Industrial Applications of Evolutionary Testing

JOACHIM WEGENER

10TH SEPTEMBER 2017

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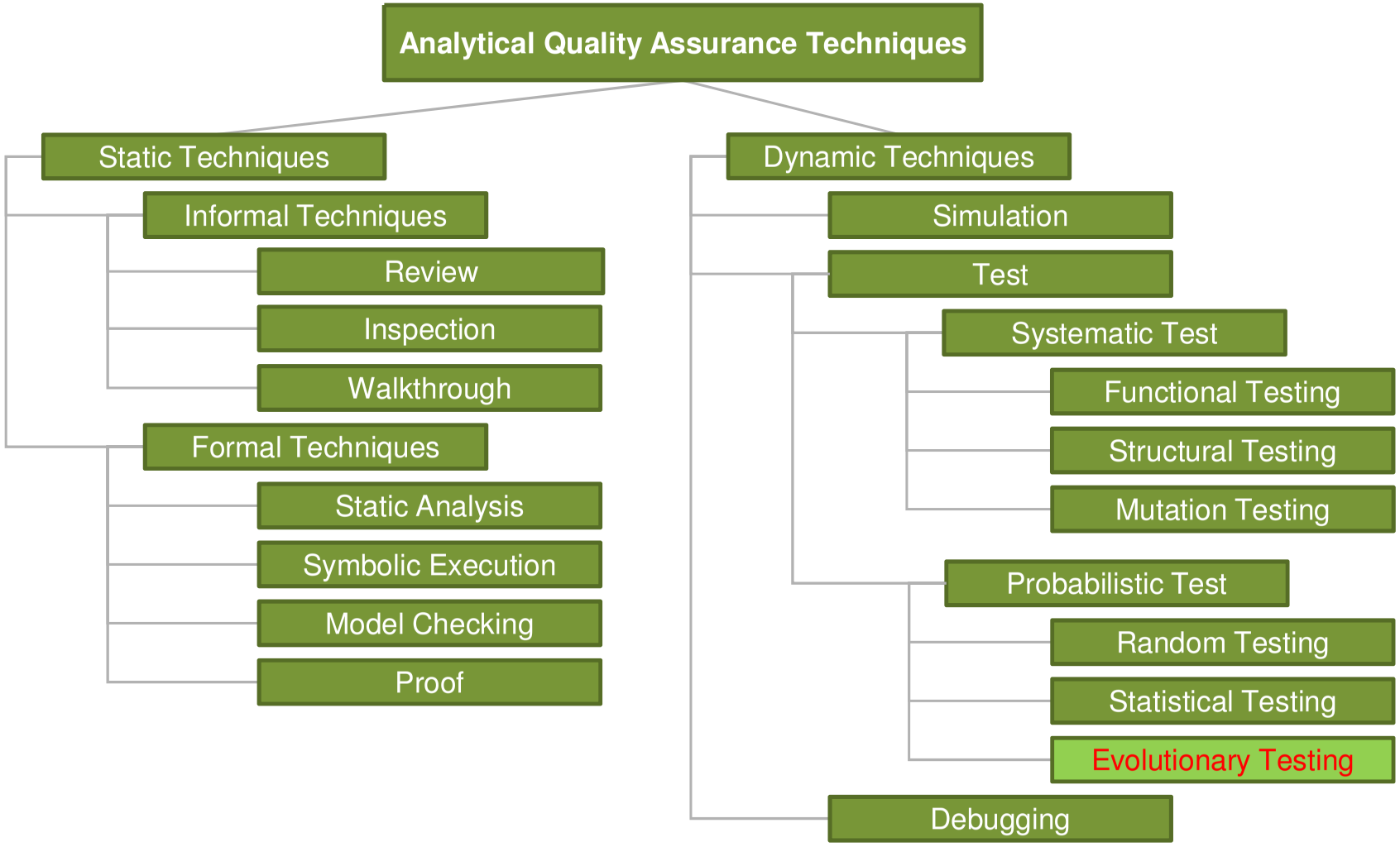
Analytical Quality Assurance



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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]	+	+	+	+

Functional Test

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)	+	+	+	++

Structural Test

Table 15 — Structural coverage metrics at the software architectural level

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

Structural Test

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

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

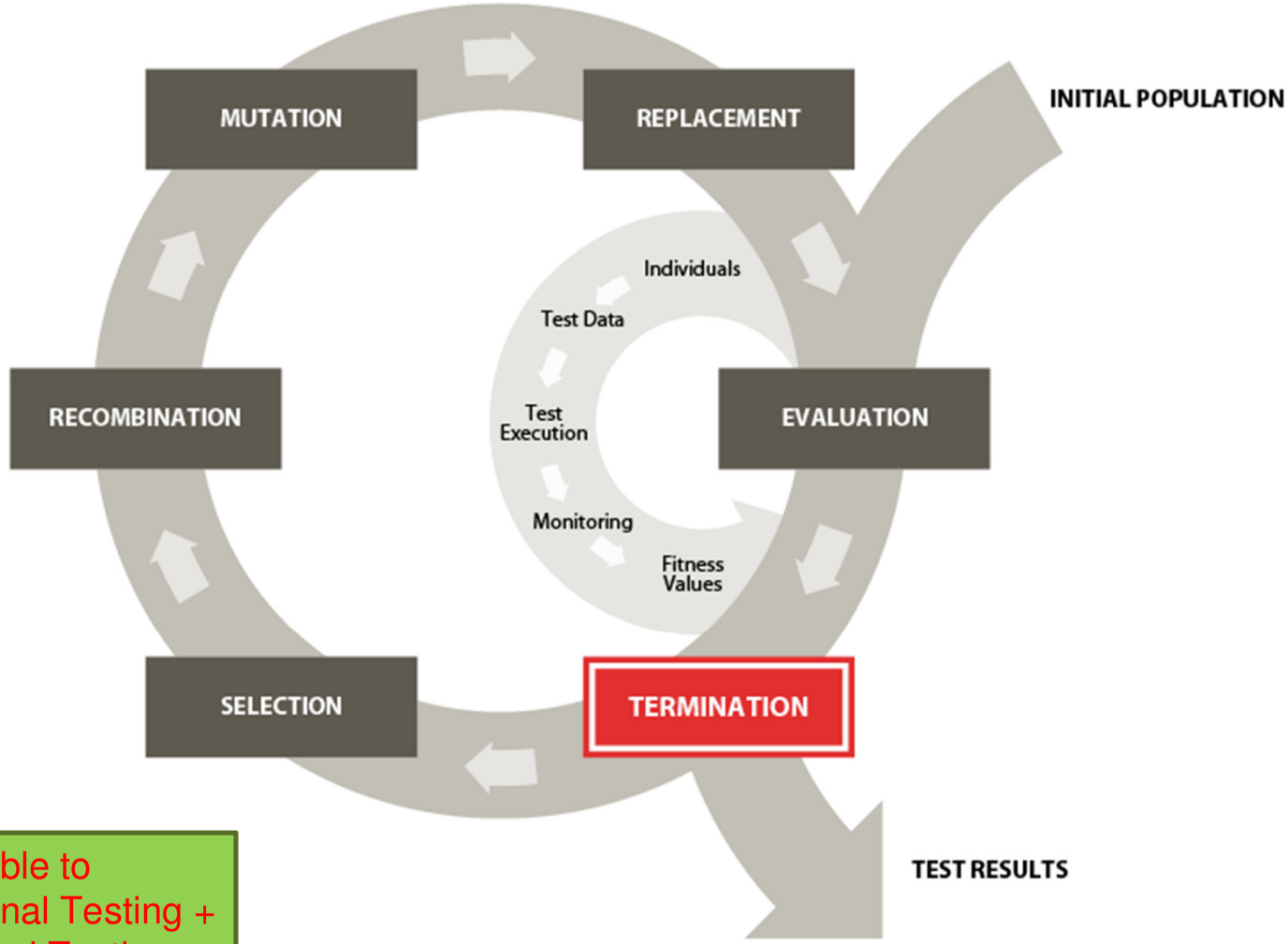
Experience-Based Testing Techniques:
- Error Guessing

