Zündung	IMPLIES(Kl15==1 && FernlichSchalter, FernLicht, 50)
Quittierungsblinken	CAUSALLY_IMPLIES((K15==0 && TürAuf), Blinker_Vo_Li, 40))

Implementation

Technical Realisation of Test Environment



Agenda

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What is AUTOSAR

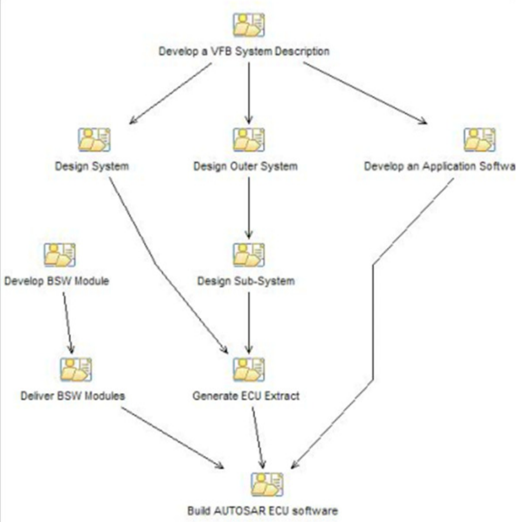
"AUTOSAR (AUTomotive Open System ARchitecture) is an **open** and **standardized** automotive **software architecture**, jointly developed by **automobile manufacturers**, **suppliers** and **tool developers**."

www.autosar.org

Scope

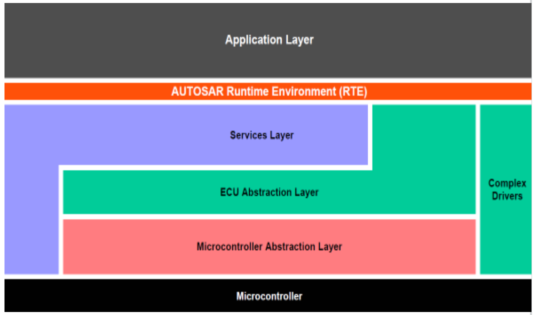
SW-Development Methodology

- „Function-based“ software development
- Several abstraction layers, e.g. „Virtual Functional Bus“
- Use of modern SW-engineering-methods (Meta-Modelling, UML, XML ...)



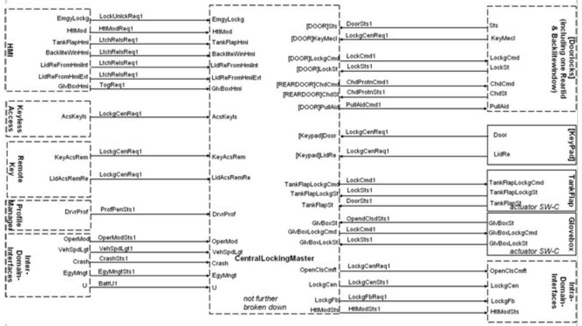
ECU-SW-Architecture

- Common base architecture for Control-, Sensor, Actuator-ECUs
- Layeres SW-Architectur: µC – BSW – RTE – Application
- Aims to support all relevant automotive µCs and ECU-interfaces
- Basic Software consists of about ca. 50 Modules



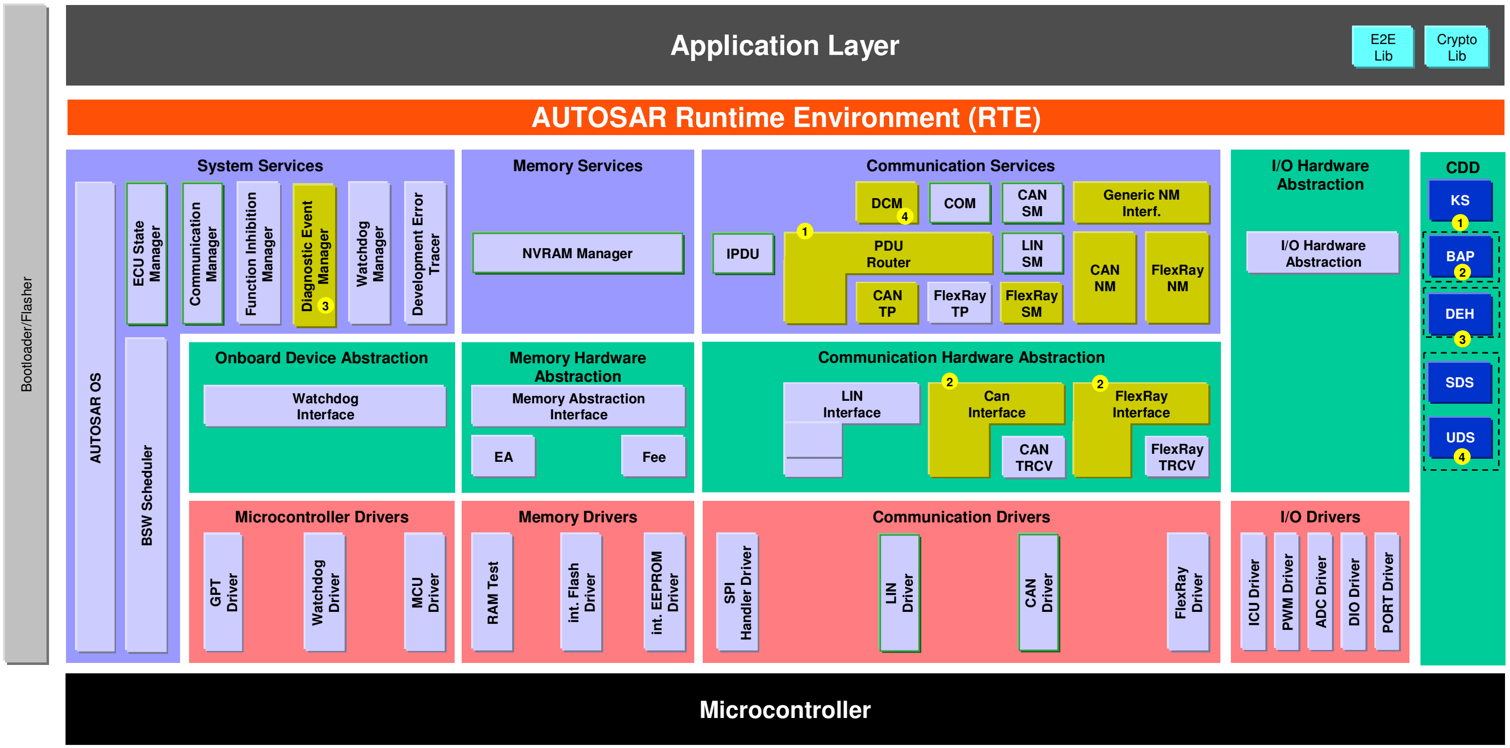
Application-Interfaces

- Body and Comfort
- Powertrain
- Chassis Control
- Occupants and Pedestrians Safety
- Multimedia, Telematics and Human-Machine-Interfaces…



Use of AUTOSAR at VW

Releases for MQB: AUTOSAR 3.1 Rev. 002 + Extensions

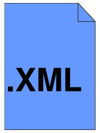


ECUs already using AUTOSAR:

- „Kombiinstrument“ vby JCI (MQB)
- „Lademanager“ (VW360/7)

Phases of the AUTOSAR-Methodology

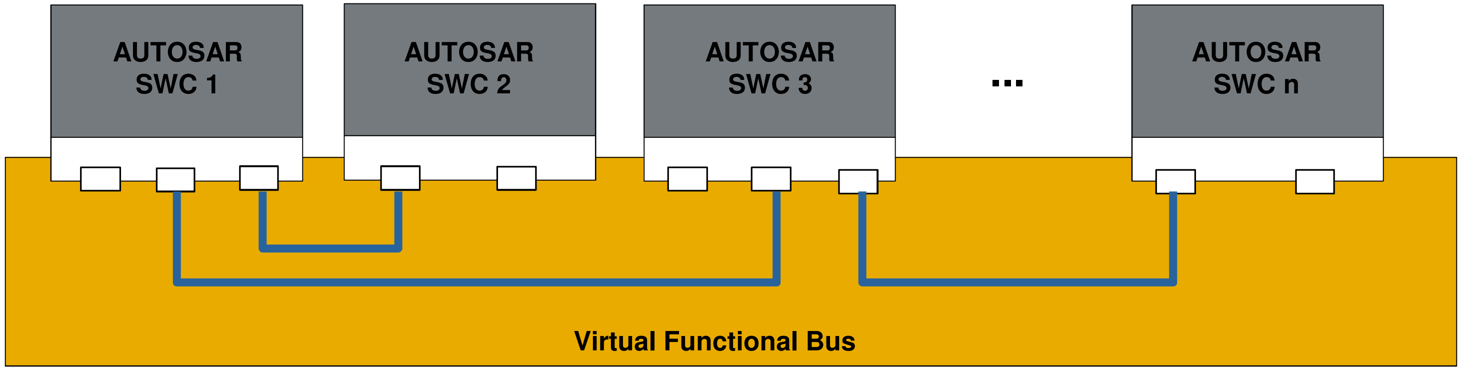
Funktion Level.



SWC-
Description

Function Design

- Definition of functional architecture on an abstract level
- Base Concept: „Virtual Functional Bus“ (VFB)
  - Software-Components (SWCs)
  - Communication
    (Ports + Data Elements)



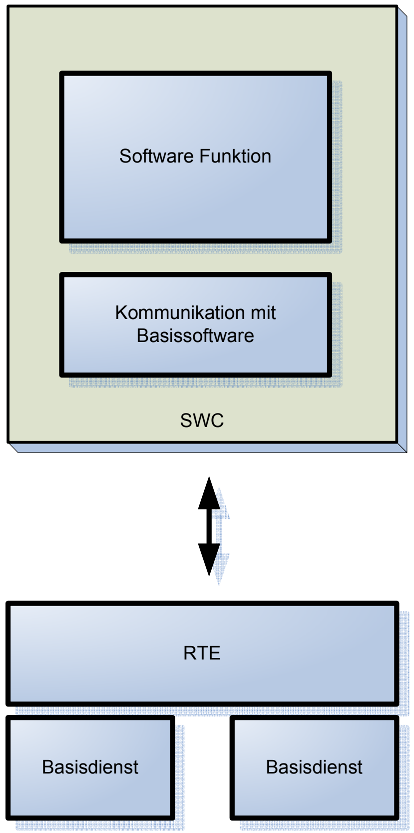
Function Realisation

- Implementation of function using generated header-files based on VFB-model

(1) Integration of model-based software development with AUTOSAR

- **Current Situation:** proprietary interfaces to ECU
- AUTOSAR offers standardised interfaces and base services such as
  - ECU management,
  - Network management,
  - Storage management,
  - Diagnostic management
- Not all base services can be directly mapped to Simulink
  - Development methodology of Simulink is dataflow-oriented rather than service-oriented, i.e. procedural communication (Client/Server) is difficult to realise.
  - No out-of-the-box solutions for all base services available

➔ **Possible Solution:** Declarative specification of functions incl. base services for automatic code-generation



