

Quassystem

Industrial Applications of Evolutionary Testing

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10TH SEPTEMBER 2017

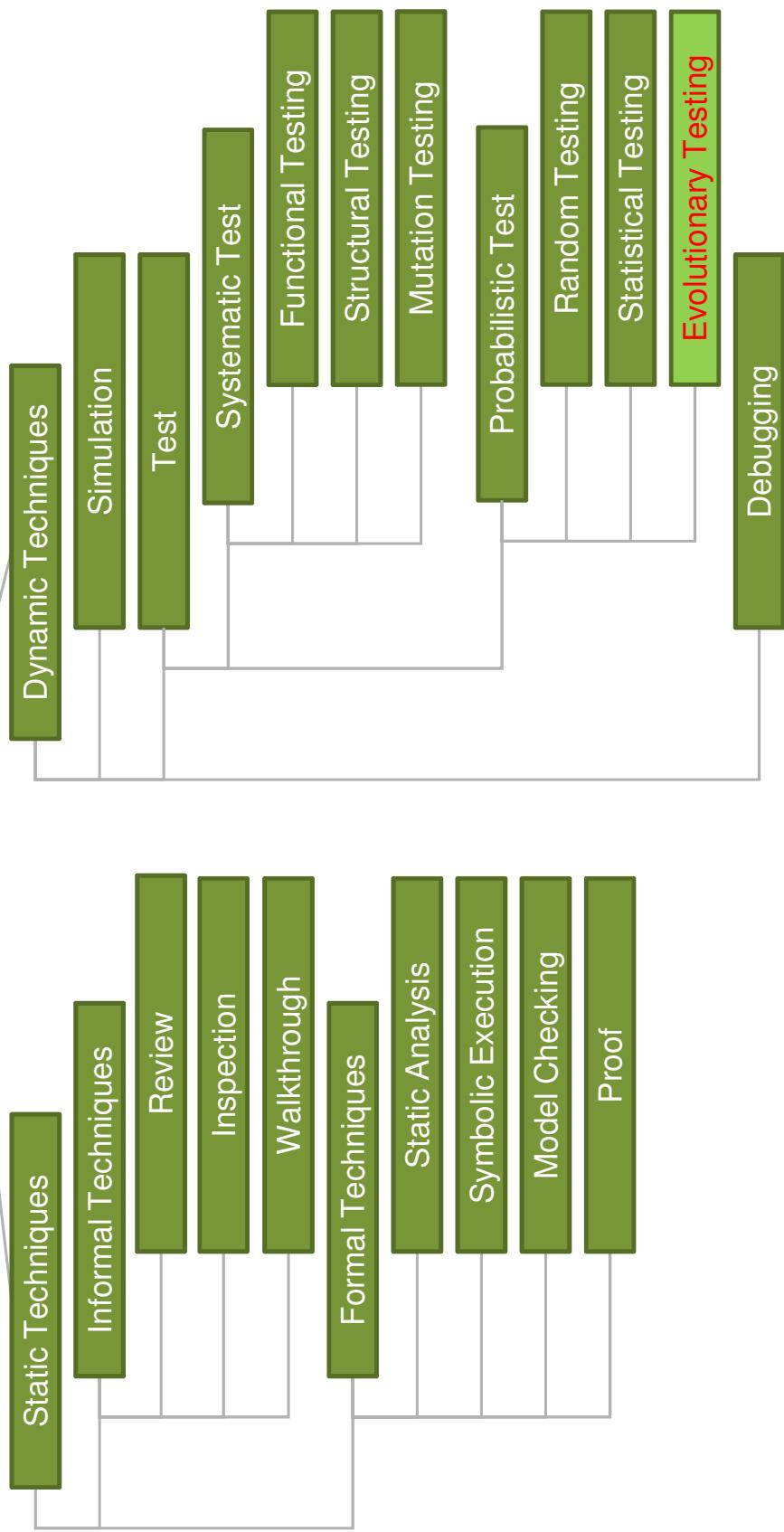
TABLE OF CONTENTS

Testing Background
Major Trends in the Automotive Industry
Applicability of Evolutionary Testing to ADAS
Next Generation ADAS Architecture
Future Challenges
Summary

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Analytical Quality Assurance

Analytical Quality Assurance Techniques



Testing Methods demanded

- E.g. by ISO 26262 – Road vehicles – Functional safety

Table 11 — Methods for deriving test cases for software unit testing

	Methods	ASIL			
		A	B	C	D
1a	Analysis of requirements	++	++	++	++
1b	Generation and analysis of equivalence classes ^a	+	++	++	++
1c	Analysis of boundary values ^b	+	++	++	++
1d	Error guessing ^c	+	+	+	+

Table 12 — Structural coverage metrics at the software unit level

	Methods	ASIL			
		A	B	C	D
1a	Statement coverage	++	++	+	+
1b	Branch coverage	+	++	++	++
1c	MC/DC (Modified Condition/Decision Coverage)	+	+	+	++

Table 15 — Structural coverage metrics at the software architectural level

	Methods	ASIL			
		A	B	C	D
1a	Function coverage ^a	+	+	++	++
1b	Call coverage ^b	+	+	++	++

Testing Methods recommended

- E.g. by ISO 29119 – Software Testing

Specification-Based Testing Techniques:

- Equivalence Partitioning
- Classification Tree Method
- Boundary Value Analysis
- State Transition Testing
- Decision Table Testing
- Cause-Effect Graphing
- Syntax Testing
- Combinatorial Test Techniques, including:
 - > All Combinations
 - > Pairwise Testing
 - > Each Choice Testing
 - > Base Choice Testing
 - Scenario Testing (including Use Case Testing)
 - Random Testing

Functional Test

Functional Test

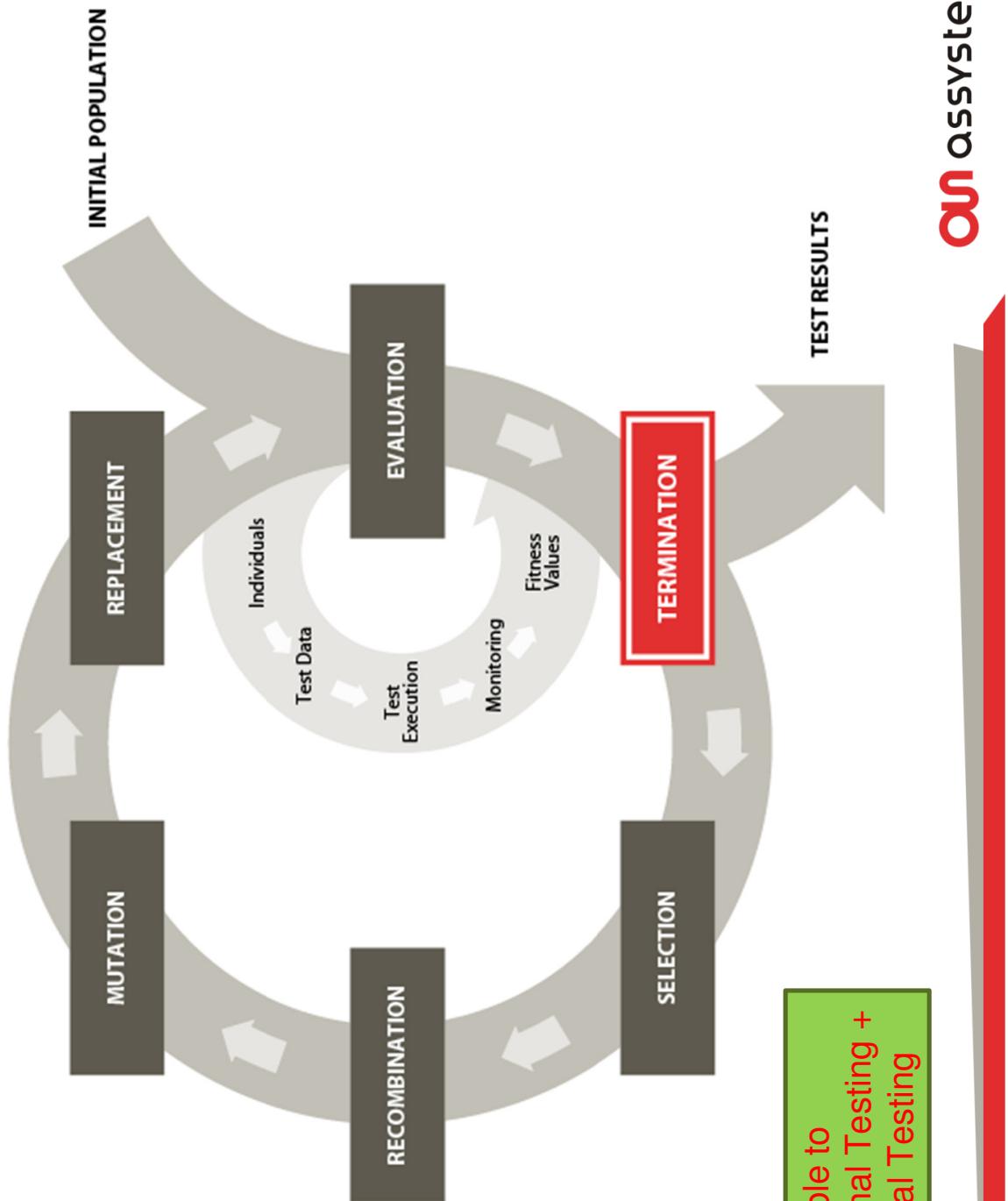
Structure-Based Testing Techniques:

- Statement Testing
- Branch Testing
- Decision Testing
- Condition Testing, including:
 - > Branch Condition Testing
 - > Branch Condition Combination Testing
 - > Modified Condition Decision Condition (MCDC) Testing
- Data Flow Testing, including:
 - > All definitions
 - > All-c-uses
 - > All-p-uses
 - > all-uses
 - > all-du-paths

Experience-Based Testing Techniques:

- Error Guessing

Evolutionary Testing - Procedure



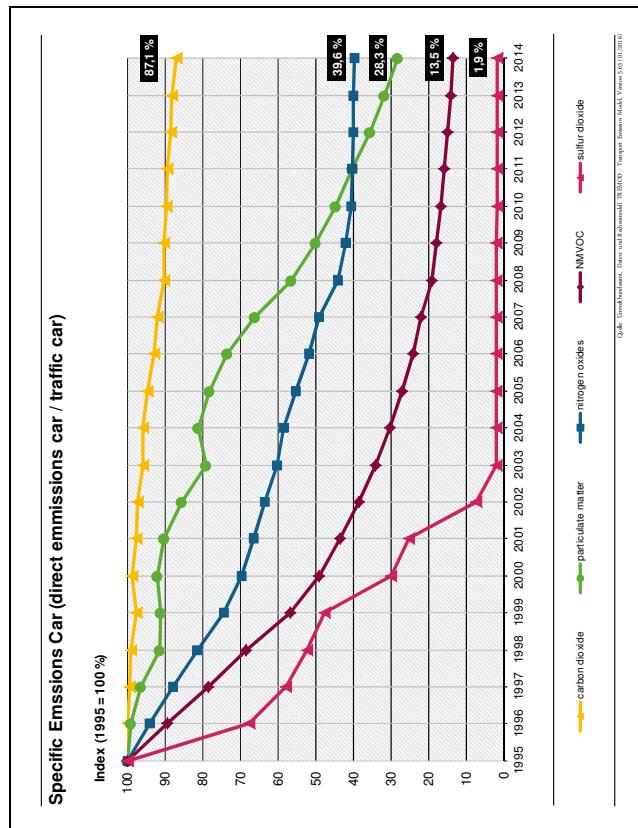
Major Drivers and Trends in Automotive Industry