Functional Test

Functional Test

Structural Test

Evolutionary Testing - Procedure

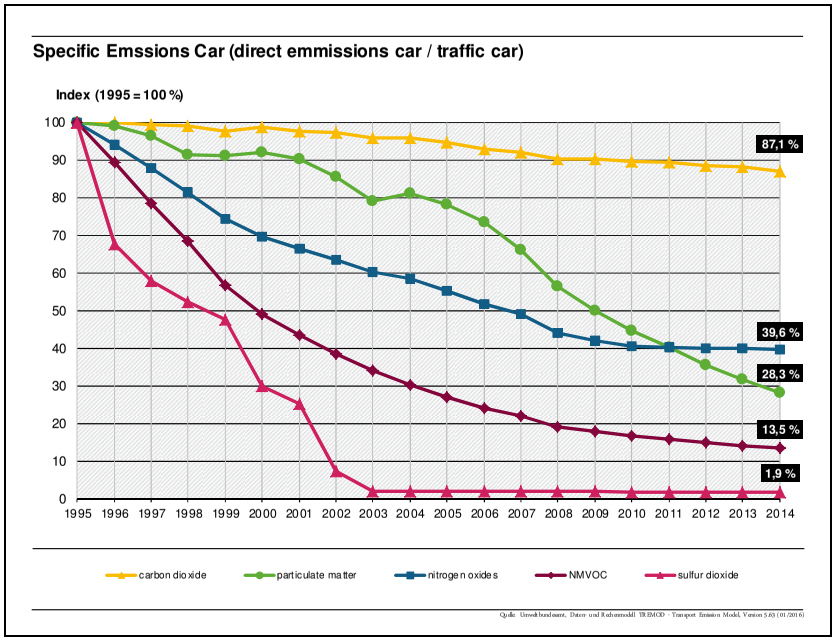


Applicable to Functional Testing + Structural Testing

Major Drivers and Trends in Automotive Industry

Drivers

- 30 % of all urban traffic is caused by searching for parking spaces[1]
- 42 hours per year spent in traffic jams by the average commuter[2]
- 50 % of delivery costs are spent on the last mile[3]
- >95 % of the time private cars are idle[4]



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)

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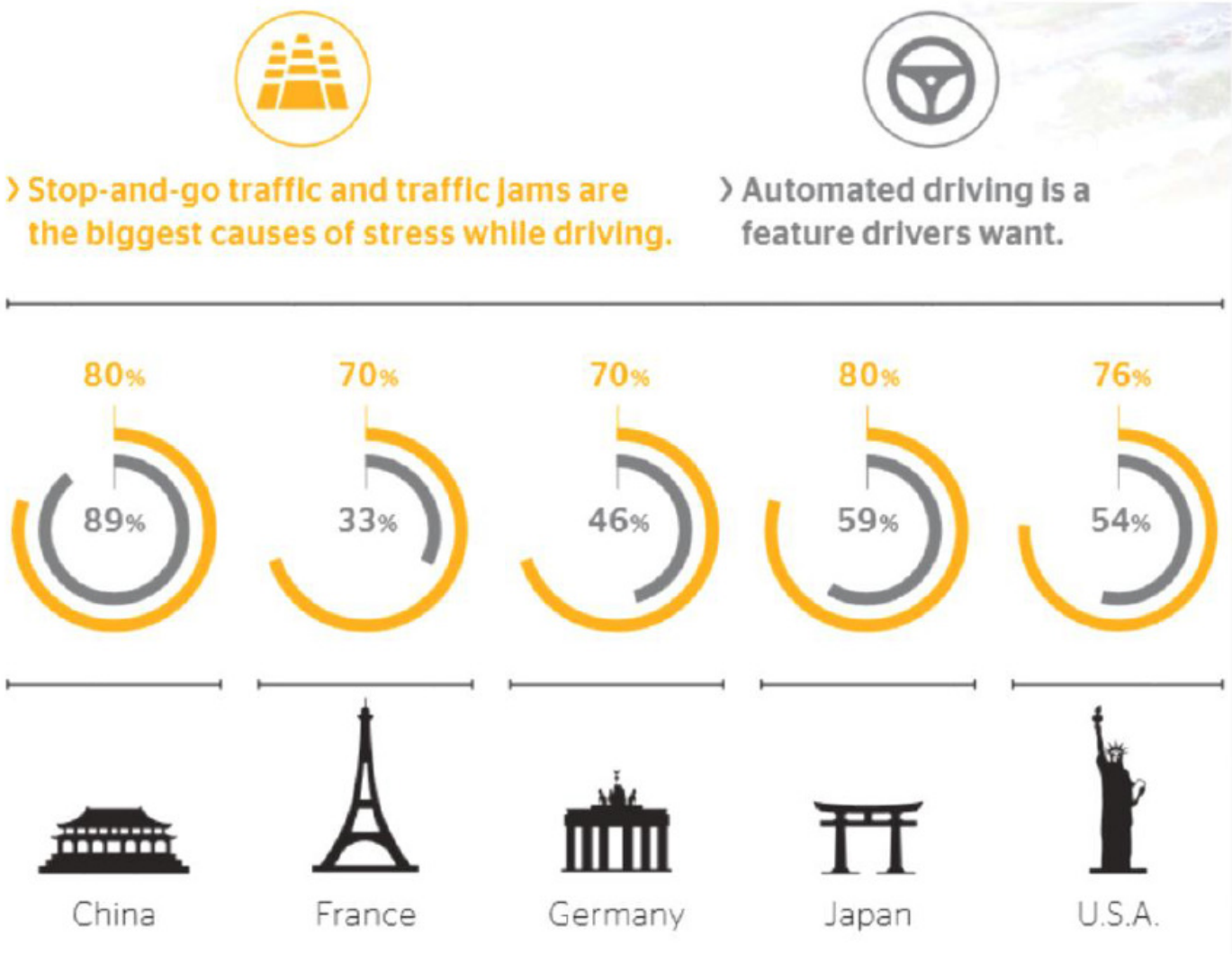
Automated Driving & Parking – Market Demands



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

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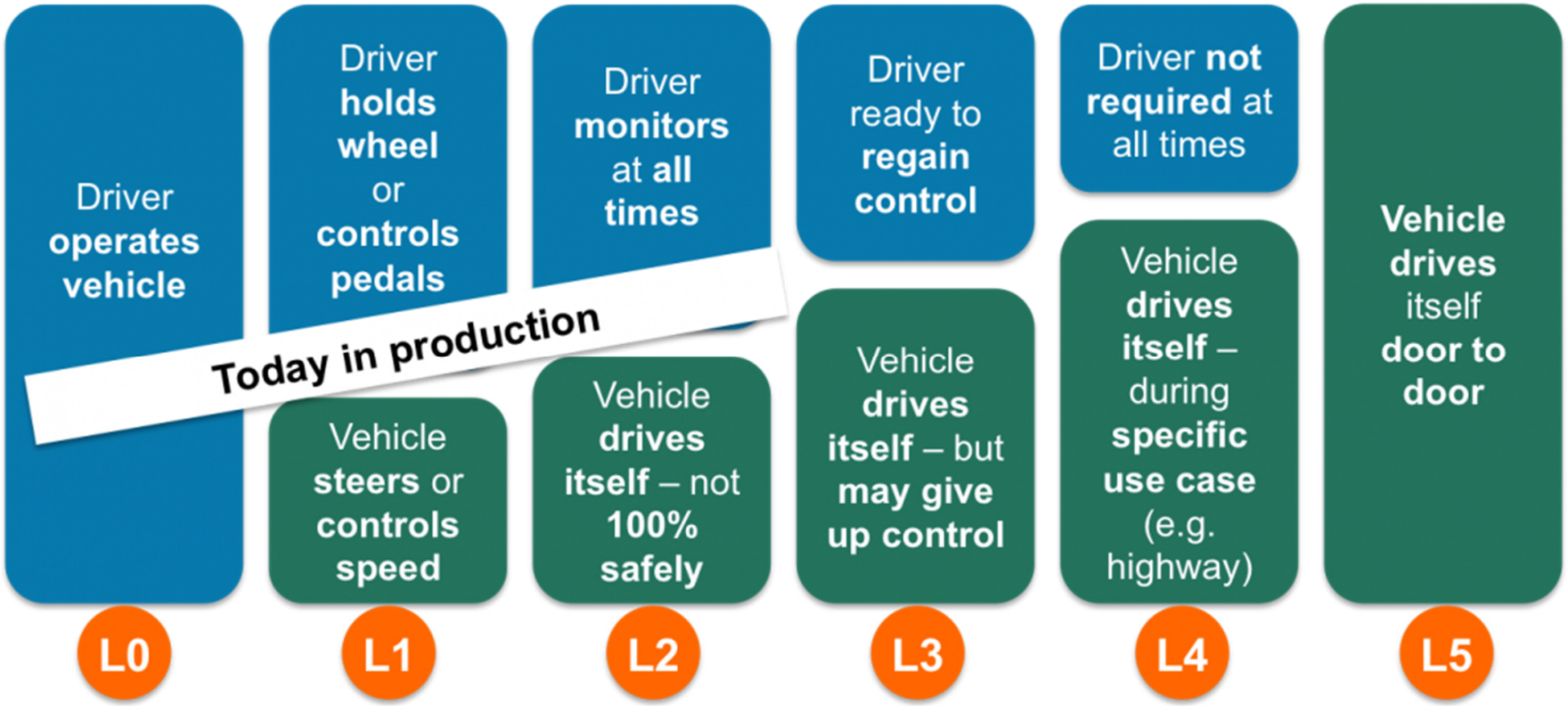
Levels of Driving Automation for On-Road Vehicles