(2) Adapting Software Component Testing to AUTOSAR

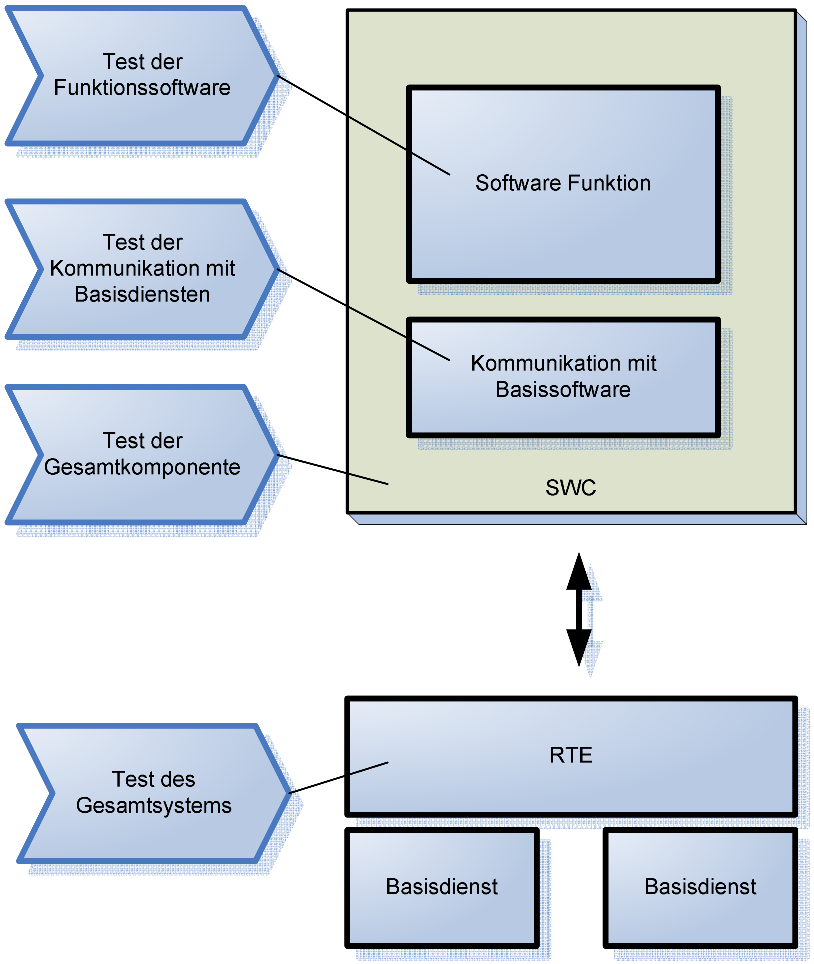
Current Situation

- Testtools chains adapted for every ECU and supplier

AUTOSAR

- Separation of software parts and standardised interfaces allow for common testing process and tool chain.
  - Use of current tool chain for testing functional software
  - Testing of generated communication with base services (more early)
  - Testing of complete SWC
  - Testing of SWC in the complete system

→ Testing can be performed more early
→ Tool chain can be reused



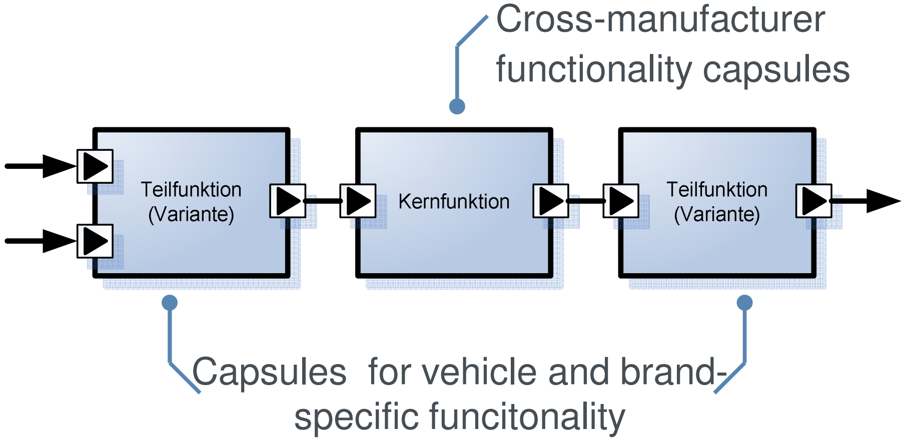
(3) Implications of SW-Development using AUTOSAR

Current Situation

- Currently *monolithical* functions are exchanged with suppliers

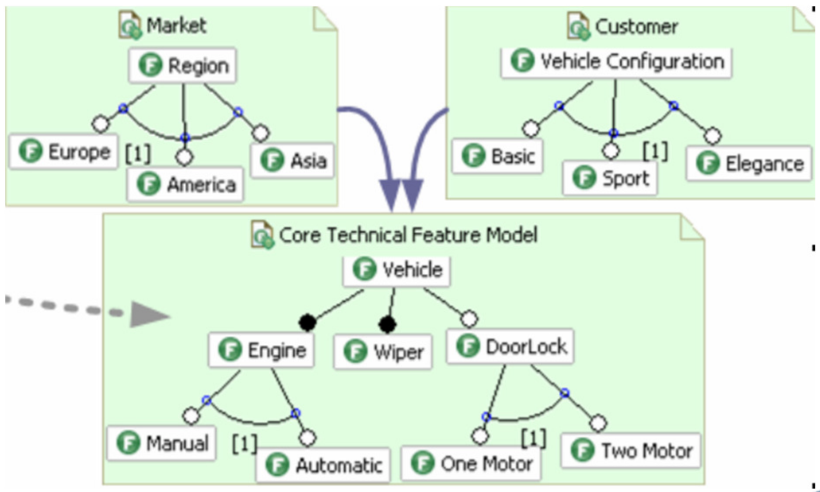
Function Design

- Optimisation of partitioning of software components
  - standardised AUTOSAR interfaces allows for moving SWCs between tasks and ECUs
  - Better testability due to lower complexity of individual components



Variability Management

- Partitioning of software components improves variability management :
  - Finer-grain modeling of variants
  - Less variants for individual components
  - Better management of variants und their dependencies



Agenda

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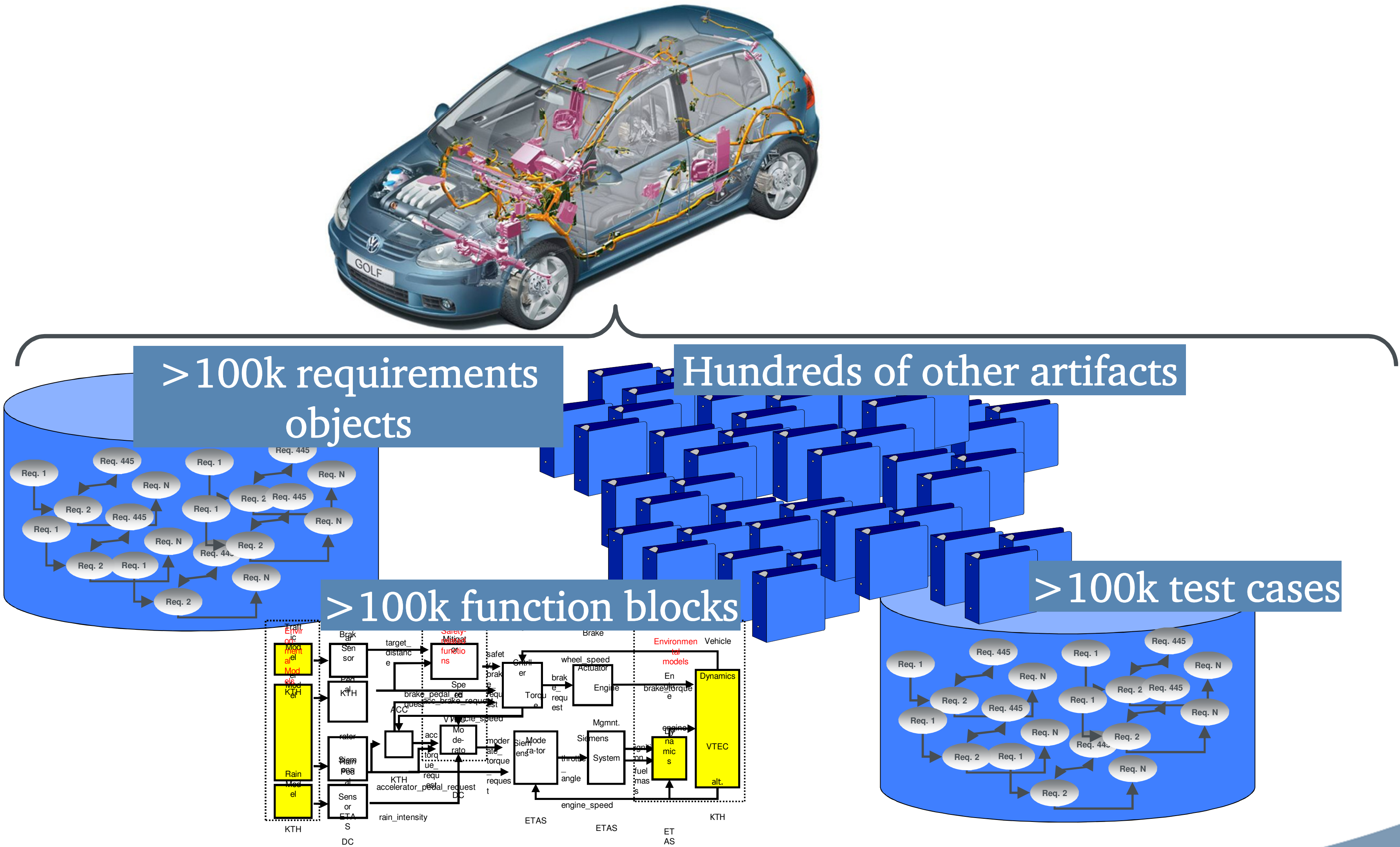
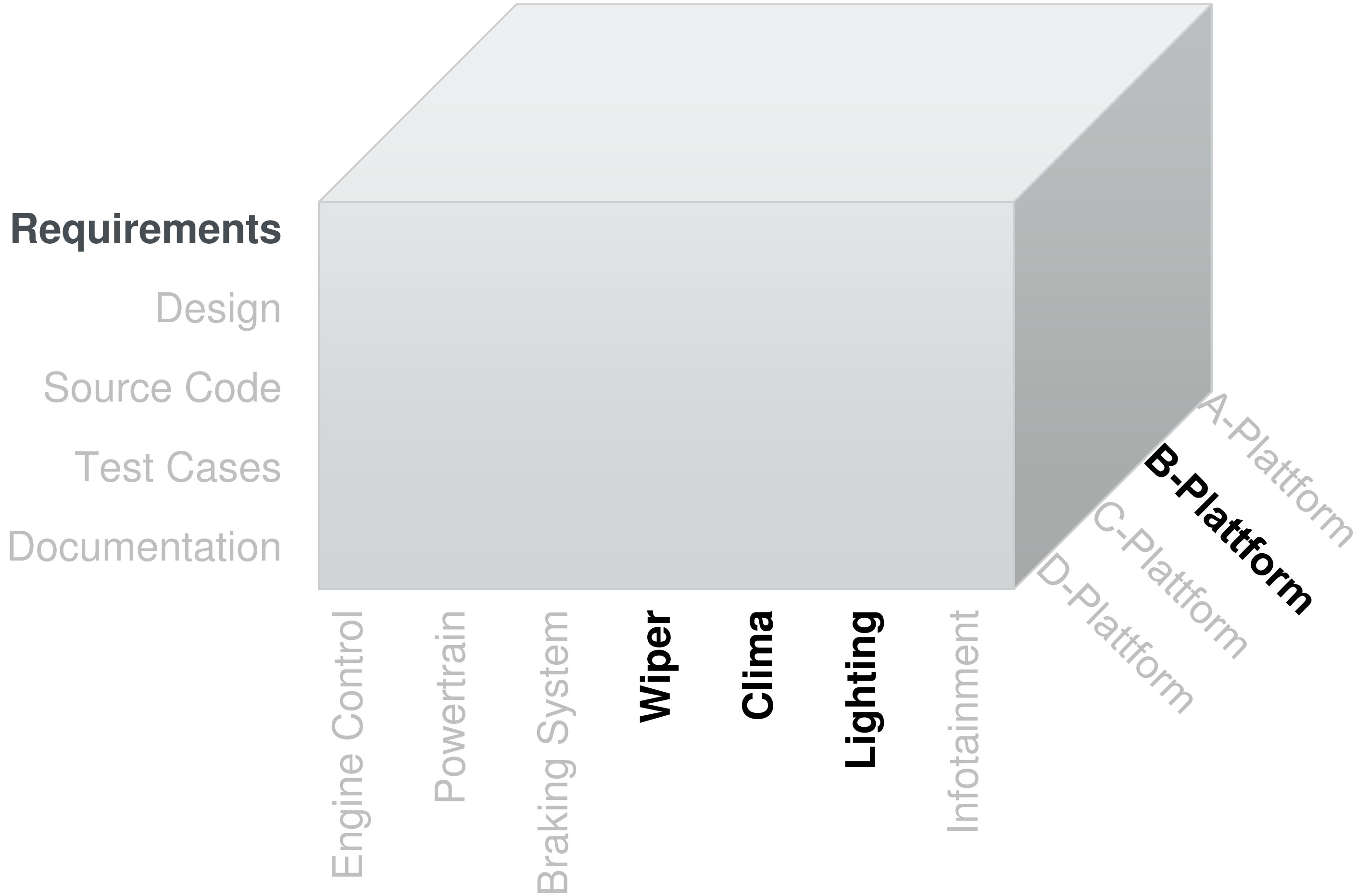
Development Objects of an Electronic Platform

