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FUNCTIONAL DECOMPOSITION

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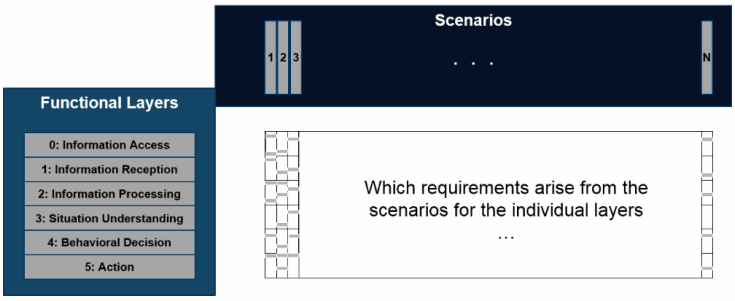
An Approach to Reduce the Approval Effort for Highly Automated Driving.

A statistically approval of the Highway-Chauffeur in public traffic would require several billion kilometer test distance. This is not feasible.

A scenario based approach can reduce testing effort, BUT the different scenarios are still proving simultaneously the skills in all functional layers. Additionally the number of possible combinations of influence parameters lead to an explosion of the parameter space.

The functional decomposition of the driving function and the following segmentation of relevant scenarios in particular tests, that test one ore more functional layers, promises

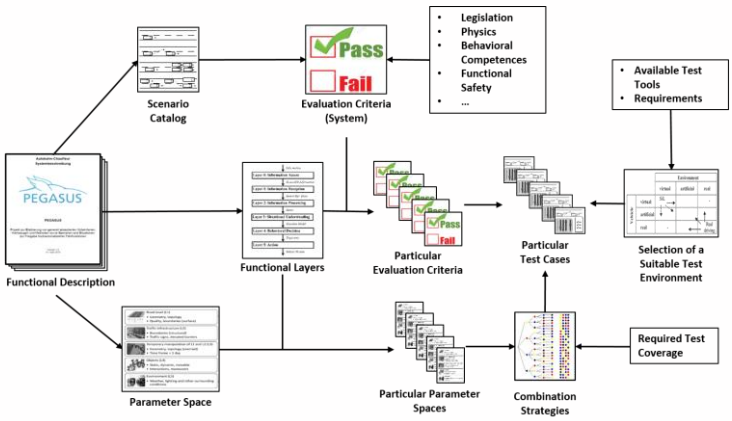
- The reduction of testing effort to a feasible level
- The targeted usage of test environments depending on their validity.



The different scenarios contain redundant requirements for the functional layers.

Challenges for a implementation of the approach:

- Definition of independent decomposition layers and accessible interfaces.
- Definition of pass / fail criteria for the particular tests.
- Approval of the completeness of the approach.



Methodology of the decomposition approach.

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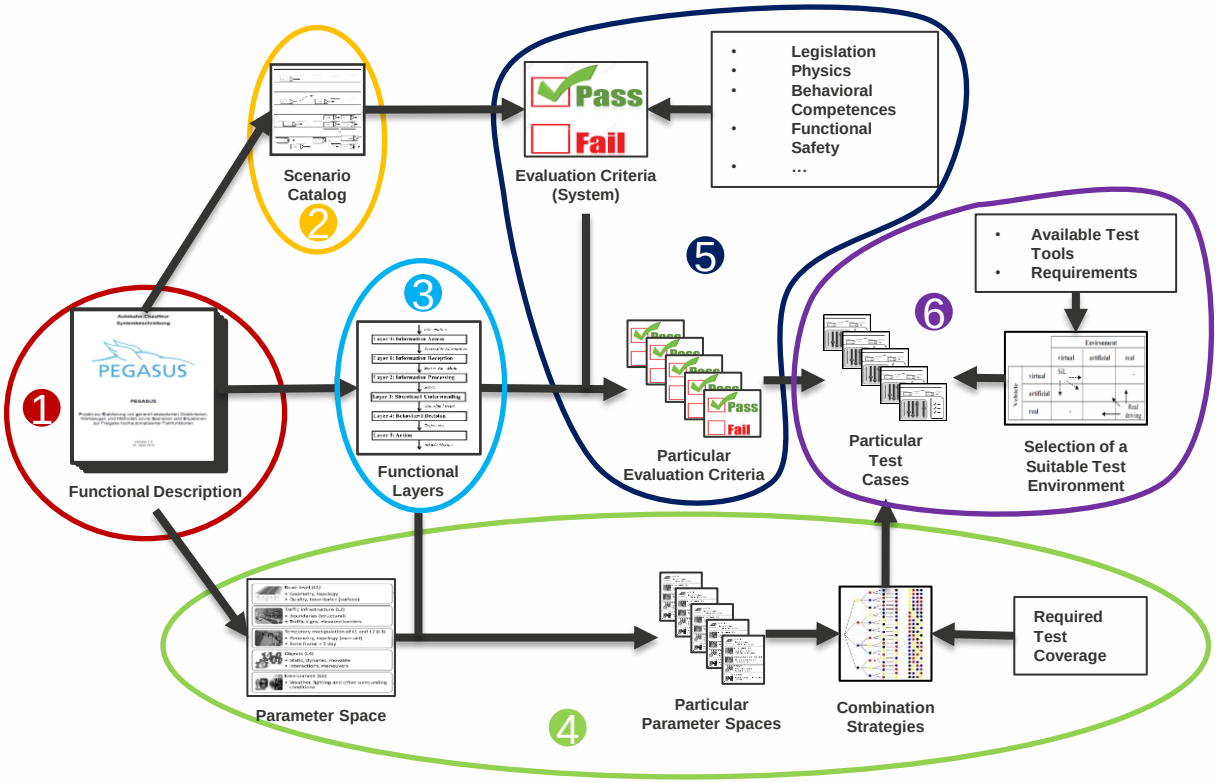
Slide 2: Functional Decomposition Methodology Overview