Drivers

- 30 % of all urban traffic is caused by searching for parking spaces¹
- 42 hours per year spent in traffic jams by the average commuter²
- 50 % of delivery costs are spent on the last mile³
- >95 % of the time private cars are idle⁴

Trends

- Shared Mobility (individual mobility will not require ownership of a personal vehicle)
- Digitalization and Connectivity (20 billion connected devices worldwide in 2020)
- Electrification (powertrain will be electrified)
- Automated Driving & Parking



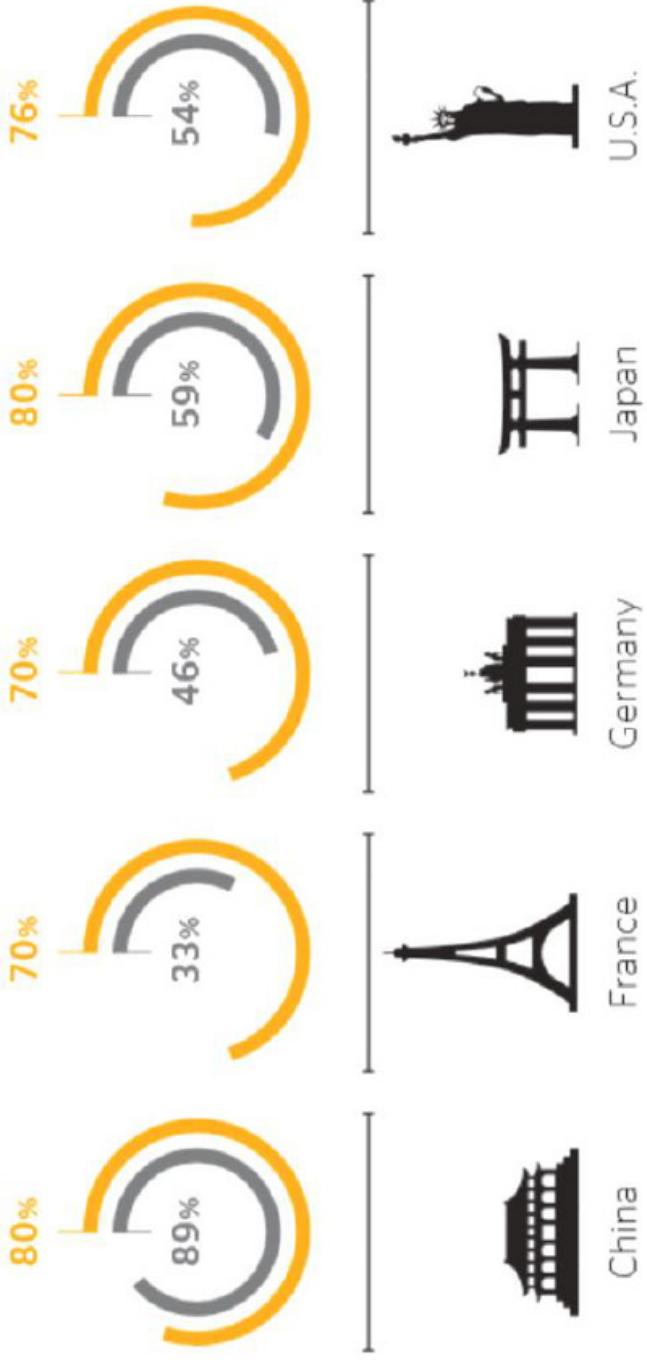
(1) Roland Berger, "Shared Mobility" (2014), (2) US DOT, "Beyond Traffic 2045" (2017),
 (3) McKinsey, "Parcel delivery: The future of last mile" (2016), (4) RAC Foundation, "Spaced out" (2012)

Automated Driving & Parking – Market Demands



> Stop-and-go traffic and traffic jams are the biggest causes of stress while driving.

> Automated driving is a feature drivers want.



Source: http://report.conti-online.com/report2014/service/download/docs/mobilitaetsstudie_2015_de.pdf

Levels of Driving Automation for On-Road Vehicles



Source: <http://www.videantis.com/what-are-all-these-automotive-cameras-doing.html>

Levels of Driving Automation for On-Road Vehicles

This table summarizes SAE International's levels of driving automation for on-road vehicles. Information Report J3016 provides full definitions for these levels and for the italicized terms used therein. The levels are descriptive rather than normative and technical rather than legal. Elements indicate minimum rather than maximum capabilities for each level.

"System" refers to the driver assistance system, combination of driver assistance systems, or *automated driving system*, as appropriate.

The table also shows how SAE's levels definitively correspond to those developed by the Germany Federal Highway Research Institute (BASt) and approximately correspond to those described by the US National Highway Traffic Safety Administration (NHTSA) in its "Preliminary Statement of Policy Concerning Automated Vehicles" of May 30, 2013.

Level	Name	Narrative definition	Execution of steering and acceleration/deceleration	Monitoring of driving environment	Fallback performance of dynamic driving task	System capability (driving modes)	Base level	NHTSA level
Human driver monitors the driving environment								
0 No Automation	No Automation	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1 Driver Assistance	Driver Assistance	the <i>driving mode-specific execution</i> by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2 Partial Automation	Partial Automation	the <i>driving mode-specific execution</i> by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	System	Human driver	Human driver	Some driving modes	Partially automated	2
Automated driving system ("system") monitors the driving environment								
3 Conditional Automation	Conditional Automation	the <i>driving mode-specific performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>	System	System	Human driver	Some driving modes	Highly automated	3
4 High Automation	High Automation	the <i>driving mode-specific performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> , even if a <i>human driver</i> does not respond appropriately to a <i>request to intervene</i>	System	System	System	Some driving modes	Automated	3/4
5 Full Automation	Full Automation	the <i>full-time performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>	System	System	System	All driving modes	-	-

Source: <http://cyberlaw.stanford.edu/oda>

10

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Source: <http://cyberlaw.stanford.edu/oda>



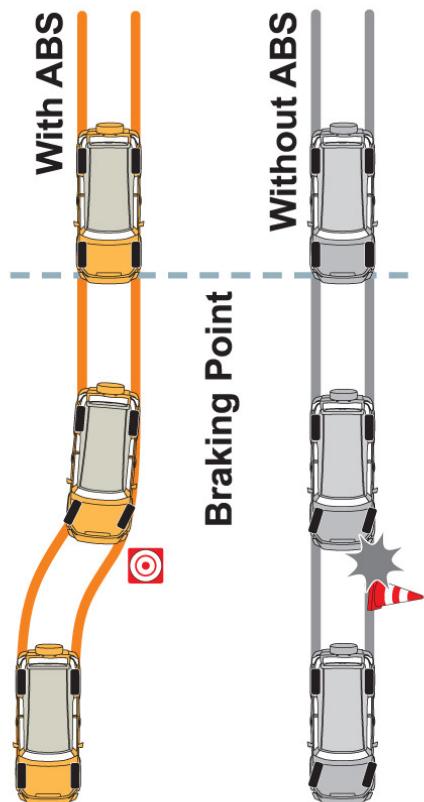
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1	Driver Assistance	the <i>driving mode-specific execution</i> by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the driving task	System	Human driver	Human driver	Some driving modes	Assisted	1
ABS, ESP/ESC, Lane Departure Warning, Blind Spot Monitoring, ...								
			System	System	Human driver	Some driving modes	Partially automated	2
			f	System	System	Some driving modes	Highly automated	3
			f	System	System	Some driving modes	Fully automated	3/4
			f	System	System	All driving modes	-	-



Source: autotechnicblog

Source: <http://cyberlaw.stanford.edu/loada>

12

Level 0: Testing of Anti Blocking System



Functionality

- maximum deceleration at about 20% slip (wheel rolls 0.8 m when the vehicle is traveling 1m)
- Ensuring lateral guiding force for vehicle (optimal with 0% slip: wheel rolls 1m while vehicle is traveling 1 m; still good with 20% slip, nearly 0 with blocking wheels)
- Considering road conditions (ice, rain-slicked, gravel, dry asphalt)
- Sensors: wheel speed sensors for all four wheels
- Actuators: solenoid valves of the ABS hydraulic (responsible for controlling braking pressure)

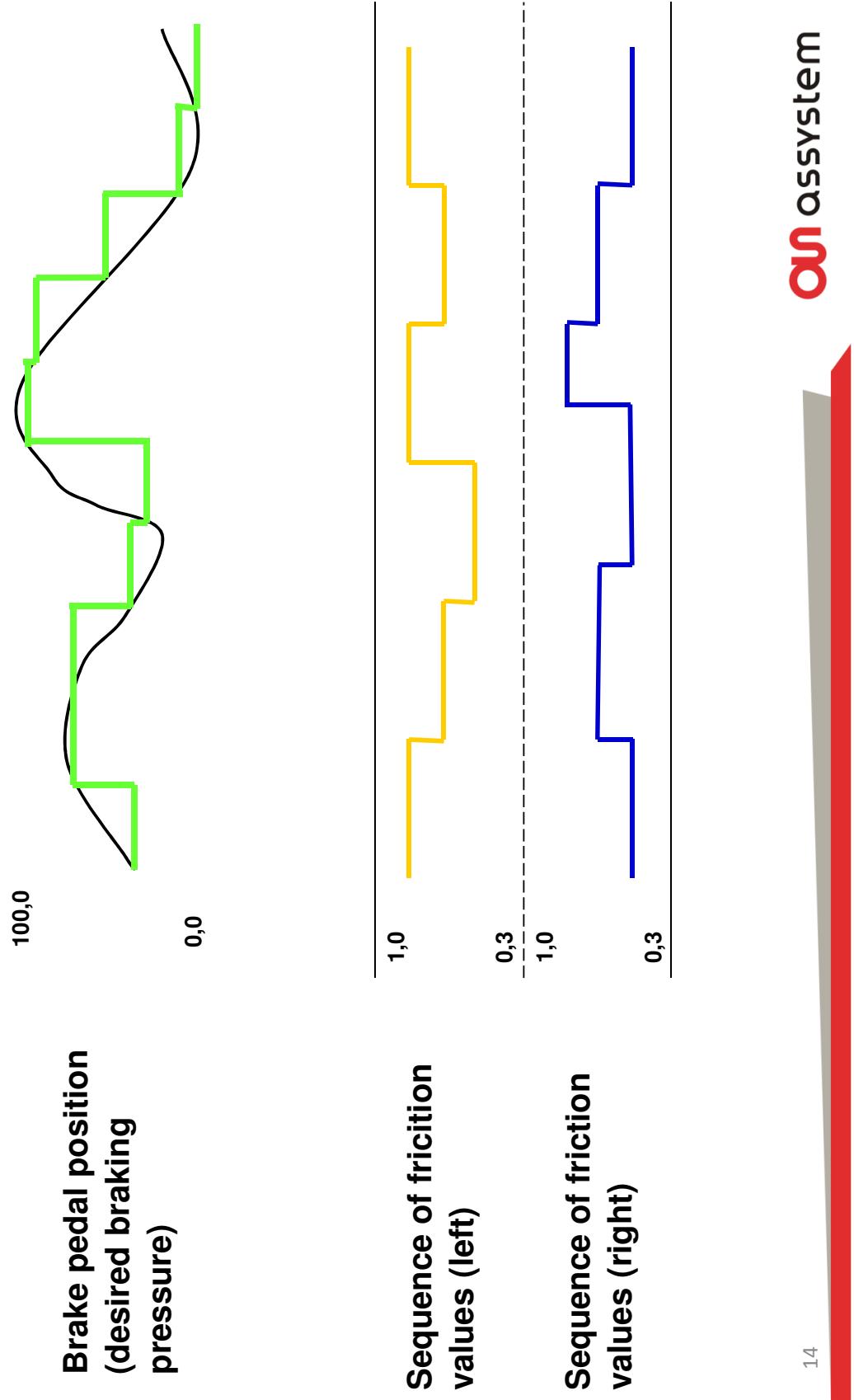
Testing Goal

- Find testing scenarios which result in **blockage of at least one wheel ("mal function of ABS ECU functionality")**

