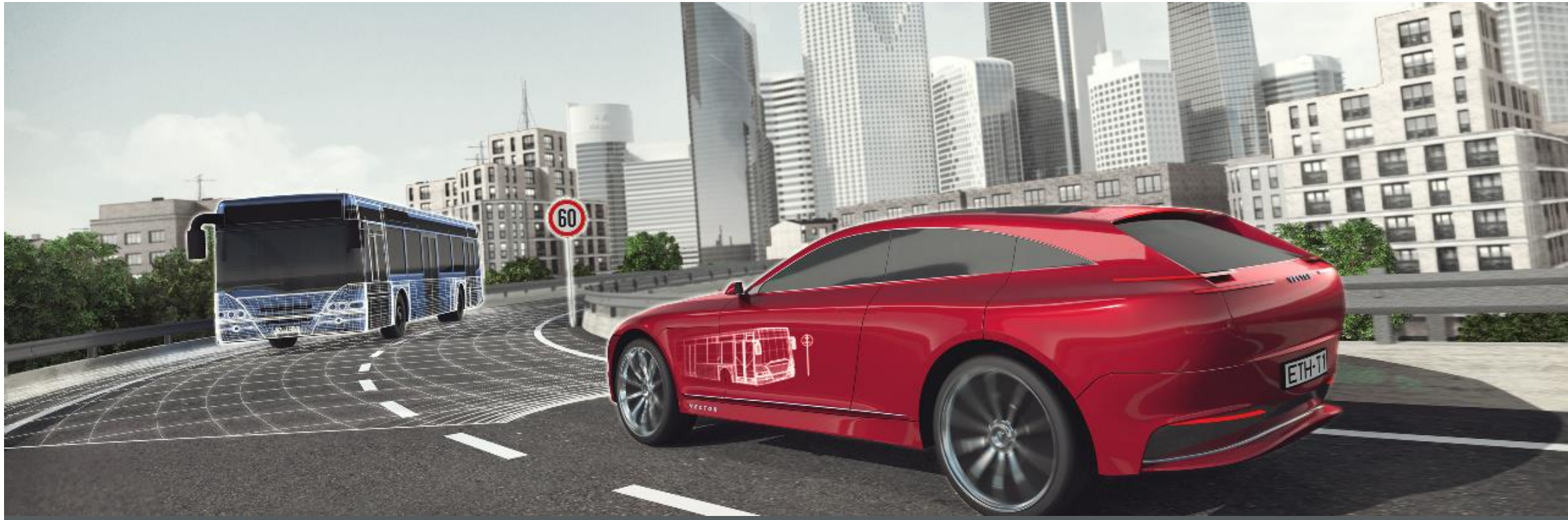
VECTOR

Robo-Test

Universität Stuttgart

Institut für Automatisierungstechnik und Softwaresysteme



Systematic Validation for Automated Driving

Christof EBERT and Michael WEYRICH

V1.1 | 2021-02-10

Who We Are

Prof. Dr.
Christof Ebert

- Dr.-Ing. on complex system development and AI with research in Univ. Stuttgart and USA
- Since 2006 Managing Director of Vector Consulting Services
- Professor at IAS

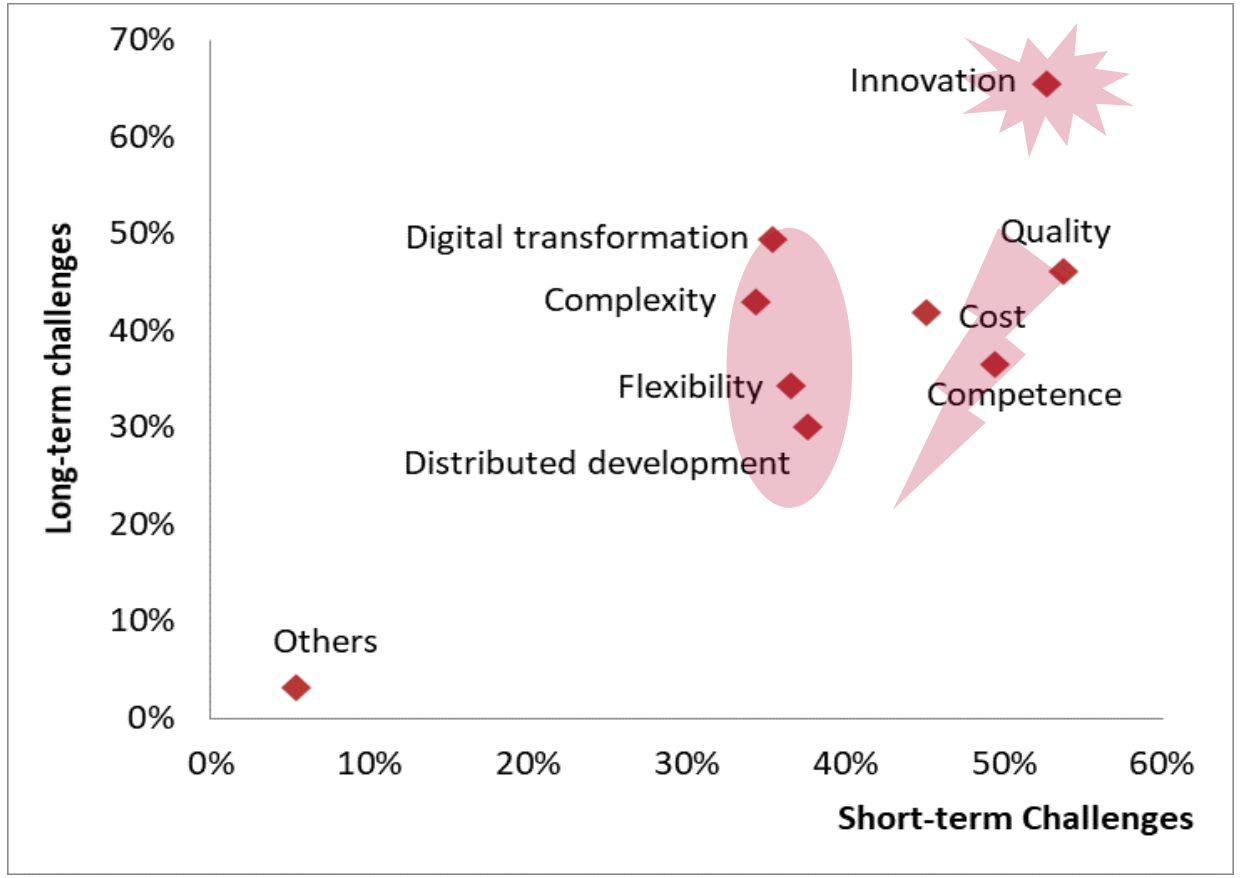
Prof. Dr. Dr. h.c.
Michael Weyrich

- Dr.-Ing. in mechanical engineering (RWTH)
- Since 2013 head of IAS and dean of studies M.Sc. "Autonomous Systems"
- Head of the VDI/VDE GMA committee "Testing of networked systems"