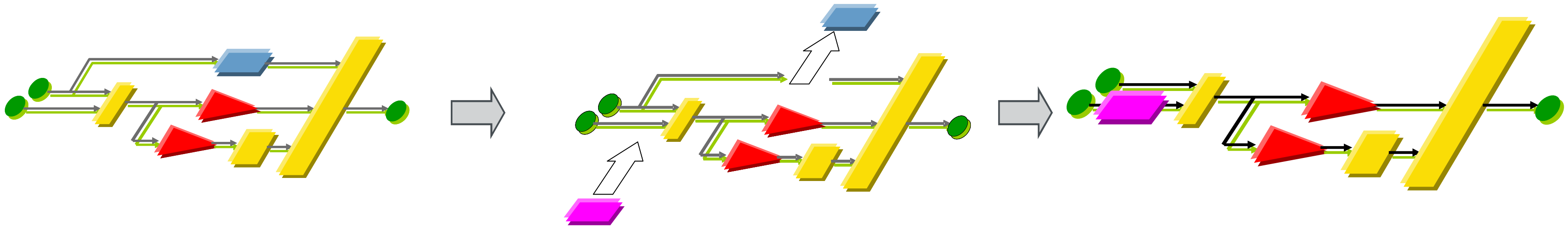


Multi-Dimensional PL-Decomposition – Example



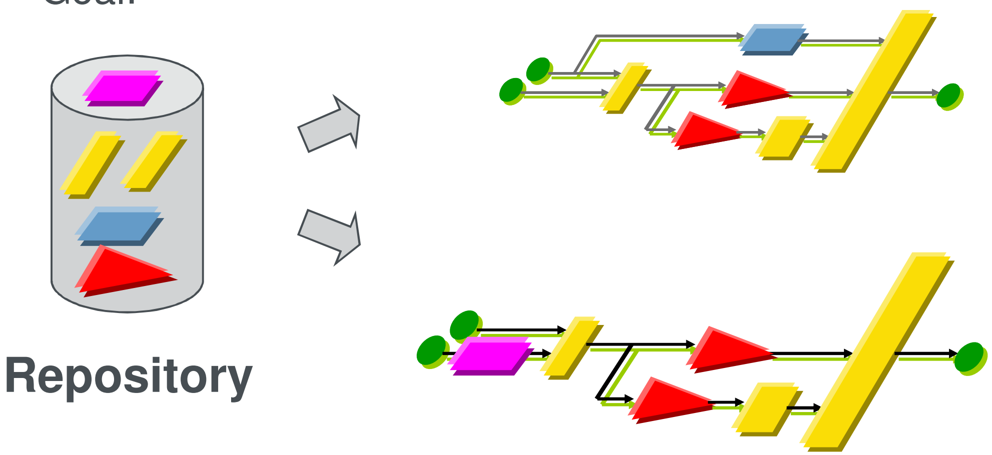
Reuse

State of the Art:



Project **copy & modify** **new Project**

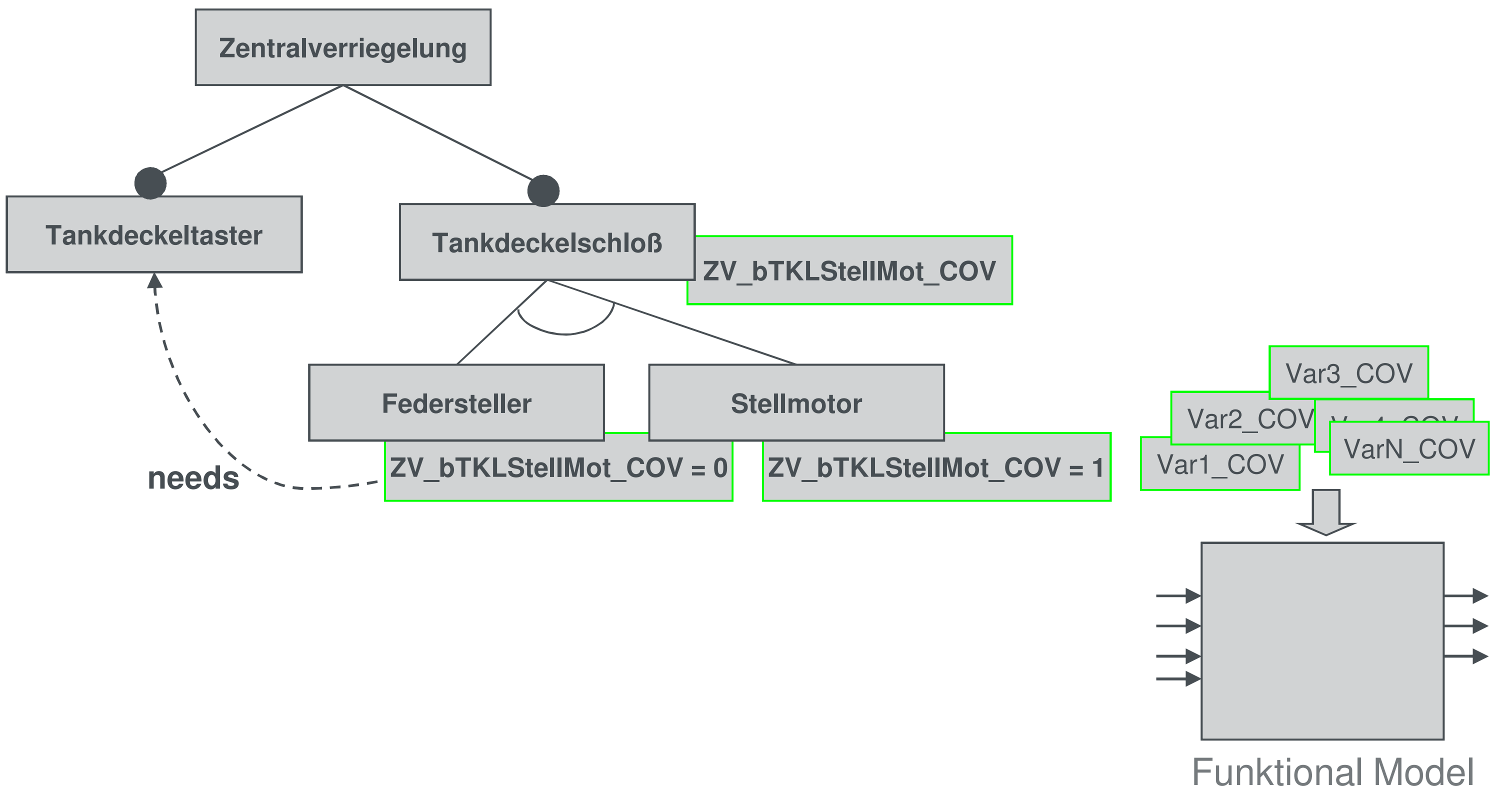
Goal:



Granularity of Resuable Assets ?

