Robotics and
Embedded Systems

Seminar "Reinforcement Learning in Autonomous Driving"

Safe Reinforcement Learning and the Future of ISO 26262

Jonas Riebel & Max Ulmke

Summer Semester 2018

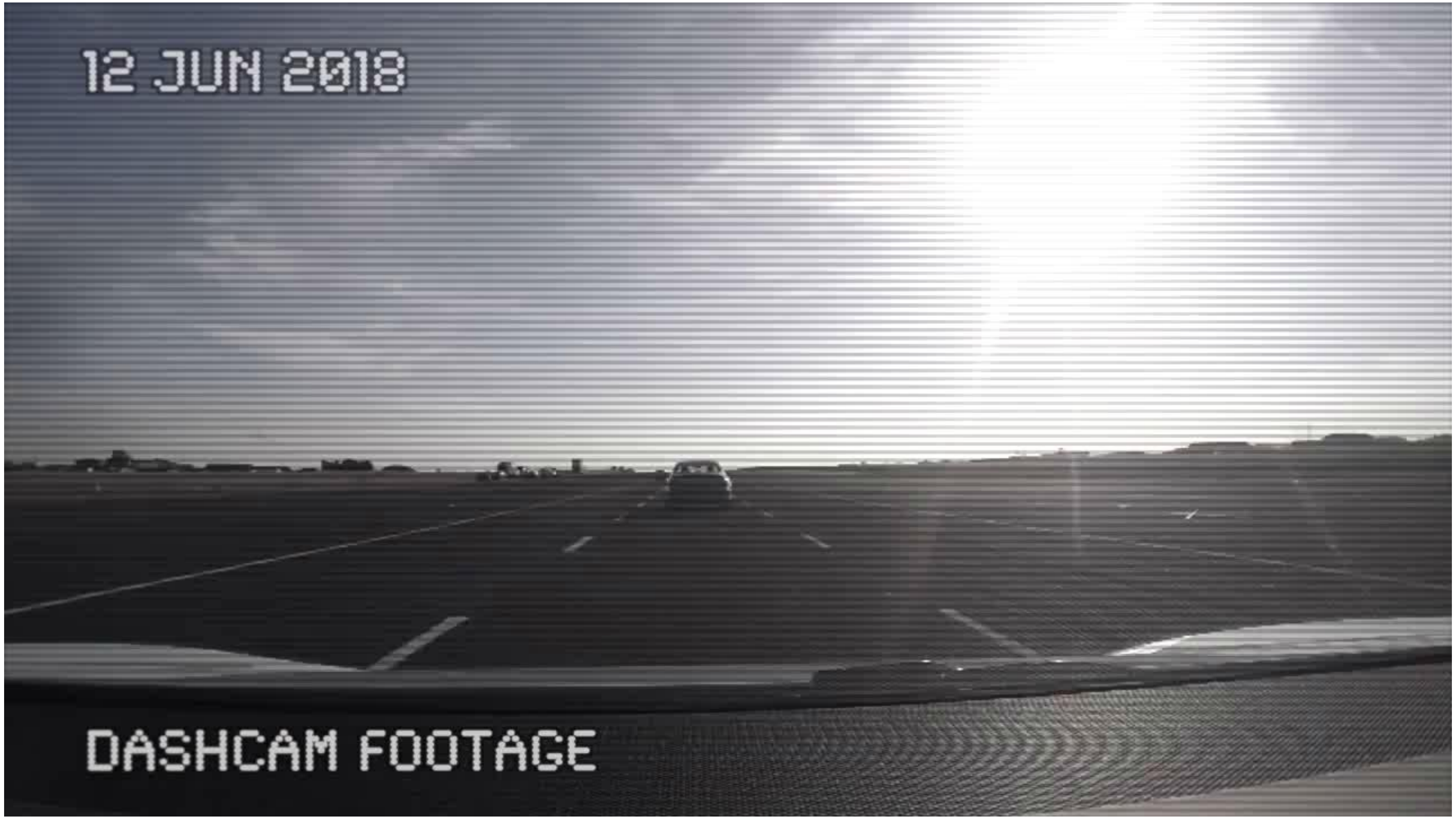
Agenda

1. Introduction
2. How to combine Machine Learning and ISO 26262?
3. Solution Approaches
4. Conclusion and Outlook

Agenda

1. Introduction
    1. What is safety?
    2. Functional Safety
    3. ISO26262
    4. ASIL
    5. Changes from first to second edition
2. How to combine machine learning and ISO 26262?
3. How to move on from here?
4. Conclusion and Outlook

How to prove that it is safe?



Source: Source: https://www.thatcham.org/

Safety of technical systems

- What is safety?

Safety: „Absence of unreasonable risk“
[ISO26262]

- Risk must be below a certain limit

“Risk: combination of the probability of occurrence of harm and the severity of that harm” [ISO26262]

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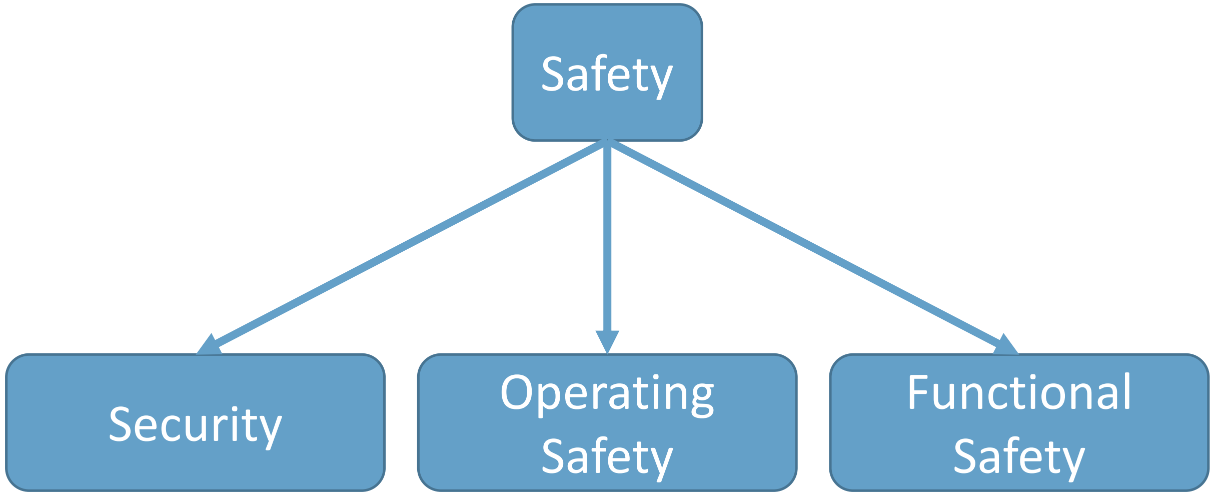

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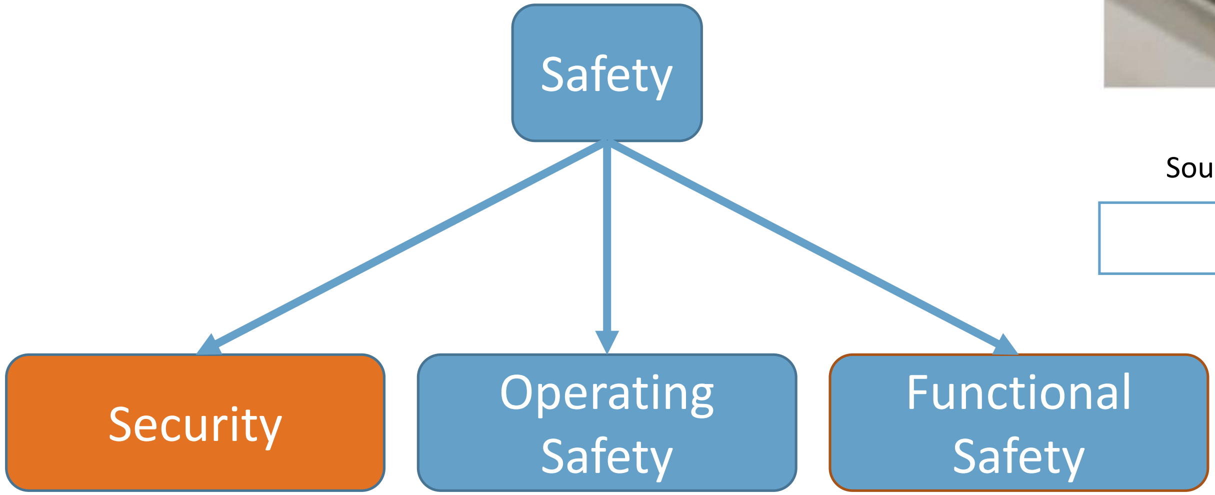

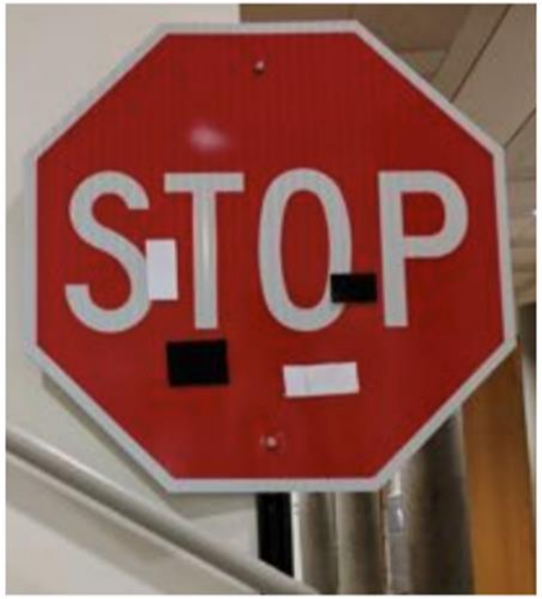

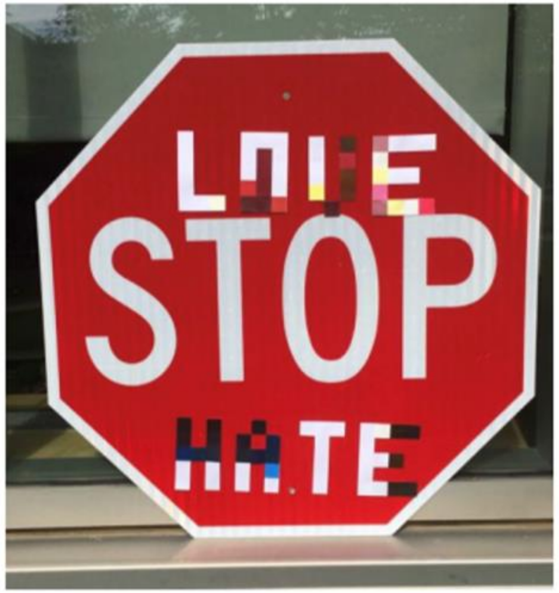

Source: Lecture Advanced Deep Learning for Robotics, Bäuml, SS18, TUM

Adversarial Example

Safety of technical systems

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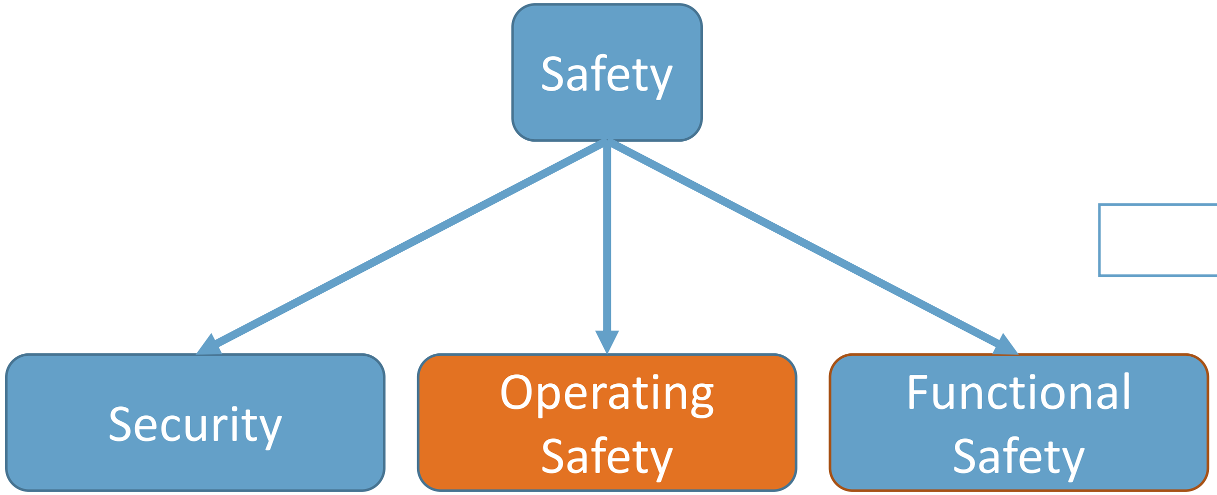

