EDCC 2024: 1ST INTERNATIONAL WORKSHOP ON SAFE AUTONOMOUS SYSTEMS

PROVIDING EVIDENCE FOR THE VALIDITY OF THE VIRTUAL VERIFICATION OF AUTOMATED DRIVING SYSTEMS

Birte Neurohr, Thies de Graaff, Andreas Eggers, Tom Bienmüller and Eike Möhlmann

BTC embedded systems

DLR

Motivation

- For the verification of Automated Driving Systems (ADS)
  - Formal verification as well as statistical verification that solely relies on real-world testing methods, become infeasible
  - Virtual testing seems like a promising alternative to traditional methods

Motivation

- For the verification of Automated Driving Systems (ADS)
  - Formal verification as well as statistical verification that solely relies on real-world testing methods, become infeasible
  - Virtual testing seems like a promising alternative to traditional methods
- If testing shall be performed in a simulation, one has to provide evidence that the simulation is sufficiently similar to the real world
  - This is a hard problem: a lot of real world data is needed to perform validation

Valid?

Motivation

- For the verification of Automated Driving Systems (ADS)
  - Formal verification as well as statistical verification that solely relies on real-world testing methods, become infeasible
  - Virtual testing seems like a promising alternative to traditional methods
- If testing shall be performed in a simulation, one has to provide evidence that the simulation is sufficiently similar to the real world
  - This is a hard problem: a lot of real world data is needed to perform validation

Valid?

Research Question

How can the amount of needed real world data for the validation of simulated traces be decreased?

Contribution

To address the aforementioned challenge we

Contribution

To address the aforementioned challenge we

- present a method to validate simulation traces based on real world data,

Contribution

To address the aforementioned challenge we

- present a method to validate simulation traces based on real world data,
- propose two enhancements via decomposition and recombination of real world data along so called (1) validity aspects and (2) time, and finally

Contribution

To address the aforementioned challenge we

- present a method to validate simulation traces based on real world data,
- propose two enhancements via decomposition and recombination of real world data along so called (1) validity aspects and (2) time, and finally
- demonstrate the effectiveness of these enhancements.

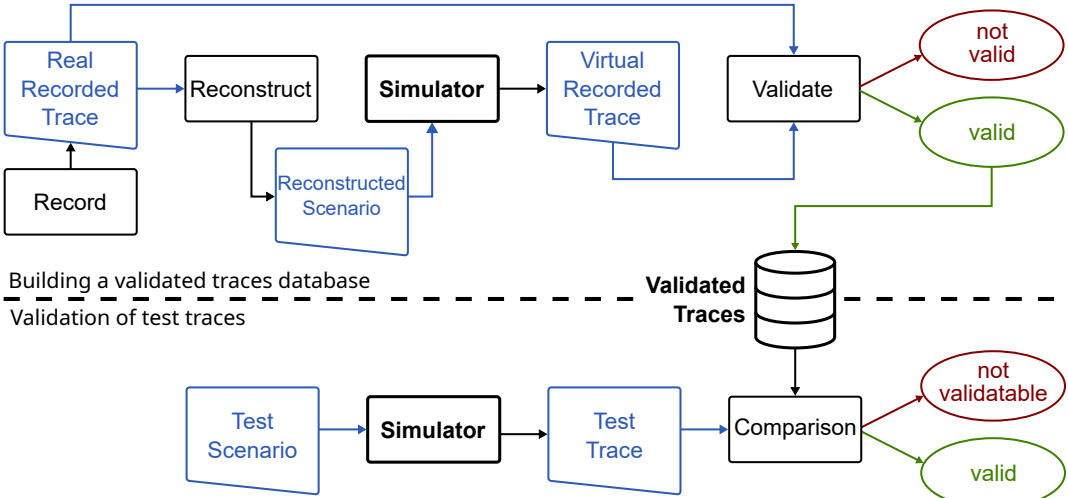
Outline

1. Motivation
2. Naive Validation
3. Snippet-based Trace Validation
   - Decomposition of Traces along Validity Aspects
   - Decomposition of Traces along Time
4. Proof of Concept
5. Conclusion