Explicit Representation of Variability

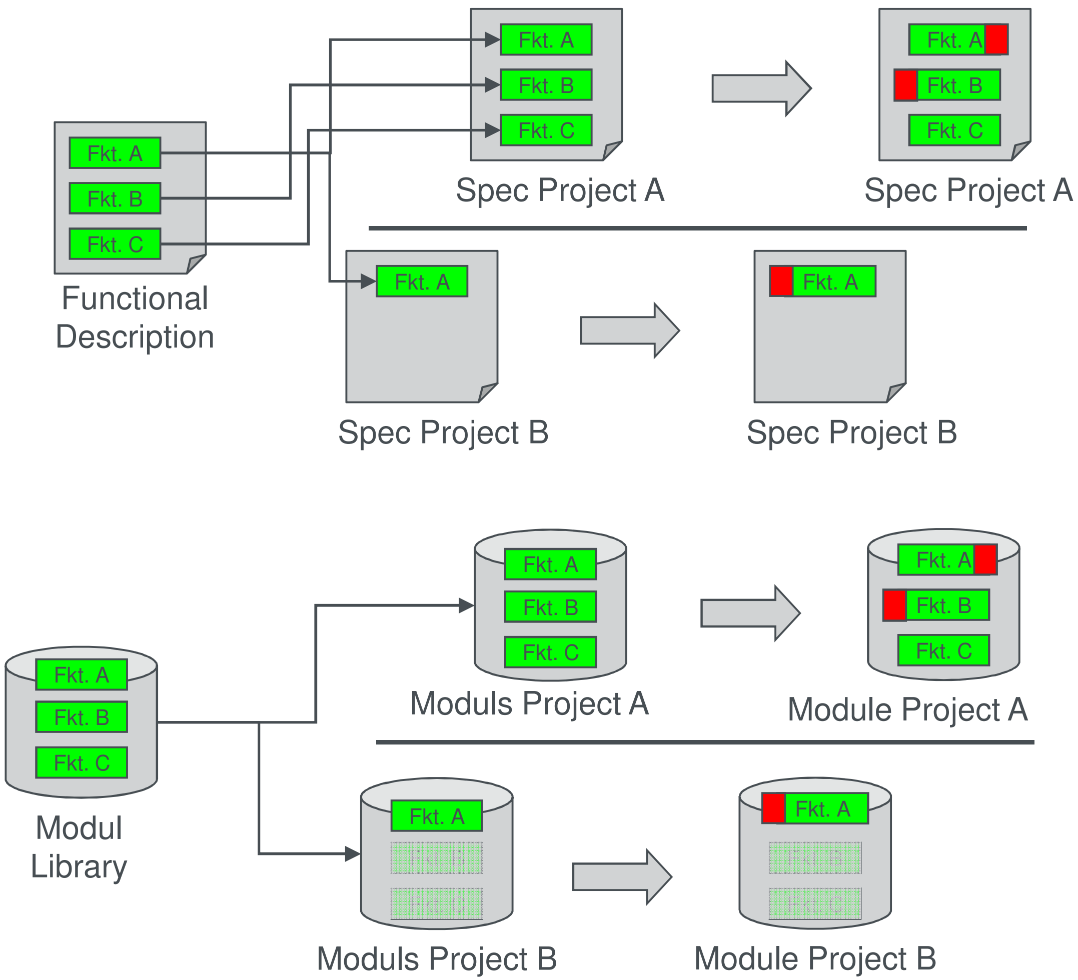
Representation of Dependencies between Coding Values by variability modeling, e.g. feature trees



Reuse of Models

State of the Art:

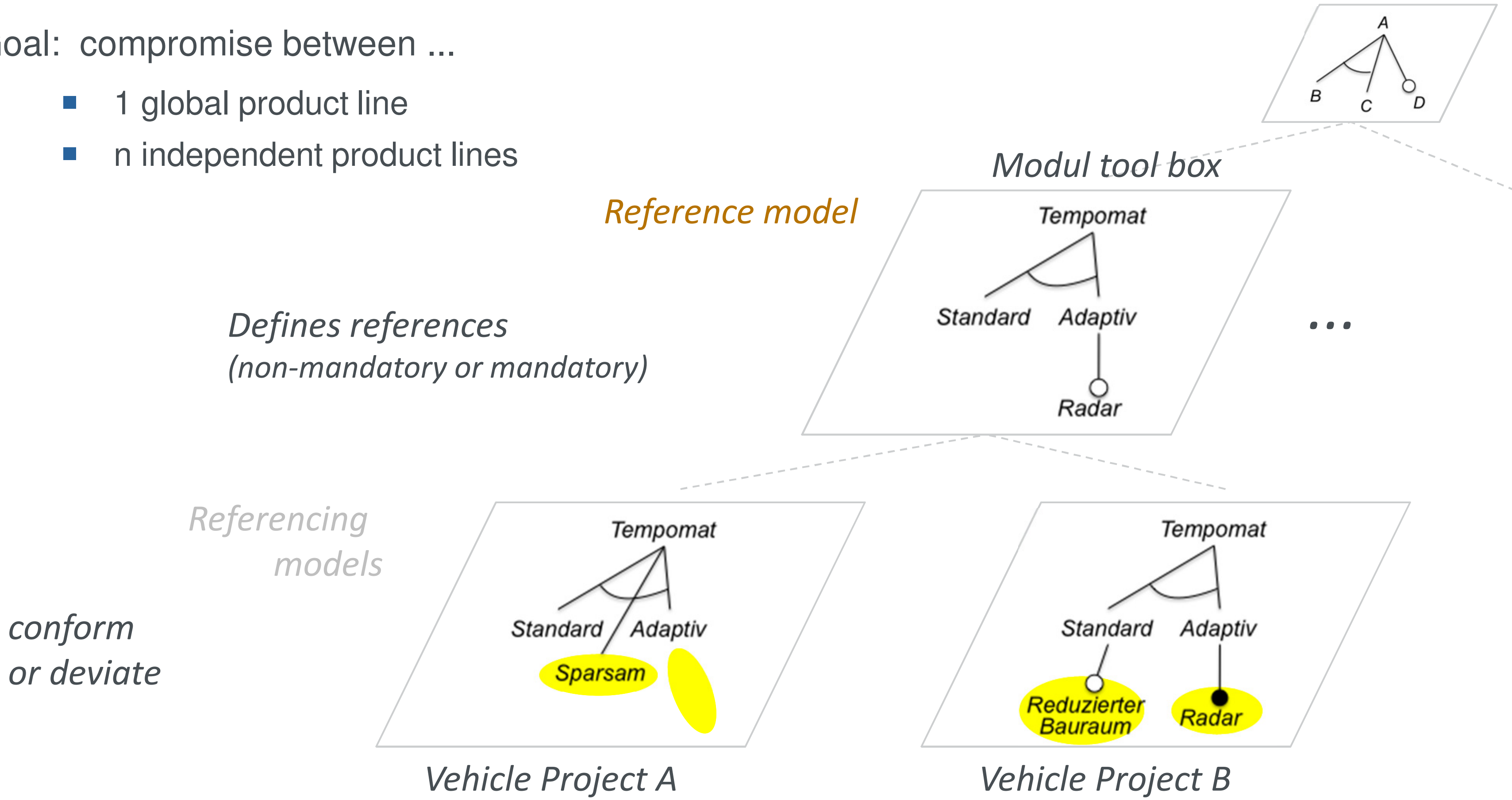
- Function-oriented development, i.e. functional requirements are structured in technical parts
- Functions in the specifications use the same name and the same decomposition
- Running projects lead to project specific differences
- Differences must be considered in retrospect



Reuse Approach: Multi-Level Concept

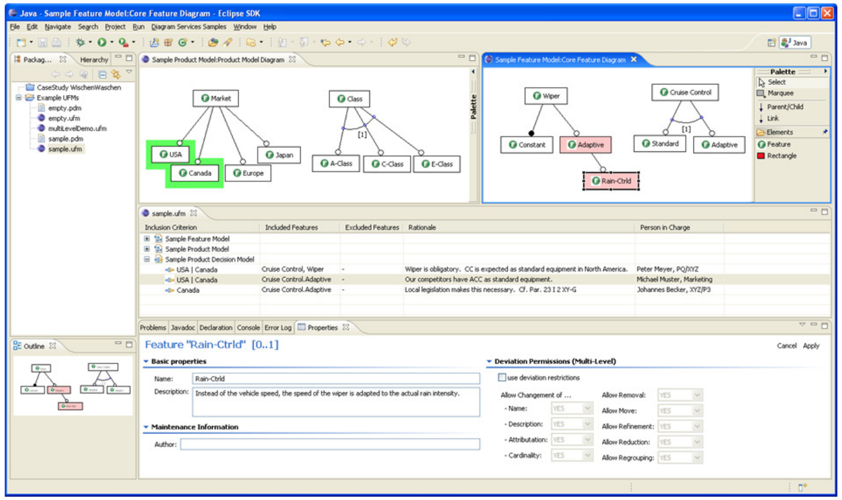
Goal: compromise between ...

- 1 global product line
- n independent product lines



Tool Support Multi-Level Concept

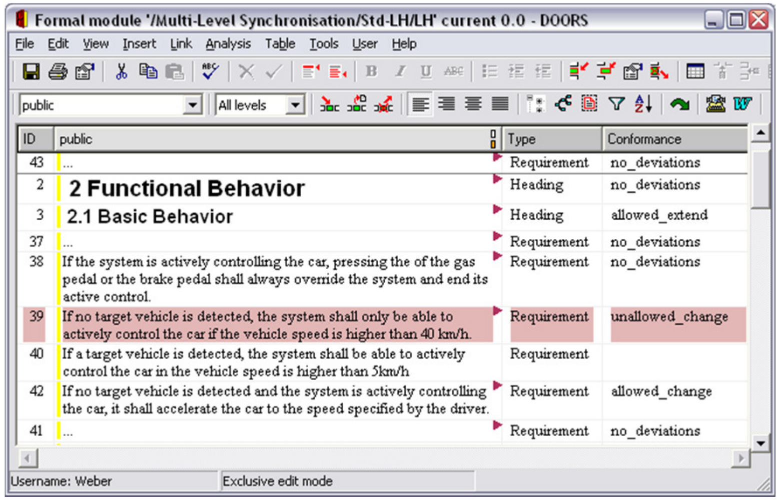
CVM-Framework (Eclipse Plugin)



Multi-Level Feature Models:

- Show deviations
- autom. conformity checking

MuLe (Doors-Extension)



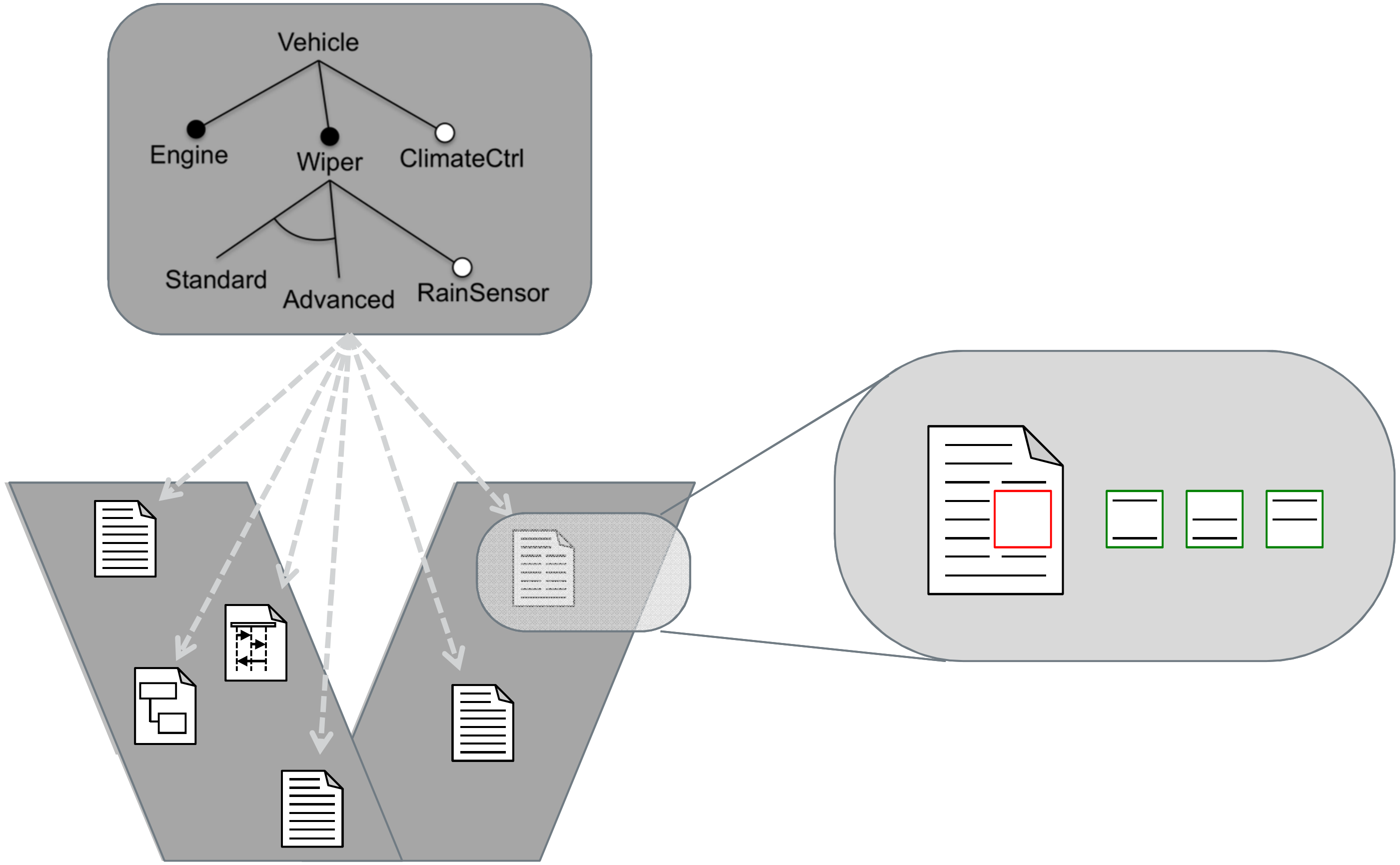
Multi-Level Concept for specification objects:

- Show deviations
- autom. conformity checking
- bidirectional transfer of deviations

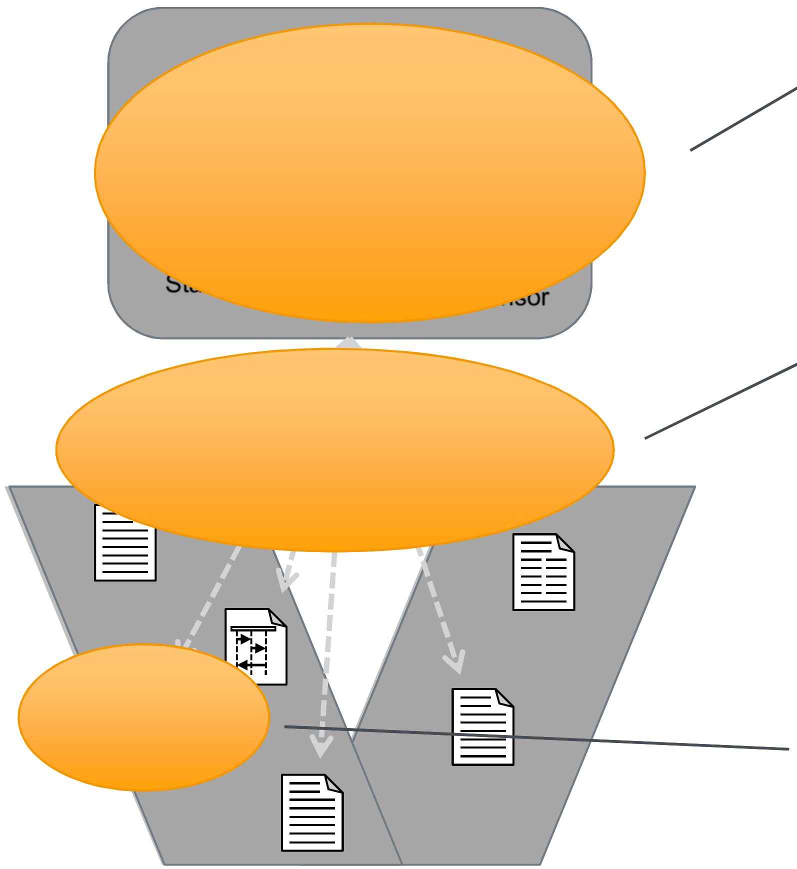
(top-down and bottom-up reuse)

Structuring of Feature Models

Current State:



Problems



Inappropriate for customers

- Complexity (>10.000 Features)
- Technical Perspective

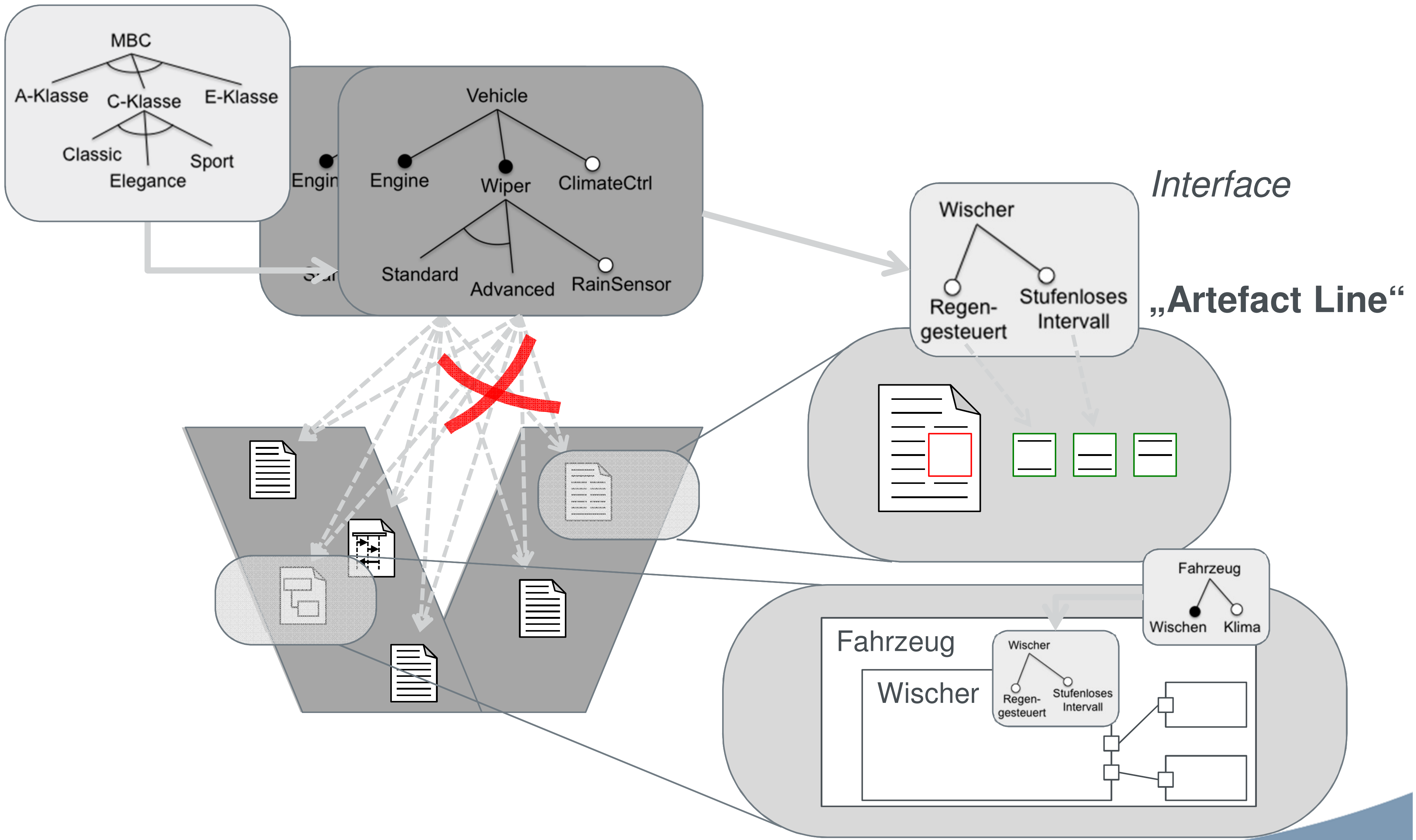
Direct connection too rigorous

- Multitude of actors
- Diverging life cycle and validities
- Heterogenity (methods, tools,...)

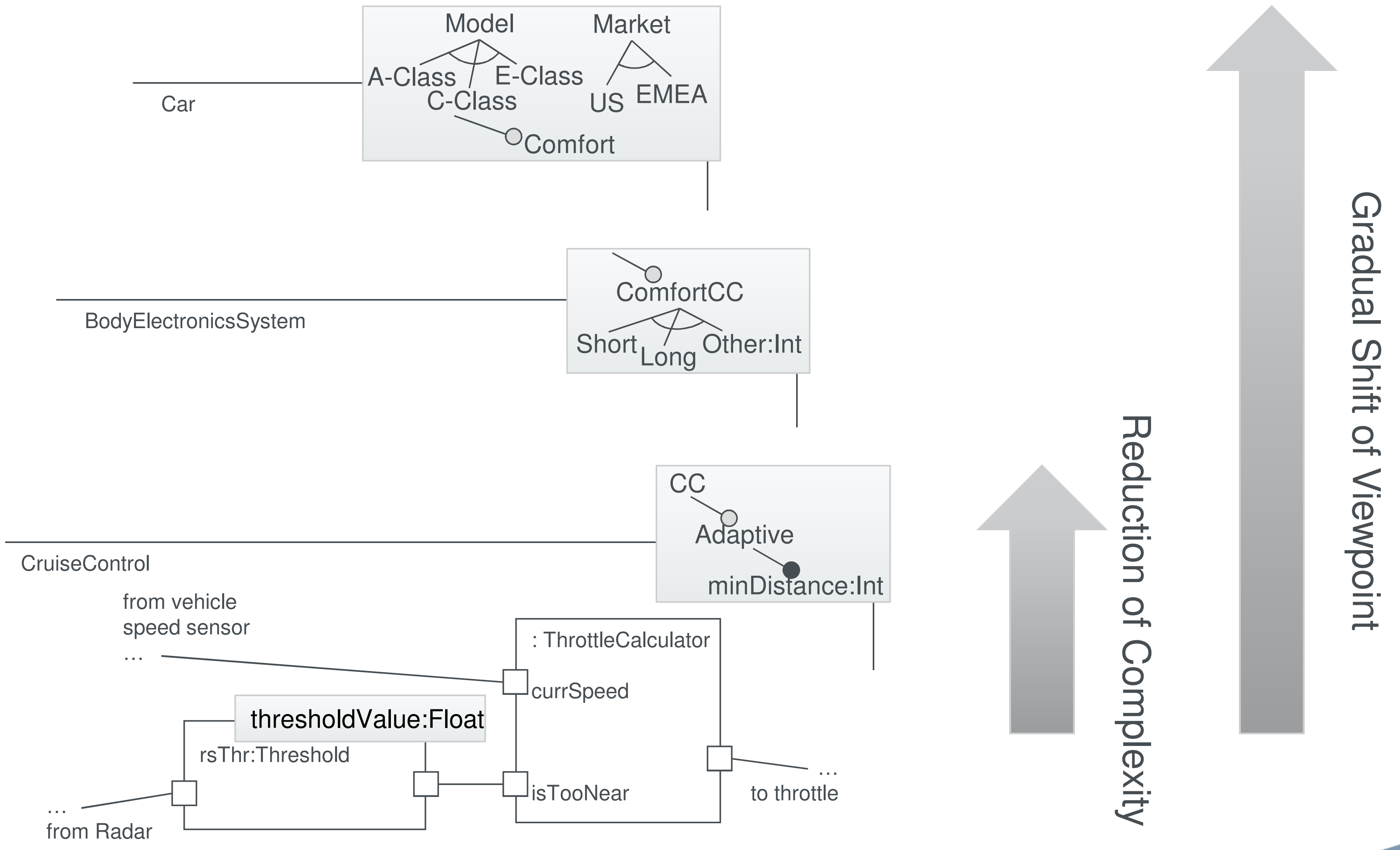
Connection to artifact too coarse

- Some artifacts very large
- Above problems within an artifact !