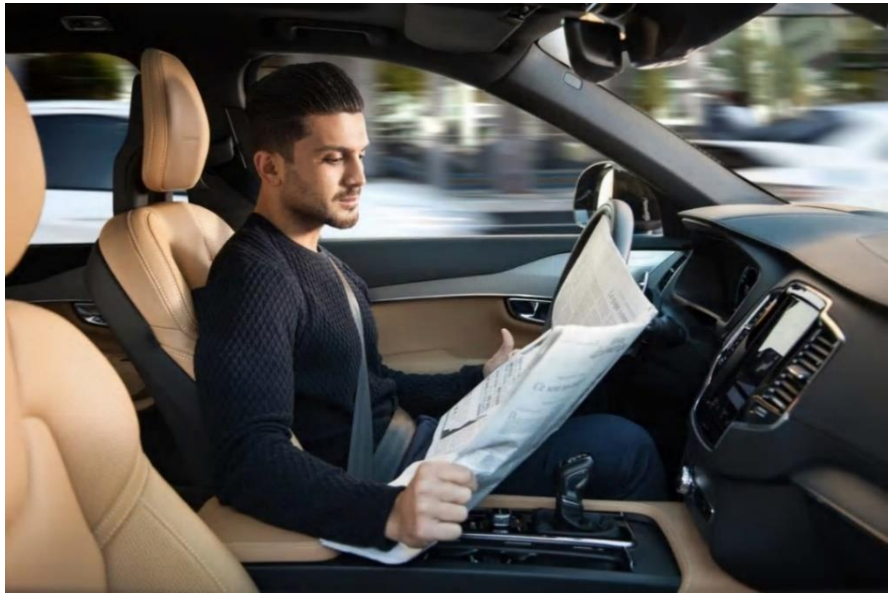

Source: https://inews.co.uk/essentials/lifestyle/cars/car-news/drivers-doubt-future-autonomous-cars/

Example for Misuse of a level 2 car.

Safety of technical systems

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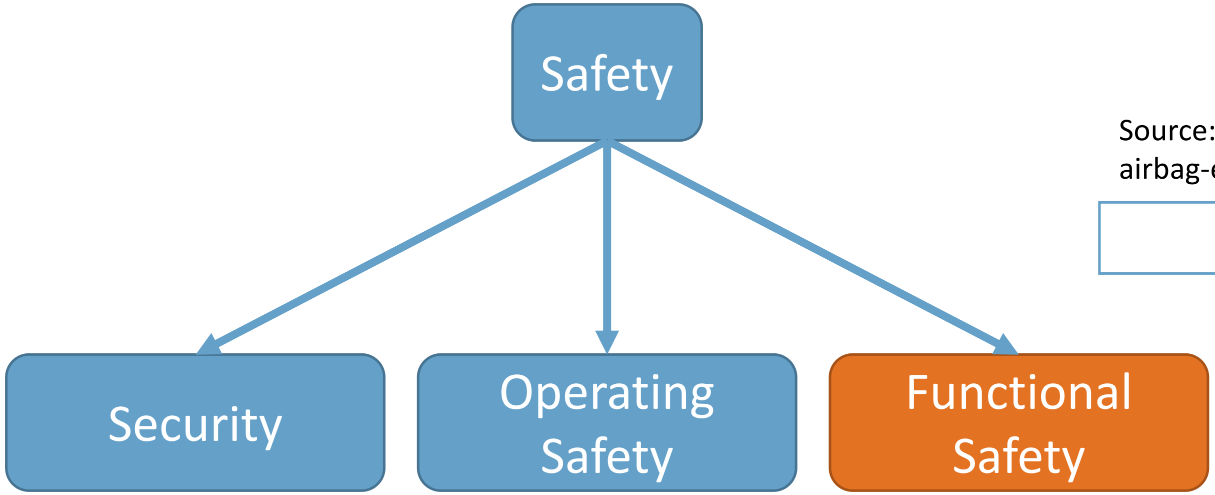


Safety

Security

Operating Safety

Functional Safety

Source: Giddens Family - https://dfw.cbslocal.com/2016/05/18/arlington-family-sues-takata-claims-airbag-endangered-their-teen/

Failed Takata Airbag

Functional safety

- Potential failure of a system in different situation
- Goal:
  - show potential hazards and classify them
  - Reduction of hazards caused by E/E systems
- Outcome:
  - safety integrity level SIL/ASIL
  - Definition of processes and countermeasure to prevent failures
  - Regulated by standards

Functional safety (ISO 26262)

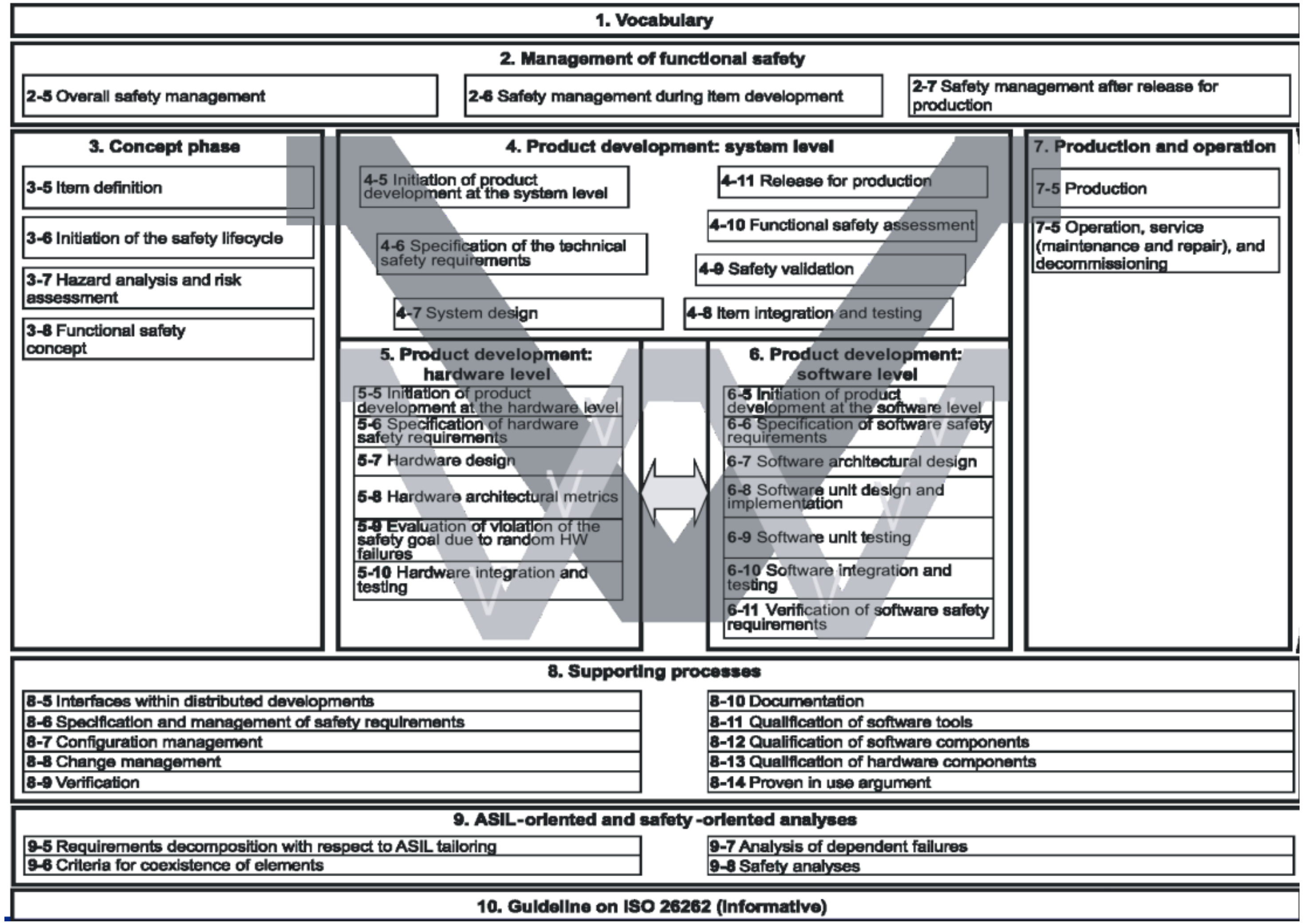
- Functional Safety: “absence of unreasonable risk due to hazards caused by malfunctioning behavior of E/E systems”

- ISO 26262: Road vehicles – functional safety
  - International standard
  - Scope: functional safety of E/E components in series production vehicles up to a mass of 3.5tons
  - Specialization of the IEC 61508 for the automotive sector: Functional Safety of Electrical/Electronic/Programmable Electronic Safety Related Systems

Relevant for all advanced driver assistance systems (ADAS)

[ISO26262, 2011]