Outline

1. Motivation
2. Naive Validation
3. Snippet-based Trace Validation
   - Decomposition of Traces along Validity Aspects
   - Decomposition of Traces along Time
4. Proof of Concept
5. Conclusion

Naive Validation Pipeline



Outline

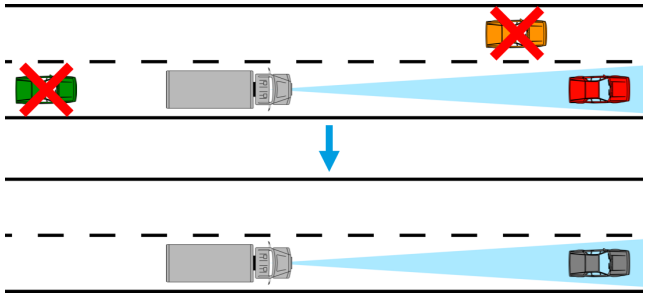
BTC embedded systems DLR

Decomposition along Validity Aspects

- some aspects of the simulation may work independently from each other (e.g. radar is independent from lidar sensor) → **Validity Aspects**

Decomposition along Validity Aspects

- some aspects of the simulation may work independently from each other (e.g. radar is independent from lidar sensor) → **Validity Aspects**
- trace of a validity aspect does not have to depend on every variable in the scenario (e.g. objects, daytime, weather conditions) but only on a subset, the so-called *key variables*



Decomposition along Validity Aspects

- some aspects of the simulation may work independently from each other (e.g. radar is independent from lidar sensor) → **Validity Aspects**
- trace of a validity aspect does not have to depend on every variable in the scenario (e.g. objects, daytime, weather conditions) but only on a subset, the so-called *key variables*
- we recommend to start with all available variables as key variables, and then remove those variables, which are *sure* to be irrelevant for the VA e.g. with a sensitivity analysis

Decomposition along Validity Aspects

- some aspects of the simulation may work independently from each other (e.g. radar is independent from lidar sensor) → **Validity Aspects**
- trace of a validity aspect does not have to depend on every variable in the scenario (e.g. objects, daytime, weather conditions) but only on a subset, the so-called *key variables*
- we recommend to start with all available variables as key variables, and then remove those variables, which are *sure* to be irrelevant for the VA e.g. with a sensitivity analysis
- can now validate each Validity Aspect individually

Outline

Decomposition along Time

- A validity aspect may depend on some time window – we call it *history* of length τ – in which changes of variables have an effect on a VA at timestep *t*

Decomposition along Time

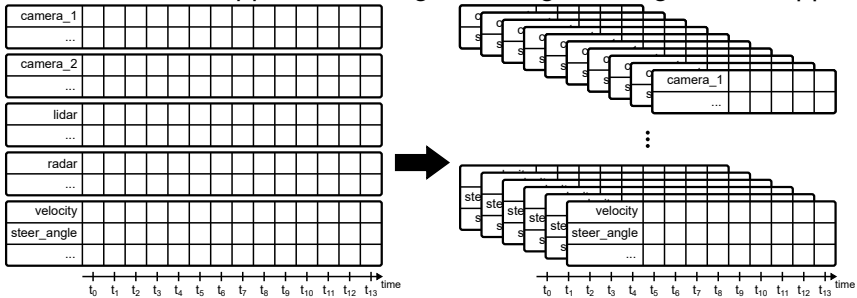
- A validity aspect may depend on some time window – we call it *history* of length τ – in which changes of variables have an effect on a VA at timestep t
- Longest relevant causal chain for a VA determines its minimal history length

Decomposition along Time

- A validity aspect may depend on some time window – we call it *history* of length τ – in which changes of variables have an effect on a VA at timestep t
- Longest relevant causal chain for a VA determines its minimal history length
  - Cut the traces into *snippets* with length τ using a sliding window approach

