Chasing critical situations in large parameter spaces

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www.pegasusprojekt.de

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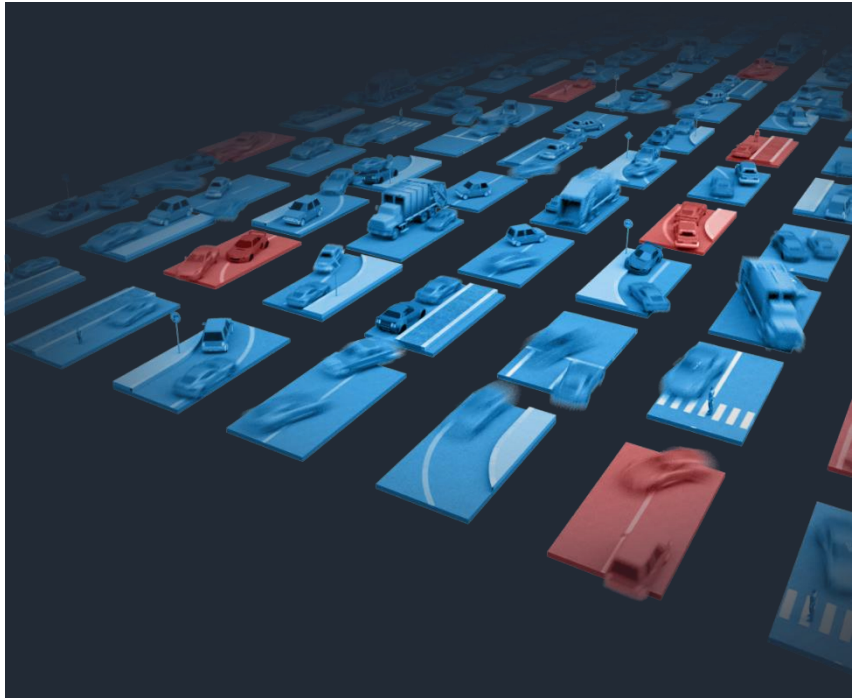
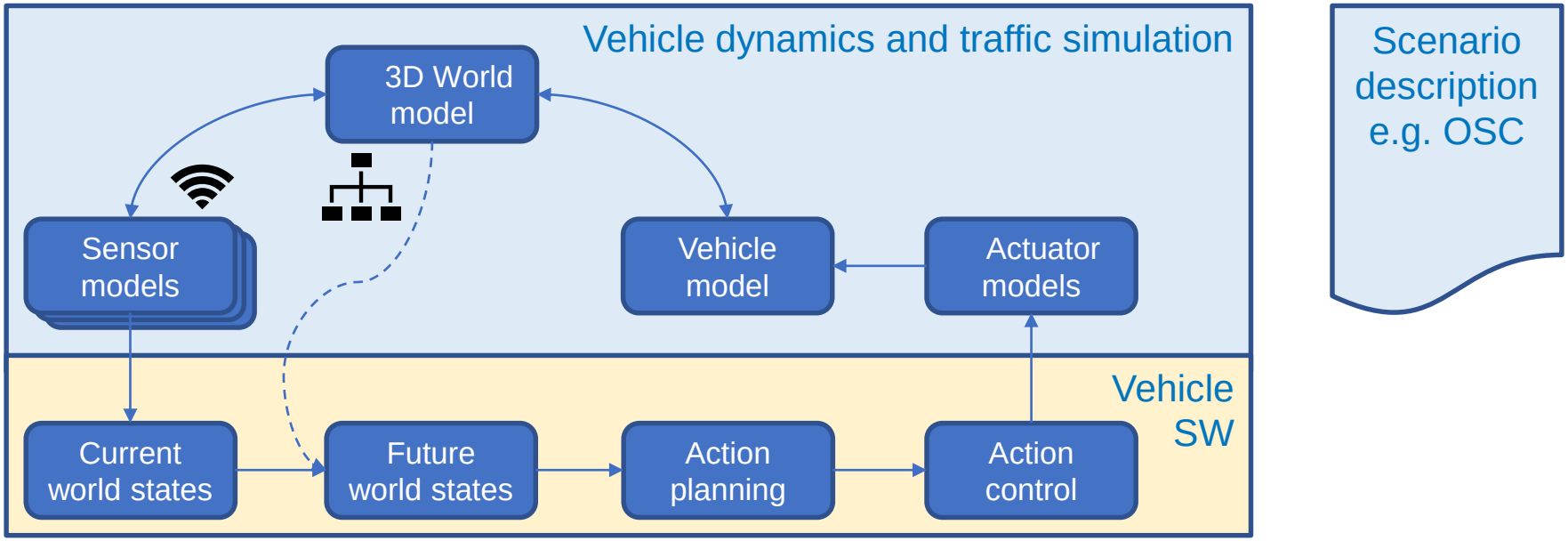
The responsibility for the contents of this presentation is assumed entirely by the author.