Robo-Test Team

- Algorithm for test selection based on scenarios with conditional probabilities and correlations trained and tested for years
- Model extraction from black/grey box behaviors for digital twin with data analytics
- Demonstrator at the university, close collaboration with companies such as Bosch, Daimler and Vector
- Patents, filed since 2019

Industry Trends 2021: Innovation in Stormy Waters



Vicious circle
> cost pressure
> lack of competences
> quality and liability risks

Source: Vector Client Survey 2021.
Details: www.vector.com/trends.
Horizontal axis shows short-term challenges; vertical axis shows mid-term challenges.
Sum > 300% due to 5 answers per question.
Good validity with 3.5% response rate of 2700 recipients from different industries worldwide.

Automation and autonomy will further grow and need efficient yet high-quality engineering. Innovative validation and homologation techniques are the call of the day.

robo-test Incubator
@ Univ. Stuttgart, IAS

Robo-Test

- Together with industry partners the University of Stuttgart drives the vision of 'Intelligent Systems for a Sustainable Society’
- Robo-Test mission is to achieve trust in autonomous systems.
- Robo-Test delivers the core technology for safe and dependable behavior of autonomous systems and thus set the standard for efficient and transparent validation, certification and homologation based on AI driven analysis and tests.

Autonomy: Cooperating Systems

- By 2030 driverless systems will, be established specifically for trucks and robo-taxis
- Level 5 autonomy will show biggest yield, e.g. transport, bus, taxi
- Level 3 autonomy has high challenge on driver
- Cost and technology can be managed: 5 radar sensors, 5 lidar sensors, 10+ cameras, ASIL-D ECU and IT equipment with full redundancy like in airplanes
- Challenge: Handling unexpected events, corner-cases, ML deficiencies, SUMS with Cx
- Demands for new verification, validation and simulation strategies for full consistency

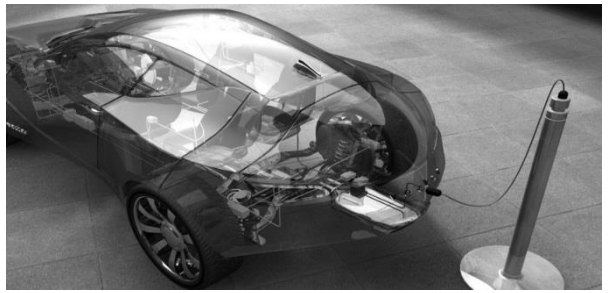
Regular driving

We know what we see. But we don't see what matters…

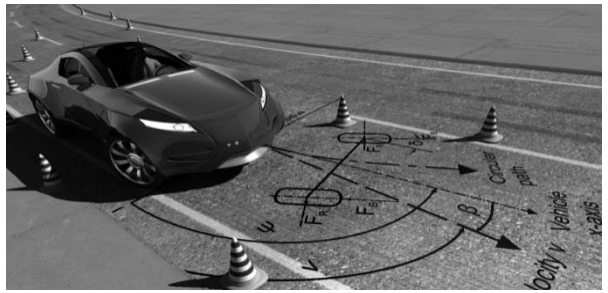
Autonomy

Car unexpectedly enters. Brake system is activated.

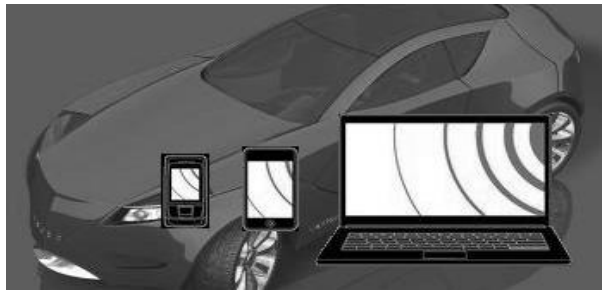
Autonomy Amplifies Existing Challenges: Safety and Cybersecurity



1. Powertrain
   - → Energy efficiency
   - → **Unintended speed change**



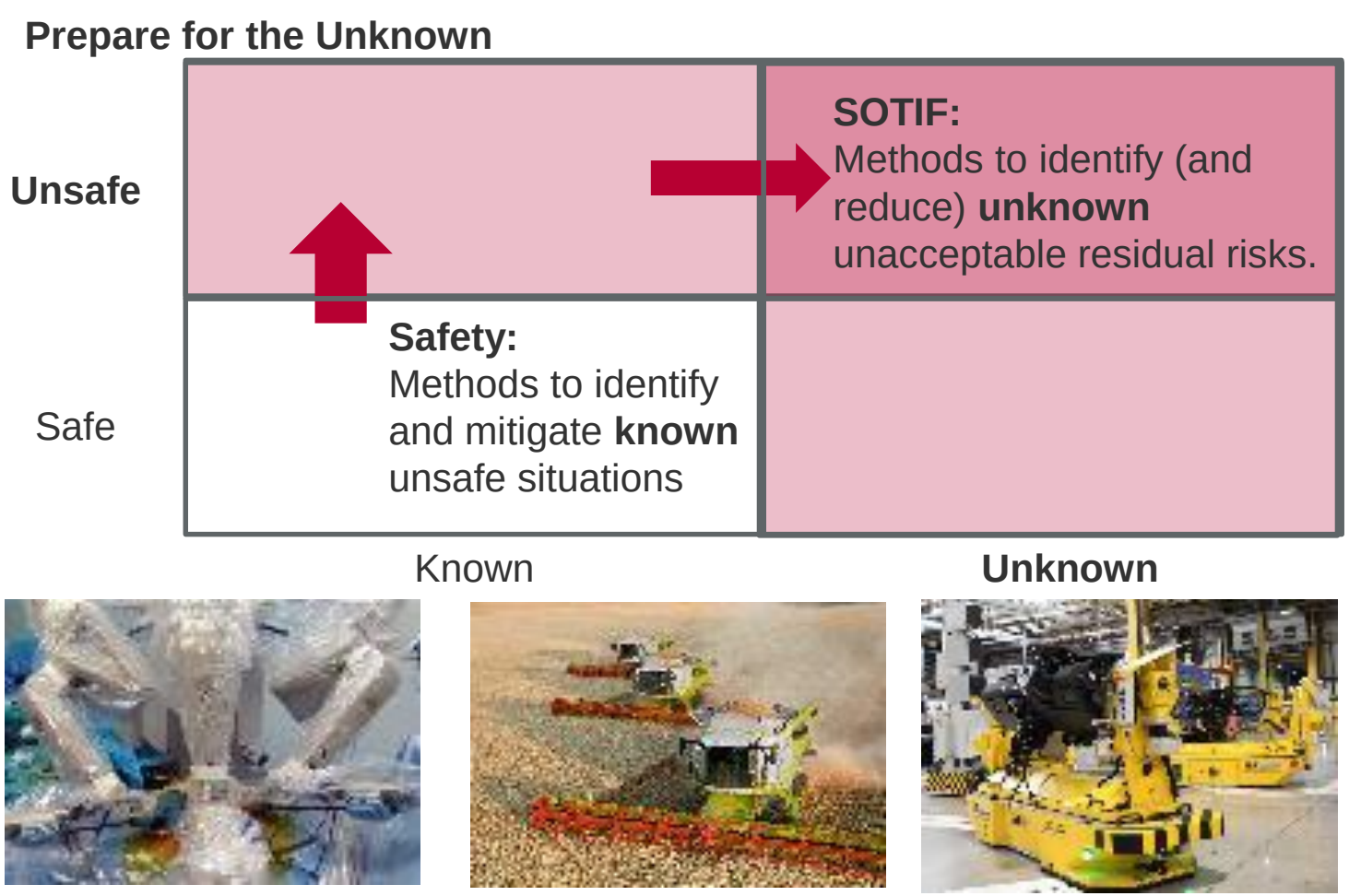
2. Driver Assistance
   - → Autonomous driving
   - → **Signal confusion**