ISO26262



1. Vocabulary

2. Management of functional safety

2-5 Overall safety management

2-6 Safety management during item development

2-7 Safety management after release for production

3. Concept phase

3-5 Item definition

3-6 Initiation of the safety lifecycle

3-7 Hazard analysis and risk assessment

3-8 Functional safety concept

4. Product development: system level

4-5 Initiation of product development at the system level

4-6 Specification of the technical safety requirements

4-7 System design

4-8 Item integration and testing

4-9 Safety validation

4-10 Functional safety assessment

4-11 Release for production

5. Product development: hardware level

5-5 Initiation of product development at the hardware level

5-6 Specification of hardware safety requirements

5-7 Hardware design

5-8 Hardware architectural metrics

5-9 Evaluation of violation of the safety goal due to random HW failures

5-10 Hardware integration and testing

6. Product development: software level

6-5 Initiation of product development at the software level

6-6 Specification of software safety requirements

6-7 Software architectural design

6-8 Software unit design and implementation

6-9 Software unit testing

6-10 Software integration and testing

6-11 Verification of software safety requirements

7. Production and operation

7-5 Production

7-5 Operation, service (maintenance and repair), and decommissioning

8. Supporting processes

8-5 Interfaces within distributed developments

8-6 Specification and management of safety requirements

8-7 Configuration management

8-8 Change management

8-9 Verification

8-10 Documentation

8-11 Qualification of software tools

8-12 Qualification of software components

8-13 Qualification of hardware components

8-14 Proven in use argument

9. ASIL-oriented and safety-oriented analyses

9-5 Requirements decomposition with respect to ASIL tailoring

9-6 Criteria for coexistence of elements

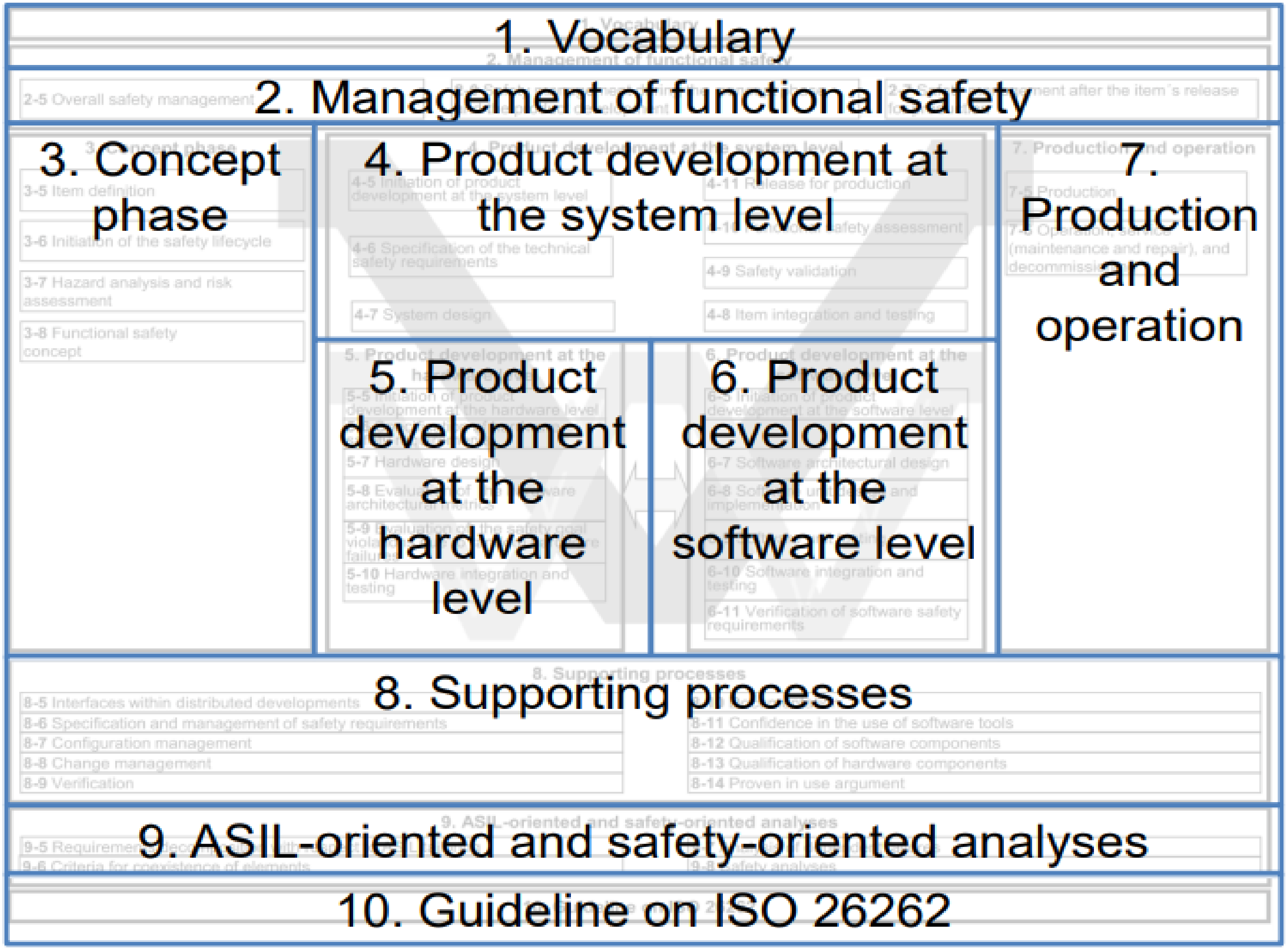
9-7 Analysis of dependent failures

9-8 Safety analyses

10. Guideline on ISO 26262 (informative)

Source: ISO26262

ISO26262



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4. Product development at the system level

5. Product development at the hardware level

6. Product development at the software level

7. Production and operation

8. Supporting processes

9. ASIL-oriented and safety-oriented analyses

10. Guideline on ISO 26262

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7. Production and operation
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5-7 Hardware design
5-10 Hardware integration and testing
6-7 Software architectural design
6-10 Software integration and testing
6-11 Verification of software safety requirements
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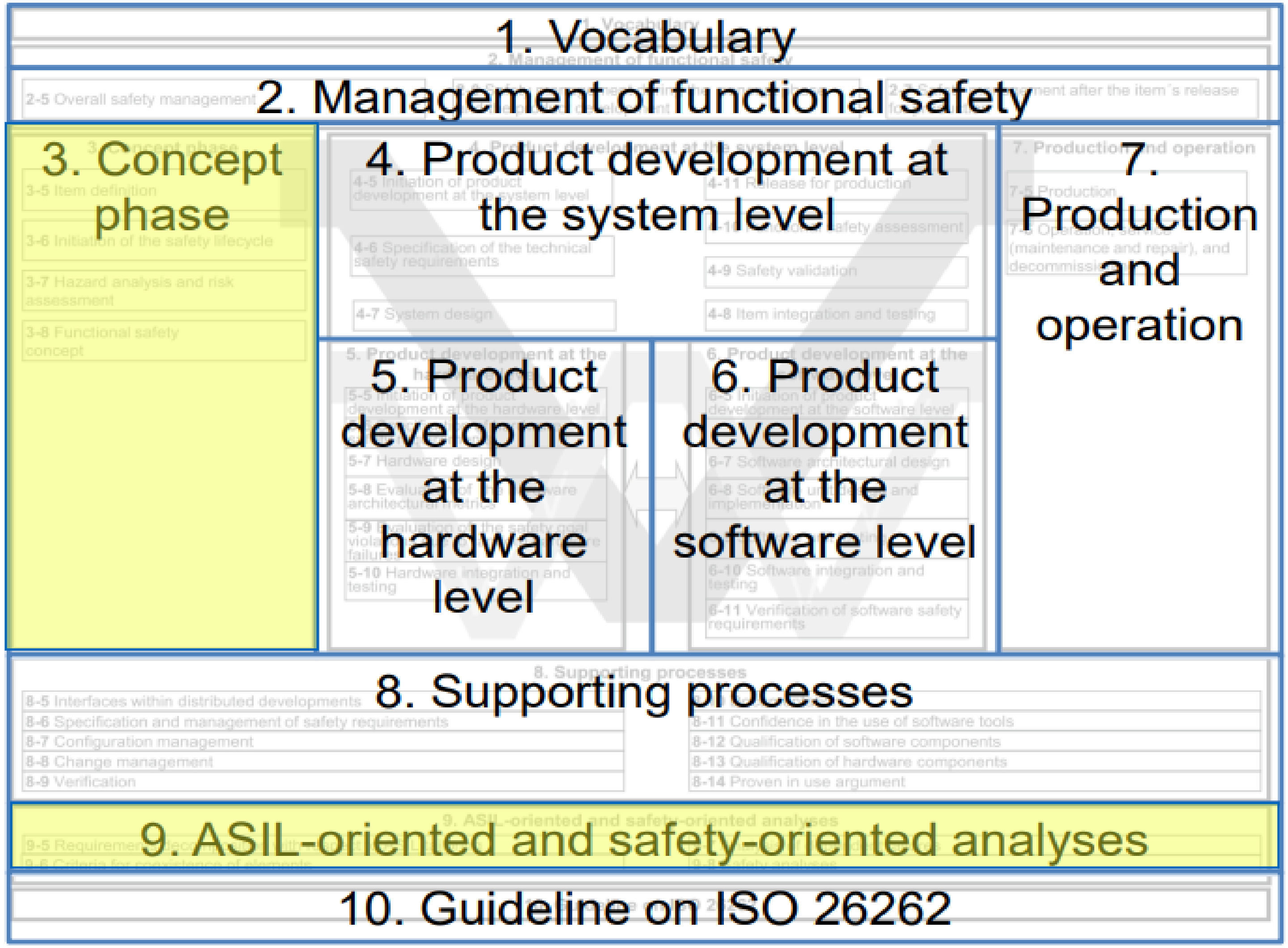
8-6 Specification and management of safety requirements
8-7 Configuration management
8-8 Change management
8-9 Verification
8-11 Confidence in the use of software tools
8-12 Qualification of software components
8-13 Qualification of hardware components
8-14 Proven in use argument
9. ASIL-oriented and safety-oriented analyses
9-6 Criteria for coexistence of elements

Source: Lecture Fahrerassistenzsysteme, Prof. Lienkamp, WS17, TUM

ISO26262



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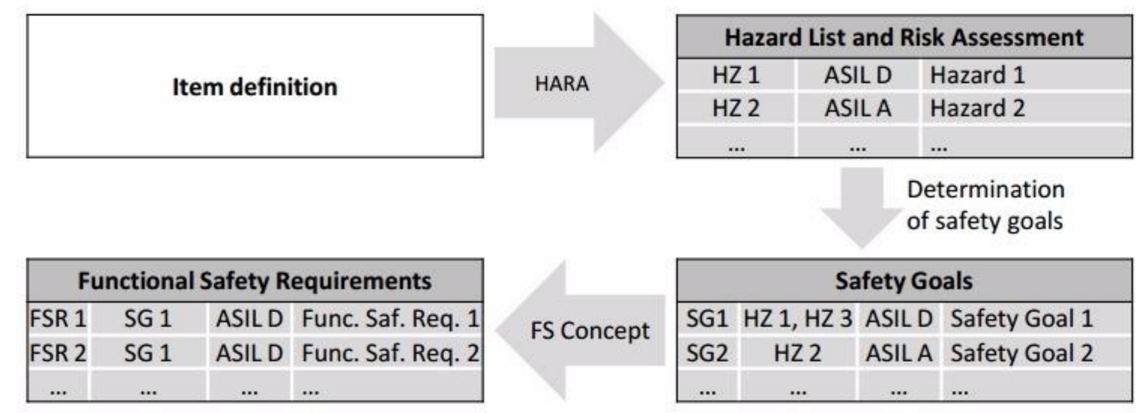
Source: Lecture Fahrerassistenzsysteme, Prof. Lienkamp, WS17, TUM

ISO26262 - HARA

Hazard and Risk Analysis with ISO26262:

1. Item Definition
2. Situation analysis
3. Hazard identification
4. Classification of hazardous events
5. Determination of ASIL
6. Determination of safety goals



Hazard List and Risk Assessment

HZ 1	ASIL D	Hazard 1
HZ 2	ASIL A	Hazard 2
...	...	...

Safety Goals

SG1	HZ 1, HZ 3	ASIL D	Safety Goal 1
SG2	HZ 2	ASIL A	Safety Goal 2
...	...	...	...

Functional Safety Requirements

FSR 1	SG 1	ASIL D	Func. Saf. Req. 1
FSR 2	SG 1	ASIL D	Func. Saf. Req. 2
...	...	...	...

Source: Henriksson et al., 2018

[ISO26262, 2011]   [Henriksson et al., 2018]

ISO26262 - HARA

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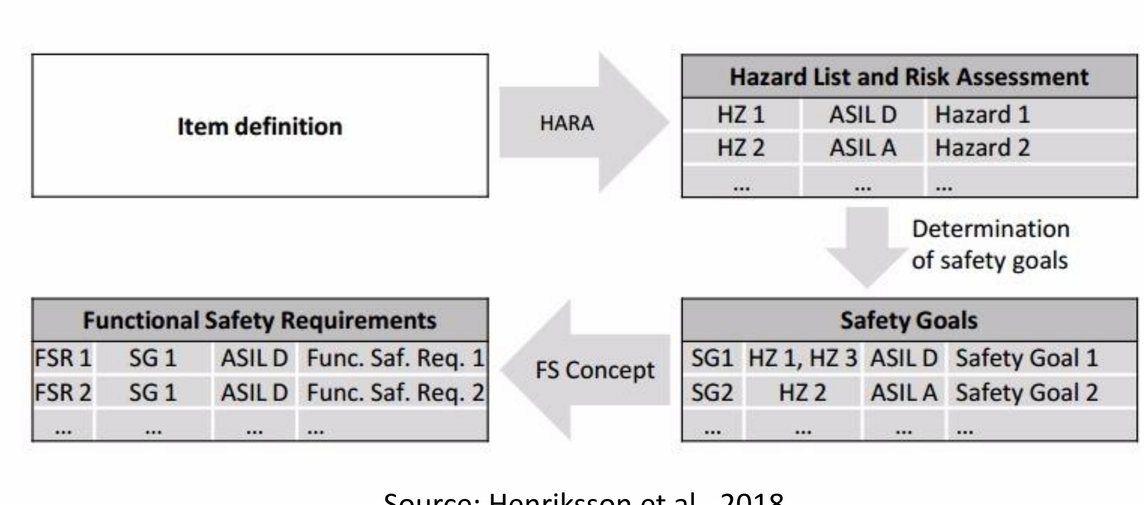


Item definition

HARA

Hazard List and Risk Assessment

HZ 1	ASIL D	Hazard 1
HZ 2	ASIL A	Hazard 2
...	...	...

Determination of safety goals

Safety Goals

SG1	HZ 1, HZ 3	ASIL D	Safety Goal 1
SG2	HZ 2	ASIL A	Safety Goal 2
...	...	...	...