Agenda - Touched Topics

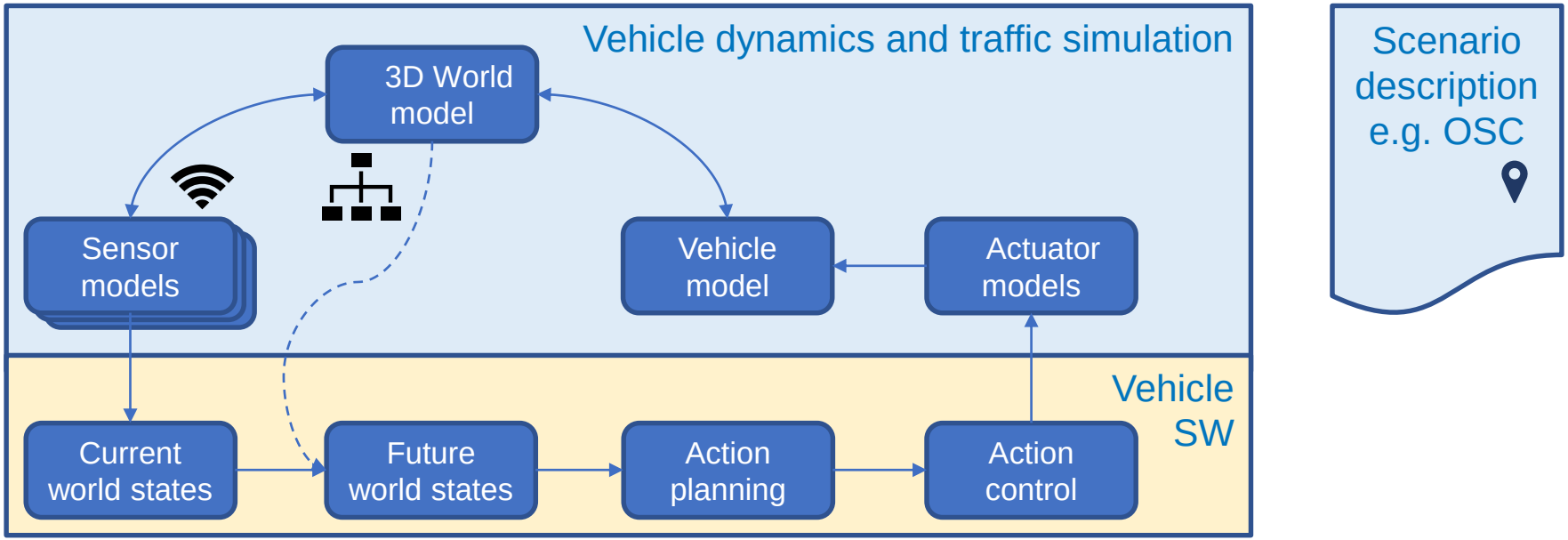


- Context:
  Simulation-based Test of ADAS / AV
- Search Space:
  Static Parameters vs. Dynamic Events
- Test Assessments for
  Correctness & Safety
- Test Objectives
  Worst Cases & System Characterization
- Exploration Strategies: Combinatorial, Stochastic Optimization, Coverage-Driven
- Concluding Remarks &
  Discussion