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

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1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	**Partial Automation**	the *driving mode*-specific execution 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 *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes	Partially automated	2
***Automated driving system* ("system") monitors the driving environment**								
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*	System	**System**	Human driver	Some driving modes	Highly automated	3
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*	System	System	**System**	Some driving modes	Fully automated	3/4
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	System	**All driving modes**	-	

Source: http://cyberlaw.stanford.edu/loda

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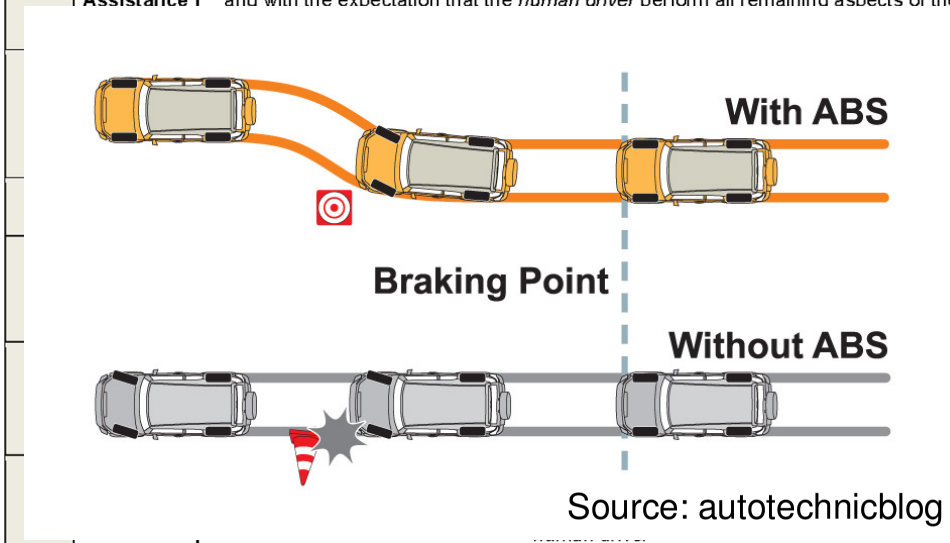

Source: autotechnicblog

Source: http://cyberlaw.stanford.edu/loda

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Level 0: Testing of Anti Blocking System

Functionality

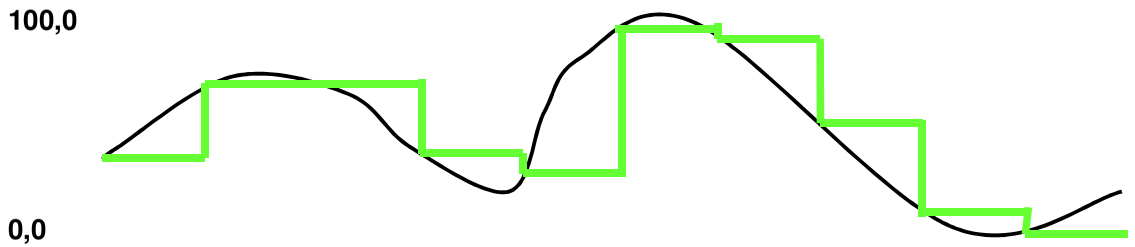
- maximum deceleration at about 20% slip (wheel rolls 0.8 m when the vehicle is traveling 1m)
- Ensuring lateral guiding force for vehicle (optimal with 0% slip: wheel rolls 1m while verhicle is traveling 1 m; still good with 20% slip, nearly 0 with blocking wheels)
- Considering road conditions (ice, 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

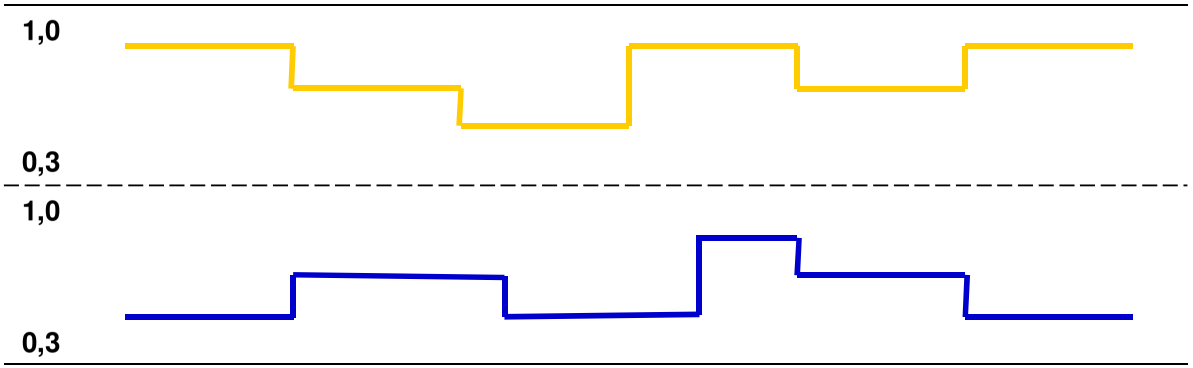
Input Domain of ABS

Brake pedal position (desired braking pressure)



Sequence of fricition values (left)

Sequence of friction values (right)



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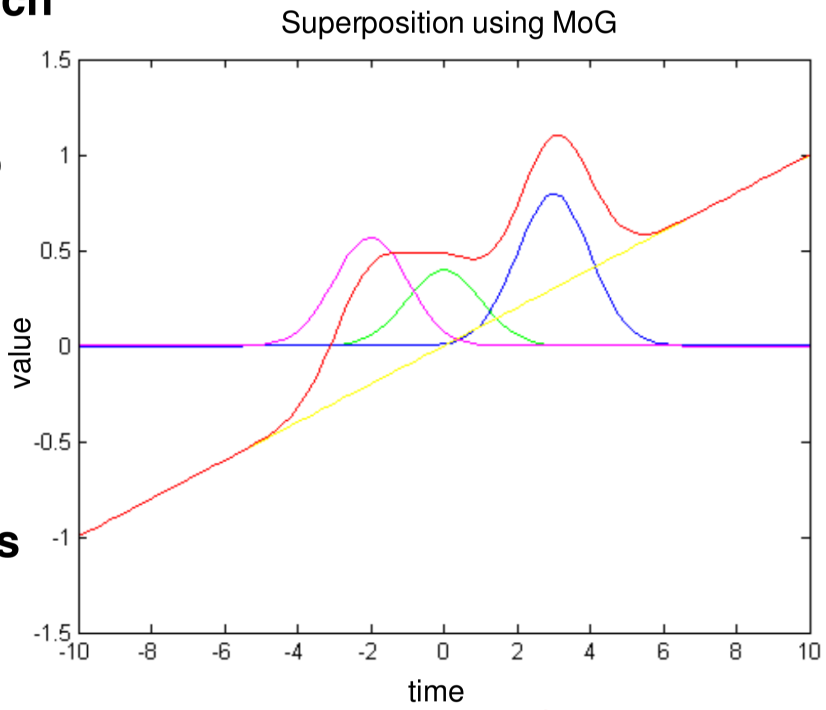
Generation of continuous signal values

. . . 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**



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Individual Configuration and Fitness Function