FS Concept

Functional Safety Requirements

FSR 1	SG 1	ASIL D	Func. Saf. Req. 1
FSR 2	SG 1	ASIL D	Func. Saf. Req. 2
...	...	...	...

Source: Henriksson et al., 2018

[ISO26262, 2011] [Henriksson et al., 2018]

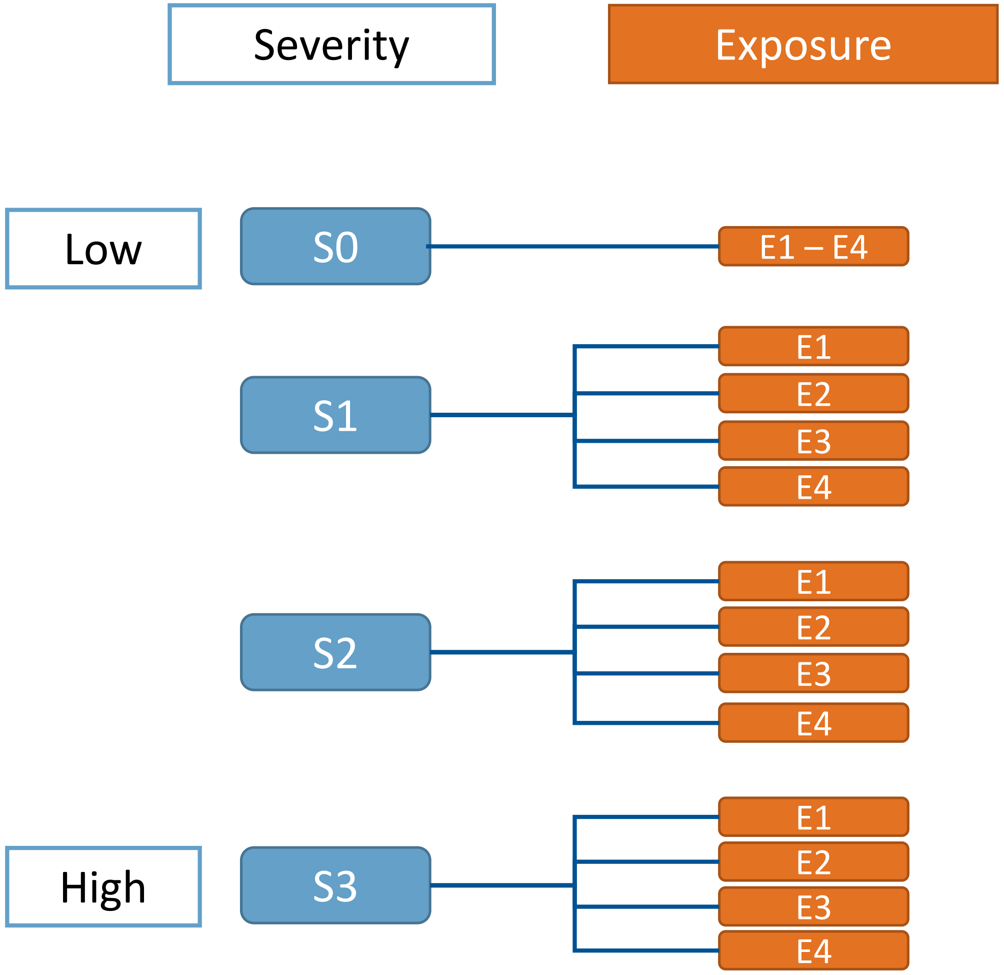
ASIL Level

Severity

Low	S0	S0 No injuries
	S1	S1 Light to moderate injuries
	S2	S2 Severe to life-threatening (survival probable) injuries
High	S3	S3 Life threatening (survival uncertain) to fatal injuries

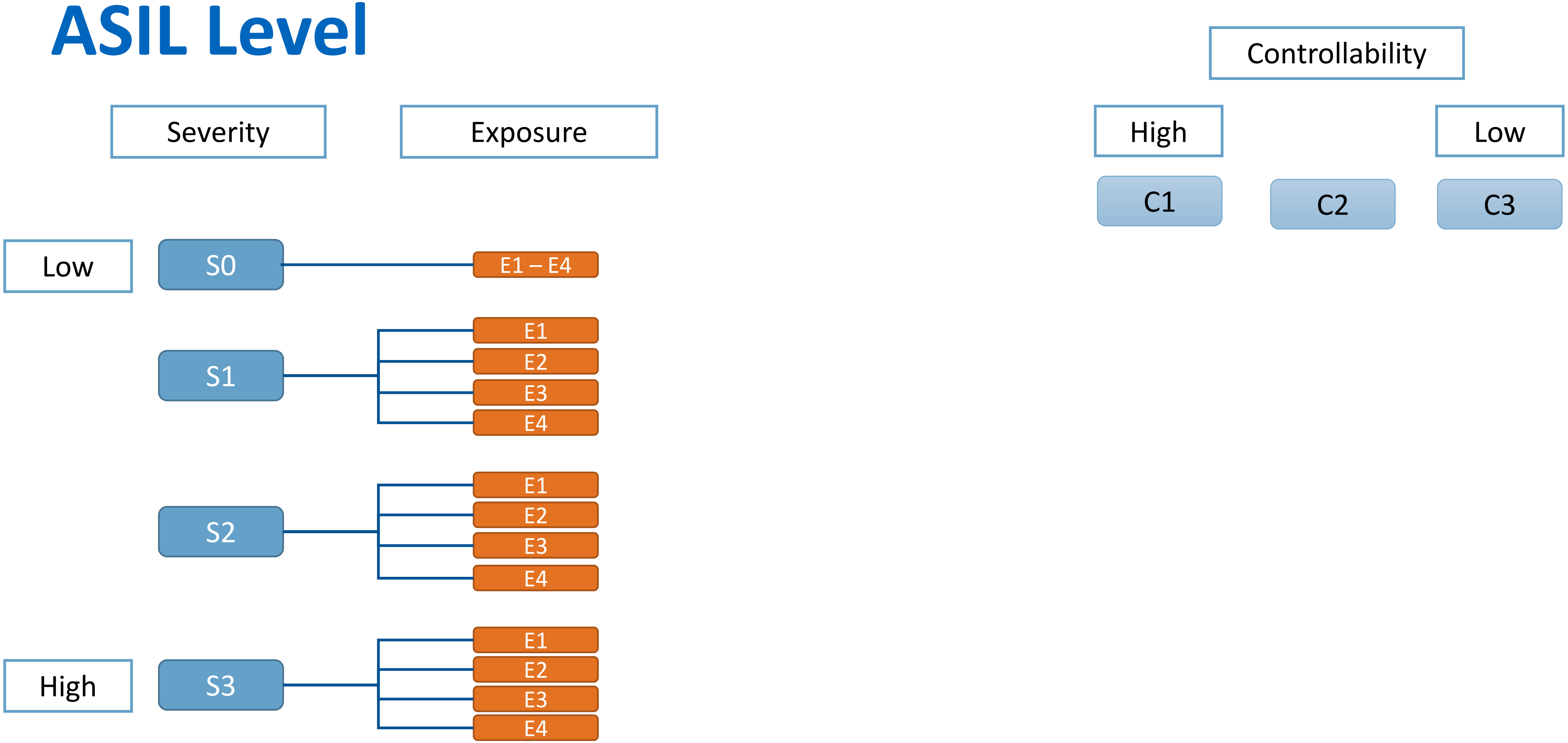
[ISO26262, 2011]

ASIL Level



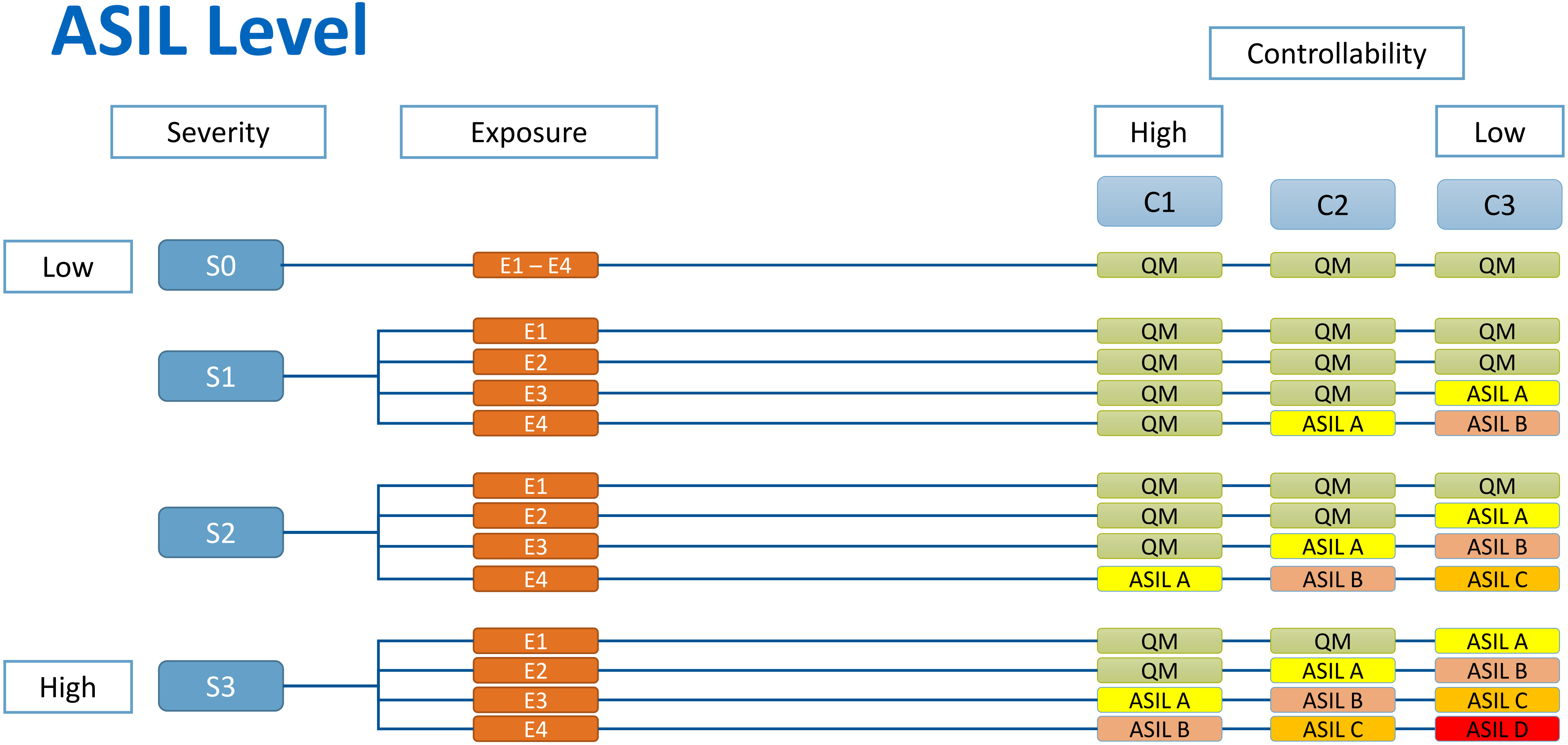
[ISO26262, 2011]

ASIL Level



[ISO26262, 2011]

ASIL Level



	Severity	Exposure	Controllability		
			High		Low
			C1	C2	C3
Low	S0	E1 – E4	QM	QM	QM
	S1	E1	QM	QM	QM
		E2	QM	QM	QM
		E3	QM	QM	ASIL A
		E4	QM	ASIL A	ASIL B
	S2	E1	QM	QM	QM
		E2	QM	QM	ASIL A
		E3	QM	ASIL A	ASIL B
		E4	ASIL A	ASIL B	ASIL C
High	S3	E1	QM	QM	ASIL A
		E2	QM	ASIL A	ASIL B
		E3	ASIL A	ASIL B	ASIL C
		E4	ASIL B	ASIL C	ASIL D