3. Connectivity
   - → Always connected
   - → **Sudden Driver distraction**

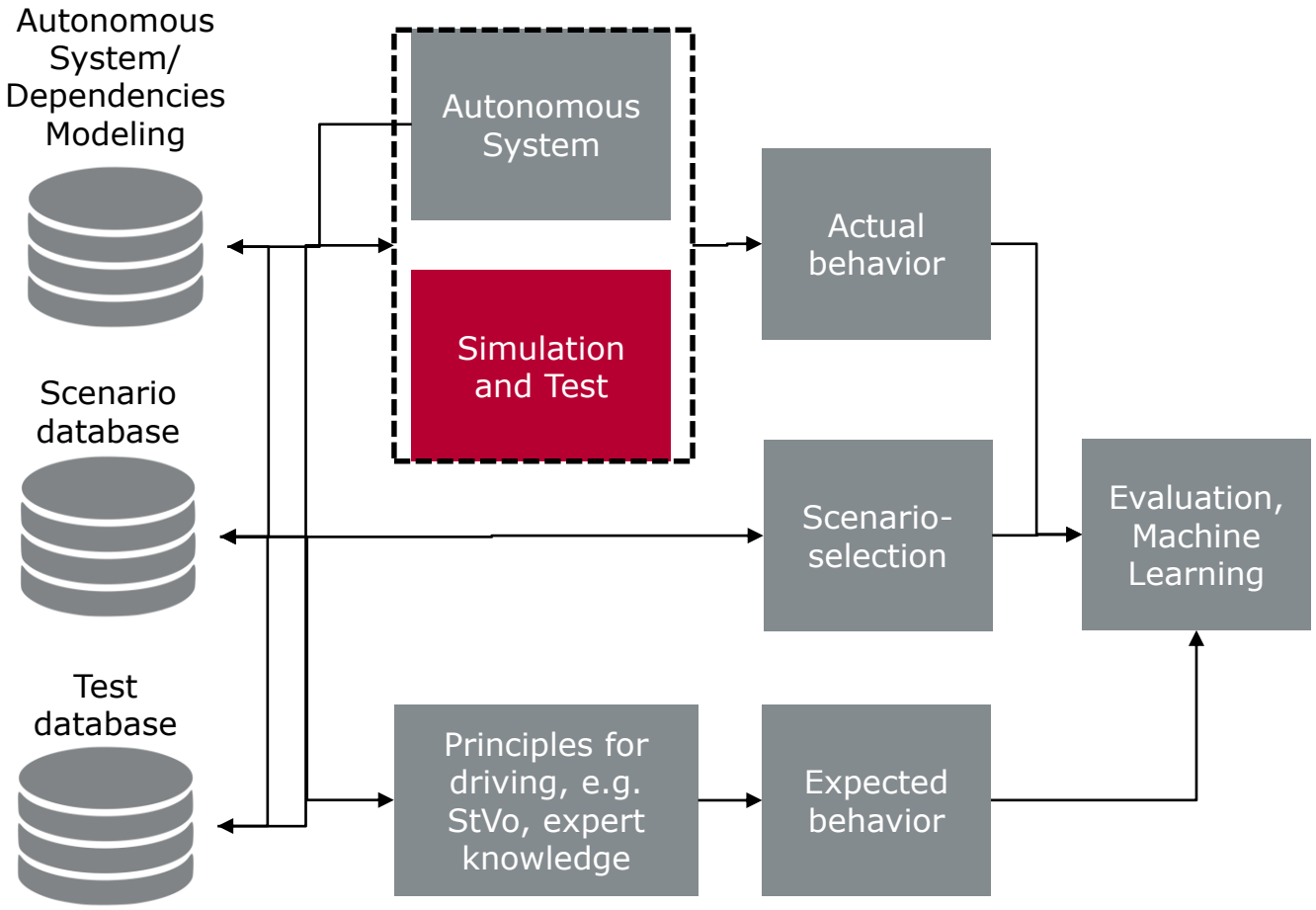
Automation needs Functional Safety, which needs Cybersecurity.
And all need much better Testing than what we see today