Reuse Approach: Configuration Links



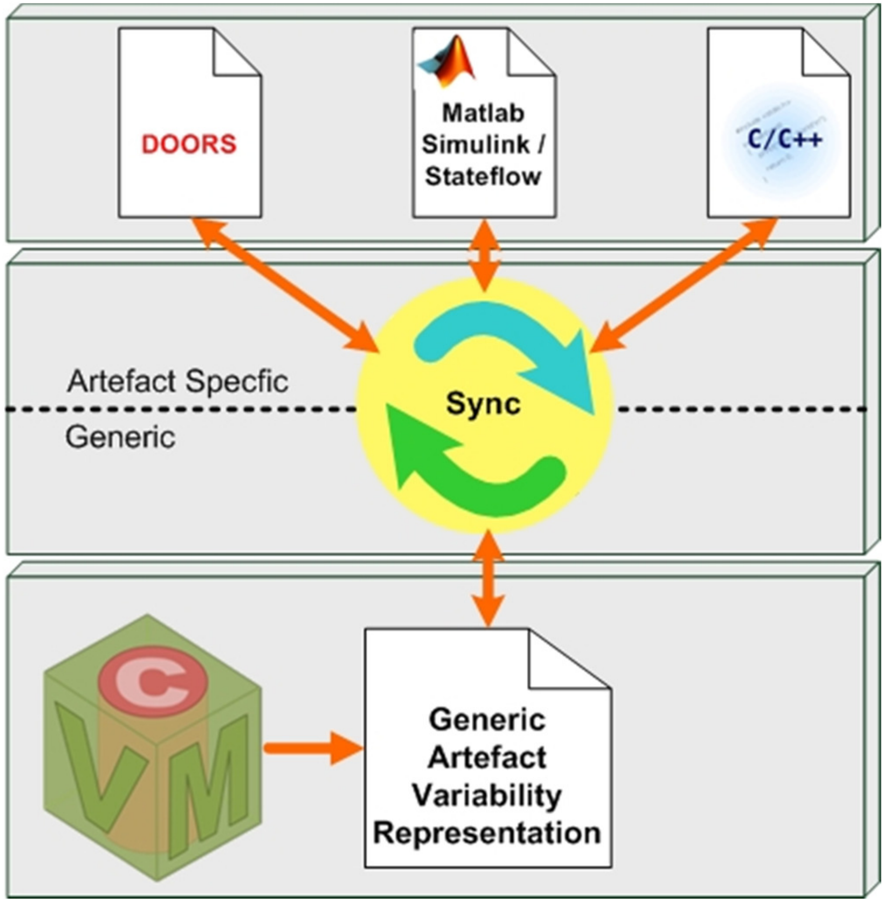
Benefits



Model
Market
A-Class
E-Class
C-Class
US
EMEA
Comfort
Car
ComfortCC
Short
Long
Other:Int
BodyElectronicsSystem
CC
Adaptive
minDistance:Int
CruiseControl
from vehicle
speed sensor
…
: ThrottleCalculator
currSpeed
thresholdValue:Float
rsThr:Threshold
isTooNear
…
to throttle
…
from Radar
Reduction of Complexity
Gradual Shift of Viewpoint

Connection of CVM to development artifacts

- Identification von artifact-specific variability components
- Transformation of CVM Entity-Types resp. –Parts
  - Type-Instance-Structure must be considered
- Construct Feature-Models + Configuration Links for Artifact
- Backtransformation into proprietary artifact format incl. added information
- Bidirectional Transformation without information loss



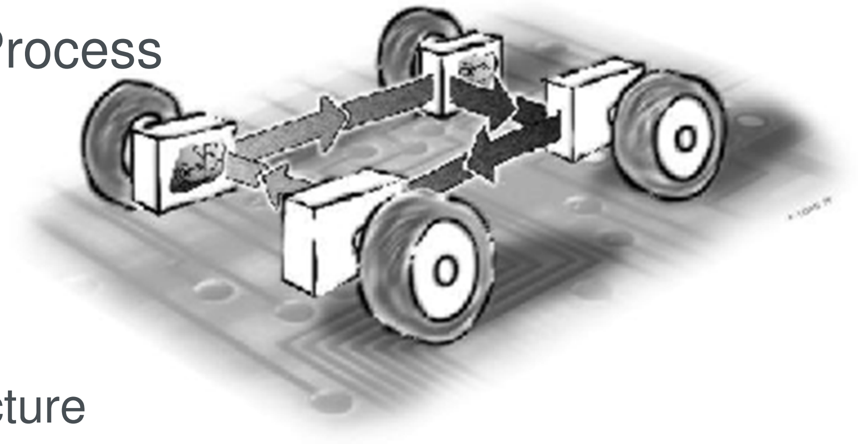
Agenda

The Challenge

Product Related Challenges

- Functionality increase
- Complexity increase
- Increased Safety-criticality
- Quality concerns

Challenges Related to Development Process

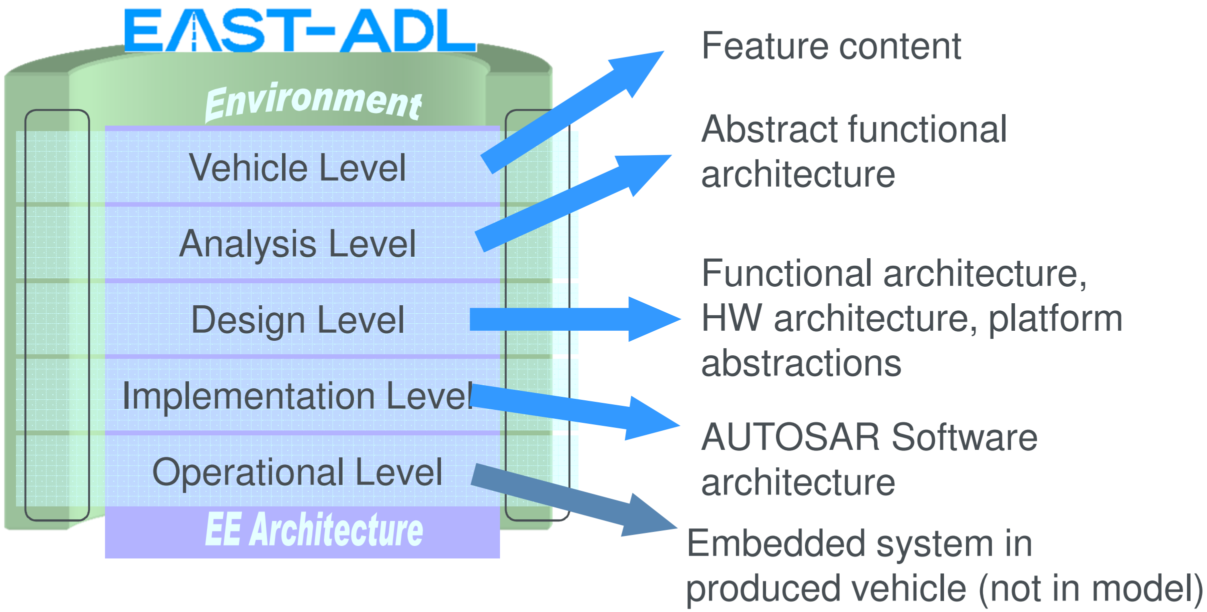


- Supplier-OEM relationship
- Multiple sites & departments
- Product families
- Componentization
- Separation of application from infrastructure
- Safety Requirements, ISO 26262

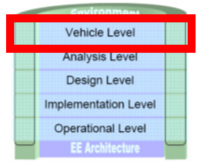
EAST-ADL

A System Modeling Approach/Architectural Framework that

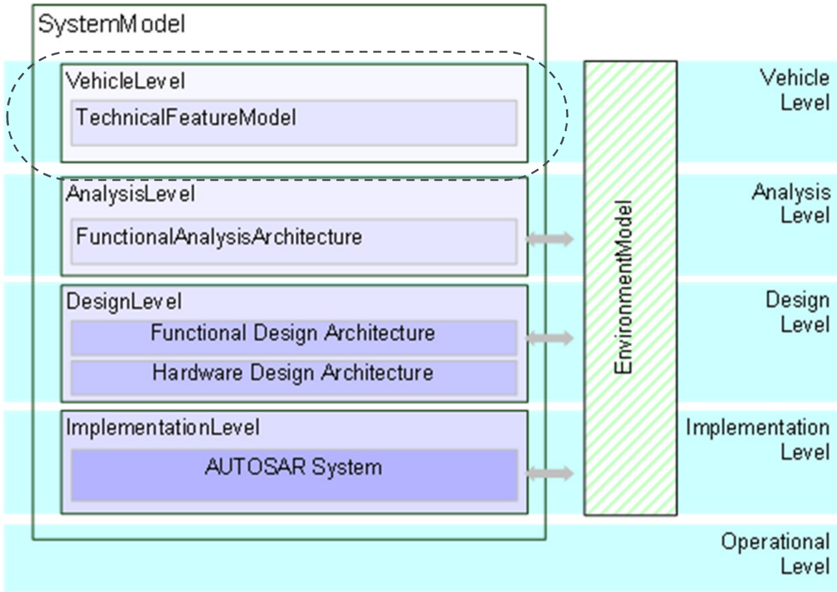
- Is a template for how engineering information is organized and represented
- Provides separation of concerns
- Embrace the de-facto representation of automotive software – AUTOSAR