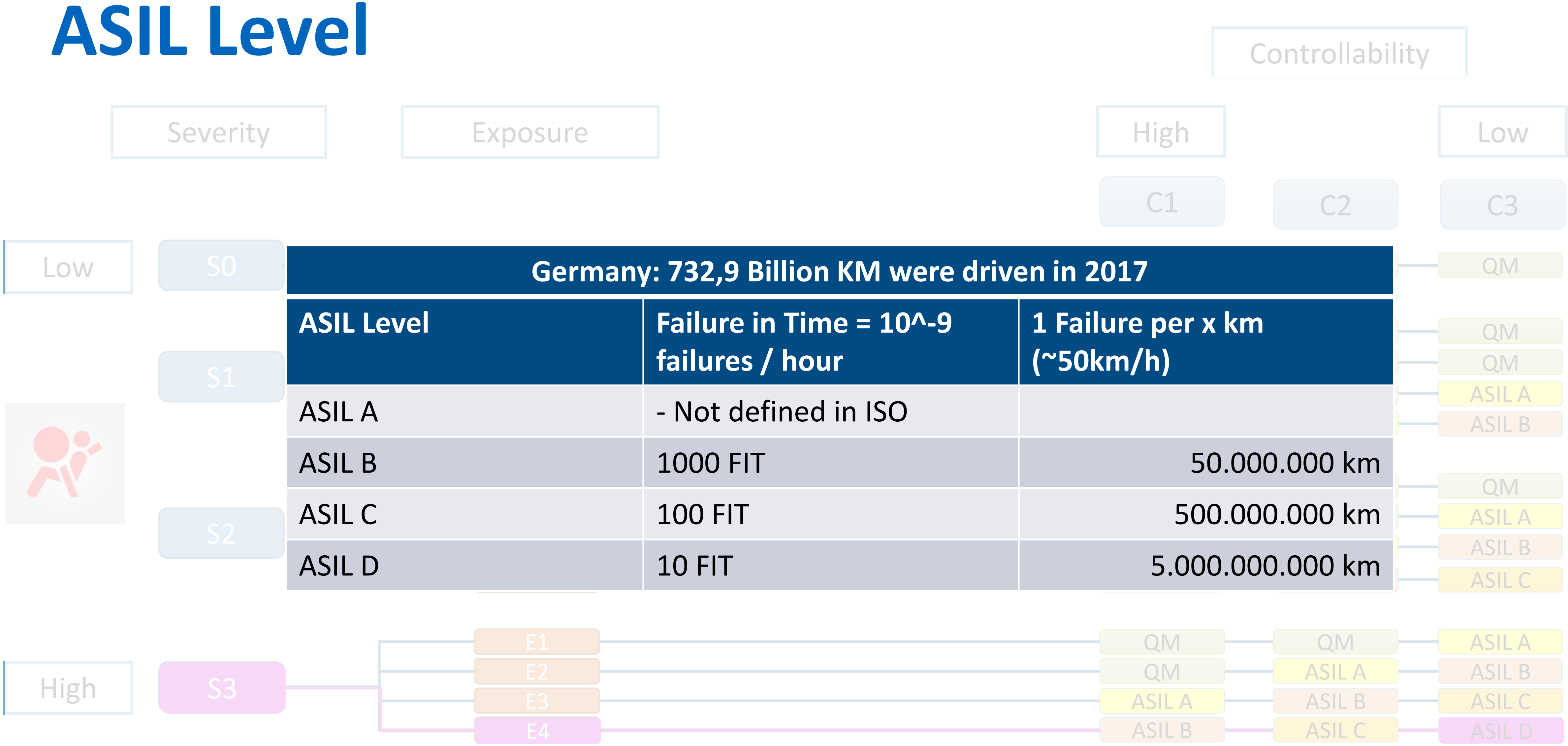
[ISO26262, 2011]

ASIL Level

			Controllability		
	Severity	Exposure	High		Low
			C1	C2	C3
Low	S0	E1 – E4	QM	QM	QM
	S1	E1	QM	QM	QM
		E2	QM	QM	QM
		E3	QM	QM	ASIL A
		E4	QM	ASIL A	ASIL B
	S2	E1	QM	QM	QM
		E2	QM	QM	ASIL A
		E3	QM	ASIL A	ASIL B
		E4	ASIL A	ASIL B	ASIL C
High	S3	E1	QM	QM	ASIL A
		E2	QM	ASIL A	ASIL B
		E3	ASIL A	ASIL B	ASIL C
		E4	ASIL B	ASIL C	ASIL D

[ISO26262, 2011]

ASIL Level



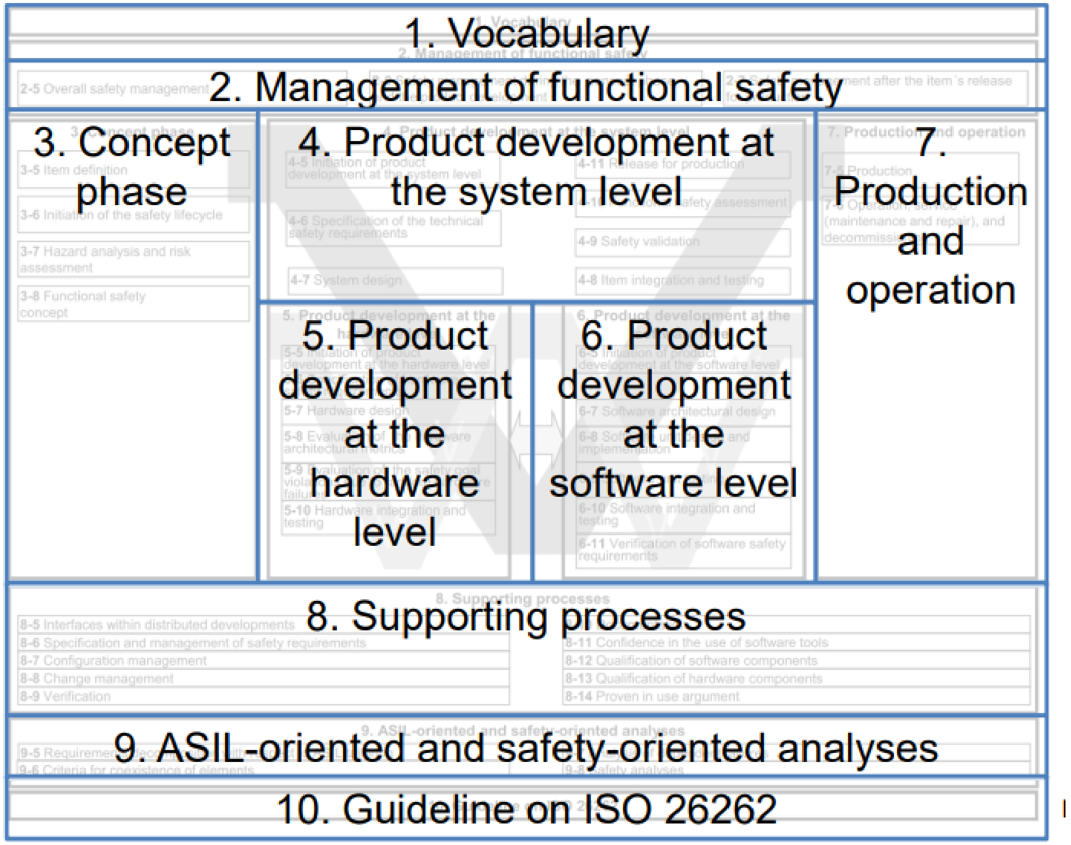
Germany: 732,9 Billion KM were driven in 2017		
ASIL Level	**Failure in Time = 10^-9 failures / hour**	**1 Failure per x km (~50km/h)**
ASIL A	- Not defined in ISO	
ASIL B	1000 FIT	50.000.000 km
ASIL C	100 FIT	500.000.000 km
ASIL D	10 FIT	5.000.000.000 km

https://www.kba.de/DE/Statistik/Kraftverkehr/VerkehrKilometer/verkehr_in_kilometern_node.html

[ISO26262, 2011]

Changes to 2nd edition

1st Edition (2011)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Source: Lecture Fahrerassistenzsysteme, Prof. Lienkamp, WS17, TUM

2nd Edition (2018)

- Removal of 3.5t weight limit
- New part 11 on semi conductors
- Guidelines on the application of ISO 26262 to semiconductors
- New qualification methods for ASIL
- Updates to the PMHF (Probabilistic Metric for Hardware Failure) equation and verification of safety analysis
- → No changes regarding ML

[Schloeffel and Dailey,]

Agenda

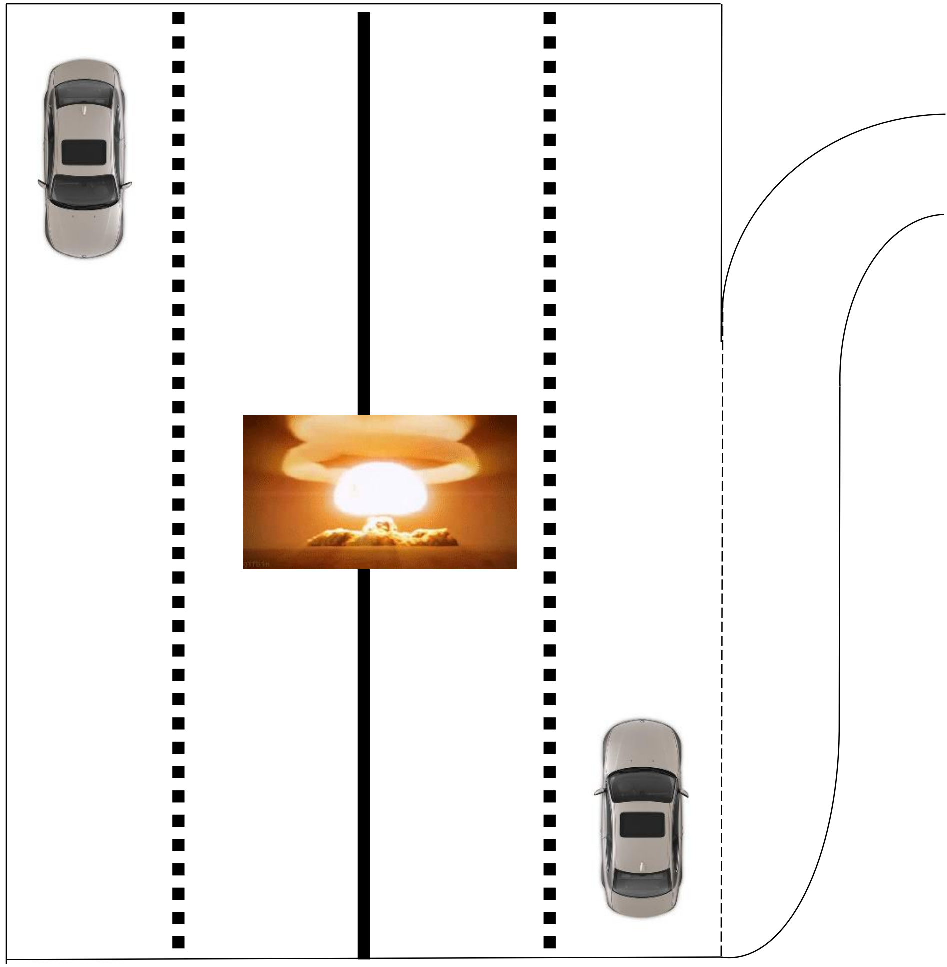
1. Introduction
2. How to combine Machine Learning and ISO 26262?
   1. What is safe in regards to AD?
   2. Possible Applications of ISO26262 to ML
   3. Conflicts between ISO26262 and ML
3. How to move on from here?
4. Conclusion and Outlook

What is safe in regards to AD?