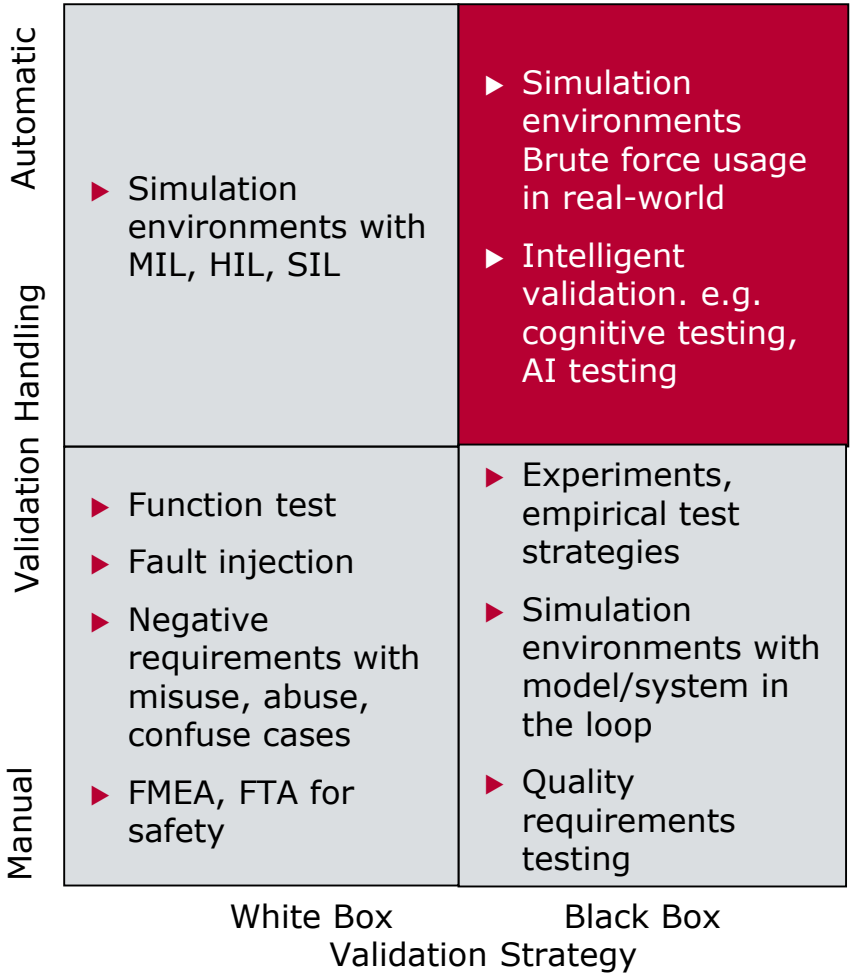
Safety of Autonomous Systems: Brute Force Will Not Help



Quality matters: Anticipate the Unthinkable. Specify the Unknown Unknowns.

Methodology for Intelligent Validation and Homologation of Autonomous Systems





Overlay classic validation with expert knowledge, heuristics and machine learning

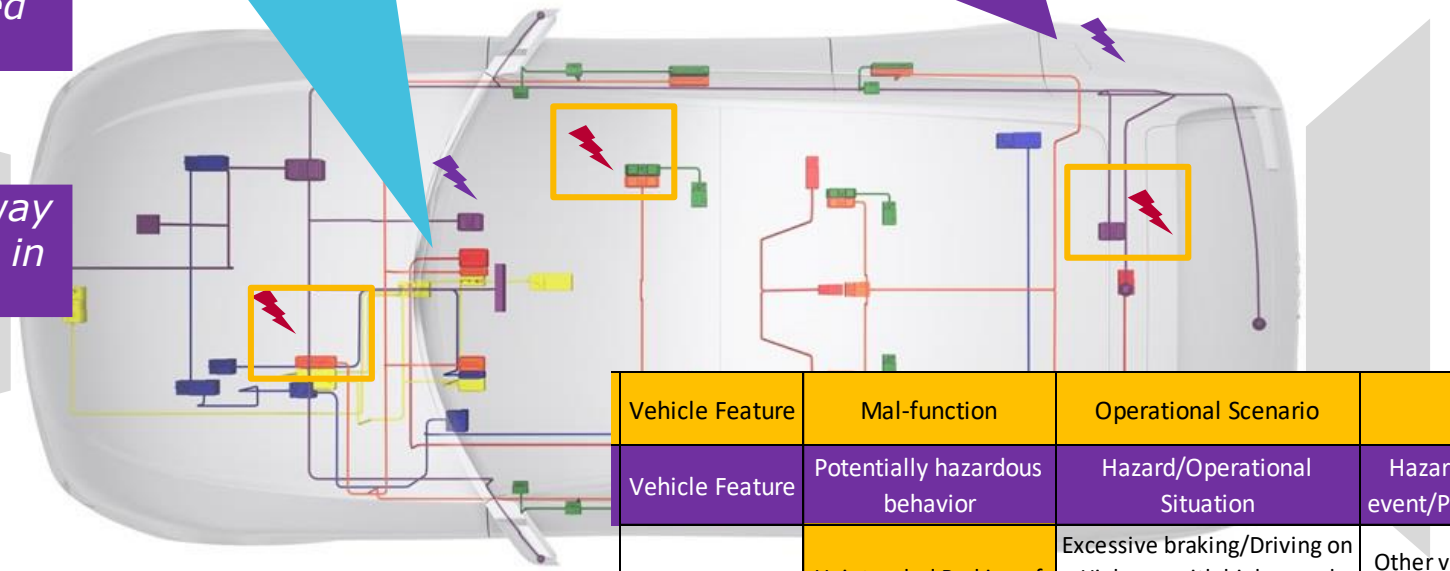
Product Liability Demands Strict Governance

Triggering event: *Camera sensor blinded by sunset*

Misuse: *Appling highway traffic sign recognition in urban traffic*

Triggering event: *Non deterministic algorithm (e.g. Neural network) fails*

Triggering event: *Limited max torque*



= limitations of sensors, actuators and algorithms, environmental conditions and foreseeable misuse (ISO 21448) and misuse/abuse (ISO 21434, UN-ECE)

= systematic and random faults of HW and SW (ISO 26262)

Vehicle Feature	Mal-function	Operational Scenario	Hazard		Safety Goal
Vehicle Feature	Potentially hazardous behavior	Hazard/Operational Situation	Hazardous event/Persons	Harm	Measure
Emergency Braking Assist	Unintended Braking of vehicle	Excessive braking/Driving on Highway with high speed and another vehicle is closly following (E3)	Other vehicle brakes to avoid crash (C2)	Rear-Front Collison (S3)	SG1 (ASIL B)
	Unintended Braking of vehicle (ice on sensor)	see above	see above	see above	Measure: Ice-detection by sensor selftest
	...				