Vehicle Level



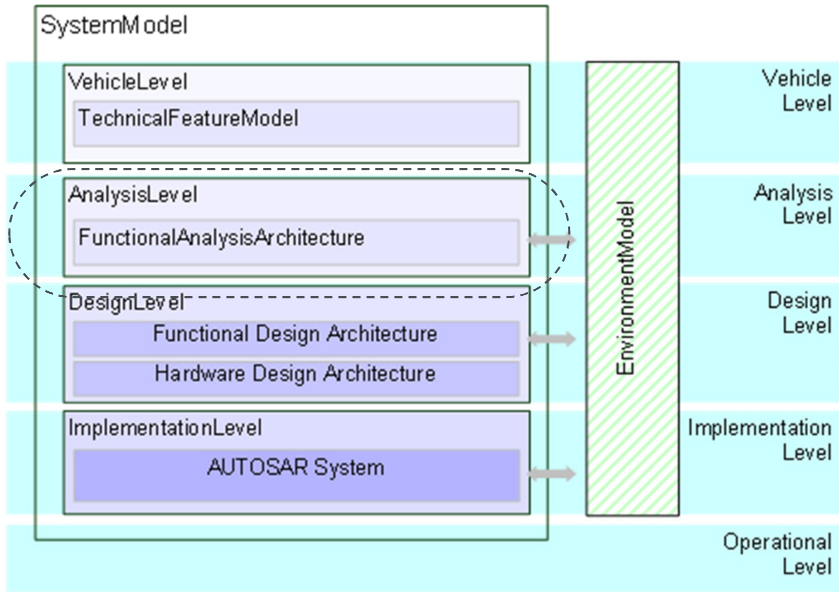
- A Vehicle is characterized by a set of Features
- Features are *stakeholder* requested functional or non-functional characteristics of a vehicle
- A Feature describes the "what", but shall not fix the "how"
- A Feature is specified by requirements and use cases
- From a top-down architecture approach the features are the configuration points to create a vehicle variant



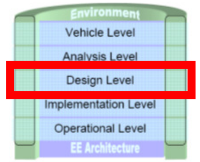
Analysis Level

Analysis Level is the abstract Functional description of the EE system

- Realizes functionality based on the features and requirements
- Captures abstract functional definition while avoiding implementation details
- Defines the system boundary
- Environment model and stakeholders define context
- Basis for safety analysis

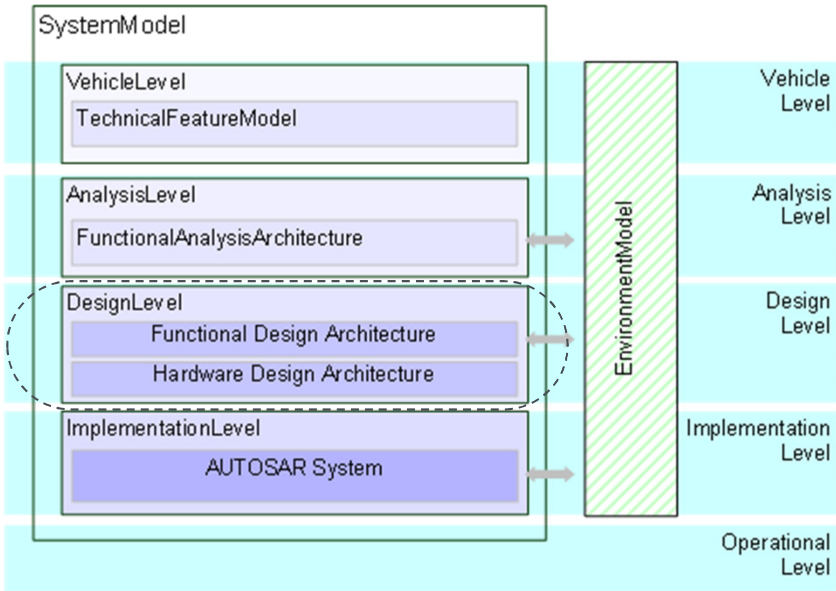


Design Level

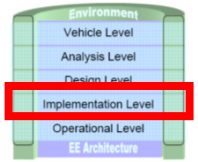


Design Level captures the concrete functional definition with a close correspondance with the final implementation

- Captures functional definition of application software
- Captures functional abstraction of hardware and middleware
- Captures abstract hardware architecture
- Defines Function-to-hardware allocation

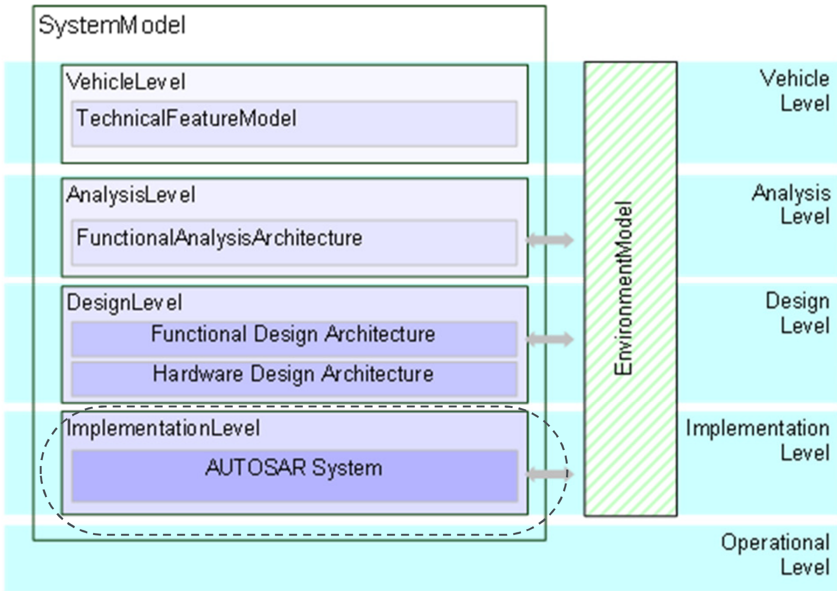


Implementation Level

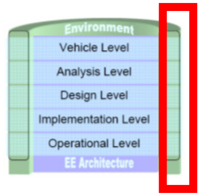


The Implementation Level represents the software-based implementation of the system

- Software components represent application functionality
- AUTOSAR Basic software represents platform
- ECU specifications and topology represent hardware
- Model is captured in AUTOSAR
  - Software component template
  - ECU resource template
  - System Template

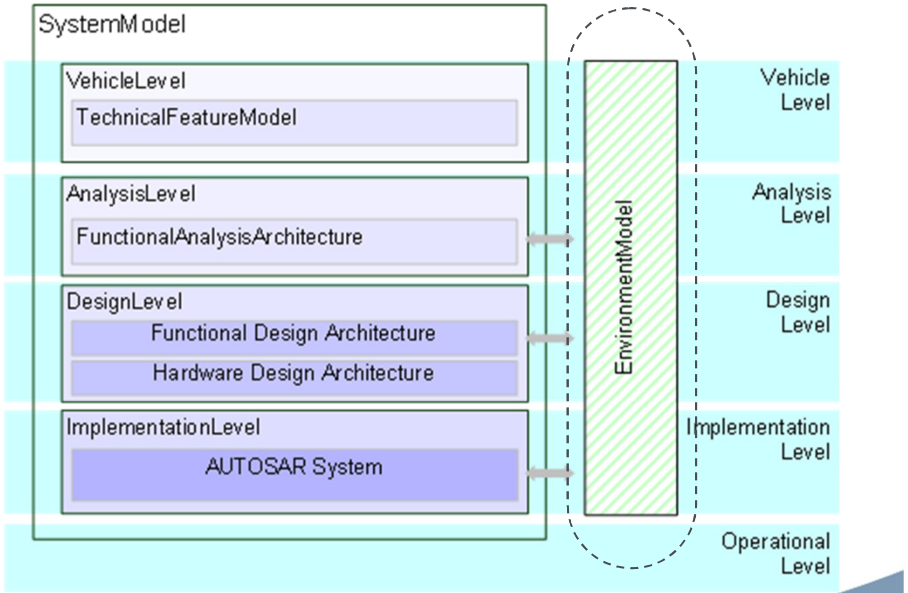


Environment Model



The Environment model captures the plant that the EE system control and interact with

- In-vehicle, near and far environment is covered
- Same Environment Model may be used on all abstraction levels
- Different Environment models may be used depending on validation scenario



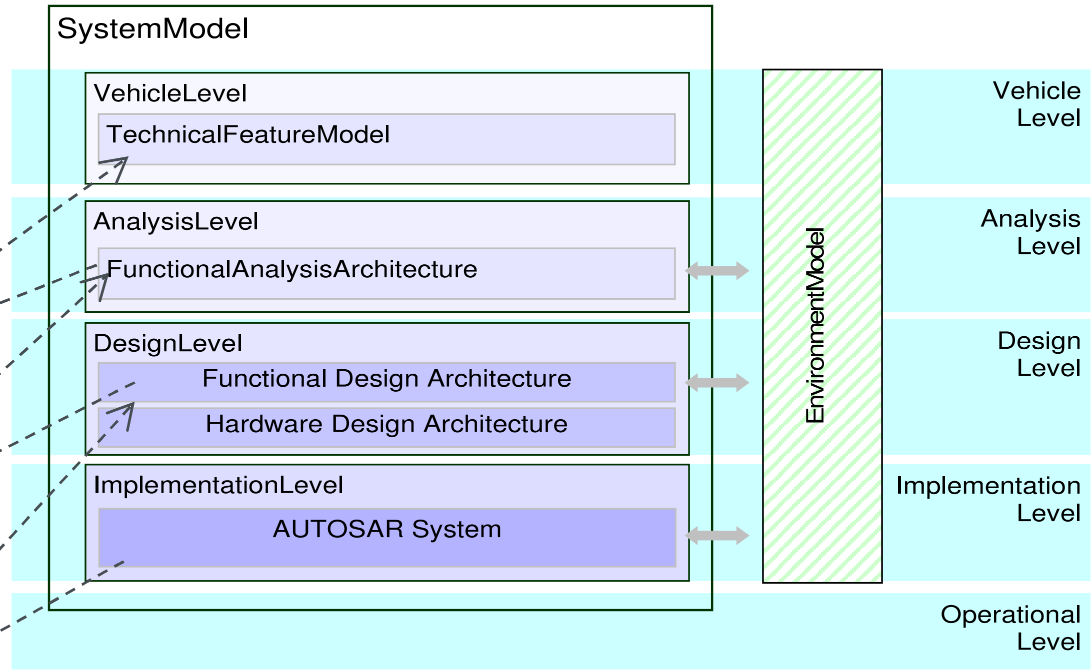
Traceability between abstraction levels

Realization relations identify which abstract element is realized by a more concrete entity