- What is “safe enough” for AD ?
  - No accidents at all (“Absence of unreasonable risk…”)
  - (significant) higher safety than today (lower accident rate)

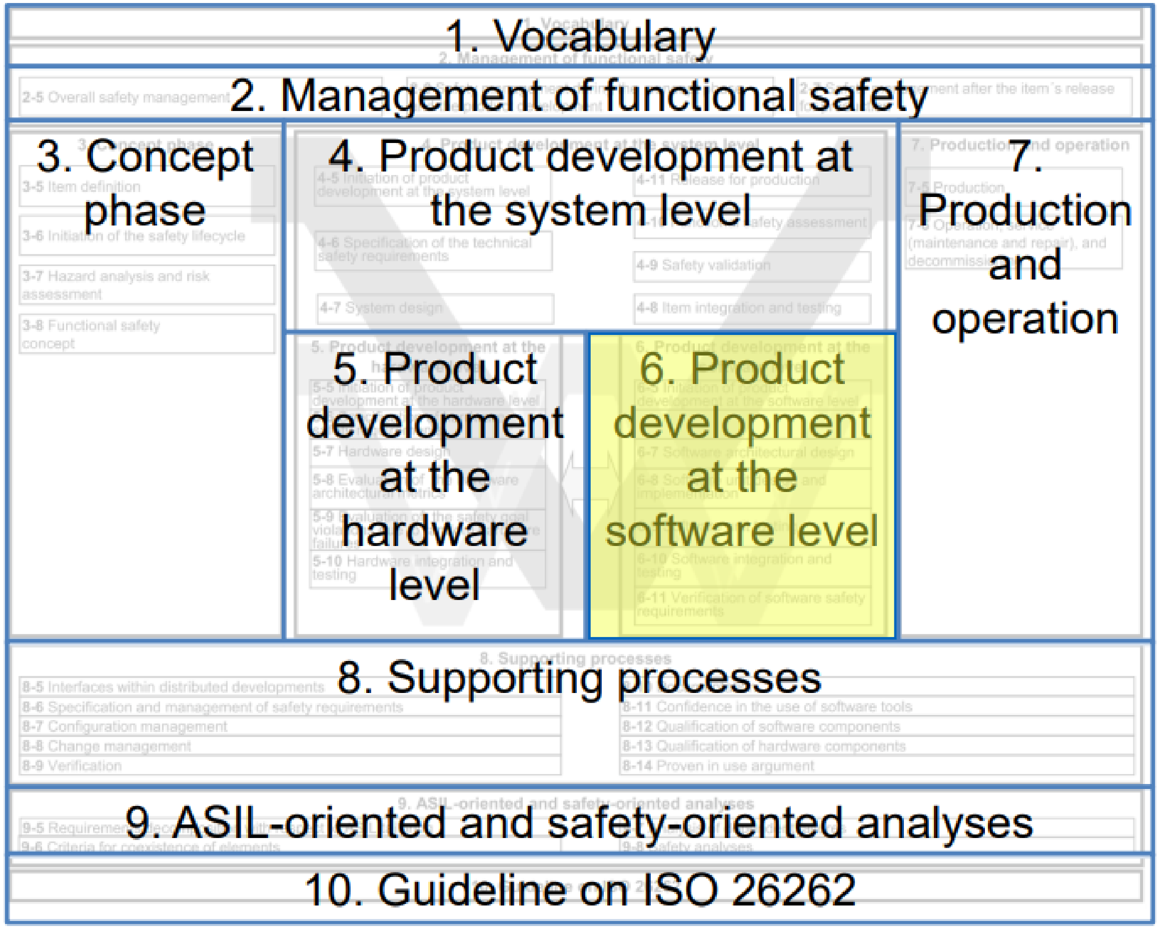
- 5 billion test miles necessary for real-world verification
  - How do we define test cases (border cases)?
  - What is correct behaviour in tests ?

[Bates, 2017] [Dailey, 2018]



Source: https://giphy.com/gifs/XDLJpjzyw76Sc / EVOX Images

Possible Applications of ISO26262 to ML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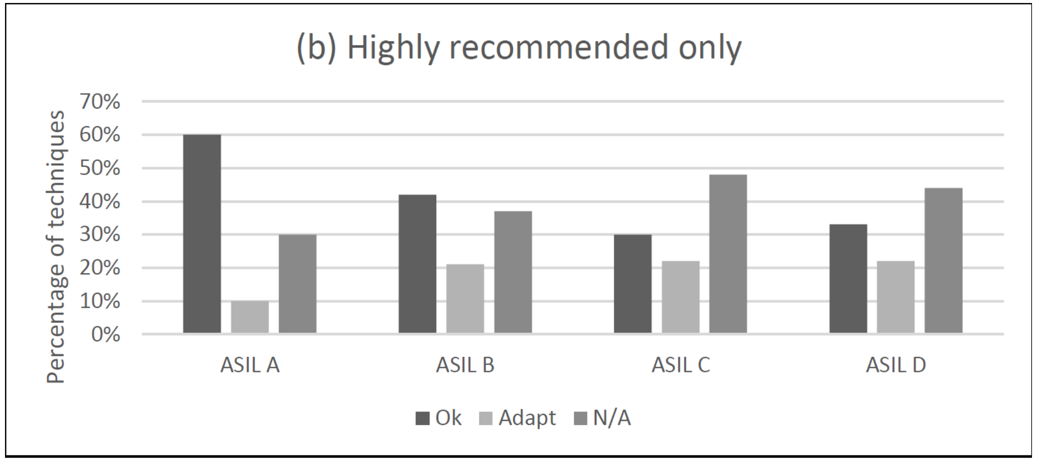
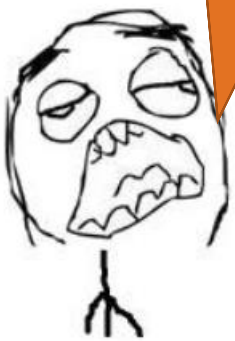
Source: Lecture Fahrerassistenzsysteme, Prof. Lienkamp, WS17, TUM

- 34 of 75 ISO SW-Develpoment techniques at unit level
- black box techniques are “ok”
- “walk through” can be “adapted”
- Code oriented / white box techniques can not be used

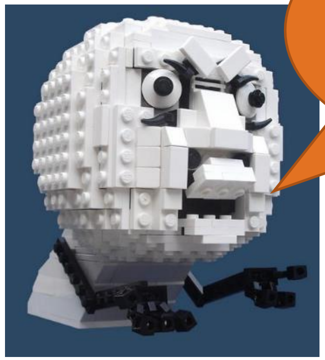


[Salay et al., 2017]

What about incomplete training sets?



What about new types of hazards?



Which SW techniques to use?

Source: https://memegenerator.net/instance/74873992/salt-bae-let-me-sprinkle-some-deep-learning-magic, http://knowyourmeme.com/memes/all-the-things, https://c1.staticflickr.com/1/264/19718083479_d6589c5404_b.jpg, http://www.relatably.com/m/img/meme-center-american-dad/american-dad_o_721757.jpg

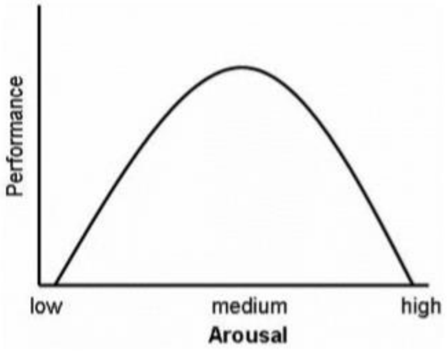
Conflicts

- Identifying hazards
- Fault and failure modes
- The use of training sets
- The level of ML usage
- Required software techniques

[Salay et al., 2017]

Conflicts

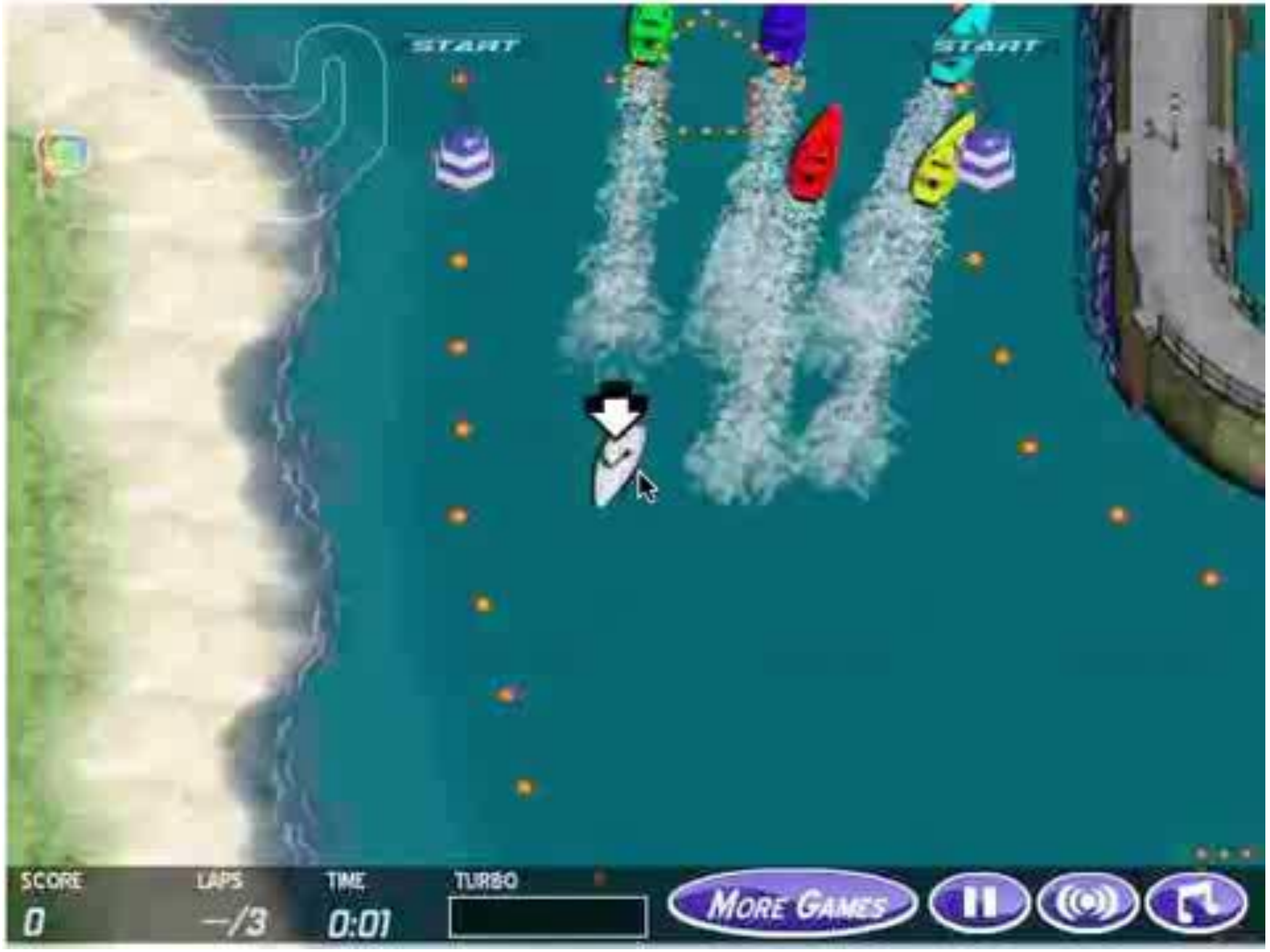
- Identifying hazards
  - ML can create new types of hazards
  - Complex behavioral interactions between humans and ML
    - Overestimation of the ML performance
    - Human has not the optimal level of employment
    - Reduced human skill level and situation awareness
  - RL plays with the reward function or has unintended behavior through wrong reward function
- Fault and failure modes
- The use of training sets
- The level of ML usage
- Required software techniques



Yerkes-Dodson-Law (1908):
Source: Lecture Fahrerassistenzsysteme, Prof. Lienkamp, WS17, TUM

[Salay et al., 2017]