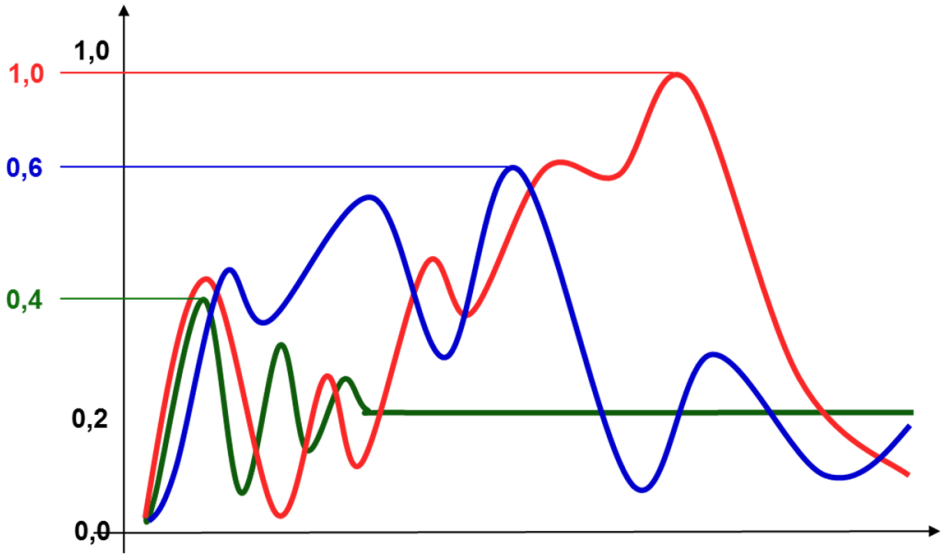
Individual

- **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

30 Individuals per generation

Fitness =
maximum slip
reached through braking
maneuver +
vehicle speed / 1000



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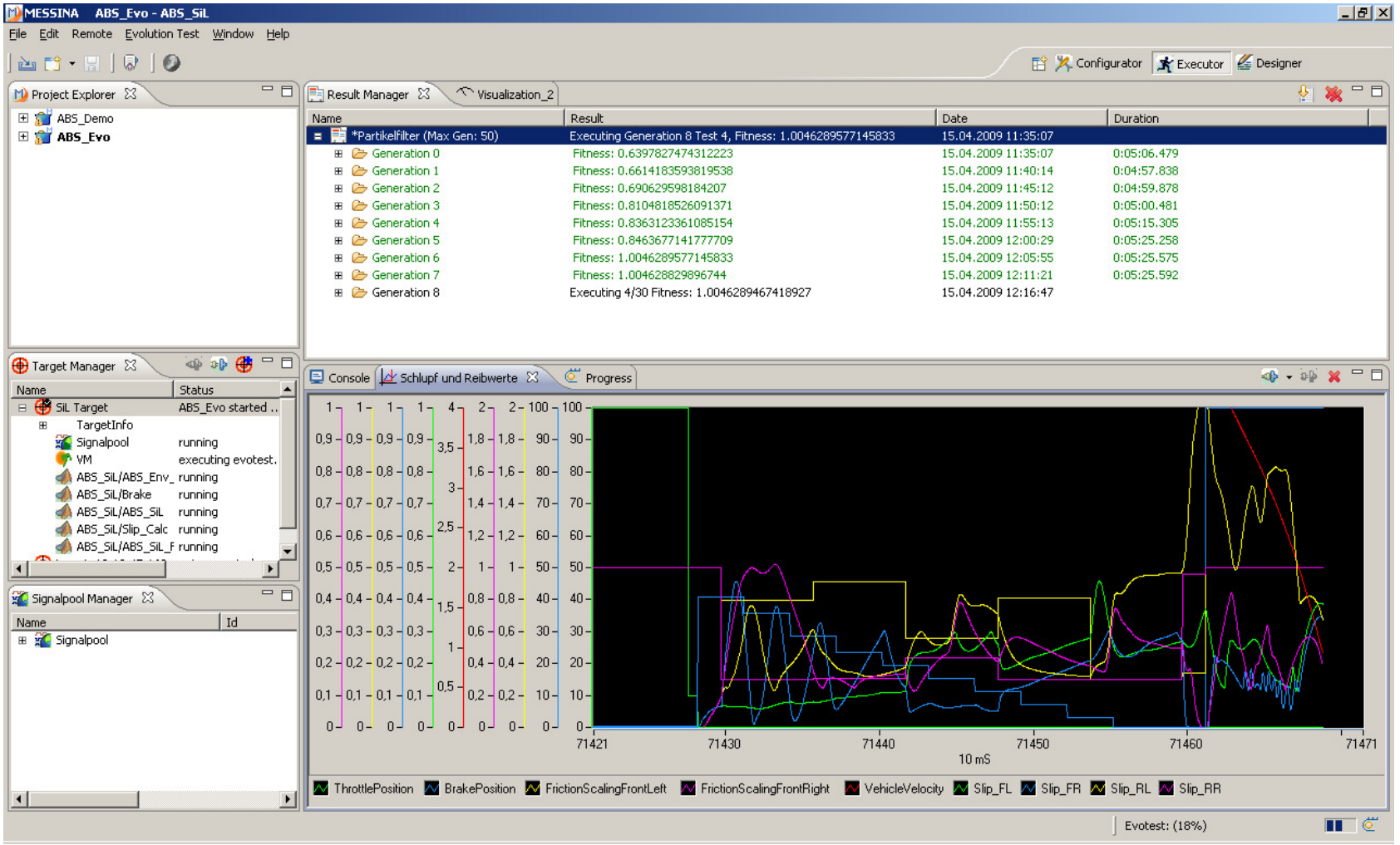
✓ Application for Level 0 Functions



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1	**Driver**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment	**Brake Assistant, Autonomous Emergency Braking, Adaptive Cruise Control, Lane Keeping, …**				Assisted	1
2	**Partial**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment	**System**	Human driver	Human driver	Some driving modes	Partially automated	2
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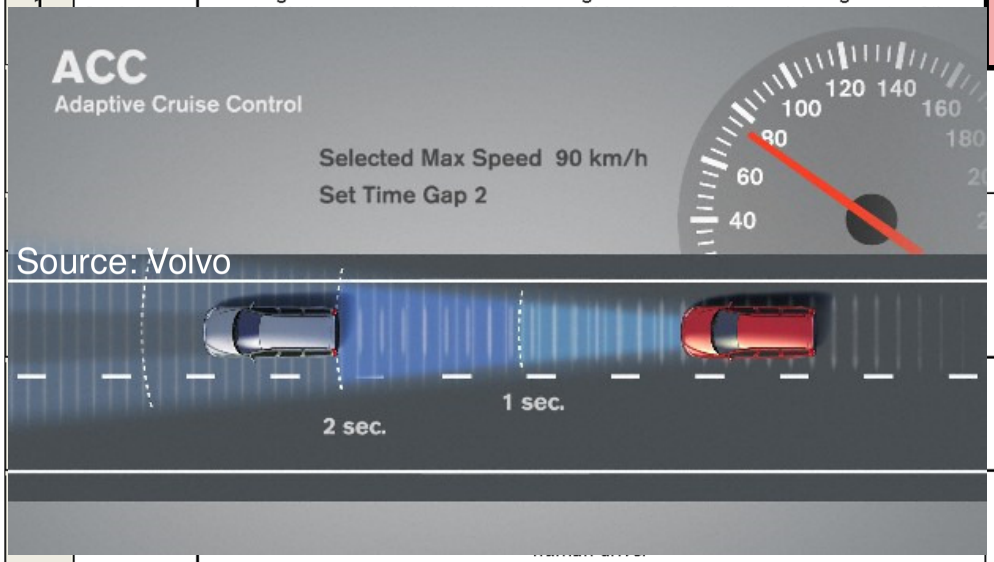

Source: http://cyberlaw.stanford.edu/loda

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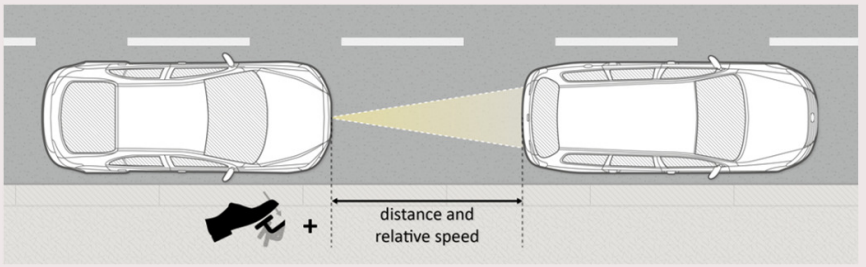
Level 1: Testing of 2nd Generation Brake Assistant

Functionality

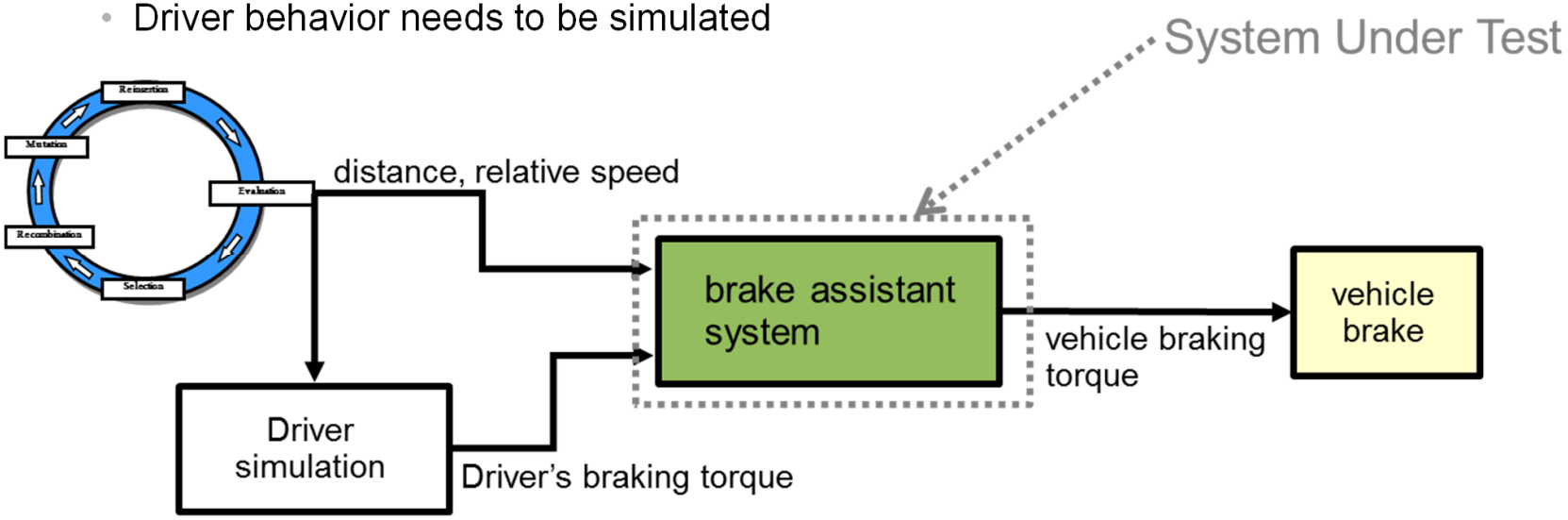
- Aim: to add brake momentum in emergency braking situations automatically