- Difficulties:

- in most cases the ABS control function operates correctly, find sequences of high and low friction that are critical in correlation with different brake pressure
- Generate continuous signal values

Input Domain of ABS



Generation of continuous signal values

... for braking pressure

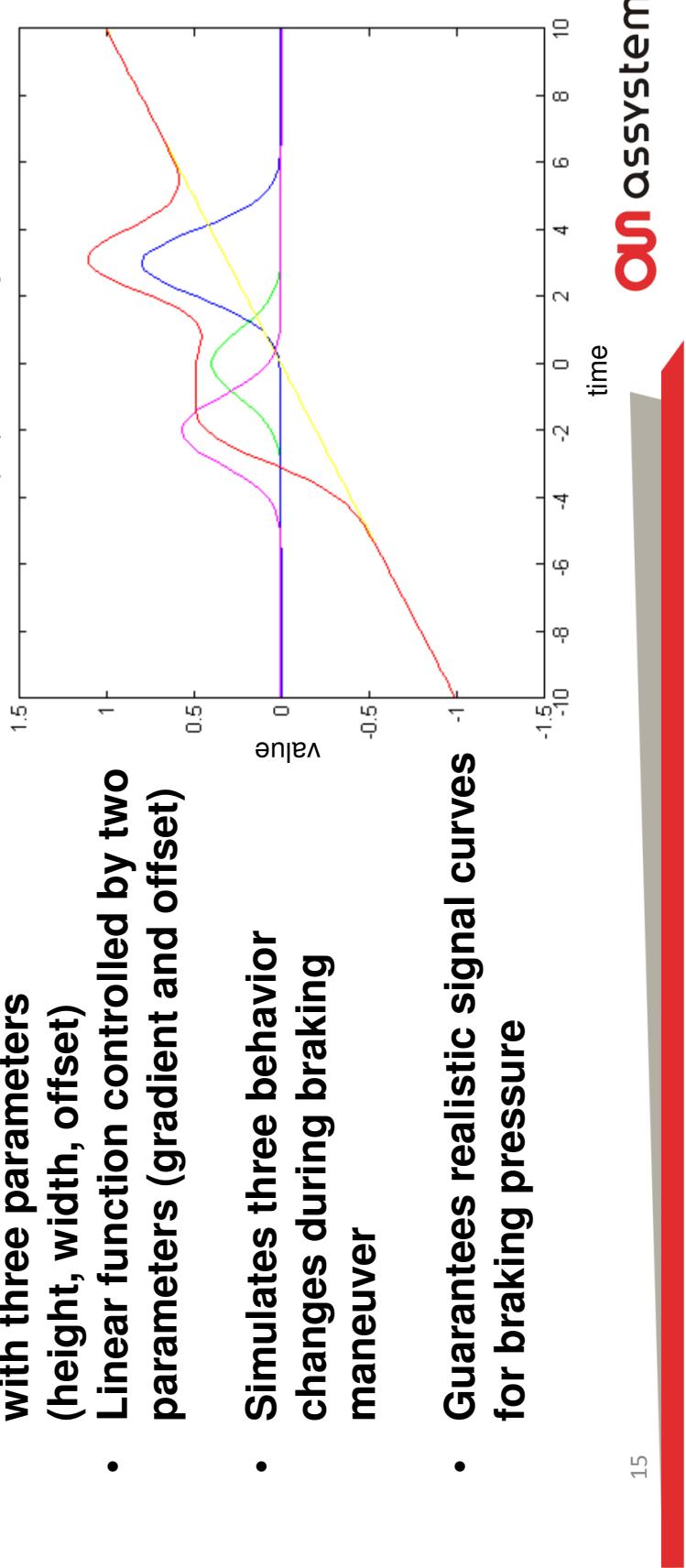
Approach: MoG – Mixture of Gaussians

- Superposition of 3 Gaussian functions and one linear function

- Gaussian functions controlled each with three parameters (height, width, offset)
- Linear function controlled by two parameters (gradient and offset)

- Simulates three behavior changes during braking maneuver

- Guarantees realistic signal curves for braking pressure

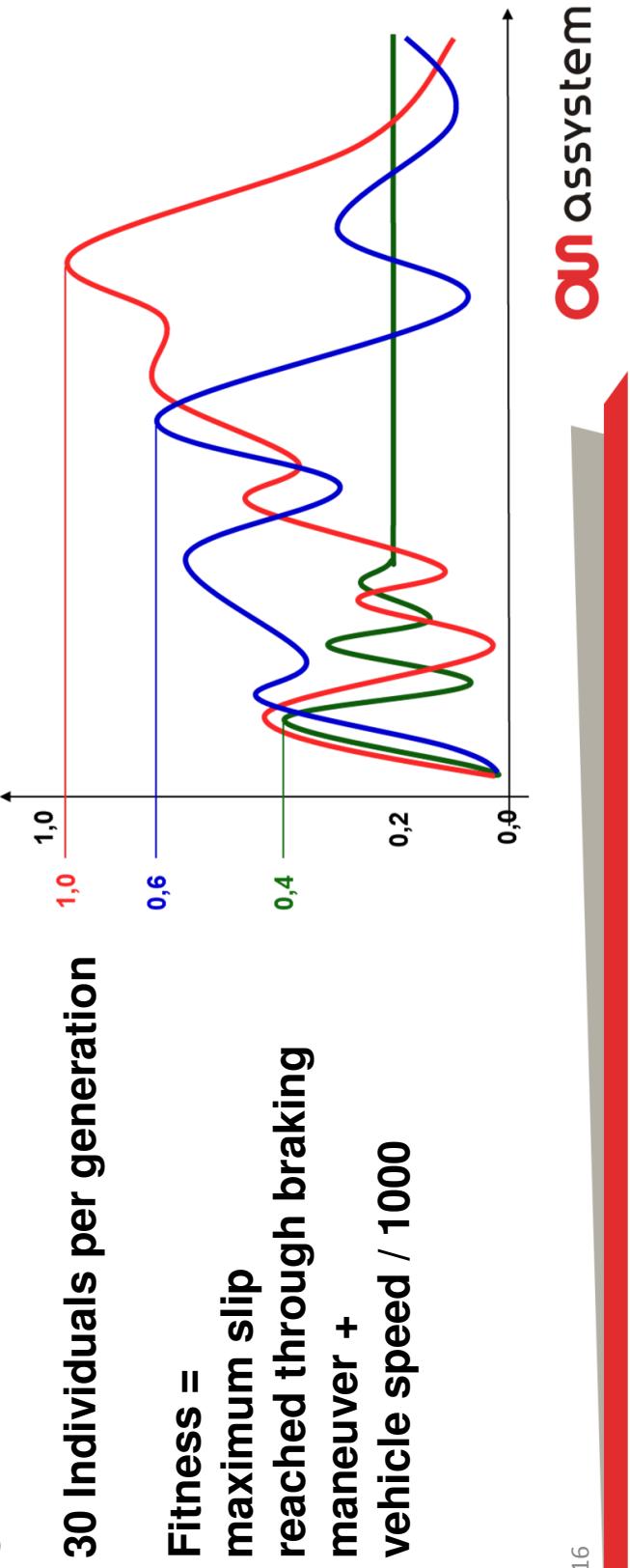


Individual Configuration and Fitness Function

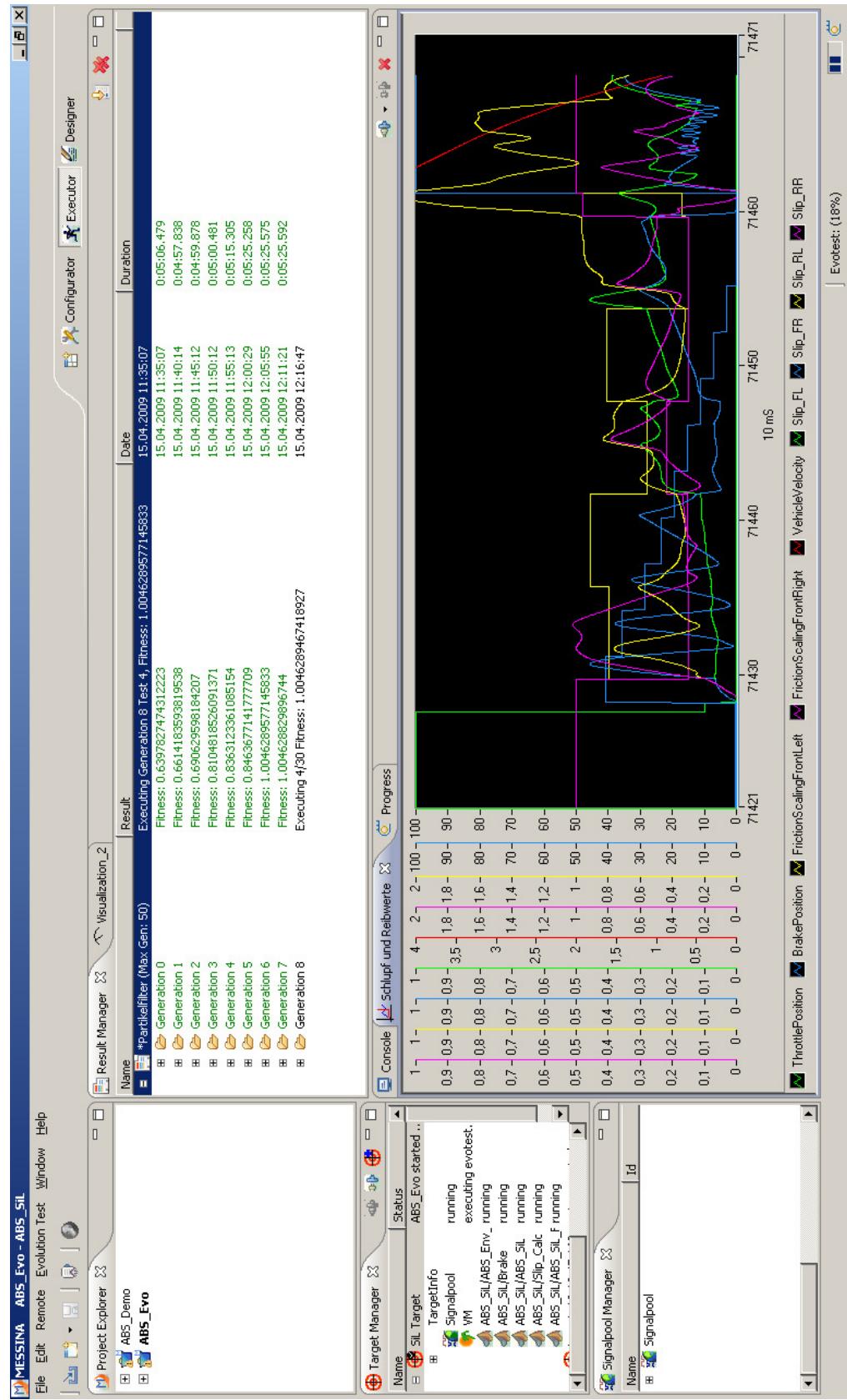
Individual

- 11 parameters for braking pressure
- 12 parameters for friction values left (length, friction)
- 12 parameters for friction values right (length, friction)
- 1 parameter for throttle
- Total length of 5 sec