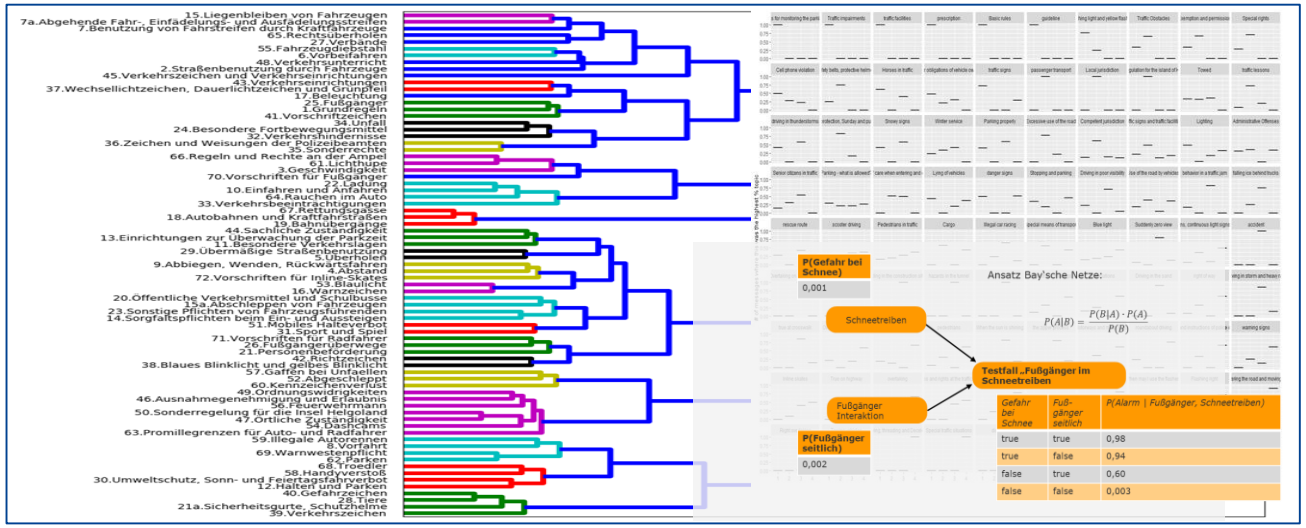
Get proficient with standards for safety, SOTIF, cybersecurity and SW Updates

Towards Systematic Testing of Autonomous Systems

1. **Identify and index scenarios and derive test cases with AI**
   - Basic principles (e.g., laws)
   - Expert knowledge (e.g., Goslar convention)
   - Heuristics for corner conditions (e.g., weather, road, light, scenarios: child on road)
   - White-box architecture information (e.g., rules, components, signals)

2. **Apply Digital Twin and deep rule learning to analyze, prioritize and automate test cases**
   - Bayesian networks with conditional rules, etc.
   - Testing RPA (robot process automation)

3. **Facilitate certification and homologation with algorithm transparency**
   - Fuzzy transformations
   - AI rule checkers

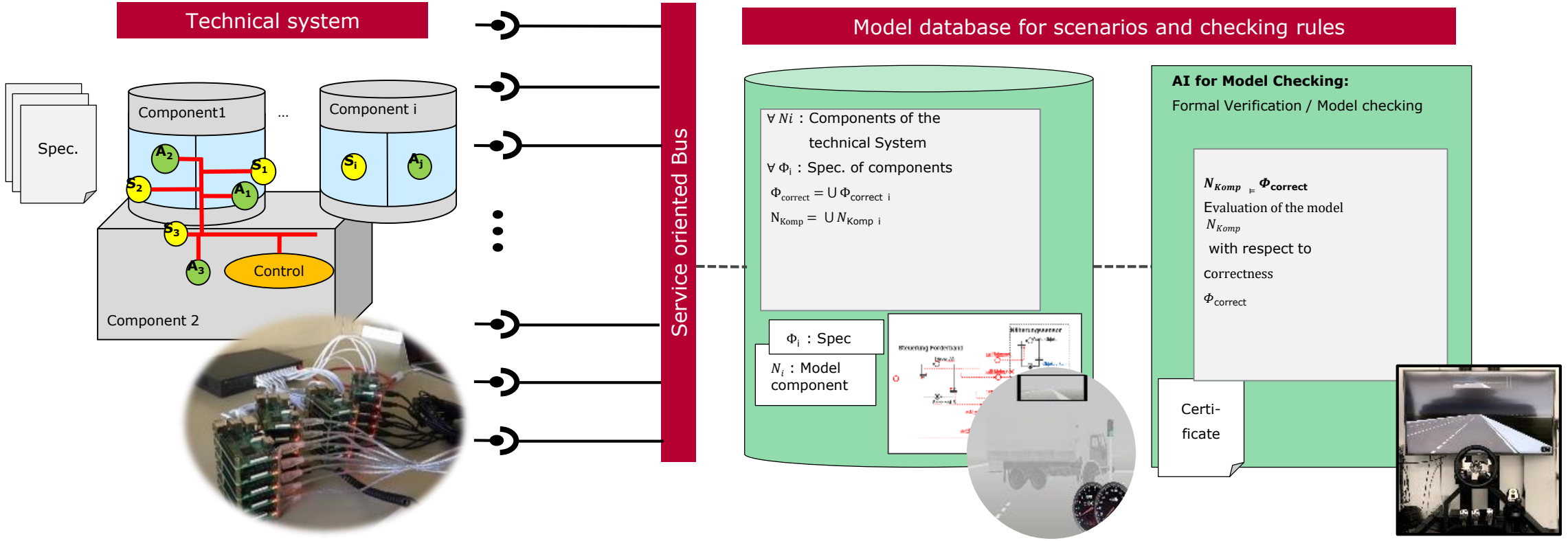


Introduce New Coverage Schemes for Validation: Intelligent Testing

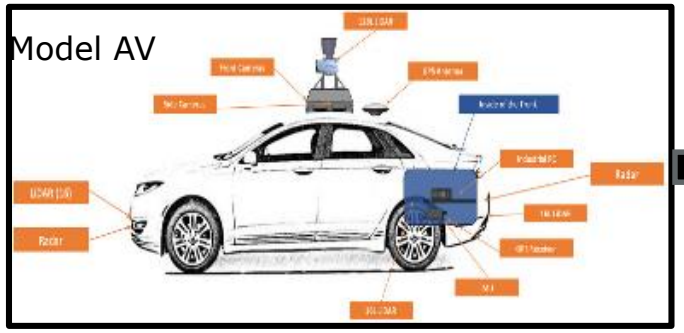
Intelligent Testing with AI-Based Scenario Selection and Simulation