	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

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



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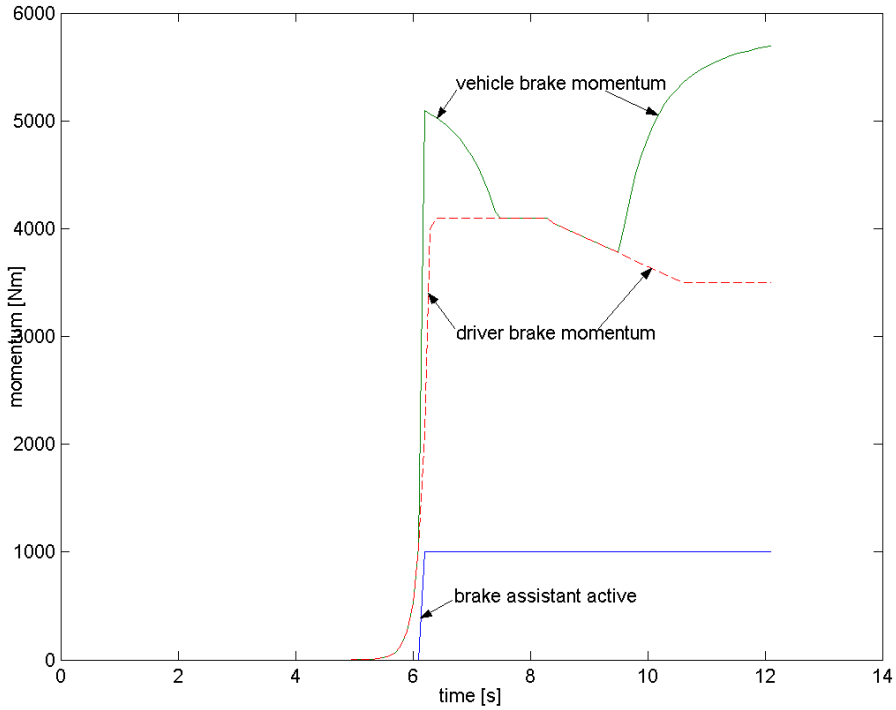
✓ Level 1: Testing of 2nd Generation Brake Assistant

$$v_{fit} = \int TTC \bullet M_{brake}\, dt$$

Maximization:
long TTC, high momentum

Minimization:
short TTC, low momentum

Sample of an erroneous braking behaviour found during evolutionary testing



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2			**Assisted Parking**, Trailer Assist, …				Partially automated	2
Au								
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4			System	System	**System**	Some driving modes	Fully automated	3/4
5			System	System	System	**All driving modes**		

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

Source: http://cyberlaw.stanford.edu/loda

Level 2: Functional Testing of Automatic Parking System

Functionality

- Measuring the size of the parking space using environmental sensors and parking space model
- Signaling 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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Level 2: Functional Testing of Automatic Parking System

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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

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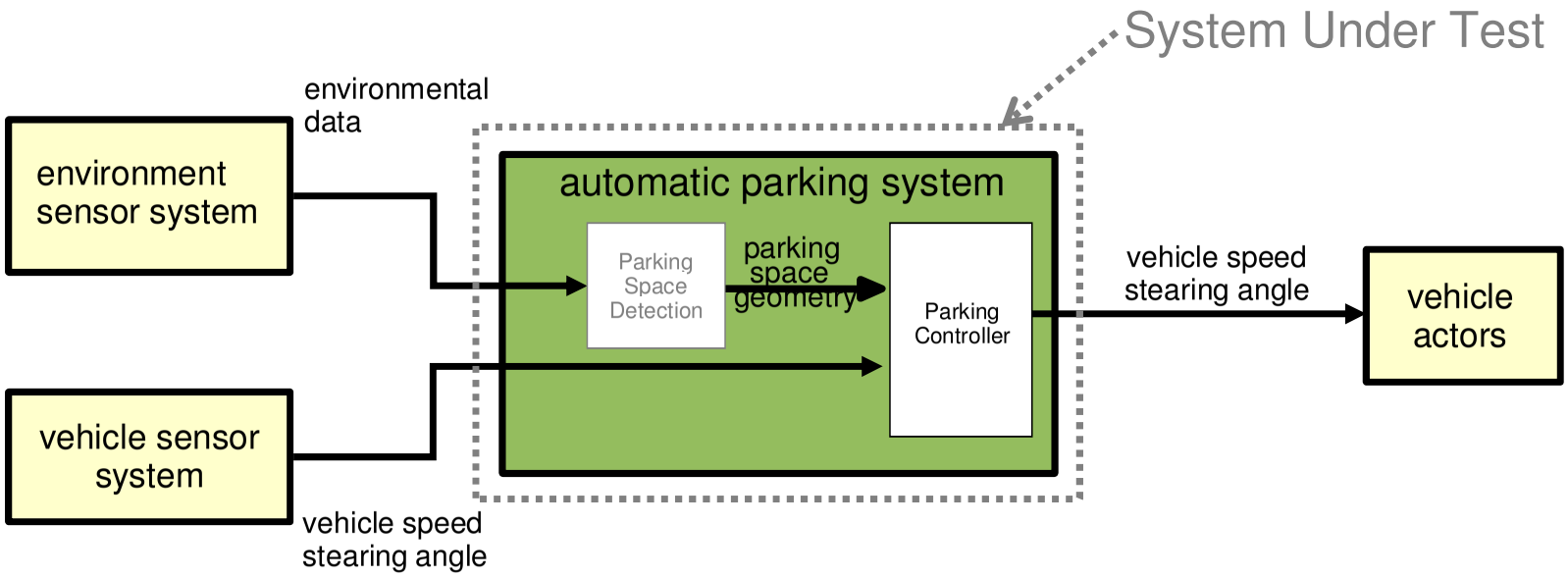
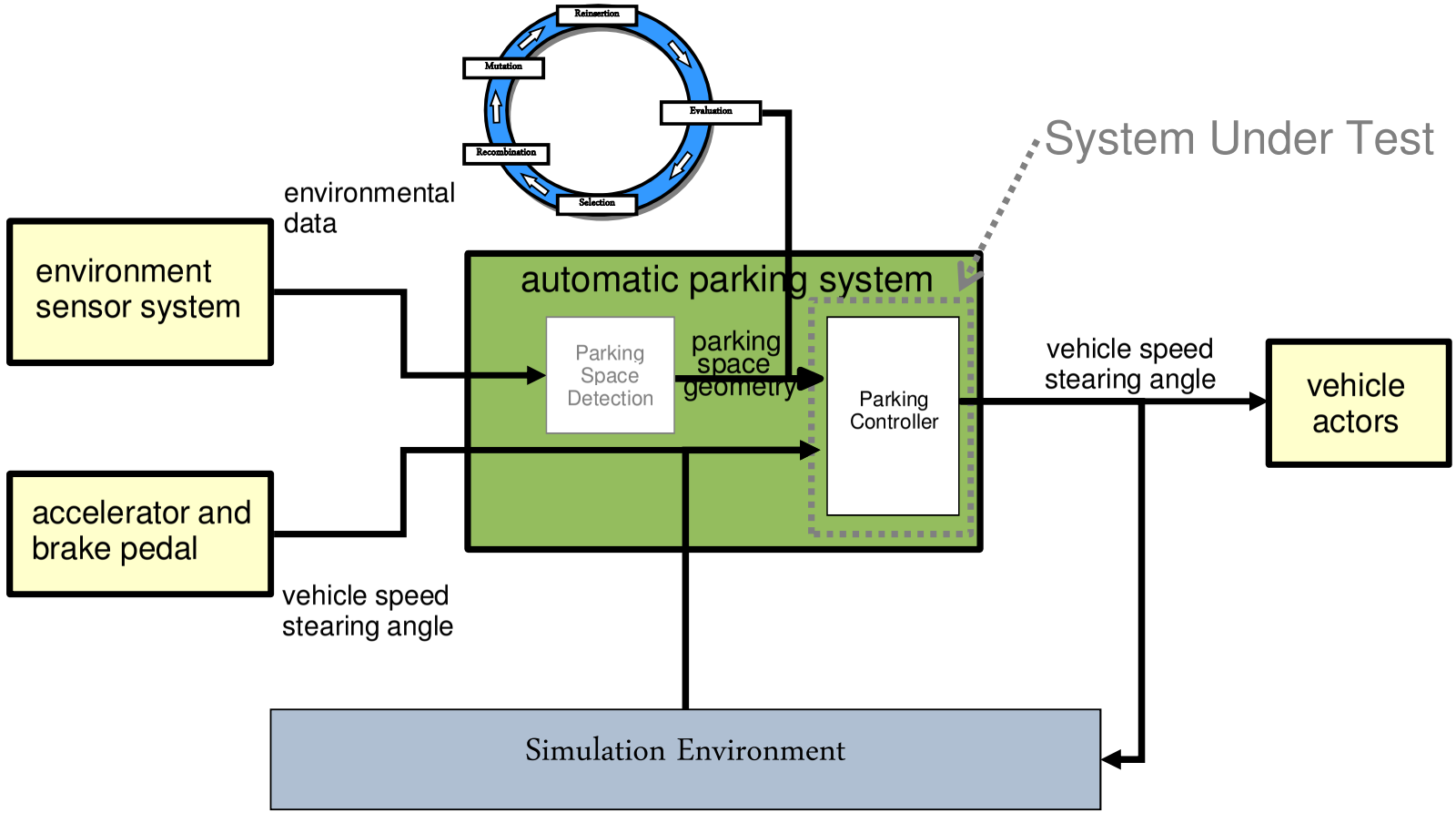
Level 2: Functional Testing of Automatic Parking System