Individual configuration and allowed value ranges guarantee generation of realistic scenarios



✓ Application for Level 0 Functions



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							NHTSA Level	BASt Level	SAE Level	Highly automated	Fully automated
Human driver monitors the driving environment											
ABS, ESP/ESC, Lane Departure Warning, Blind Spot Monitoring, ...											
0 No Automation	No Automation	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems	Human driver and system	Human driver	Human driver	Some driving modes	0	Assisted	Driver only	Driver only	Driver only
1 Driver Assistance	Driver Assistance	the <i>driving mode-specific execution</i> by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	System	Human driver	Human driver	Some driving modes	1	Assisted	Driver only	Driver only	Driver only
2 Partial Automation	Partial Automation	the <i>driving mode-specific execution</i> by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	System	Human driver	Human driver	Some driving modes	2	Partially automated	Driver only	Driver only	Driver only
Automated driving system ("system") monitors the driving environment											
3 Conditional Automation	Conditional Automation	the <i>driving mode-specific performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>	System	System	Human driver	Some driving modes	3	Partially automated	Driver only	Driver only	Driver only
4 High Automation	High Automation	the <i>driving mode-specific performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> , even if a <i>human driver</i> does not respond appropriately to a <i>request to intervene</i>	System	System	System	Some driving modes	3/4	Partially automated	Driver only	Driver only	Driver only
5 Full Automation	Full Automation	the <i>full-time performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>	System	System	System	All driving modes	-	Highly automated	Driver only	Driver only	Driver only

Source: <http://cyberlaw.stanford.edu/loada>

18

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Human driver monitors the driving environment								
0 No Automation	No Driver	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems					Driver only	0
1 Driver	Driver	the <i>driving mode-specific execution</i> by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment					Assisted	1
Brake Assistant, Autonomous Emergency Braking, Adaptive Cruise Control, Lane Keeping, ...								
ACC Adaptive Cruise Control	Selected Max Speed 90 km/h Set Time Gap 2	System	Human driver	Human driver	System	Some driving modes	Partially automated	2
Source: Volvo								
							Highly automated	3
							Fully automated	-

Source: <http://cyberlaw.stanford.edu/loada>

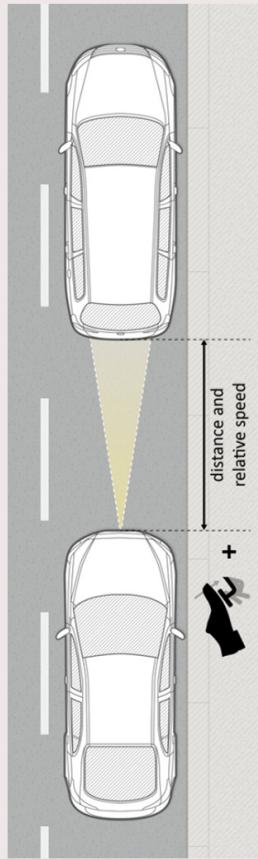
19

Level 1: Testing of 2nd Generation Brake Assistant

Functionality

- Aim: to add brake momentum in emergency braking situations automatically

	1st generation	2nd generation
Functionality	Full braking pressure when activated	controls and adjusts adequate braking pressure for situation
Decision Making	Solely based on brake pedal value change exceeding a defined gradient	reaction based on brake pedal value change and radar sensor data
Prerequisites	Standard equipment of vehicles	Radar sensor



an assystem

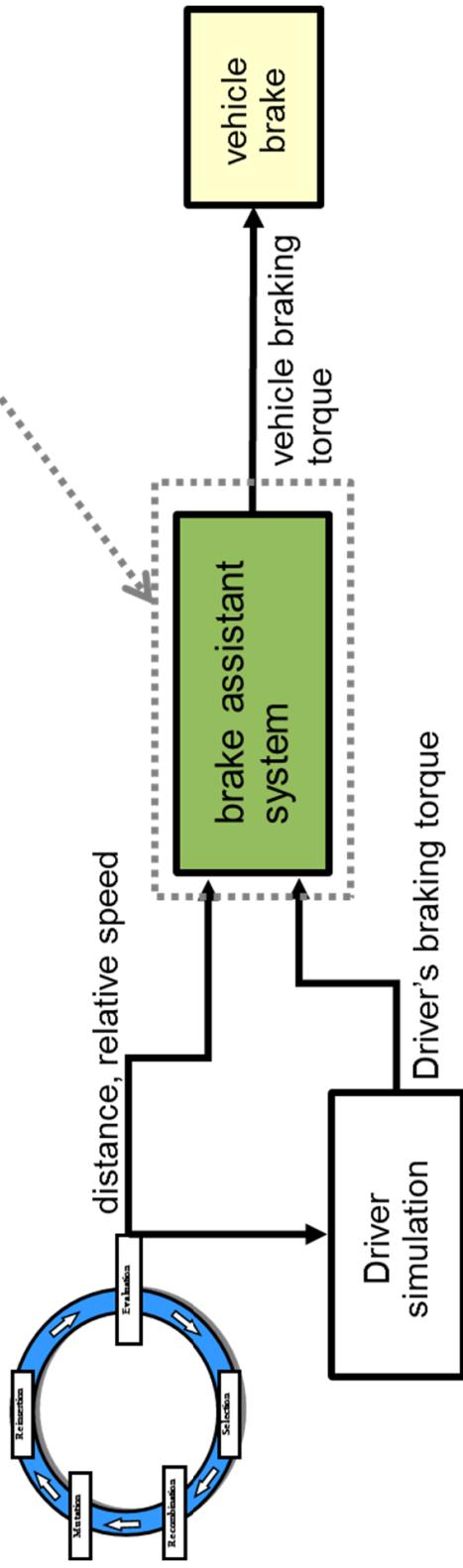
Level 1: Testing of 2nd Generation Brake Assistant

Testing Goal

- Find testing scenarios for which a large brake momentum is generated in uncritical situations
- Find testing scenarios for which a small brake momentum is generated in critical situations

Difficulties:

- Environmental sensors need to be simulated
- Driver behavior needs to be simulated



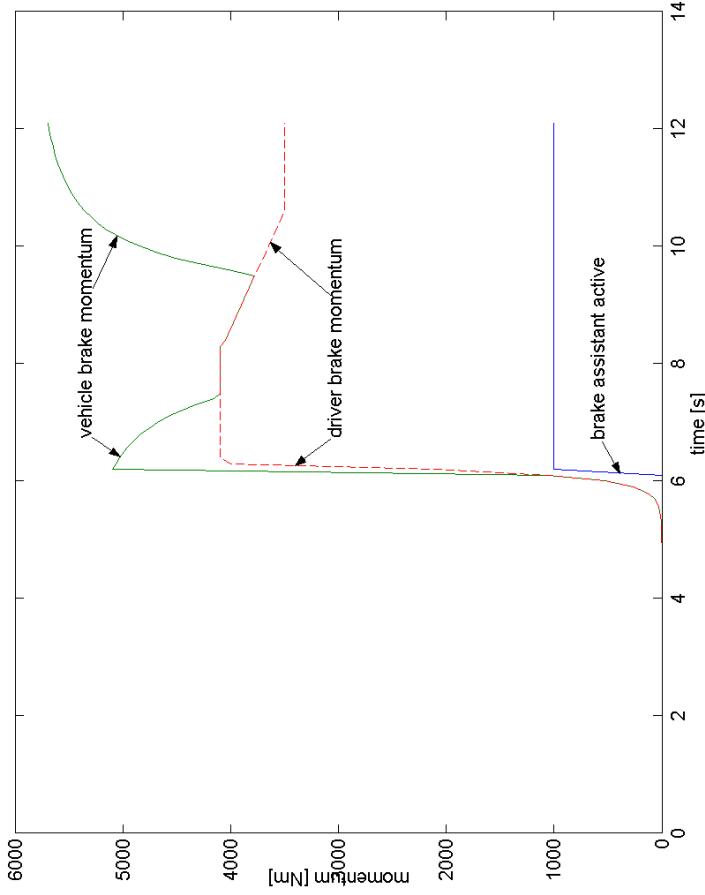
✓ Level 1: Testing of 2nd Generation Brake Assistant

$$V_{\text{fit}} = \int \text{TTC} \cdot M_{\text{brake}} dt$$

Maximization:
long TTC, high momentum

Minimization:
short TTC, low momentum

Sample of an erroneous
braking behaviour
found during evolutionary
testing



on assist system

Levels of Driving Automation for On-Road Vehicles

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							Driver	Only	Automated	Highly automated
Human driver monitors the driving environment										
0 No Automation	No Automation	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems			ABS, ESP/ESC, Lane Departure Warning, Blind Spot Monitoring, ...					
1 Driver Assistance	Driver Assistance	the <i>driving mode-specific execution</i> by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>			Autonomous Emergency Braking, Adaptive Cruise Control, Lane Keeping, ...					
2 Partial Automation	Partial Automation	the <i>driving mode-specific execution</i> by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>			System	Human driver	Human driver	Some driving modes	Partially automated	Partially automated
Automated driving system ("system") monitors the driving environment										
3 Conditional Automation	Conditional Automation	the <i>driving mode-specific performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>	System	System	Human driver			Some driving modes	Partially automated	Partially automated
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5 Full Automation	Full Automation	the <i>full-time performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>	System	System	System			All driving modes	-	Highly automated

Source: <http://cyberlaw.stanford.edu/oda>

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2 Partially automated	Partially automated				Assisted Parking, Trailer Assist, ...		Partially automated	2
3 Highly automated	Highly automated		System	System	Human driver	Some driving modes	Highly automated	3
4 Fully automated	Fully automated		System	System	System	Some driving modes	Fully automated	3/4
5 Autonomous	Autonomous		System	System	System	All driving modes	-	-

Video on Trailer Assist ->
 Search on YouTube for
 Volkswagen Laughing Horses

Source: <http://cyberlaw.stanford.edu/loada>

Level 2: Functional Testing of Automatic Parking System

Functionality

- Measuring the size of the parking space using environmental sensors and parking space model
- Signalling sufficient sized parking spaces to the driver
- If parking is committed by the driver:
 - Determine the position of the car with respect to the parking space
 - Plan the trajectory path for the parking maneuver
- Drive the car into the parking space autonomously