Decomposition along Time

- A validity aspect may depend on some time window – we call it *history* of length τ – in which changes of variables have an effect on a VA at timestep t
- Longest relevant causal chain for a VA determines its minimal history length
  - Cut the traces into *snippets* with length τ using a sliding window approach

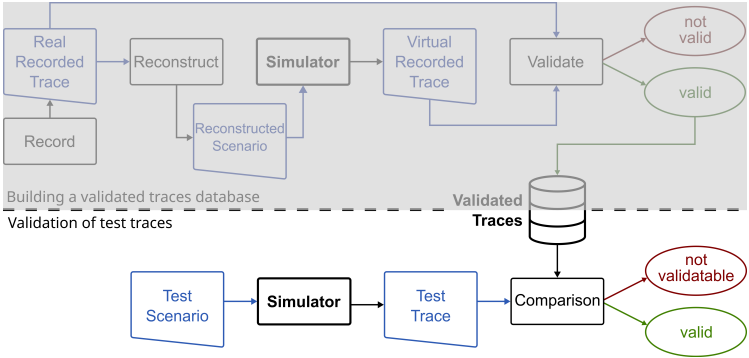


Outline

1. Motivation
2. Naive Validation
3. Snippet-based Trace Validation
   - Decomposition of Traces along Validity Aspects
   - Decomposition of Traces along Time
4. Proof of Concept
5. Conclusion

Set Up Proof of Concept

- Goal: quantify the amount of required validated traces to validate a set of test traces
- assume the validated traces to be valid without having comparable real world data as we focus on the second phase of the presented method

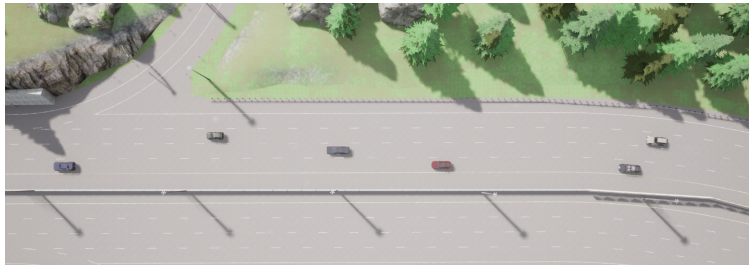


Set Up Proof of Concept

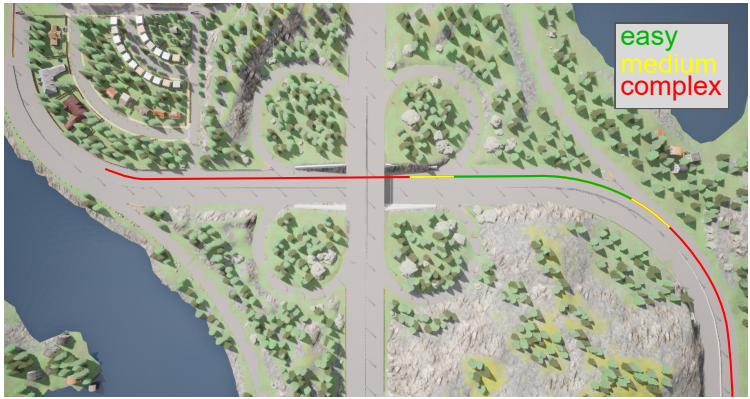
- Goal: quantify the amount of required validated traces to validate a set of test traces
- assume the validated traces to be valid without having comparable real world data as we focus on the second phase of the presented method
- we used the simulator CARLA 0.9.13 and designed parameterizable highway scenarios:

	N_{MIN}	N_{MAX}	V_{MIN} [km/h]	V_{MAX} [km/h]	O_{MAX} [m]	lc
easy	0	3	80	80	100	0
medium	0	5	80	90	150	1
complex	0	10	60	100	500	1