Simulation-based Testing of ADAS / AV



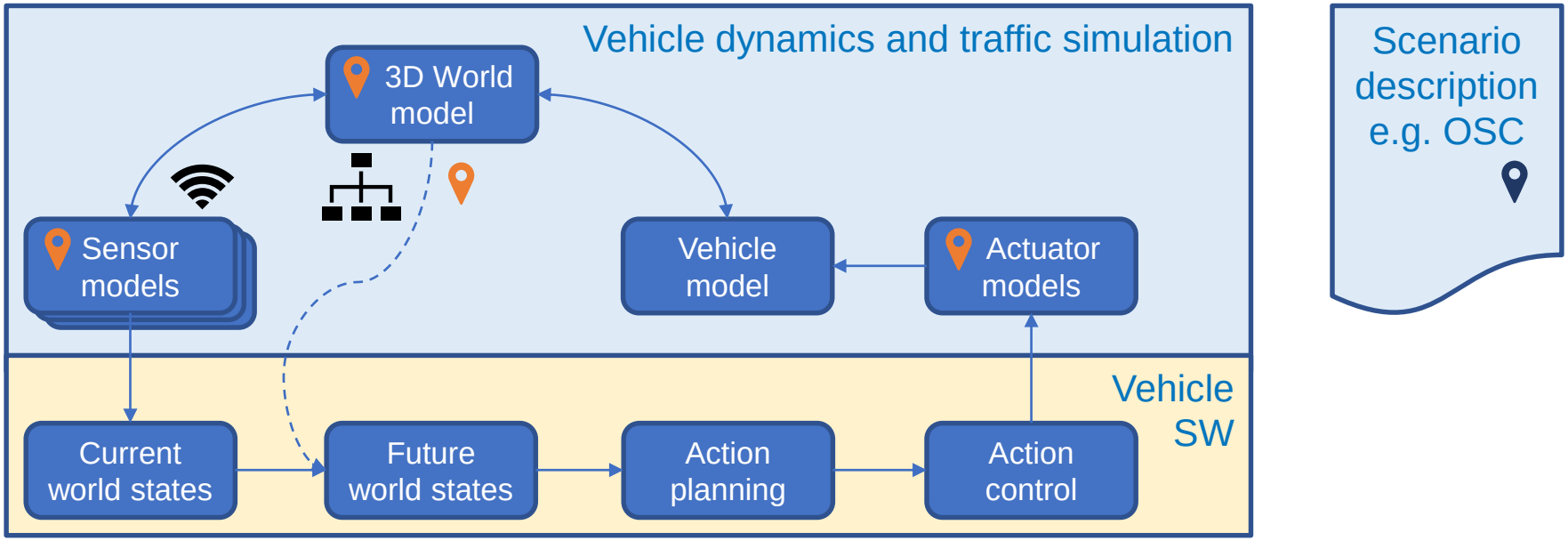
Simulation-based Testing of ADAS / AV



Possible changes by test instrumentation:

- static changes in scenario description: road, traffic objects, behaviors, starting states