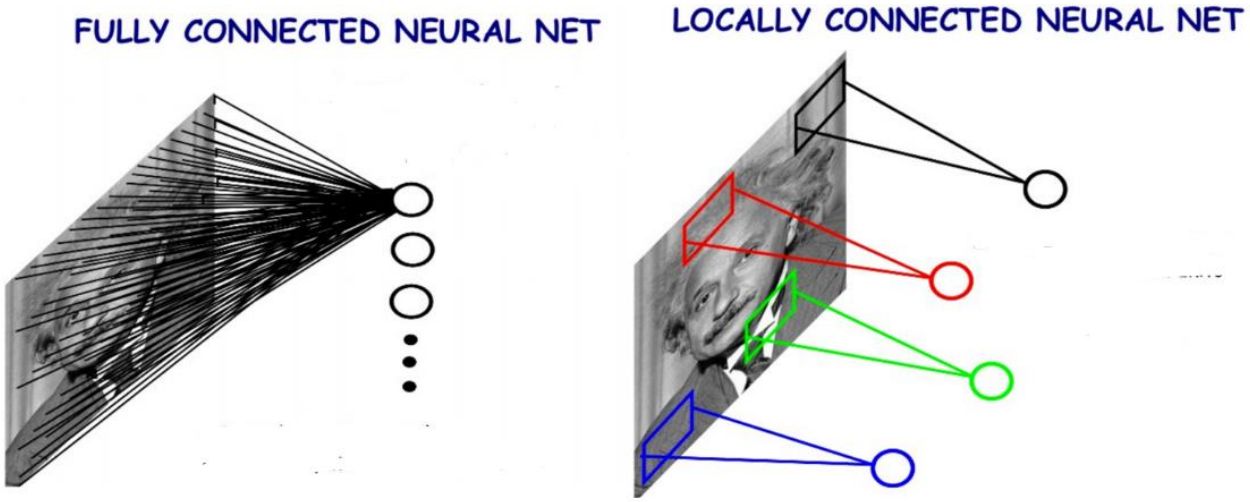
RL plays with the reward function



Source: https://blog.openai.com/faulty-reward-functions/

Conflicts

- Identifying hazards
- Fault and failure modes
  - Specific fault types and failure modes for ML
    - Network topology
    - Learning algorithm
    - Training set
- The use of training sets
- The level of ML usage
- Required software techniques



Source: https://leonardoaraujosantos.gitbooks.io/artificial-inteligence/content/convolutional_neural_networks.html

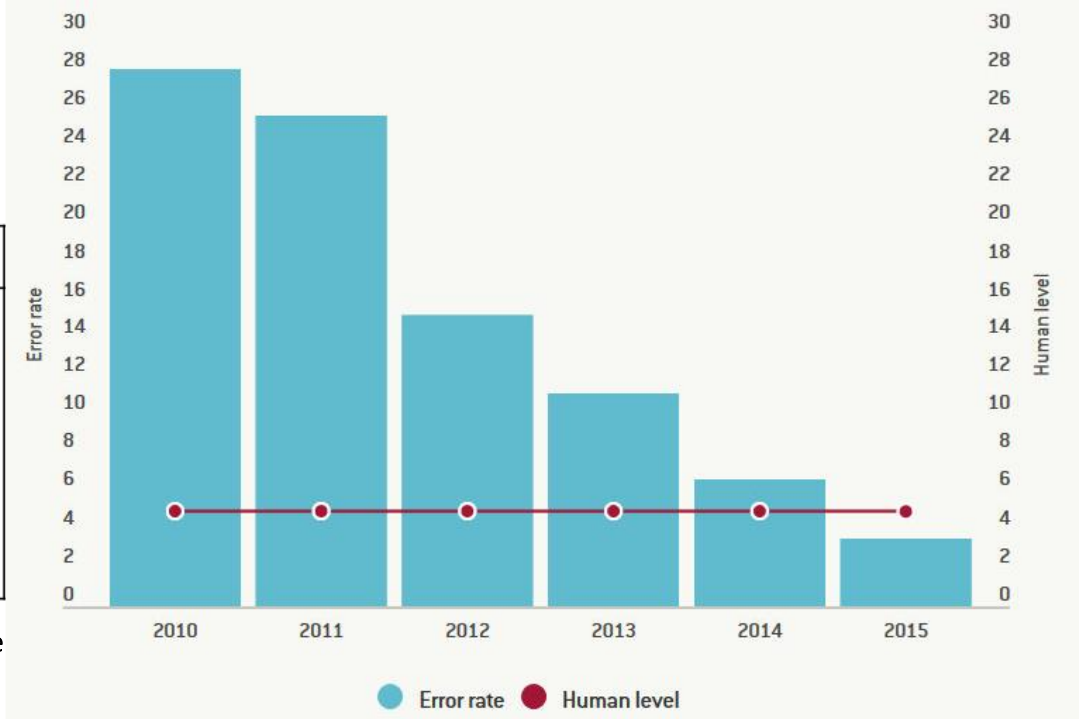
[Salay et al., 2017]

Conflicts

- Identifying hazards
- Fault and failure modes
- The use of training sets
  - Inherently incomplete data sets
  - Correct by construction with respect to the training set
  - Unspecifiable functionality (like perception)
- The level of ML usage
- Required software techniques

#	h?
1	
2	
3	
4	
5	

Source niversity

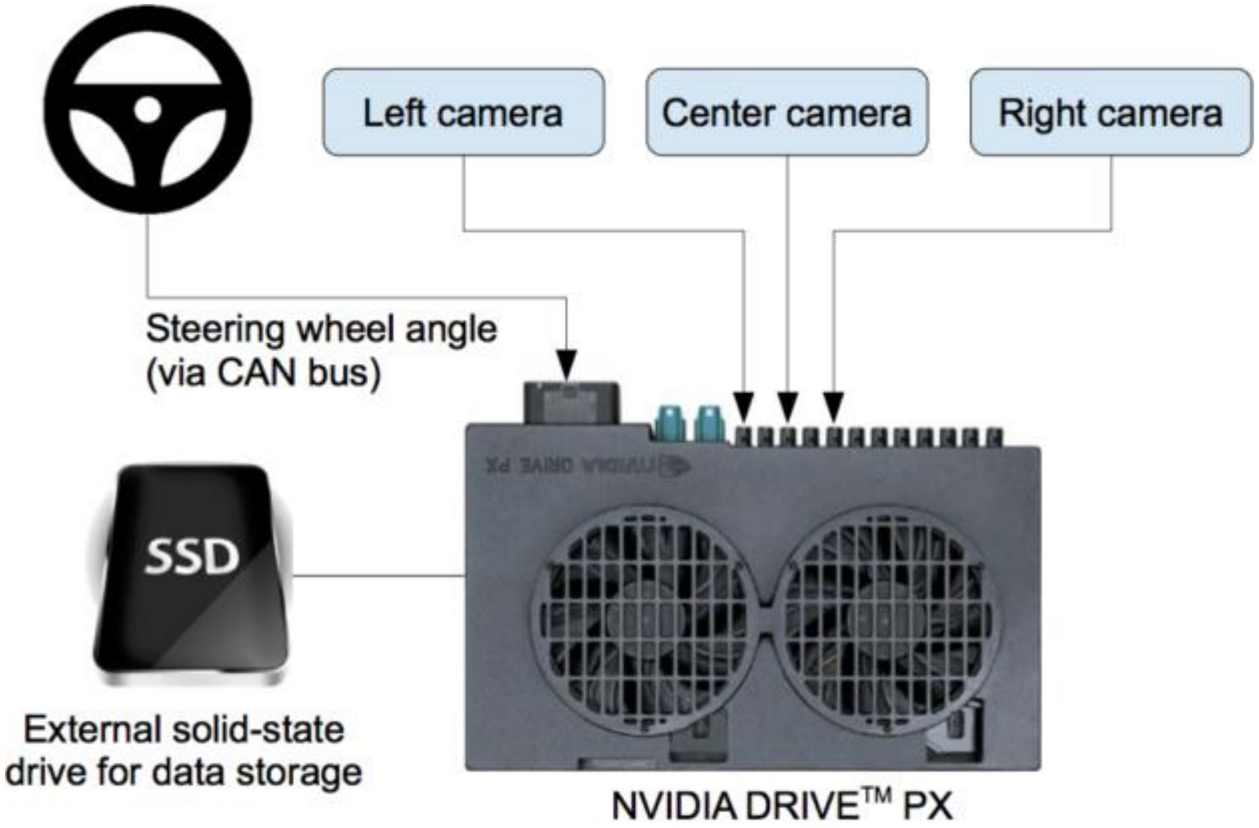


Imagenet Error Rates, Source: https://c1.staticflickr.com/5/4162/33621365014_fe35be452a_b.jpg

[Salay et al., 2017]

Conflicts

- Identifying hazards
- Fault and failure modes
- The use of training sets
- The level of ML usage
  - End-to-end learning is critical
  - Lack of transparency of ML components
- Required software techniques

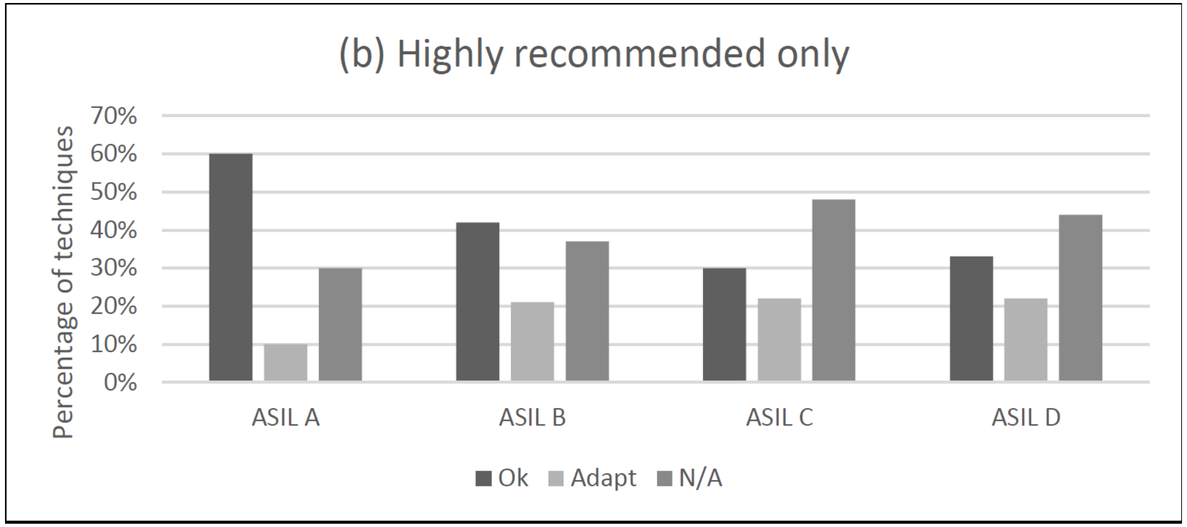


Source: https://devblogs.nvidia.com/deep-learning-self-driving-cars/

[Salay et al., 2017]

Conflicts

- Identifying hazards
- Fault and failure modes
- The use of training sets
- The level of ML usage
- Required software techniques
  - Assumption that code is implemented using an imperative programming language
  - Difficult to use with ML, but also with Functional or logic programming, etc.



Source: Salay et al., 2017

[Salay et al., 2017]

Agenda

1. Introduction
2. How to combine Machine Learning and ISO 26262?
3. How to move on from here?
    1. Recommendations for applying ISO26262 to ML
    2. Usage of a new standard
        1. Pegasus
        2. SOTIF
    3. Radical new approach
4. Conclusion and Outlook

Recommendations for applying ISO26262 to ML

Changes to ISO26262

- Consider ML specific hazards

How to use ML

[Varshney, 2016] [Salay et al., 2017]

Recommendations for applying ISO26262 to ML

Changes to ISO26262

- Consider ML specific hazards
- ML Lifecycle techniques

How to use ML

[Varshney, 2016] [Salay et al., 2017]

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- Modular ML usage

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- Modular ML usage
- Human interpretable models

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- Modular ML usage
- Human interpretable models
- Safety Reserves

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- Reject option

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- Partial specifiable functionality
- Fault tolerance strategies for software
- Intent based SW requirements

How to use ML

- Modular ML usage
- Human interpretable models
- Safety Reserves
- Reject option
- Open Source / Data