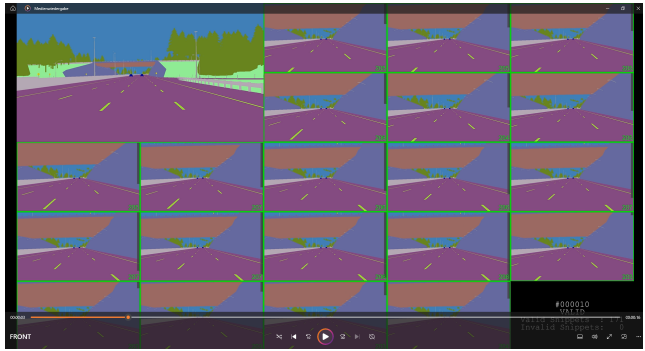
PoC: Scenarios



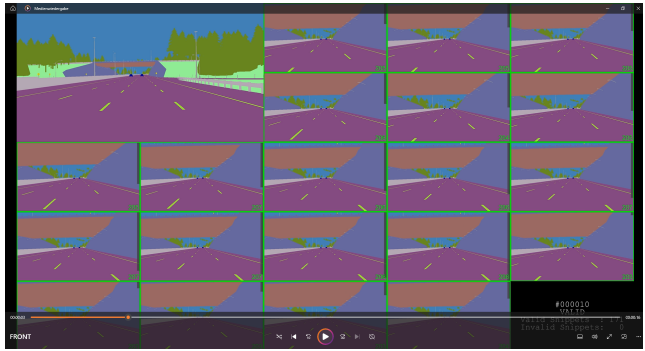
PoC: Scenarios



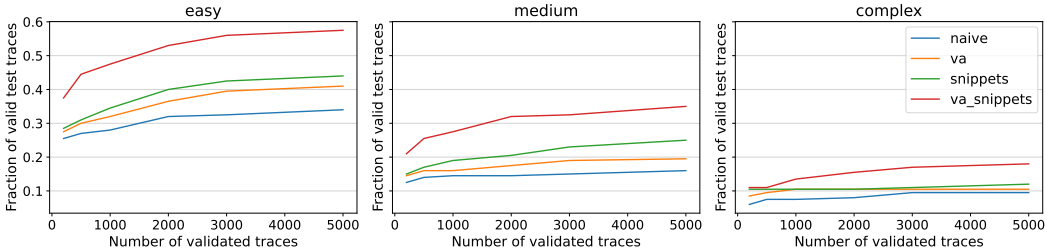
Showcase PoC: Test Trace Validatable



Showcase PoC: Test Trace Not Validatable



Results from Proof of Concept



Outline

1. Motivation
2. Naive Validation
3. Snippet-based Trace Validation
   - Decomposition of Traces along Validity Aspects
   - Decomposition of Traces along Time
4. Proof of Concept
5. Conclusion

Key Takeaways

- Snippet based trace validation provides evidences for the validity of simulation traces while reducing the amount of needed real world data

Key Takeaways

- Snippet based trace validation provides evidences for the validity of simulation traces while reducing the amount of needed real world data
- relies on generalizing from traces that were observed in reality and validly replayed in the simulation

Key Takeaways

- Snippet based trace validation provides evidences for the validity of simulation traces while reducing the amount of needed real world data
- relies on generalizing from traces that were observed in reality and validly replayed in the simulation
- proof of concept exemplary showed, that our different strategies help to increase the generalization of observed scenarios to multiple similar scenarios

Key Takeaways

- Snippet based trace validation provides evidences for the validity of simulation traces while reducing the amount of needed real world data
- relies on generalizing from traces that were observed in reality and validly replayed in the simulation
- proof of concept exemplary showed, that our different strategies help to increase the generalization of observed scenarios to multiple similar scenarios
- approach should be applied with great care as wrongfully declared valid traces, have the potential to lead to catastrophic events

BTC embedded systems DLR

Thank you for the attention.

Contact:

Birte Neurohr, M.Sc.
German Aerospace Center (DLR) e.V.
Institute of Systems Engineering for Future Mobility
birte.neurohr@dlr.de