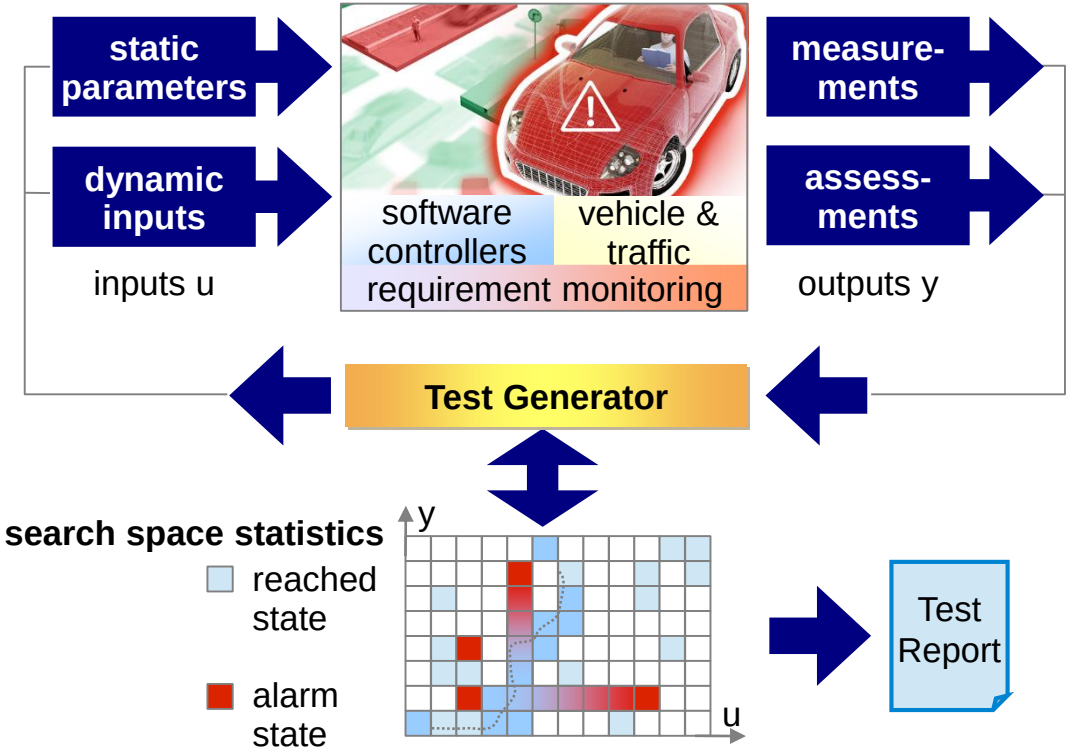
Simulation-based Testing of ADAS / AV



Possible changes by test instrumentation:

- static changes in scenario description: road, traffic objects, behaviors, starting states
- dynamic changes: random disturbances, object insertion, etc.

Simulation-based Explorative Testing - Architecture



- Maintained search space statistics can include
  - distance to violation of requirement
  - coverage information
- Generation strategies
  - search for requirement violations, border cases, worst cases
  - maximization of coverage

Search Space - Static Parameters & Dynamic Events

Commonalities

- Mix of continuous and discrete controllable variables
- Additional logical and algebraic constraints on allowed values, e.g.

```
vStart_ego > vStart_A
```

Static search space

- Predefined parametric scenarios for qualitatively differing classes, such as
  - “lane merge”
  - “obstacle ahead”
- See for instance Pegasus, www.pegasusprojekt.de

Dynamic search space

- In addition to the static case, constrained random changes are allowed, for instance:
  - other traffic objects can perform random manoeuvres, accelerate / break / change position in/across lanes, fault injections
- Main difference to the static search space:
  - number of interventions / scenario not limited

Test Assessments

Functional Requirements

- Requirement-bases test part of ISO26262
- Functional requirements monitored at all times in all scenarios with *requirement watchers*

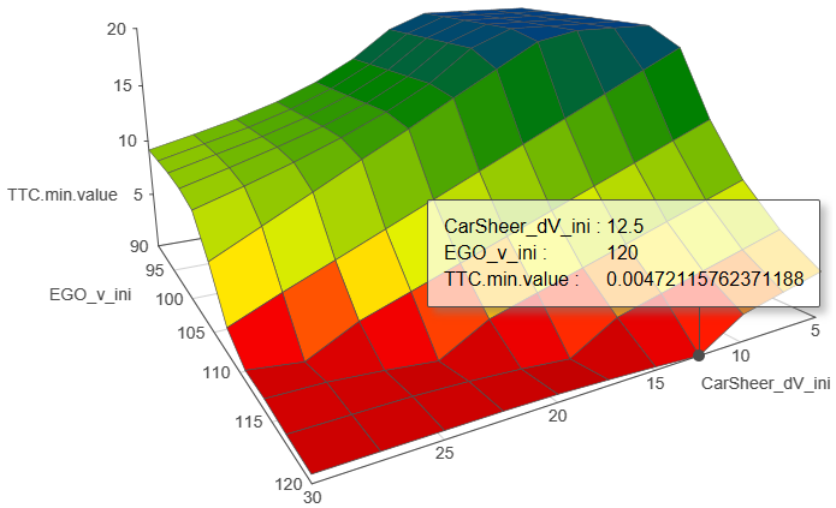
whenever "vehicle ahead signals lane change"
expect "ego-car stops accelerating"
within 2s

- Encoded with, for instance, the TestWeaver Requirement Modelling Language
- Hundreds to thousands of requirements continuously monitored!