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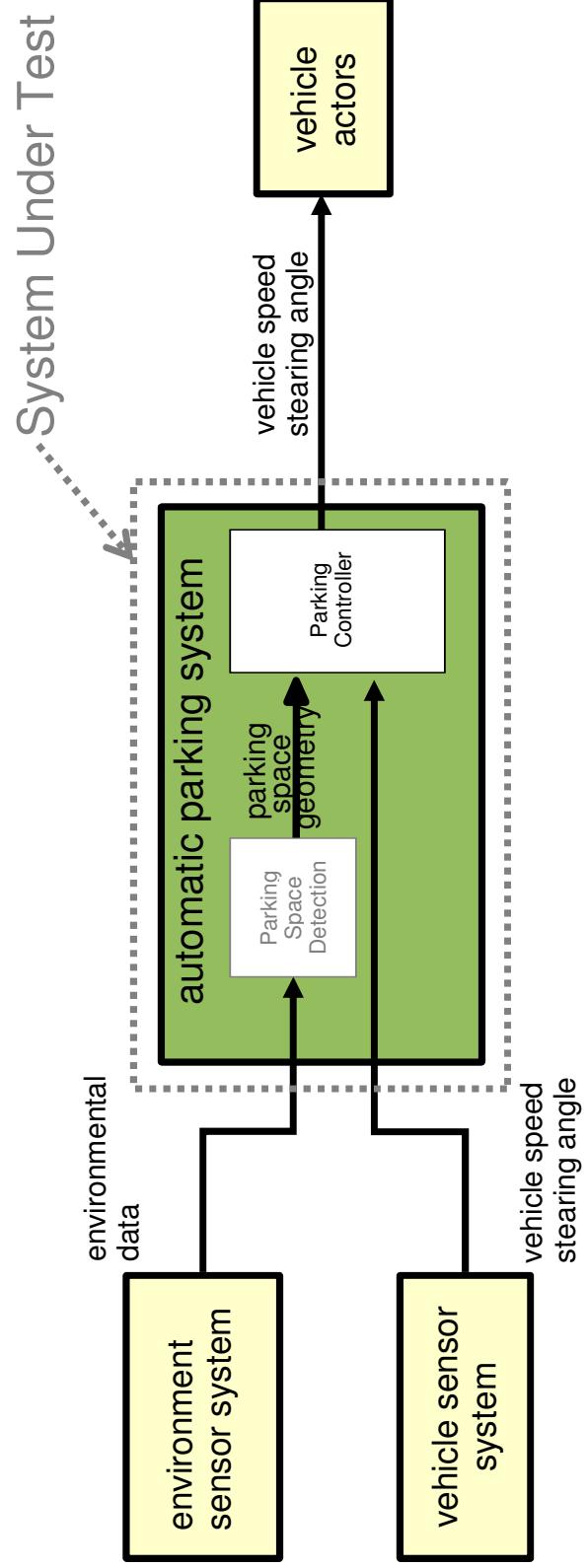
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 - Plan the trajectory path for the parking maneuver
 - Drive the car into the parking space autonomously

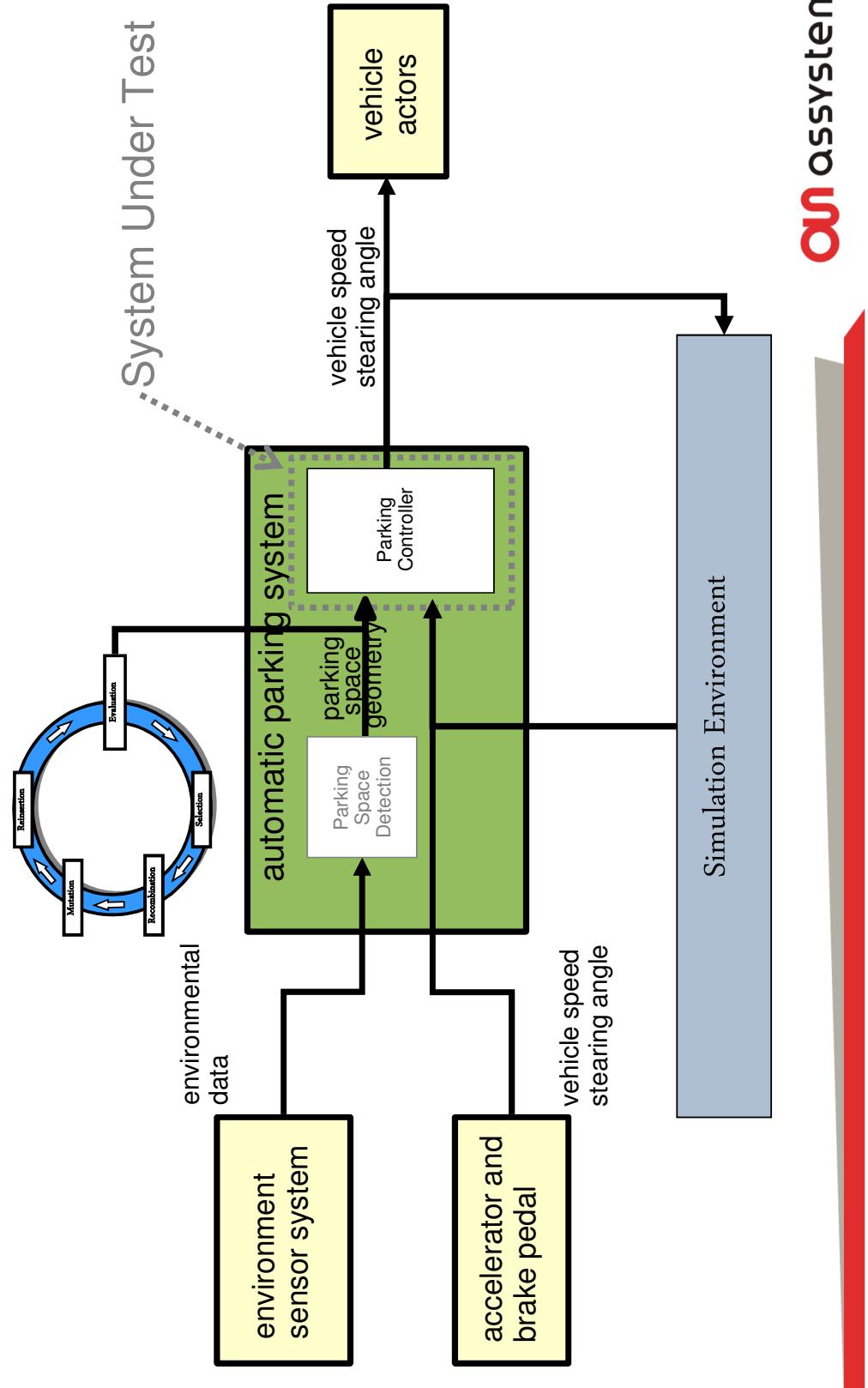
Testing Goal

- **Find testing scenarios which result in a malfunction of the Autonomous Parking, e.g. a) find parking scenarios leading to a collision with other objects, b) initiating a parking attempt for a parking space too short or c) miss a parking space large enough for a parking attempt**
- Difficulties:
 - Environmental sensors need to be simulated
 - Length of parking maneuvers, only ~4320 test executions per day