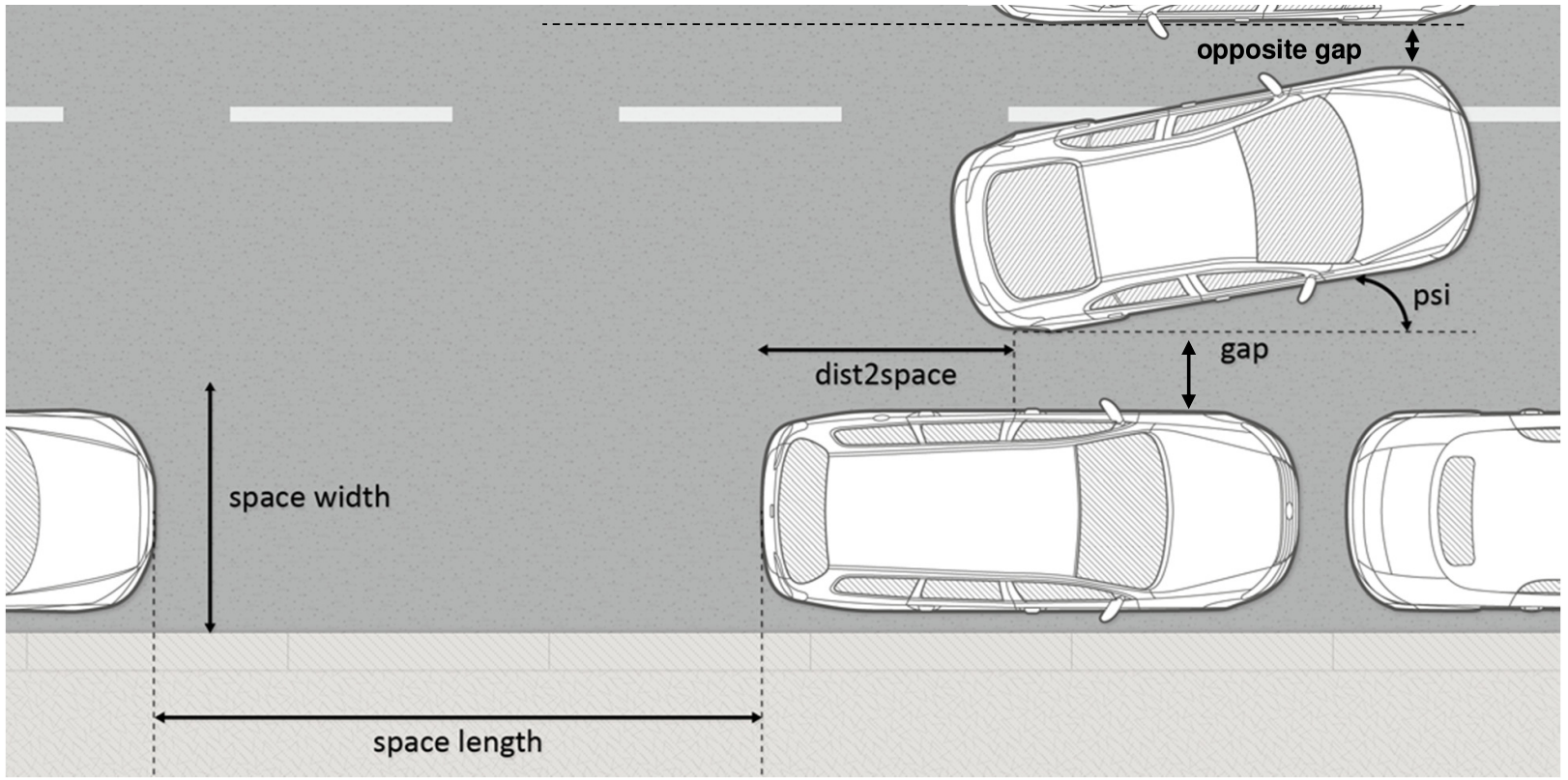
Level 2: Functional Testing of Automatic Parking System



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



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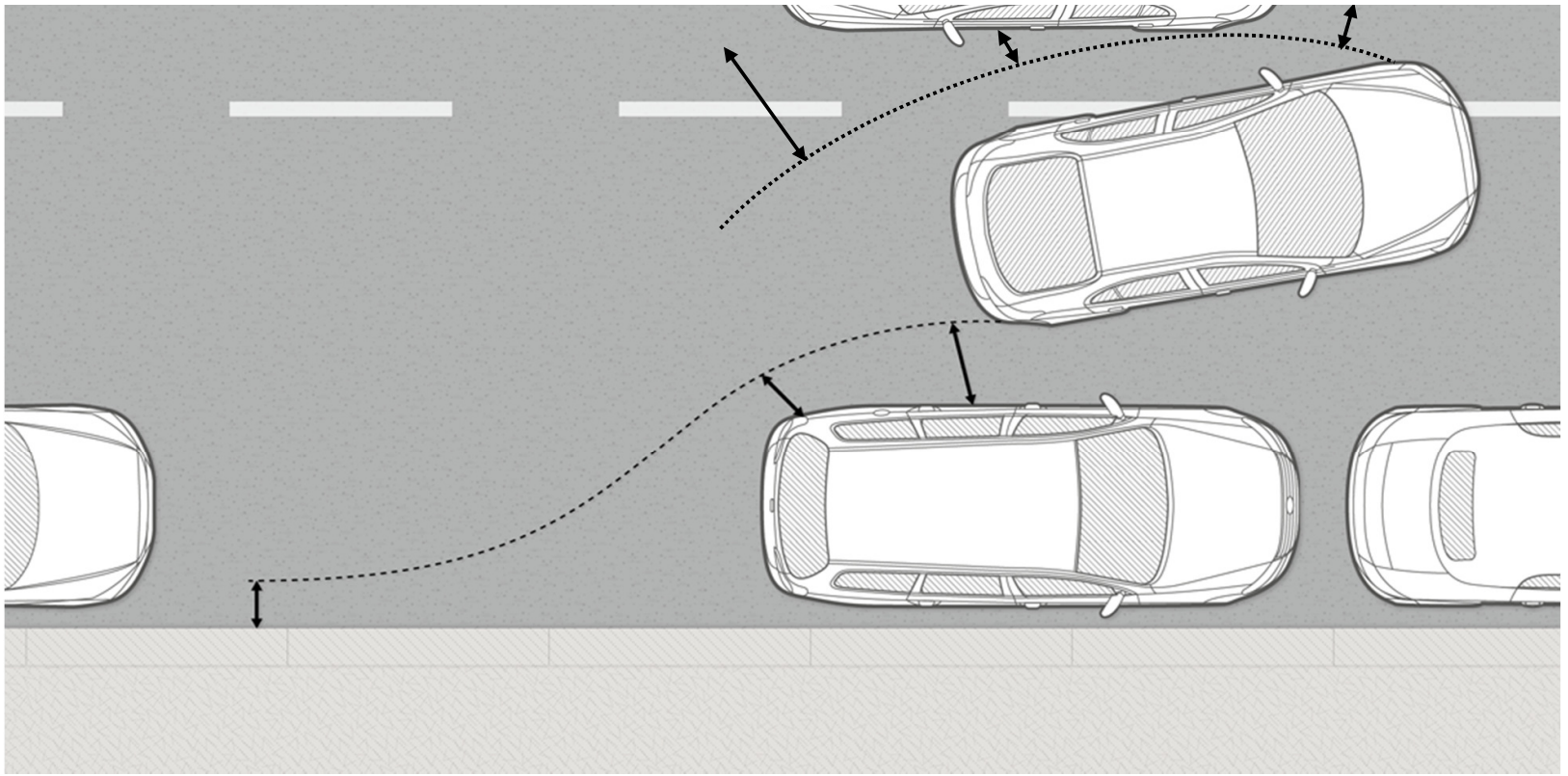
Level 2: Functional Testing of Automatic Parking System