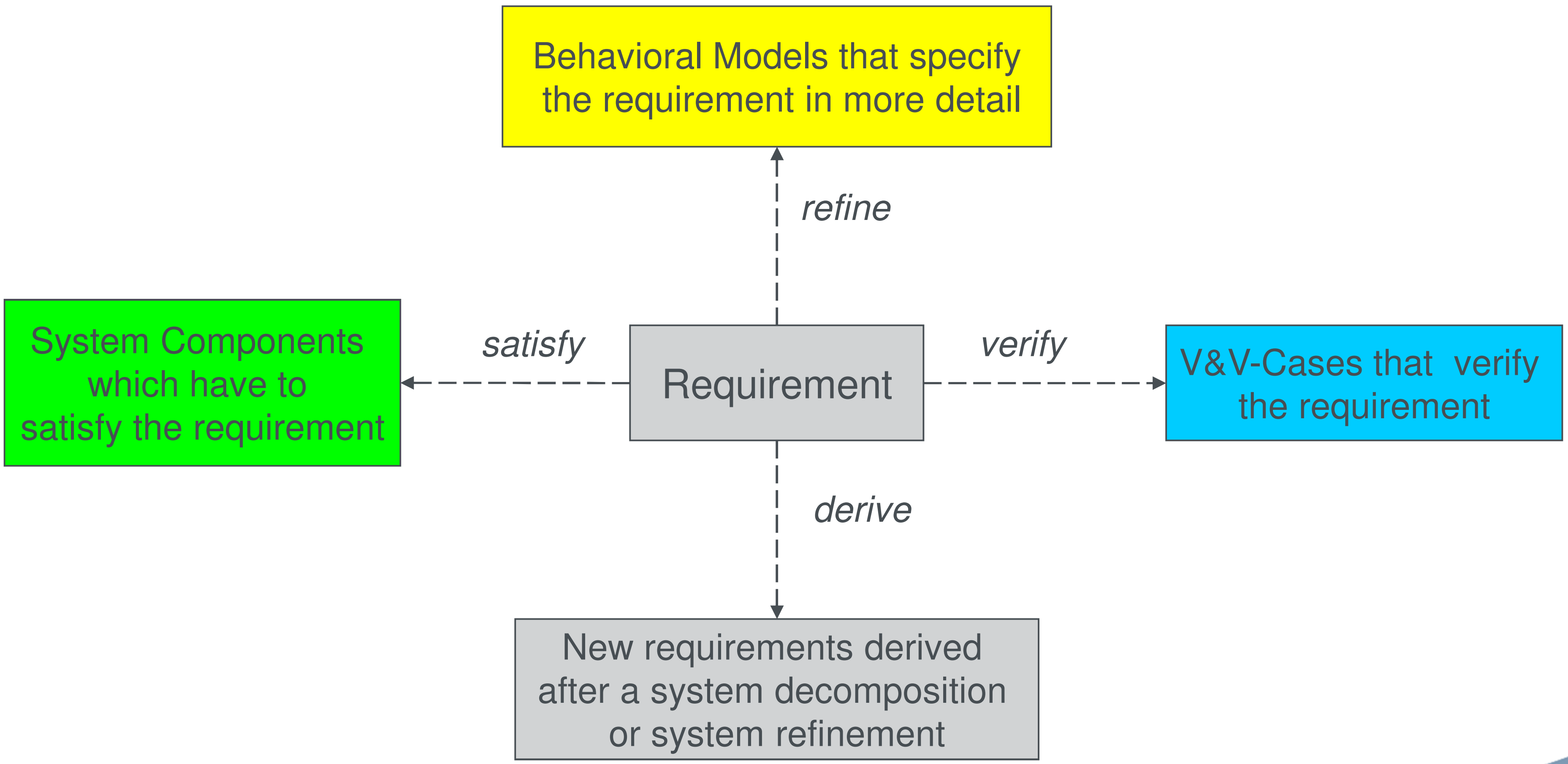
Functions on analysis level realizes features on vehicle level

Functions on design level realizes functions on analysis level

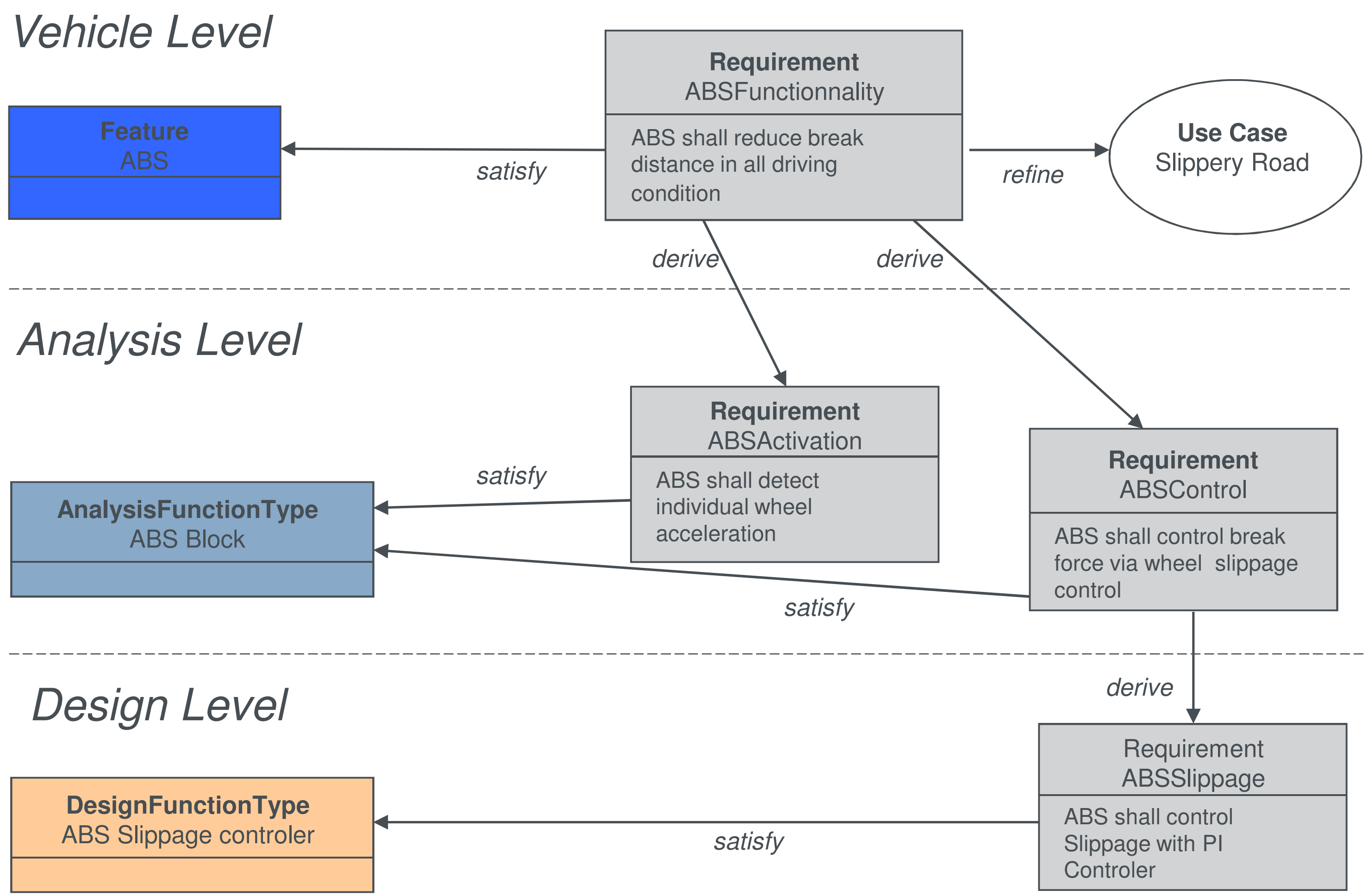
SW components or runnables on implementation level realizes functions on design level



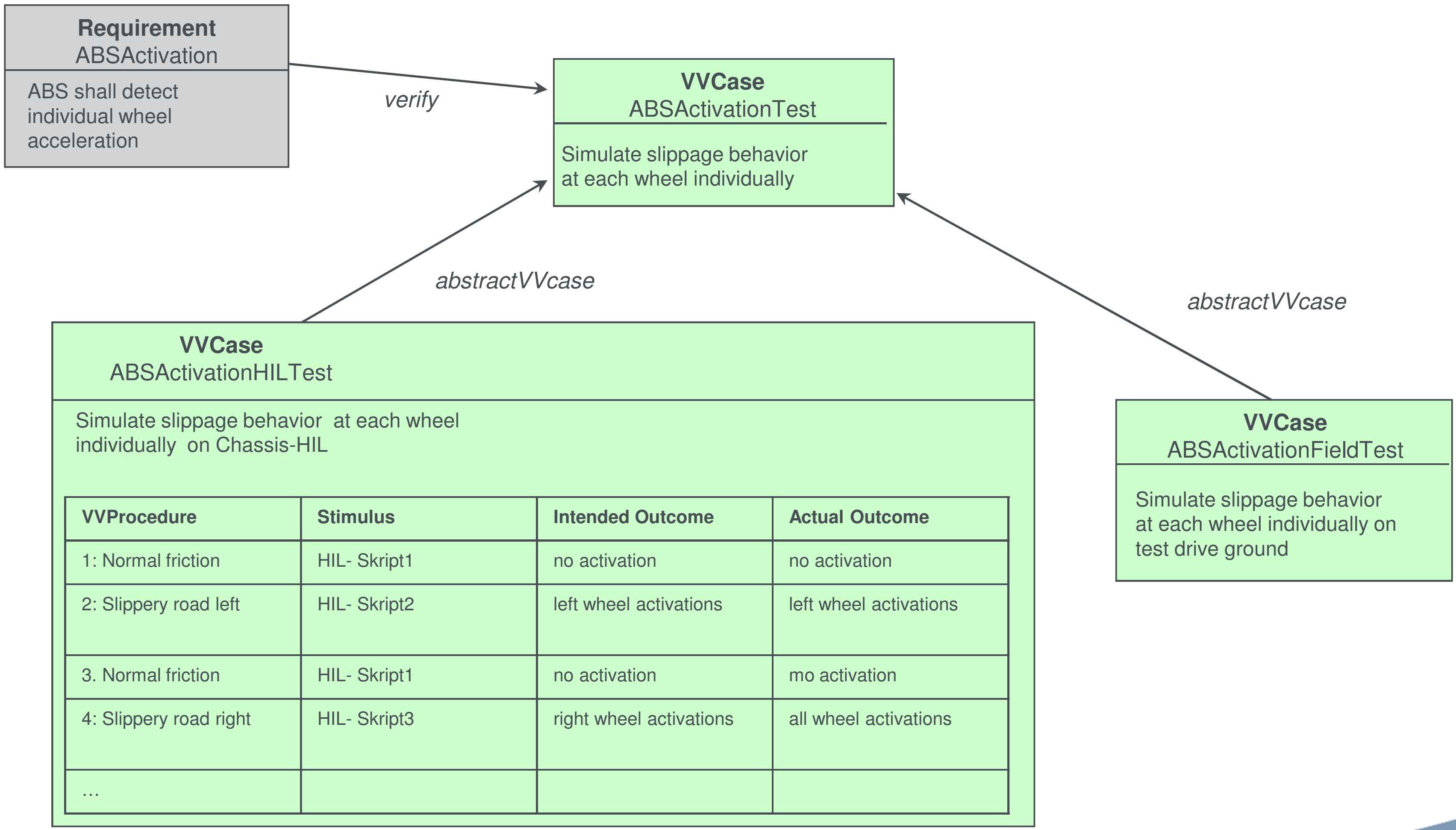
Requirements – Basic Relations



Requirements – Example of Relations (1)



Requirements – Examples of Relations (2)



VVProcedure	Stimulus	Intended Outcome	Actual Outcome
1: Normal friction	HIL- Skript1	no activation	no activation
2: Slippery road left	HIL- Skript2	left wheel activations	left wheel activations
3. Normal friction	HIL- Skript1	no activation	mo activation
4: Slippery road right	HIL- Skript3	right wheel activations	all wheel activations
…			

Wrap up

1. Model-Based Development at Carmeq
2. Stochastic Robustness Testing
3. AUTOSAR
4. The Challenge of Variability
5. The EAST-ADL Architecture Description Language

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Discussion

Your questions?