Level 2: Functional Testing of Automatic Parking System

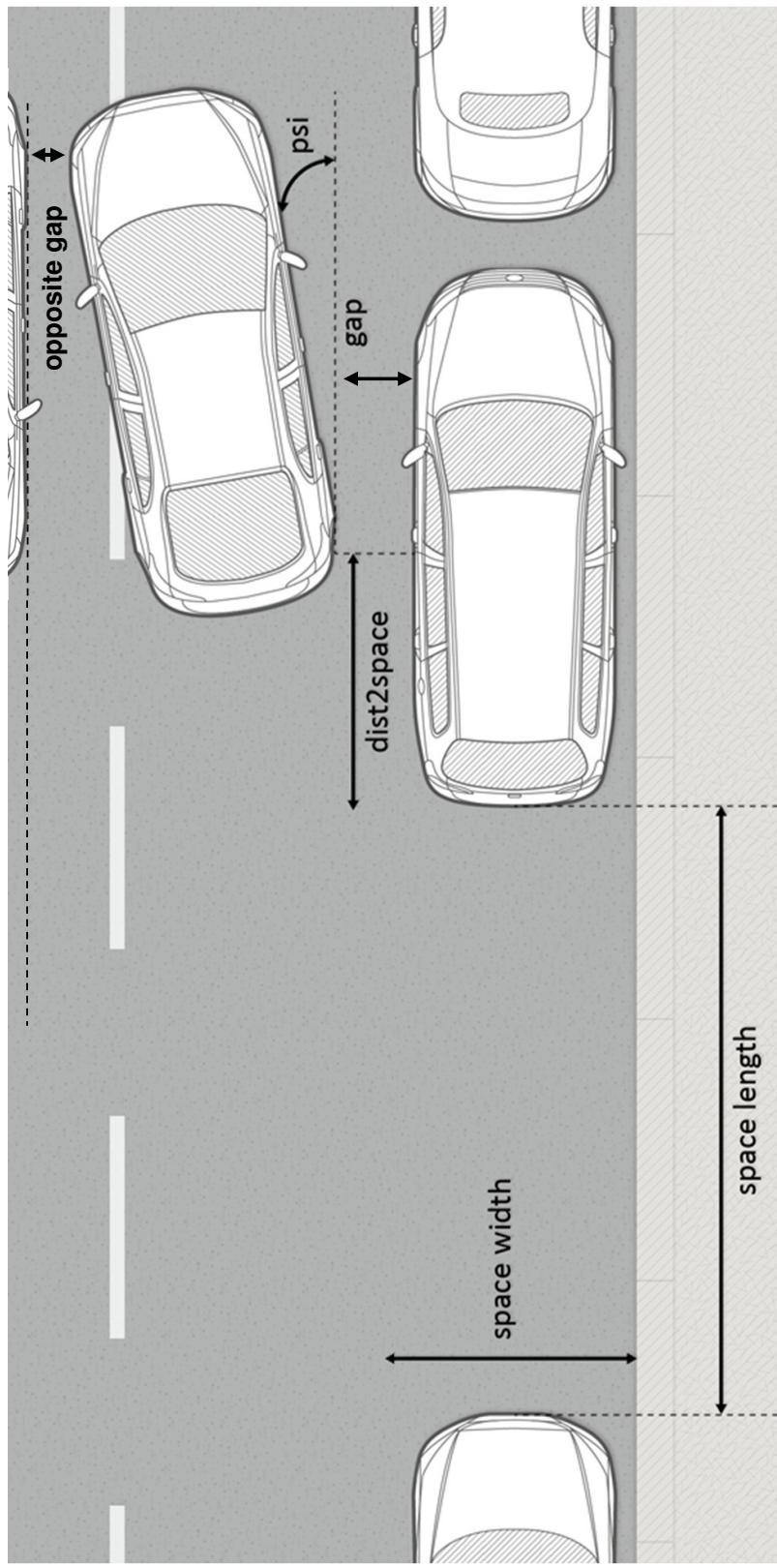


Level 2: Functional Testing of Automatic Parking System



Level 2: Functional Testing of Automatic Parking System

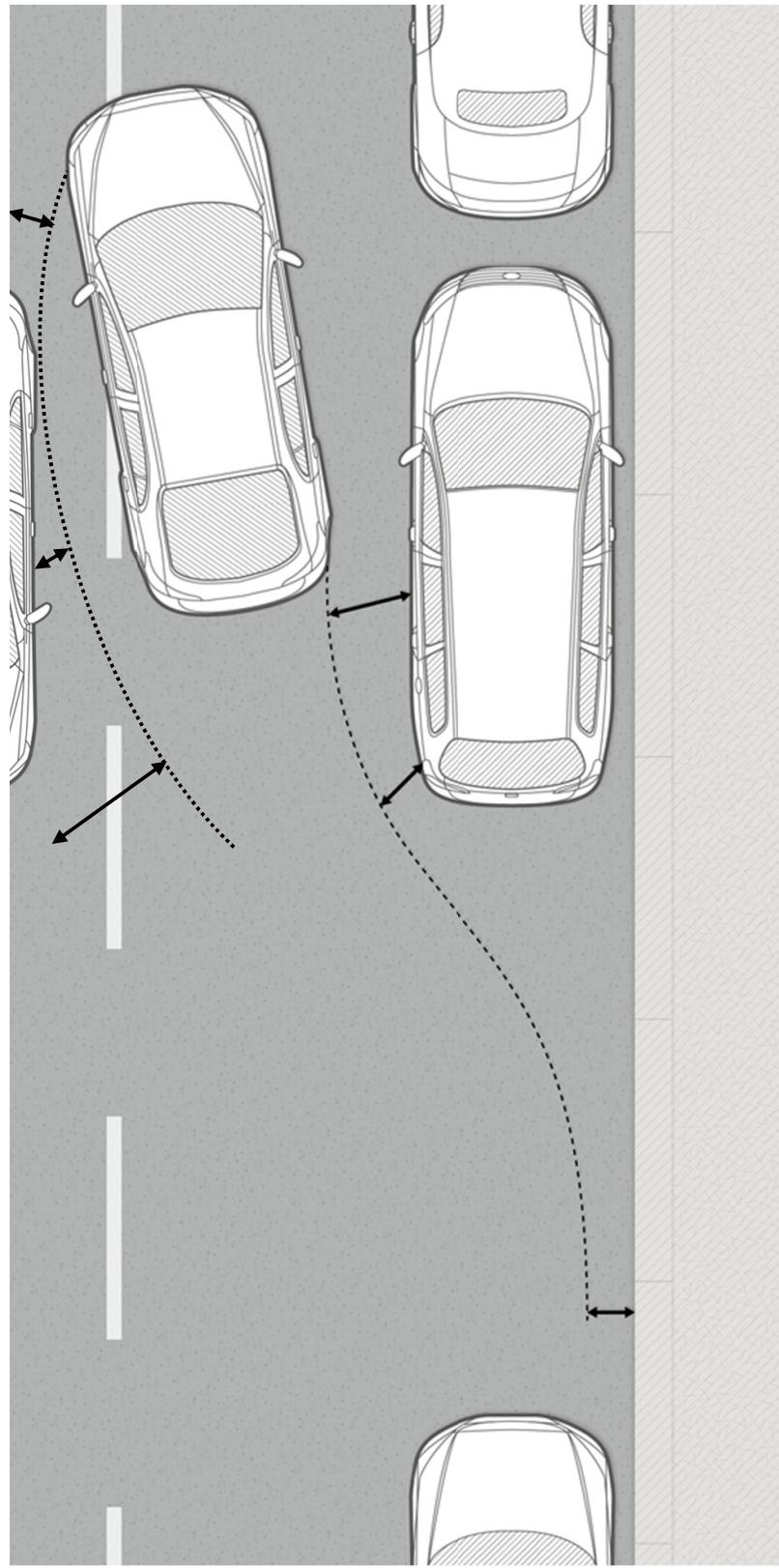
Generation of parking scenarios by evolutionary algorithms varying
parking space width, parking space length, dist2space, gap, opposite gap, psi



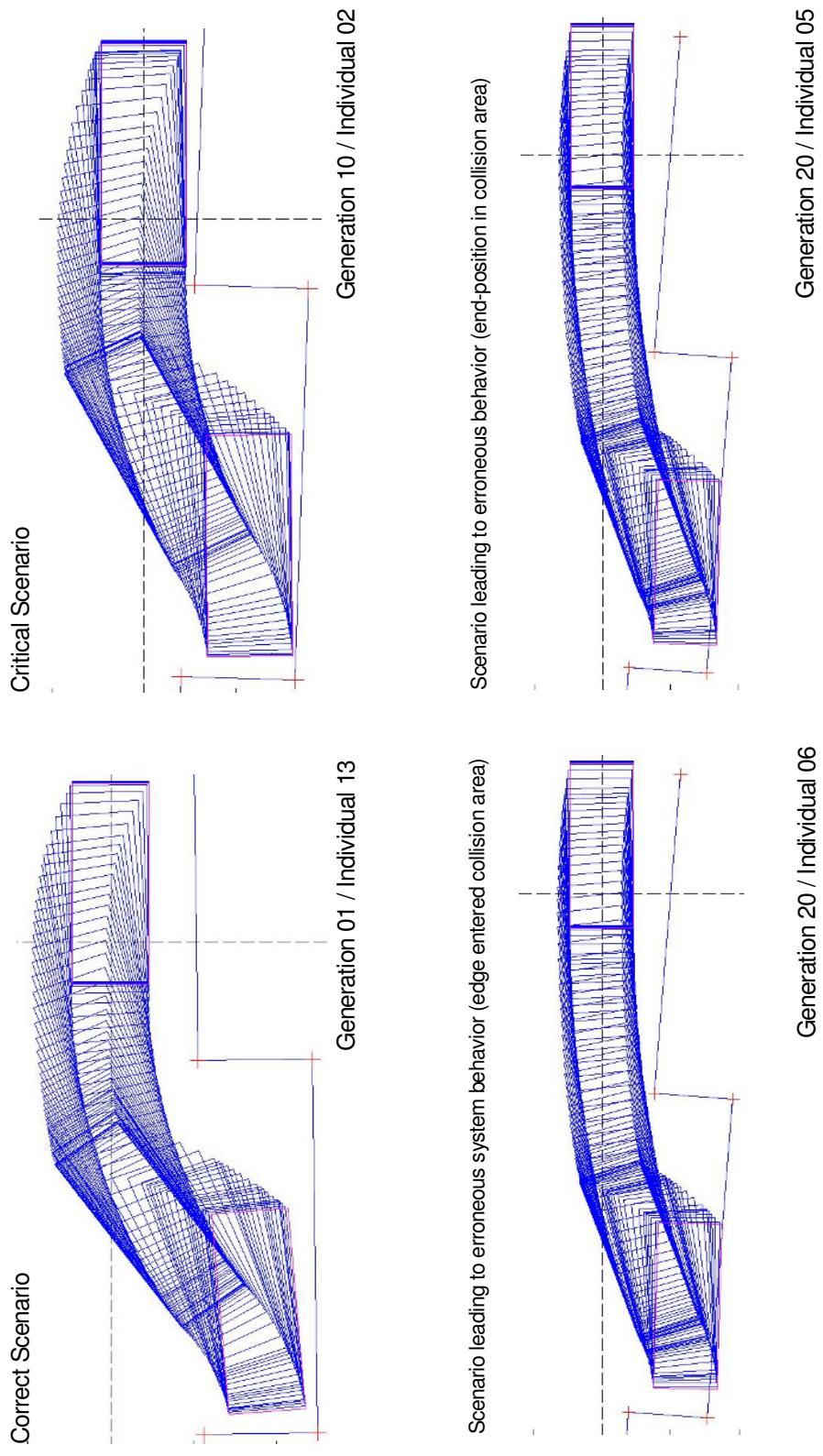
Level 2: Functional Testing of Automatic Parking System

Selection of smallest distance between car and collision area as objective value (negative values also allowed)

Error found if parking maneuver could be generated leading to an objective value ≤ 0



✓ Level 2: Functional Testing of Automatic Parking System



Levels of Driving Automation for On-Road Vehicles

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"System" refers to the driver assistance system, combination of driver assistance systems, or *automated driving system*, as appropriate.

The table also shows how SAE's levels definitively correspond to those developed by the Germany Federal Highway Research Institute (BASt) and approximately correspond to those described by the US National Highway Traffic Safety Administration (NHTSA) in its "Preliminary Statement of Policy Concerning Automated Vehicles" of May 30, 2013.

Level	Name	Narrative definition	Execution of steering and acceleration/deceleration	Monitoring of driving environment	Fallback performance of dynamic driving task	System capability (driving modes)	Base level	NHTSA level
Human driver monitors the driving environment								
0 No Automation	No Automation	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems			ABS, ESP/ESC, Lane Departure Warning, Blind Spot Monitoring, ...		Driver only	0
1 Driver Assistance	Driver Assistance	the <i>driving mode-specific execution</i> by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>			Autonomous Emergency Braking, Adaptive Cruise Control, Lane Keeping, ...		Assisted	1
2 Partial Automation	Partial Automation	the <i>driving mode-specific execution</i> by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>			Assisted Parking, Trailer Assist, ...		Partially automated	2
Automated driving system ("system") monitors the driving environment								
3 Conditional Automation	Conditional Automation	the <i>driving mode-specific performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>	System	System	Human driver	Some driving modes	Highly automated	3
4 High Automation	High Automation	the <i>driving mode-specific performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> , even if a <i>human driver</i> does not respond appropriately to a <i>request to intervene</i>	System	System	System	Some driving modes	Highly automated	3/4
5 Full Automation	Full Automation	the <i>full-time performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>	System	System	System	All driving modes	Fully automated	-

Source: <http://cyberlaw.stanford.edu/loada>

36

Levels of Driving Automation for On-Road Vehicles

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Human driver monitors the driving environment								
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1 Driver Assistance	Driver Assistance	the <i>driving mode-specific execution</i> by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>			Autonomous Emergency Braking, Adaptive Cruise Control, Lane Keeping, ...		Assisted	1
Assisted Parking, Trailer Assist, ...								
2 Partially automated	Partially automated						Automated	2
Traffic Jam Assist, Automated Parking, Platooning, ...								
3 Highly automated	Highly automated						Automated	3
4 Fully automated	Fully automated							3/4
5 Full Automation	Full Automation	the full-time performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>						-



Source: Scania

Source: <http://cyberlaw.stanford.edu/ioda>

Levels of Driving Automation for On-Road Vehicles

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Human driver monitors the driving environment								
0 No Automation	No Automation	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems			ABS, ESP/ESC, Lane Departure Warning, Blind Spot Monitoring, ...		Driver only	0
1 Driver Assistance	Driver Assistance	the <i>driving mode-specific execution</i> by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>			Autonomous Emergency Braking, Adaptive Cruise Control, Lane Keeping, ...		Assisted	1
2 Partial Automation	Partial Automation	the <i>driving mode-specific execution</i> by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>			Assisted Parking, Trailer Assist, ...		Partially automated	2
Automated driving system ("system") monitors the driving environment								
3 Conditional Automation	Conditional Automation	the <i>driving mode-specific performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>			Traffic Jam Assist, Automated Parking, Platooning, ...		Highly automated	3
4 High Automation	High Automation	the <i>driving mode-specific performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> , even if a <i>human driver</i> does not respond appropriately to a <i>request to intervene</i>					Fully automated	3
5 Full Automation	Full Automation	the <i>full-time performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>					3/4	-

Source: <http://cyberlaw.stanford.edu/ioda>

MAJOR TRENDS IN THE AUTOMOTIVE INDUSTRY

Levels of Driving Automation for On-Road Vehicles

This table summarizes the terms used

The table also describes



Source: Volkswagen and with the expectation that the human driver performs all remaining aspects of the dynamic driving task

Information Report J3016 provides full definitions for these levels and for the italicized word. Elements indicate minimum rather than maximum capabilities for each level. Federal Highway Research Institute (BAST) and approximately correspond to those "Priority Statement of Policy Concerning Automated Vehicles" of May 30, 2013.