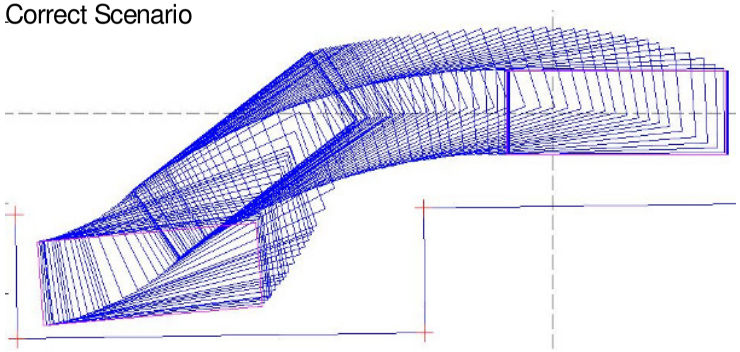
Selection of smallest distance between car and collision area as objective value (negative values also allowed)

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



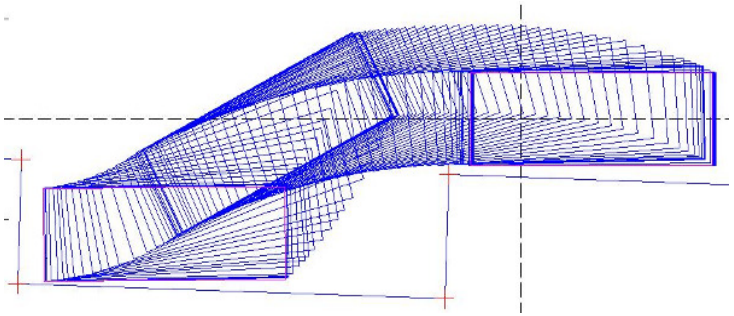
✓ Level 2: Functional Testing of Automatic Parking System

Correct Scenario



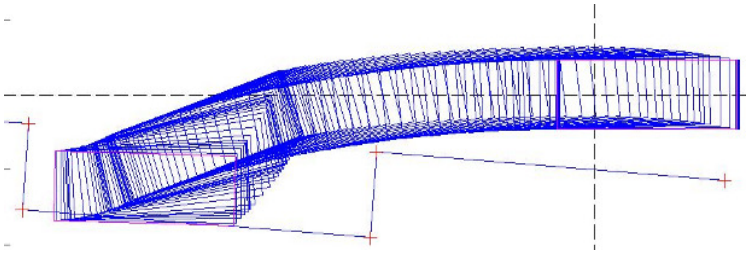
Generation 01 / Individual 13

Critical Scenario



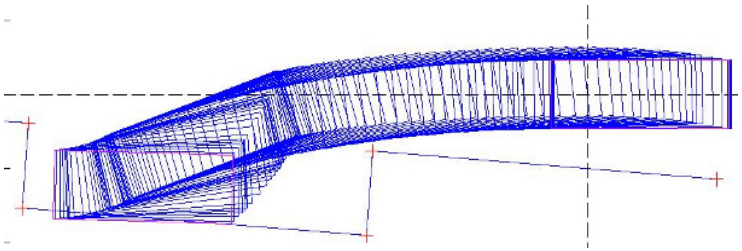
Generation 10 / Individual 02

Scenario leading to erroneous system behavior (edge entered collision area)



Generation 20 / Individual 06

Scenario leading to erroneous behavior (end-position in collision area)



Generation 20 / Individual 05

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Levels of Driving Automation for On-Road Vehicles

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***Automated driving system* ("system") monitors the driving environment**			System	**System**	Human driver	Some driving modes	Highly automated	3
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*						
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*	System	System	**System**	Some driving modes	Fully automated	3/4
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	System	**All driving modes**	-	

Source: http://cyberlaw.stanford.edu/loda

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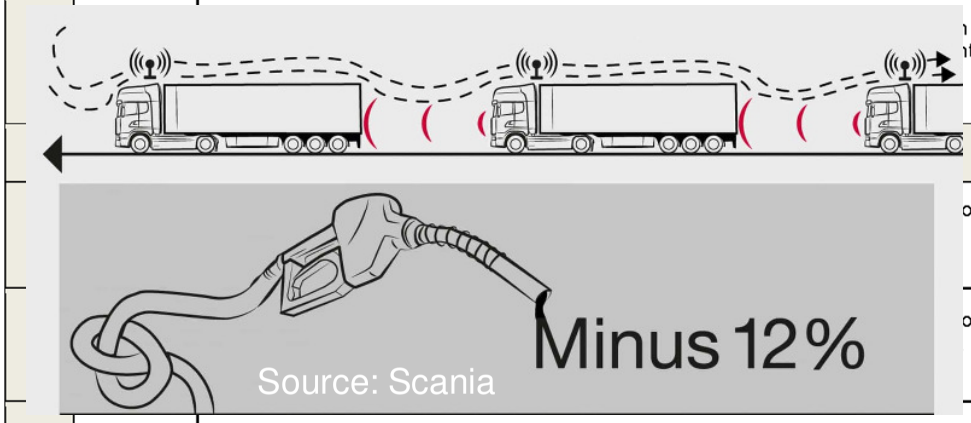

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Video on Autopilot -> Search on YouTube for Tesla Autopilot 2.0

Sou…

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Source: http://cyberlaw.stanford.edu/loda

Levels of Driving Automation for On-Road Vehicles

Level 5: Not expected before 2025

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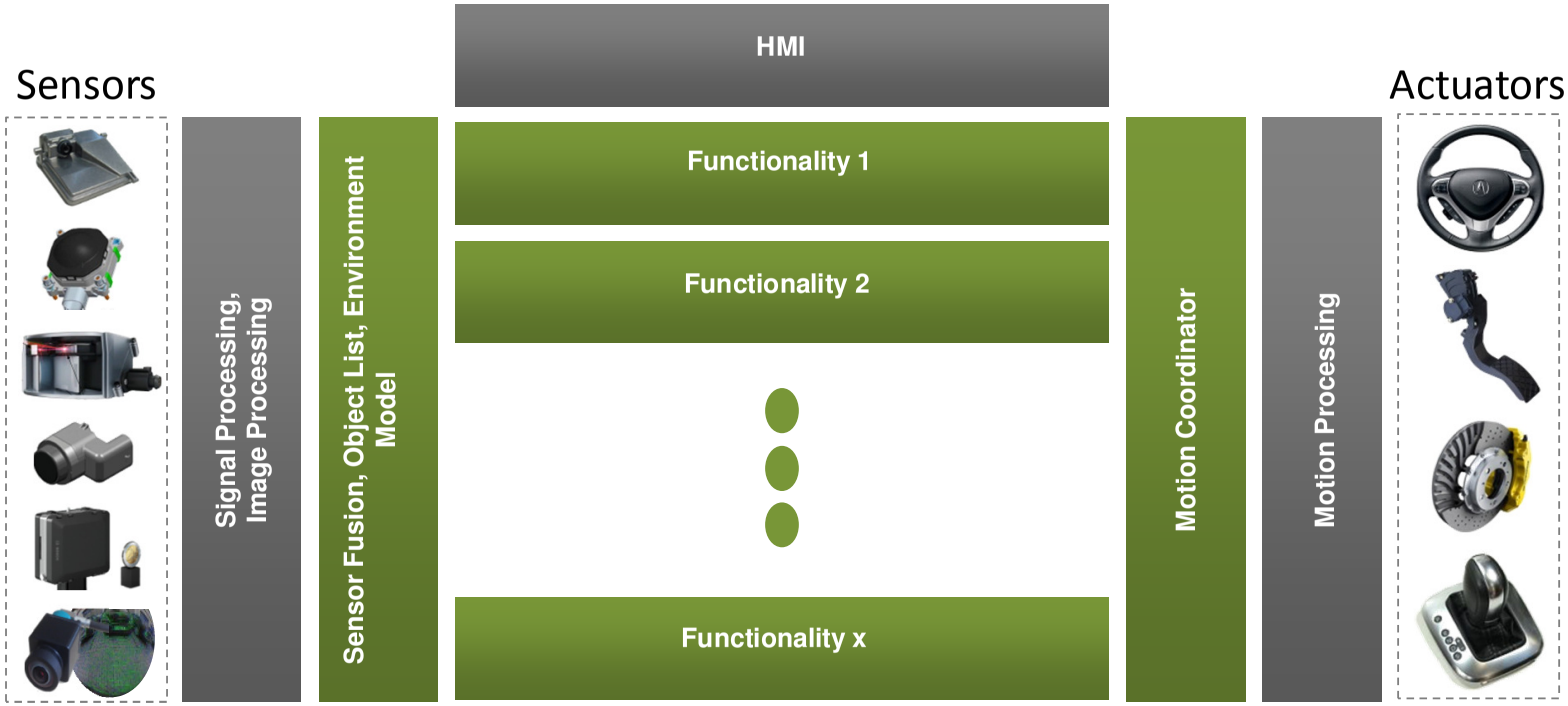
Traffic Jam Assist, Automated Parking, Platooning, …				Highly automated	3
Automated valet parking, Platooning, Highway Pilot, …				Fully automated	3/4
Fully Automated Driving (no steering wheel, no pedals, …)				-	