1	Functional Description of the Driving Function under Test	see Stand 4
2	Scenario Catalog for the Driving Function in its ODD	see Stand 5, 14 -15
3	Functional Layers and Interfaces	see Slide 3
4	Parameter Space Explosion and Effort Reduction by Funct. Decomposition	see Slide 4-5
5	Safety Requirements and Evaluation Criteria	see Slide 6
6	Particular Test Cases	see Slide 7

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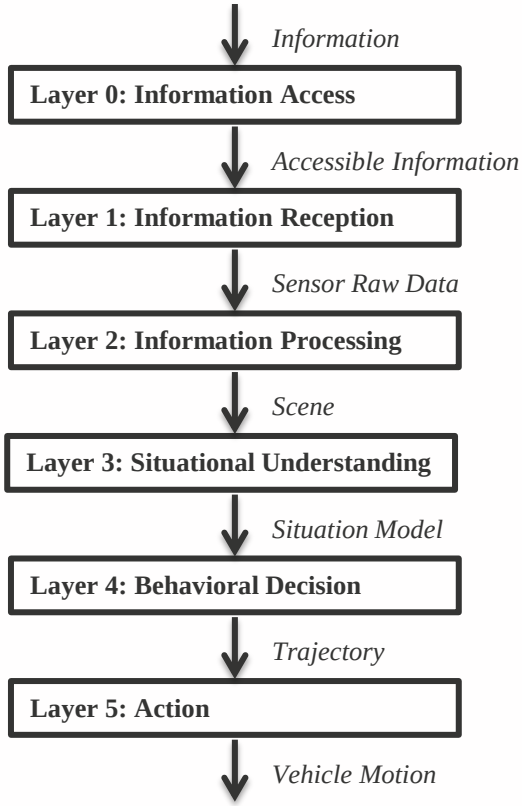
Slide 3: Functional Layers and Interfaces

- Layers are based on the decomposition of the human driving task by Graab et al. [1]
- Layers can be accessed in groups if the interfaces between them are not accessible.



- Detailed description in: Amersbach, Christian and Winner, Hermann: "Functional Decomposition: An Approach to Reduce the Approval Effort for Highly Automated Driving.“, *8. Tagung Fahrerassistenz*, München, 2017.

[1] Graab, B., Donner, E., Chiellino, U., & Hoppe, M.: „Analyse von Verkehrsunfällen hinsichtlich unterschiedlicher Fahrerpopulationen und daraus ableitbarer Ergebnisse für die Entwicklung adaptiver Fahrerassistenzsysteme.“ 3. Tagung Aktive Sicherheit durch Fahrerassistenz, München, 2008

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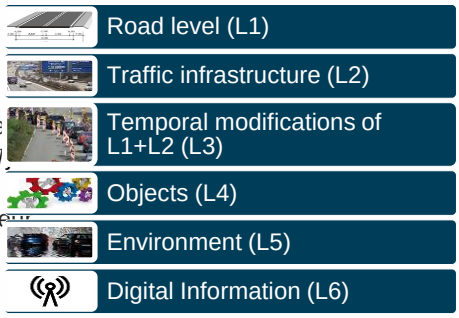
Slide 4: Parameter Space Explosion and required test coverage

Reasons for the Parameter Space Explosion:

- Huge number of Influence parameters
- $S_N = \prod_{i=1}^{N} v_i$ possible parameter combinations (test case for one functional scenario with *N* parameters $pi, i \in \{1 \ldots N$ and v_i possible values for each parameter
- Around 10^{31} concrete scenarios for the Highway- Chauffe… (depending on parameter discretization)



6-layer-model to structure scenarios based on Schuldt (2017), Bagschik et al. (2018) and Bock et al. (2018)

It is not possible to test all concrete scenarios within the parameter space.