Level	Human driver	Automated driving system ("system") monitors the driving environment	Driver only	Assisted	Partially automated	Highly automated	Fully automated
Near	Near	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of dynamic driving task	System capability (driving modes)	BasT level	NHTSA level
0 Autom.	0 Autom.	ABS, ESP/ESC, Lane Departure Warning, Blind Spot Monitoring, other environment tasks of the driving task,	... Driver only	... Driver only	0	0
1 Drive Assist	1 Drive Assist	Autonomous Emergency Braking, Adaptive Cruise Control, Lane Keeping, Driver only	Assisted	Assisted	1	1
2 Partial	2 Partial	Assisted Parking, Trailer Assist, Driver only	Partially automated	Partially automated	2	2
		Traffic Jam Assist, Automated Parking, Platooning, ...					
3 Conditional Automation	3 Conditional Automation	the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene				3	3
4 High Automation	4 High Automation	the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene					
5 Full Automation	5 Full Automation	the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver		System	System	All driving modes	-

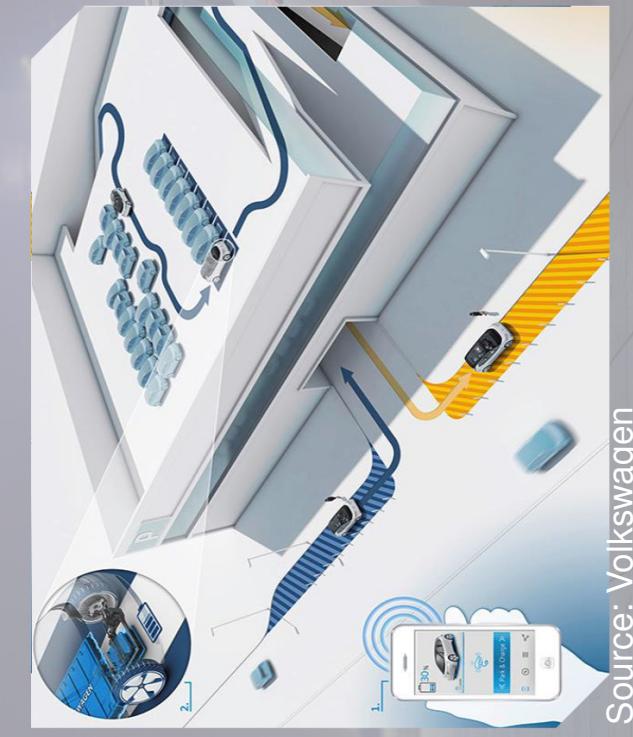
Source: <http://cyberlaw.stanford.edu/oda>

39

Levels of Driving Automation for On-Road Vehicles

This table summarizes terms used

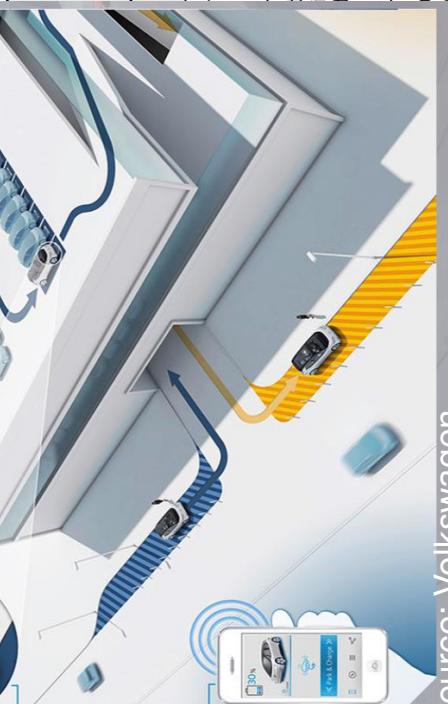
The table also



mation Report 13016 provides full definitions for these levels and for the italicized *Jal*. Elements indicate minimum rather than maximum capabilities for each level. *ance systems, or automated driving system, as appropriate.*

Federal Highway Research Institute (BAST) and approximately correspond to those "Final Statement of Policy Concerning Automated Vehicles" of May 30, 2013.

Level	Narrative	Human driver	Automated	Driver Assistance	Partially automated	Highly automated	Fully automated	Autonomous	Autonomous
0	Natural driving task.	Execution of steering and acceleration/deceleration	Monitoring of driving environment	Monitoring of dynamic driving task	Fallback performance of dynamic driving task	System capability (driving modes)	Driver only	0	NHTSA level 0
1	ABS, ESP/ESC, Lane Departure Warning, Blind Spot Monitoring, ...	Autonomous Emergency Braking, Adaptive Cruise Control, Lane Keeping, ...	Assisted	Assisted	Assisted	1	Driver only	0	NHTSA level 1
2	Assisted Parking, Trailer Assist, ...	of	of	Partially automated	Partially automated	2	Driver only	0	NHTSA level 2
3	Traffic Jam Assist, Automated Parking, Platooning, ...	of	of	Highly automated	Highly automated	3	Driver only	0	NHTSA level 3
4	Automated valet parking, Platooning, Highway Pilot, ...	of	of	Fully automated	Fully automated	4	System	System	All driving modes
5	Autopilot 2.0	Autopilot 2.0	Autopilot 2.0	Autopilot 2.0	Autopilot 2.0	Autopilot 2.0	Autopilot 2.0	Autopilot 2.0	Autopilot 2.0



Video on YouTube for Tesla Autopilot ->

Search on YouTube for Tesla Autopilot 2.0

Video on Autopilot ->
Search on YouTube for Te
Autopilot 2.0

Levels of Driving Automation for On-Road Vehicles

This table summarizes SAE International's levels of driving automation for on-road vehicles. Information Report J3016 provides full definitions for these levels and for the italicized terms used therein. The levels are descriptive rather than normative and technical rather than legal. Elements indicate minimum rather than maximum capabilities for each level.

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Human driver monitors the driving environment								
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1 Driver Assistance	Driver Assistance	the <i>driving mode-specific execution</i> by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>			Autonomous Emergency Braking, Adaptive Cruise Control, Lane Keeping, ...		Assisted	1
2 Partial Automation	Partial Automation	the <i>driving mode-specific execution</i> by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>			Assisted Parking, Trailer Assist, ...		Partially automated	2
Automated driving system ("system") monitors the driving environment								
3 Conditional Automation	Conditional Automation	the <i>driving mode-specific performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>			Traffic Jam Assist, Automated Parking, Platooning, ...		Highly automated	3
4 High Automation	High Automation	the <i>driving mode-specific performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> , even if a <i>human driver</i> does not respond appropriately to a <i>request to intervene</i>			Automated valet parking, Platooning, Highway Pilot, ...		Automated	4
5 Full Automation	Full Automation	the <i>full-time performance</i> by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>			System System System All driving modes -		Highly automated	3/4

Source: <http://cyberlaw.stanford.edu/loada>

41

Levels of Driving Automation for On-Road Vehicles



The NHTSA's definition of driving automation is based on the Society of Automotive Engineers' (SAE) standard J3016. This table provides full definitions for these levels and for the italicized terms indicate minimum rather than maximum capabilities for each level.

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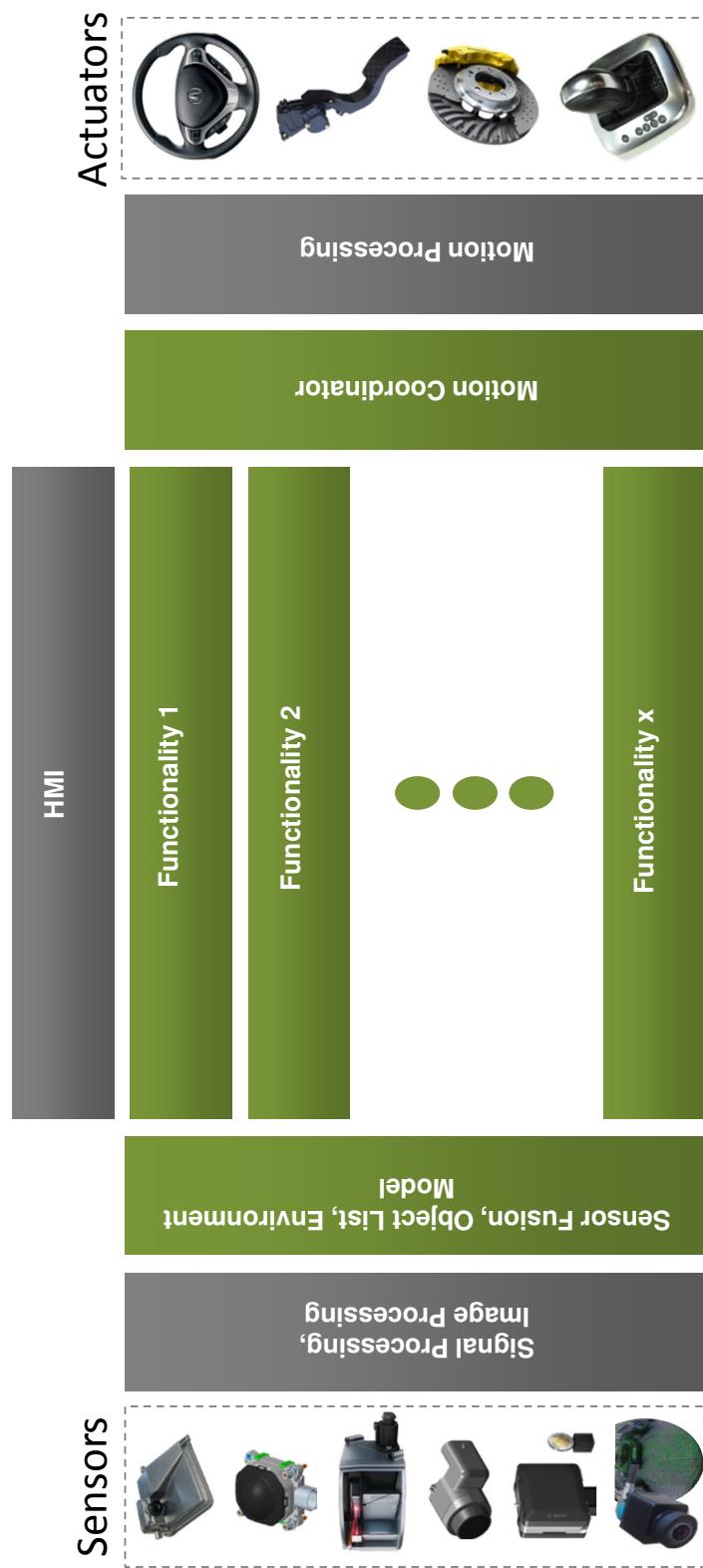
Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of dynamic driving task	System capability (driving modes)	Driver only	Assisted	Partially automated	Highly automated	Fully automated
				NHTSA level		BAST level		
ABS, ESP/ESC, Lane Departure Warning, Blind Spot Monitoring, ...				0		-		
Autonomous Emergency Braking, Adaptive Cruise Control, Lane Keeping, ...				1		-		
Assisted Parking, Trailer Assist, ...				2		-		
Traffic Jam Assist, Automated Parking, Platooning, ...				3		-		
Automated valet parking, Platooning, Highway Pilot, ...				3/4		-		
Fully Automated Driving (no steering wheel, no pedals, ...)				4		-		