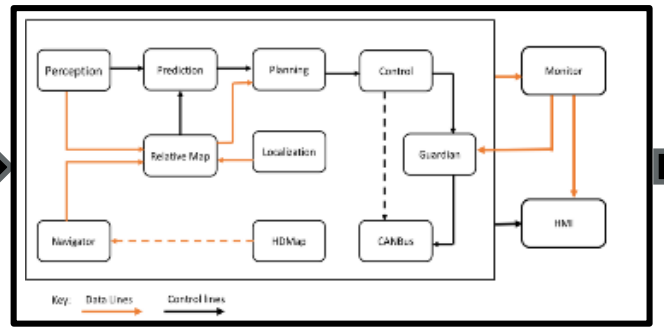
Ensuring correct functioning through high test coverage of flexible systems while guaranteeing operation

Modelling of dynamic systems for test management with need-based test initiation and automated test coordination

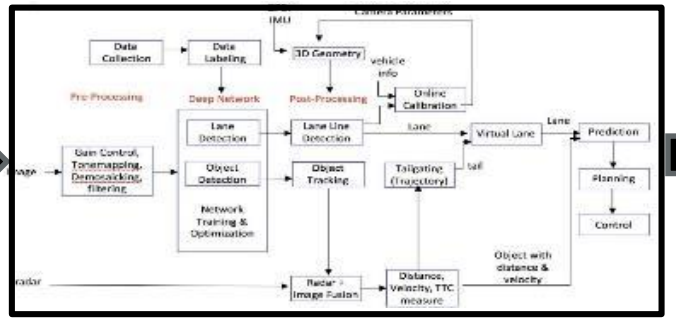


Demonstrator: Current Status

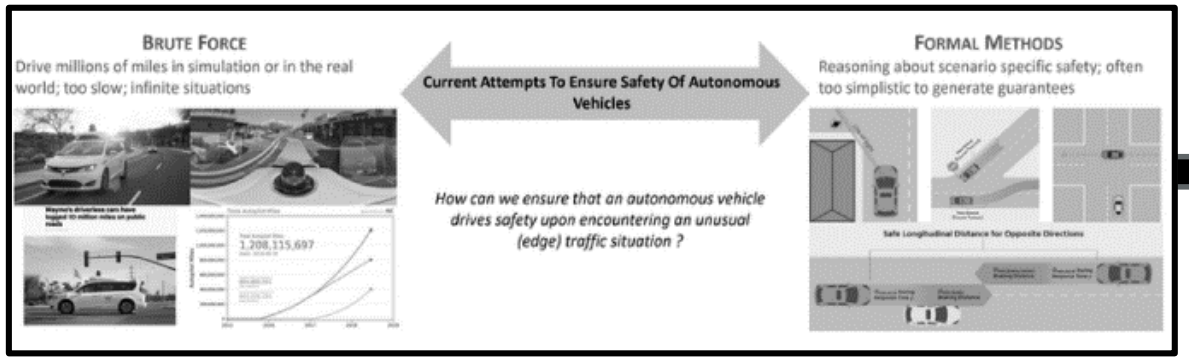




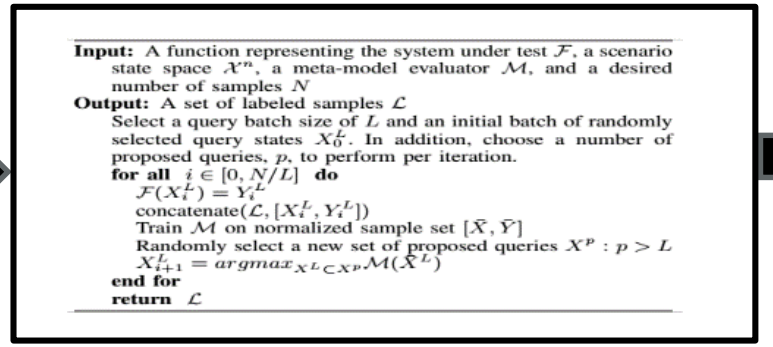
Modeling Dependences



Analyzing Dependences

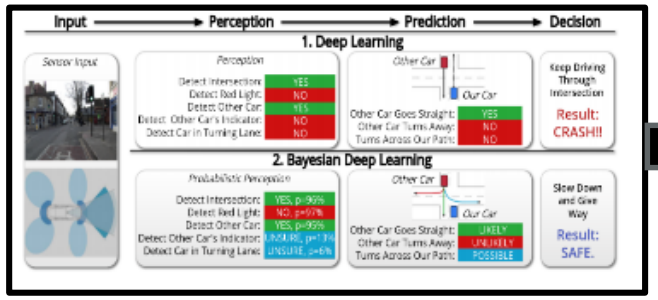


Solution

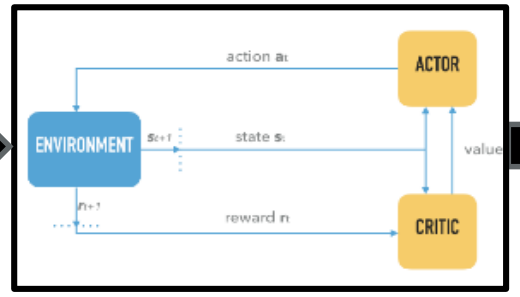


Input: A function representing the system under test $\mathcal{F}$, a scenario state space $\mathcal{X}^n$, a meta-model evaluator $\mathcal{M}$, and a desired number of samples N
Output: A set of labeled samples $\mathcal{L}$
Select a query batch size of L and an initial batch of randomly selected query states X_0^L. In addition, choose a number of proposed queries, p, to perform per iteration.
for all $i \in [0, N/L]$ **do**
$\mathcal{F}(X_i^L) = Y_i^L$
concatenate$(\mathcal{L}, [X_i^L, Y_i^L])$
Train $\mathcal{M}$ on normalized sample set $[\bar{X}, \bar{Y}]$
Randomly select a new set of proposed queries $X^p : p > L$
$X_{i+1}^L = argmax_{X^L \subset X^p} \mathcal{M}(\bar{X}^L)$
end for
return $\mathcal{L}$