Do we need to test all possible concrete scenarios? How many concrete scenarios are required to proof that an Highway-Chauffeur is safer than an human driver?

- Safety Reference: Distance between two fatal accidents (Autobahn): ca. 700 Mio. km
- Statistical proof: factor of ten required for significance level e=5% → ca. 7 Billion km
- Transfer to scenario based testing: $7 \cdot 10^8$ km → $6 \cdot 10^{10}$ concrete scenarios

How many scenarios can be feasible simulated?

- Assumptions: total simulation time = 1 year, 1000 simulations simultaneous, real time factor: 1, duration of one scenario: 5-10 s
- $4 \cdot 10^9$ concrete scenarios can be feasible simulated for the validation.

There is a factor of 15 between the number of required scenarios and the feasible number of the scenarios.

Additional means are required to reduce the approval effort to a feasible level

Detailed description in: Amersbach, Christian and Winner, Hermann: "Defining Required and Feasible Test Coverage for Scenario-Based Validation of Highly Automated Vehicles.“, Author-submitted article to 22nd IEEE Intelligent Transportation Systems Conference (ITSC) 2019. URN: urn:nbn:de:tuda-tuprints-86330

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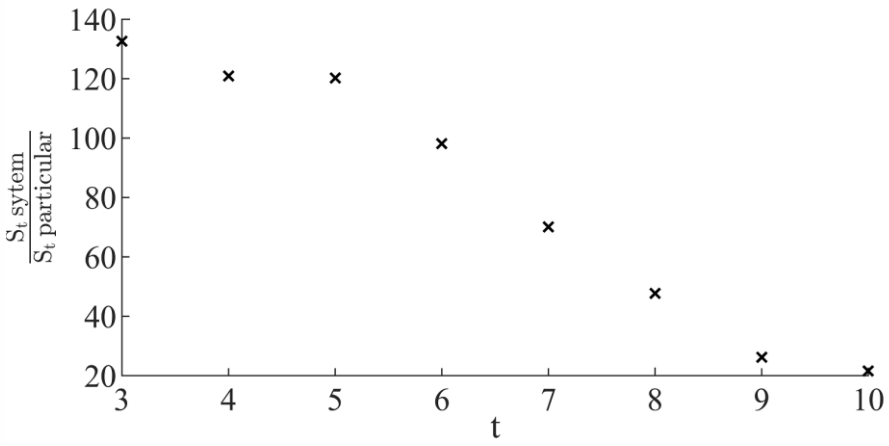
Slide 5: Potential to reduce the approval effort by Functional Decomposition

- **The parameter space of one functional layer is smaller than the parameter space of the complete system:**
  - Not all parameters have influence on every functional layer
  - Reduction of the total parameter space
- **Less complex systems (e.g. independent functional layers have smaller FTFI (failure-triggering-fault-interaction) numbers and require therefore a smaller test coverage**
  - Reduction of the test suite size about approx. one order of magnitude
- **Aggregating parameters with influence on the environment perception in equivalence class scenarios and testing the other scenarios without the perception layers is reducing test effort and increasing the real time factor**
- **Total reduction potential depending on the test coverage and parameter discretization:**



t-wise test coverage *(Grindal et al. 2007):*
For t-wise coverage "[…] every possible combination of all […] values of t parameters [has to] be included in some test case in the test suite."

Detailed description in: Amersbach, Christian and Winner, Hermann: "Funktionale Dekomposition - Ein Beitrag zur Überwindung der Parameterraumexplosion bei der Validation von höher automatisiertem Fahren." , 12. Uni-DAS e.V. Workshop Fahrerassistenz und automatisiertes Fahren, Walting, 2018