Level 5: Not expected before 2025



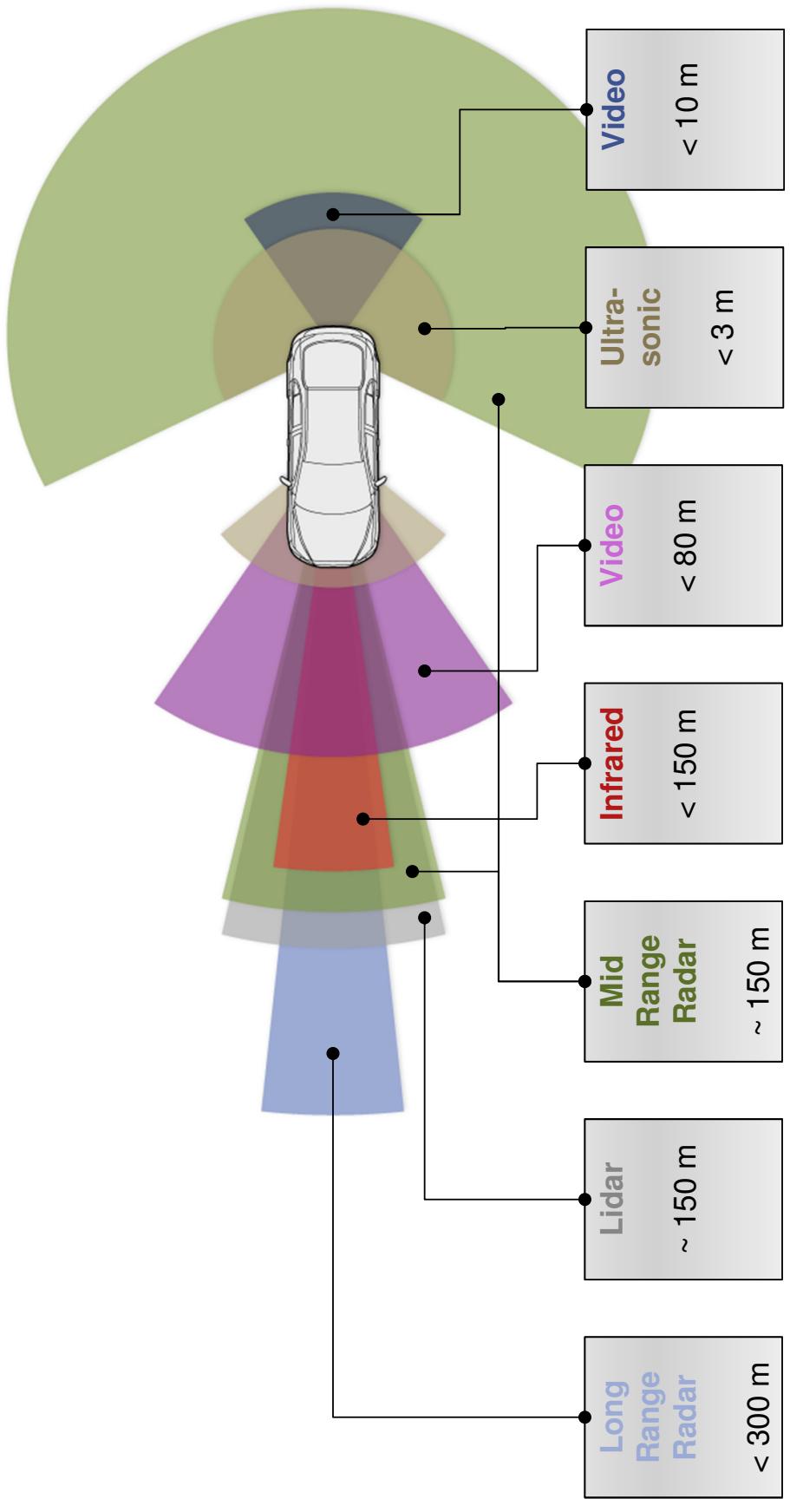
Source: www.welt.de/motor/modelle/article162738924/Im-VW-Sedric-gibt-es-weder-Lenkrad-noch-Pedale.html

Advanced Driver Assistance Systems - Architecture



A thorough test has to address the entire computation chain

Input Space: Sensors included ...

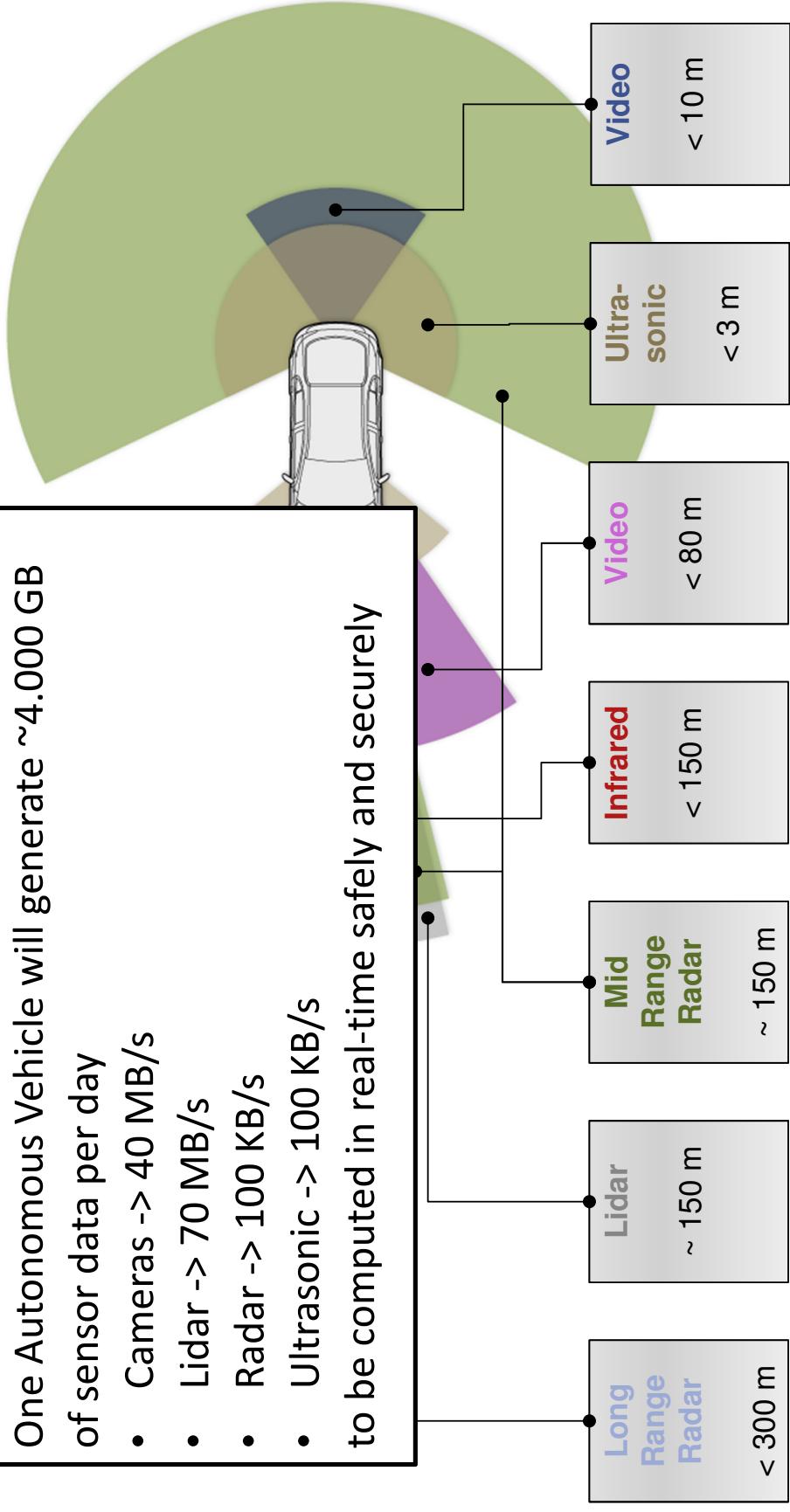


... and their data

One Autonomous Vehicle will generate ~4.000 GB of sensor data per day

- Cameras -> 40 MB/s
- Lidar -> 70 MB/s
- Radar -> 100 KB/s
- Ultrasonic -> 100 KB/s

to be computed in real-time safely and securely



Automated Driving Testing Demands

Automated Driving Benchmark¹

- Distance between two accidents with casualties on a German Autobahn
 - 12 Mio. km (corresponds to 120.000 hours of motorway driving)
- About 10 times of that distance is required to prove with significance for automated driving systems
 - Approx. 120 million km required or around 1.2 million operating hours
 - Enormous cost and time effort
 - And this time and time again

How safe do autonomous cars need to be²

- Human performance: 1 fatality per 100 million miles driven
 - 209 round trips to the moon
 - 1.6 million hours @ 60 mph

Imperative for Virtual Validation³

- The authorization of automated driving will require several hundreds of millions of kilometers of validation.
- VW Test Driver: 1 million test kilometers in several years
 - VW Target for Virtual Validation: 5 million test kilometers per day

1) Source: Dr. B. Milke: *High Tech Between Cloud and Earth*, Automobil Elektronik, Ludwigsburg, Germany, June 2017

2) Source: E. Olson: *The Road (Behind and) Ahead for Autonomous Vehicles*. Autonomous Driving Toyota Research Institute

3) Source: R. Milke: *Vision New Volkswagen*, Automobil Elektronik, Ludwigsburg, Germany, June 2017

Good News

- Growing use of virtual validation will provide us the technical environment we need for the application of evolutionary testing for highly automated driving systems and beyond
- Complexity of the systems forces skepticism towards the sole application of classical testing approaches
 - Verification and validation of learned knowledge forces the use of search-based testing
 - Number of successful applications increasing, e.g. Mark@Facebook, Tanja with her TESTAR applications, Assystem with MESSINA applications, ...
 - Rising interest in industry

Good Old Problems

- In the loop testing – not all the tests could be modeled as test sequences
- Consistent simulation of huge amount of sensor data for the sensor sets
 - Without limiting the search
- Reliability of results
 - Stopping criteria, no faults found -> meaning?, coverage achieved
 - Reproducibility of results -> new test run after each sw change?
 - Computation intensive - iterative development leading to plenty of test cycles
 - Weak tool support

Common to all
test methods

Summary

- Evolutionary Testing applied successfully up to ADAS Level 2
 - One kind of sensor involved
 - One major functionality tested on its own
- Future systems (Level 3 to Level 5)
 - Sensor fusion of various sensor sets (incl. deep learning)
 - Feature interaction
 - No safe state, but highest safety level (ASIL-D)
- Tremendous testing effort
 - Virtual validation is a must, but could not completely simulate physical realities
 - Will result in huge server farms dedicated to testing
 - Will provide a suitable infrastructure for search based testing



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