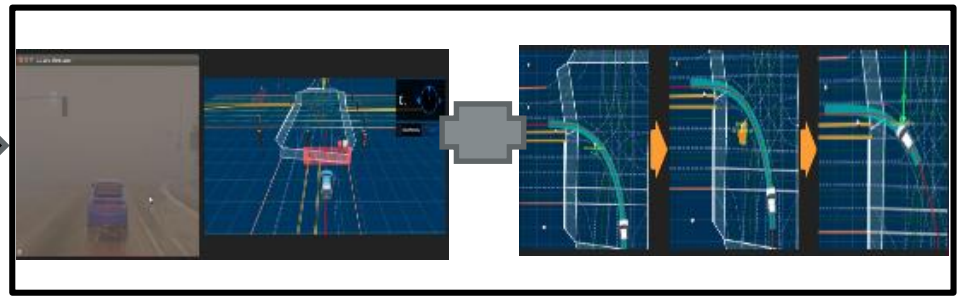
Test strategy



Uses Bayesian Deep Learning

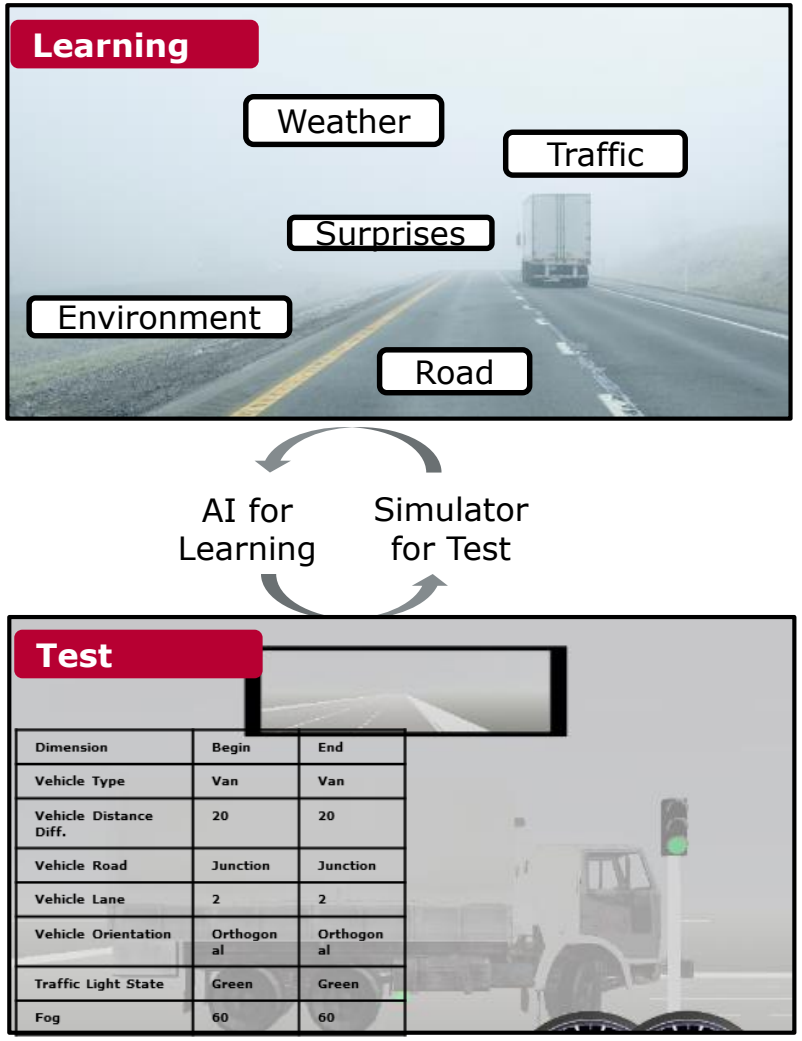


Modelled through RL



To find test cases in a given scenario

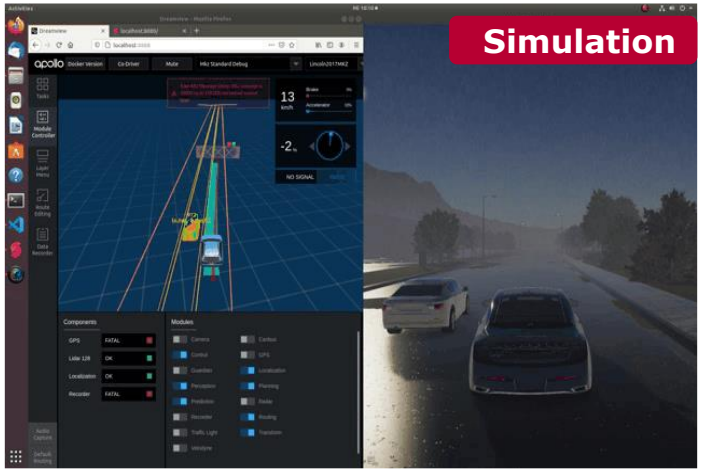
Demonstrator: Intelligent Testing with AI-Based Scenario Selection and Simulation



Dimension	Begin	End
Vehicle Type	Van	Van
Vehicle Distance Diff.	20	20
Vehicle Road	Junction	Junction
Vehicle Lane	2	2
Vehicle Orientation	Orthogonal	Orthogonal
Traffic Light State	Green	Green
Fog	60	60