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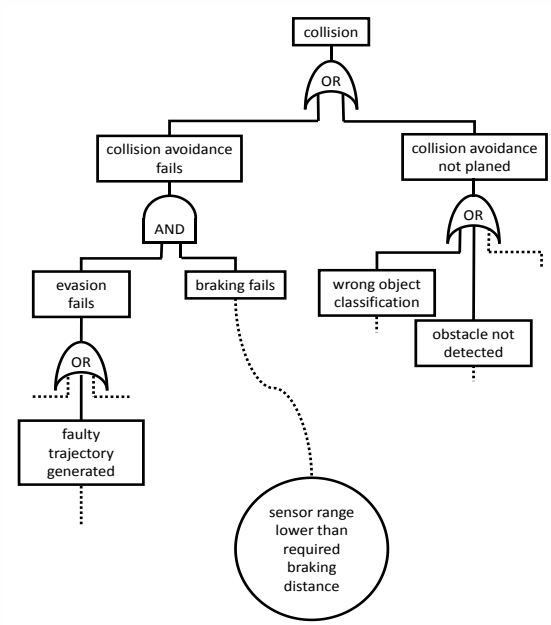
Slide 6: Evaluation Criteria

Evaluation Criteria are derived on system level for all scenarios based on:

- Legislation (e.g. StVO)
- Physical Limits
- Behavioral Competences (e.g. as proposed by NHTSA)
- Functional Safety Requirements
- …

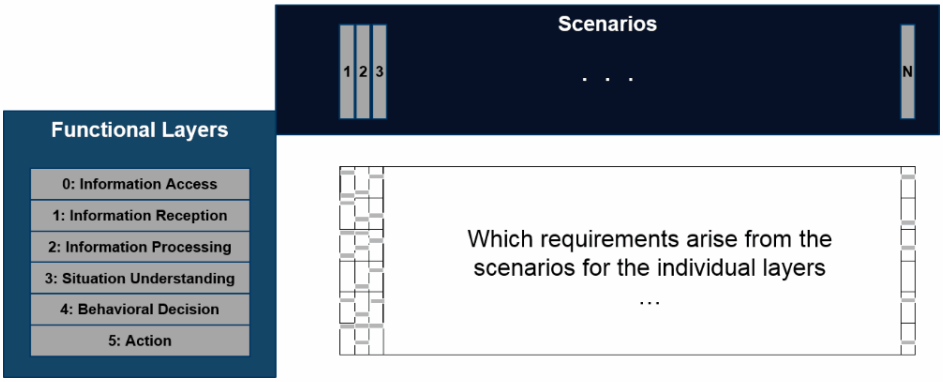
Proven methods from safety analysis are used to brake down the system level evaluation criteria and identify causal factor on the functional layers:

- FTA (fault tree analysis)
- STPA (system theoretic process analysis)
- CCA (common cause analysis)
- RCA (root cause analysis)



Exemplary Fault Tree

Redundant/ similar evaluation criteria can be eliminated/subsumed



Elimination and subsuming of evaluation criteria / requirements

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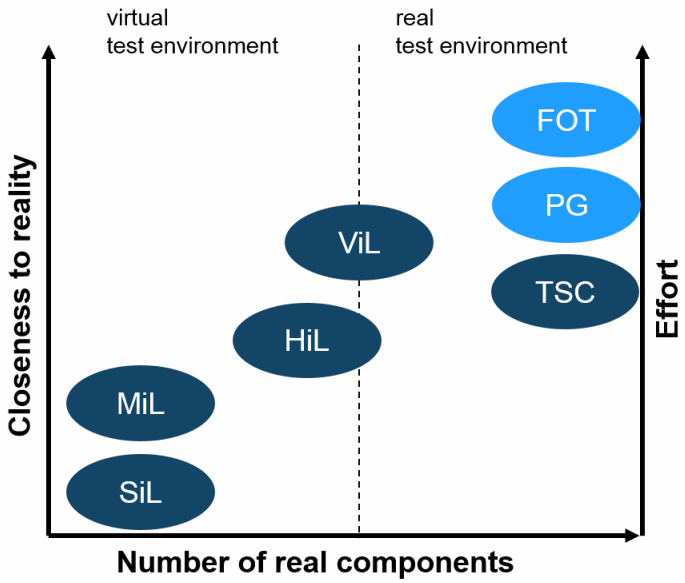
Slide 7: Particular Test Cases

- **Particular test cases are defined to prove that the evaluation criteria are fulfilled.**
- **For all evaluation criteria suitable test environments / methods (e.g. XiL, proving ground tests, etc.) are chosen depending on their validity.**
- **If particular tests require the complete system (e.g. proving ground or field tests), tests of different functional layers can be combined to increase efficiency.**



Reproducibility:
high
low

SiL: Software-in-the-Loop
MiL: Model-in-the-Loop
HiL: Hardware-in-the-Loop
ViL: Vehicle-in-the-Loop
TSC: Test of single Components
PG: Proving ground test
FOT: Field operational test

Comparison between different test environments / methods

- **See also stands 16-27 for testing in general**

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