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

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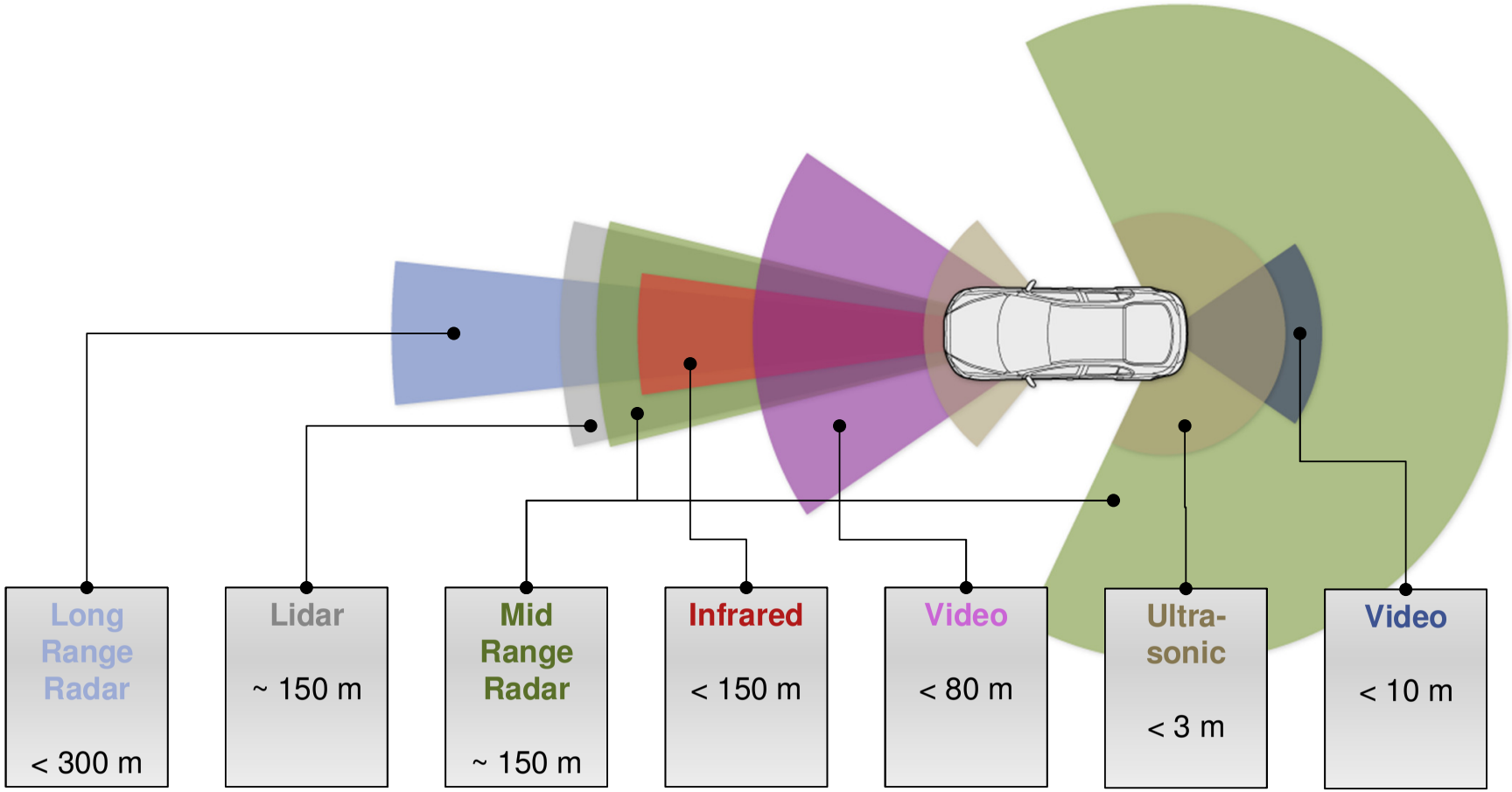
Input Space: Sensors included …

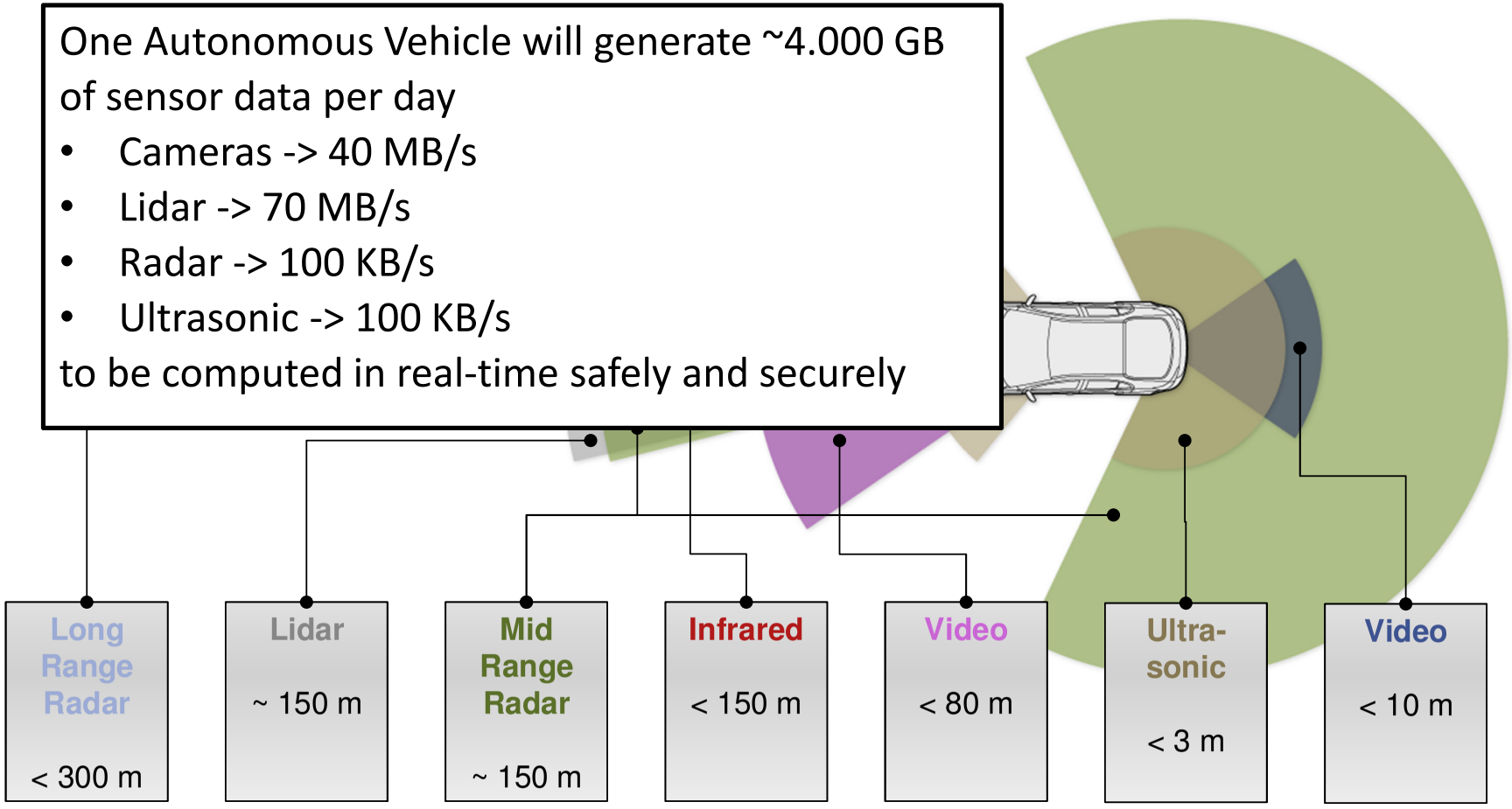


… and their data

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 Benchmark[1]

- 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 be[2]

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

Imperative for Virtual Validation[3]

- 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

A NEW PATH TO GROWTH

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