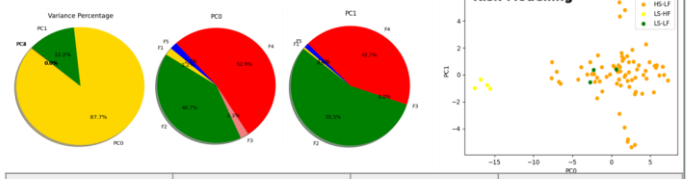
Test-DB and Indexing

Dimension	BeginValue	StateChange_Duration	IntermediateValue	EndValue
			True/False	True/False
			True/False	True/False
			True/False	True/False
			True/False	True/False
			True/False	True/False
			True/False	True/False
EmergencyRoute	True/False		True/False	True/False
SolidLine	True/False		True/False	True/False
BrokenLine	True/False		True/False	True/False
TemporaryLine	True/False		True/False	True/False
Shoulder	True/False		True/False	True/False
ConcreteBarrier	True/False		True/False	True/False
Asphalt	True/False		True/False	True/False
Concrete	True/False		True/False	True/False
Mixed	True/False		True/False	True/False
Brick	True/False		True/False	True/False
Dirt	True/False		True/False	True/False
StraightWay	True/False		True/False	True/False
Curve	True/False		True/False	True/False
Hill	True/False		True/False	True/False
Corner	True/False		True/False	True/False
NumberOfLanes	Decimal Number		Decimal Number	Decimal Number
LaneWidth	Decimal Number		Decimal Number	Decimal Number
Length	Decimal Number		Decimal Number	Decimal Number
TrafficDensity	Decimal Number		Decimal Number	Decimal Number
Accident	True/False		True/False	True/False
EmergencyVehicle	True/False		True/False	True/False
Construction	True/False		True/False	True/False
ClosedRoad	True/False		True/False	True/False
StopSign	True/False		True/False	True/False
YieldSign	True/False		True/False	True/False
PrioritySign	True/False		True/False	True/False
ZoneSign	True/False		True/False	True/False
SpeedLimitSign	10, 20, 30, ...		10, 20, 30, ...	10, 20, 30, ...
CrosswalkSign	True/False		True/False	True/False
Debris	True/False		True/False	True/False
Animal	True/False		True/False	True/False
ConstructionEquipment	True/False		True/False	True/False
TrafficLightState	Red, Yellow, Green		Red, Yellow, Green	Red, Yellow, Green
Wind	Decimal Number		Decimal Number	Decimal Number
Rain	Decimal Number		Decimal Number	Decimal Number
Snow	Decimal Number		Decimal Number	Decimal Number
Sleet	Decimal Number		Decimal Number	Decimal Number
Temperature	Decimal Number		Decimal Number	Decimal Number
Fog	Decimal Number		Decimal Number	Decimal Number
Smoke	Decimal Number		Decimal Number	Decimal Number
Smog	Decimal Number		Decimal Number	Decimal Number
Dust	Decimal Number		Decimal Number	Decimal Number
Mud	Decimal Number		Decimal Number	Decimal Number
StandingWater	True/False		True/False	True/False
IcyRoad	True/False		True/False	True/False
SnowOnRoad	True/False		True/False	True/False
Day	Decimal Number		Decimal Number	Decimal Number
Dawn	Decimal Number		Decimal Number	Decimal Number
Dusk	Decimal Number		Decimal Number	Decimal Number
Night	Decimal Number		Decimal Number	Decimal Number
StreetLight	True/False		True/False	True/False
HeadLight	True/False		True/False	True/False
TrafficCar1Type	Car, Van, Bus, ...		Car, Van, Bus, ...	Car, Van, Bus, ...
TrafficCar1Color	Red, Green, Blue, ...		Red, Green, Blue, ...	Red, Green, Blue, ...
TrafficCar1DistanceDiff	+infront - behind		+infront - behind	+infront - behind
TrafficCar1Road	Junction/integer number		Junction/integer number	Junction/integer number
TrafficCar1Orientation	Parallel/Orthogonal/Opposite		Parallel/Orthogonal/Opposite	Parallel/Orthogonal/Opposite
TrafficCar1Lane	Same/Different/integer number		Same/Different/integer number	Same/Different/integer number
TrafficCar2Type	Car, Van, Bus, ...		Car, Van, Bus, ...	Car, Van, Bus, ...
TrafficCar2Color	Red, Green, Blue, ...		Red, Green, Blue, ...	Red, Green, Blue, ...
TrafficCar2DistanceDiff	+infront - behind		+infront - behind	+infront - behind
TrafficCar2Road	Junction/integer number		Junction/integer number	Junction/integer number
TrafficCar2Orientation	Parallel/Orthogonal/Opposite		Parallel/Orthogonal/Opposite	Parallel/Orthogonal/Opposite
TrafficCar2Lane	Same/Different/integer number		Same/Different/integer number	Same/Different/integer number
TrafficCar3Type	Car, Van, Bus, ...		Car, Van, Bus, ...	Car, Van, Bus, ...
TrafficCar3Color	Red, Green, Blue, ...		Red, Green, Blue, ...	Red, Green, Blue, ...
TrafficCar3DistanceDiff	+infront - behind		+infront - behind	+infront - behind
TrafficCar3Road	Junction/integer number		Junction/integer number	Junction/integer number
TrafficCar3Orientation	Parallel/Orthogonal/Opposite		Parallel/Orthogonal/Opposite	Parallel/Orthogonal/Opposite
TrafficCar3Lane	Same/Different/integer number		Same/Different/integer number	Same/Different/integer number
PedestrianAge	integer number		integer number	integer number
PedestrianGender	male/female		male/female	male/female
PedestrianDistanceDiff	+infront - behind		+infront - behind	+infront - behind
PedestrianSidewalk	right/left		right/left	right/left
PedestrianClothesColor	Red, Green, Blue, ...		Red, Green, Blue, ...	Red, Green, Blue, ...
CyclistColor	Red, Green, Blue, ...		Red, Green, Blue, ...	Red, Green, Blue, ...
CyclistDistanceDiff	+infront - behind		+infront - behind	+infront - behind
CyclistLane	Same/Different/integer number		Same/Different/integer number	Same/Different/integer number



Functional Scenario : NPC Cutin

KPI



KPI	Reinforcement learning	Cross Entropy	Random sampler
Criticality Coverage	61.3 %	53.86 %	47.01 %
Convergence	65 samples	75 samples	-
Runtime	975.81 seconds	942.88 seconds	931.82 seconds
No. of reported collision	4	10	3

Maximum Severity region: Fog rate [0.59 ... 1.00] , NPC speed [22m/s ... 29 m/s], Rain rate [0.59 ... 0.98], Time of the day [14 ... 22.16], Wetness [0.6 ... 0.99]

Prepare YOURSELF for the Future: ACES makes Digital Winners

Industry Trends

- **A**utonomy

- **C**onvergence

- **E**cology

- **S**ervices

Business Impacts

- **From incumbent vertical supply-chain to fluid business models and eco-systems**
- Services are the real products
- "Smartphone-like" adaptive and flexible feature delivery
- Governance and liability focus

Engineering Impacts

- **From separated disciplines and functional silos to EE-IT convergence**
- Service-oriented architectures
- Agile innovation
- Continuous everything
- Intelligent testing

Benefits and Further Information

- **25 Years of experience in ML and AI for automation and the underlying intelligent validation**
- **AI and fuzzy logic** for the development of critical systems in automotive, transportation, aerospace and automation has been the focus of the founders for 20 years
- **Research and industry projects** (currently 15 PhD students and several industry partnerships) to secure networked systems, e.g., functional security, cybersecurity in digital driving, AI for protection, failure analysis, test procedures and processes
- **Several patents** proceeding on the topic of "Regressive validation and certification of autonomous systems and their configurable components"
- **Books, publications and standards**, e.g. collaboration on ISO 26262, SOTIF, ISO 21434, VDI guideline testing of networked systems

Benefit from our wide experiences in AI and ML for automation: www.robo-test.com

Thank you for your attention.
For more information please contact us.

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