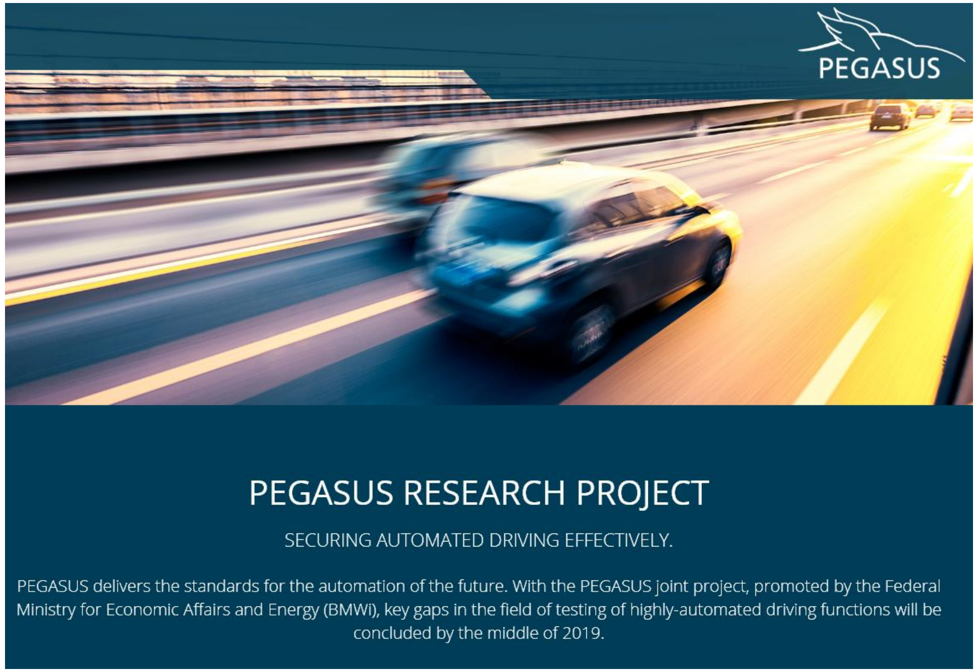
https://www.123rf.com/stock-photo/hands_reaching_out.html [Varshney, 2016] [Salay et al., 2017]

Usage of an new standard

- ⊕ No constraints of old standard with old software paradigms
- ⊕ Everything could be rethought and fitted to ML
- ⊕ E.g. open source norm (maintained by a group of e.g. Automotive developers)

- ⊖ Using a new standard correlates with retraining the companies employees
- ⊖ Difficult to make it a standard

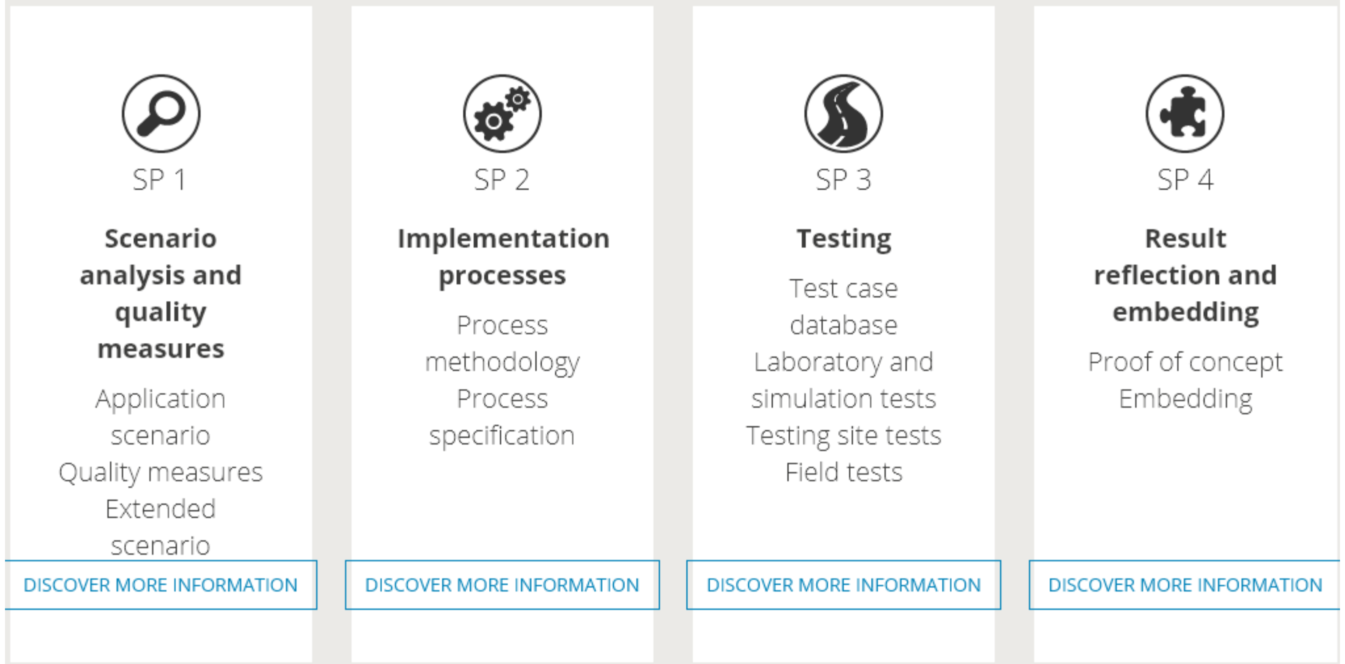
Pegasus



PEGASUS RESEARCH PROJECT

SECURING AUTOMATED DRIVING EFFECTIVELY.

PEGASUS delivers the standards for the automation of the future. With the PEGASUS joint project, promoted by the Federal Ministry for Economic Affairs and Energy (BMWi), key gaps in the field of testing of highly-automated driving functions will be concluded by the middle of 2019.



SP 1

Scenario analysis and quality measures

Application scenario
Quality measures
Extended scenario

DISCOVER MORE INFORMATION

SP 2

Implementation processes

Process methodology
Process specification

DISCOVER MORE INFORMATION

SP 3

Testing

Test case database
Laboratory and simulation tests
Testing site tests
Field tests

DISCOVER MORE INFORMATION

SP 4

Result reflection and embedding

Proof of concept
Embedding

DISCOVER MORE INFORMATION

BOSCH Technik fürs Leben   Continental

Source: https://www.pegasusprojekt.de/en/

Fundet by the german goverment (BMWi) for developing automated driving standards

SOTIF (Safety Of The Intended Functionality) – not yet released

- Will provide guidelines for Level-0, Level-1, and Level-2 autonomous drive (AD) vehicles.
- Focus on the functional safety of ADAS-related hazards caused by “normal operation” of the sensors.
- Questions to be answered by SOTIF:
  - Details on advanced concepts of the AD architecture
  - How to evaluate SOTIF hazards that are different from ISO 26262 hazards?
  - How to identify and evaluate scenarios and trigger events?
  - How to reduce SOTIF related risks?
  - How to verify and validate SOTIF related risks?
  - The criteria to meet before releasing an autonomous vehicle.

Radical new approach

"Wenn ein Problem von den Testfahrern festgestellt wurde, wird das anschließend behoben und das Ganze geht von vorne los. Aber wenn Sie etwas behoben haben, müssen Sie sehen, dass an einer anderen Stelle die Funktion genau funktioniert wie vorher. Das ist schon ein bisschen tricky, aber das ist eben die Pionierleistung", sagt Bereczki (Regulierungsexperte bei Audi).

Diese Aufgabe müsse jeder Hersteller für sich lösen, da es festgelegte Testszenarien dafür noch nicht gebe.

https://www.golem.de/news/automatisiertes-fahren-der-schwierige-weg-in-den-selbstfahrenden-stau-1807-135357-2.html

Translated:

‘If a problem has been identified by the test driver, it will be fixed and the whole thing will start again. But if you have fixed something, you have to see that in another place the function works exactly as before. That's a bit tricky, but that's just the pioneering work’ says Bereczki. (Regulationexpert at Audi).

Every manufacturer must solve this task for themselves, since there are not yet defined test scenarios for this.

Radical new approach

- Approach similar to Aerospace Industry
- Every failure has to be reported.
- Faults have to be investigated
- Resulting new test cases will be added
- Continuous improved test case database

→ Continuous Improvement and cooperation of Automotive industry

Source: http://www.newspakistan.pk/wp-content/uploads/2014/07/Federal-Aviation-Administration.jpg

[Bates, 2017]

Agenda

1. Introduction
2. How to combine Machine Learning and ISO 26262?
3. How to move on from here ?
4. Conclusion and Outlook

Conclusion

- ISO26262
  - ISO26262 and functional safety fit partially and with constraints to ML techniques
  - Changes on the standard are required (e.g. separation between fully and partially specified tasks)
  - The allowed usage of ML techniques will be restricted
- Other Standards
  - SOTIF: guidance for assuring that an autonomous vehicle functions and acts safely during normal operation
  - Pegasus: Close key gaps in the field of testing of highly-automated driving functions will be concluded by the middle of 2019.
- In general, ML is only applicable under constraints in safety critical (no end-to-end, safe guards,..)

  → Applicability of Reinforcement Learning even worse (more parameter like the correct reward function have to be estimated)

Outlook - Quotes from industry

- *December 2016: “We’re going to end up with complete autonomy, and I think we will have complete autonomy in approximately two years.” Elon Musk*

  https://electrek.co/2015/12/21/tesla-ceo-elon-musk-drops-prediction-full-autonomous-driving-from-3-years-to-2/

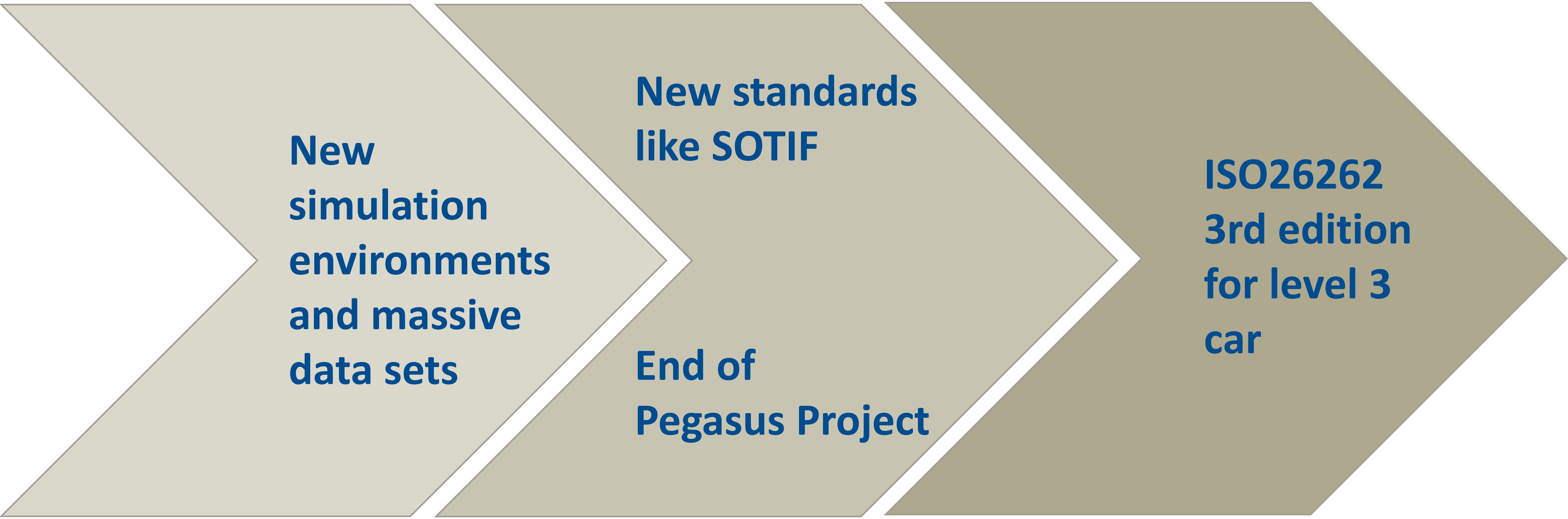
- March 2017: “*We are on the way to deliver a car in 2021 with level 3, 4 and 5*” BMW senior vice president for Autonomous Driving – Frickenstein

  Source: https://www.reuters.com/article/us-bmw-autonomous-self-driving/bmw-says-self-driving-car-to-be-level-5-capable-by-2021-i<dUSKBN16N1Y2

- March 2018: “*Level 3 will be achieved by 2021, but Level 4 is one of the biggest challenges facing the auto industry*", Elmar Frickenstein. (translated)

  Source: http://www.sueddeutsche.de/auto/autonomes-fahren-den-deutschen-herstellern-droht-ein-fehlstart-in-die-zukunft-1.3914126

Outlook – own thoughts



New simulation environments and massive data sets

New standards like SOTIF

End of Pegasus Project

ISO26262 3rd edition for level 3 car

ongoing

~2020

~2022

Resources

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Thank you for your attention

megapope

self driving cars aren't even hard to make lol
just program it not to hit stuff

ronpaulhdwallpapers

```
if(goingToHitStuff) {
dont();
}
```

Source: megapope