Safety Metrics

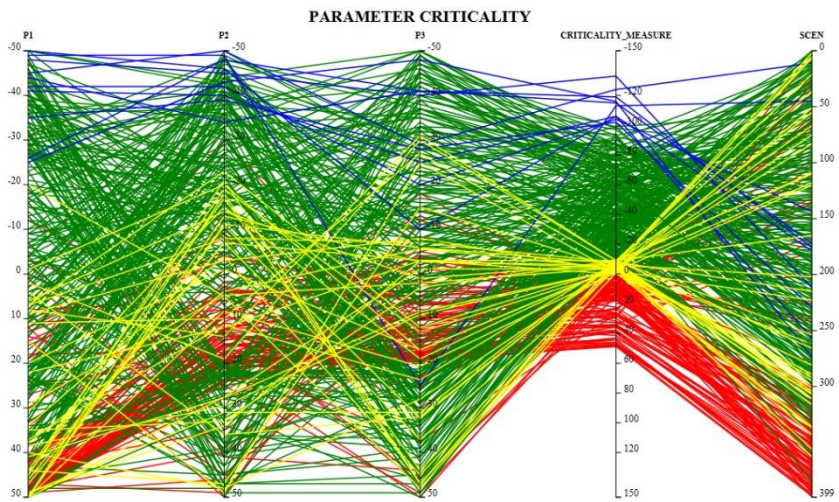
- Deliver a distance to a safety-critical situation, respectively measure the severity
- For instance:
  - Time-To-Collision
  - Collision-Severity
    relative speed at collision time
  - Combinations TTC-CS
- Certain collisions must be accepted, i.e. not caused by the AV and unavoidable
  - **A manual assessment of the identified safety-critical situations might still be required**

Test Objectives



- <u>Search</u> for safety violations / worst case(s)
- <u>Characterize</u> the regions with safety violations, e.g. find their borders
- Deliver coverage reports for one or for a suite of experiments
- Report all functional requirement violations (e.g. breaking driving rules) and safety violations found until a coverage objective is met

Test Coverage - what is / should be “coverage”?



The “coverage” definition should be customizable depending on the test objectives

Possible coverage measures

- Functional requirement coverage
- SW source code coverage
- Operational state coverage for a given scenario or across scenarios
  - Individual indicators vs. cross products
- Input coverage for a given scenario
  - Often based on equivalence classes
  - Individual variables vs. cross products
- Coverage across scenarios / situations
  - Highway / Tunnel / Parking house / etc.

Exploration Strategies - Full Cross Product

- N parameters with S sampling points (equivalence classes) require S^N scenarios
- For S=5 sampling points and assuming 10s / scenario:

S=5	5 parameters	10 parameters	15 parameters
Scenarios	3.125	9.765.625	30.517.578.125
Simulation time	8,7 Hours	3 Years	9677 Years

- Results are easy to comprehend
- “Complete, given the resolution S”
- Only usable for small N, even with very moderate S

Partial Cross Products - K-Combinations

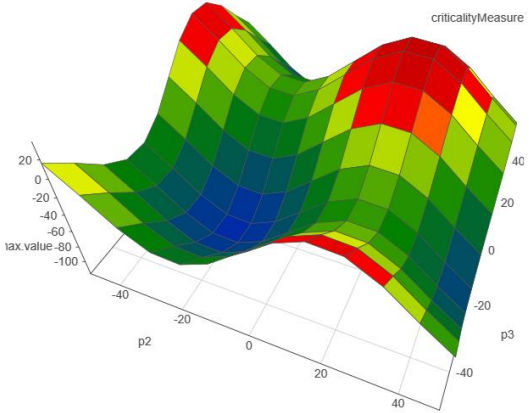
- N parameters with S sampling points (equivalence classes)
- For some/all <u>combinations of K parameters</u> C(N,K), do the <u>K-cross products</u>: C(N,K) x S^K

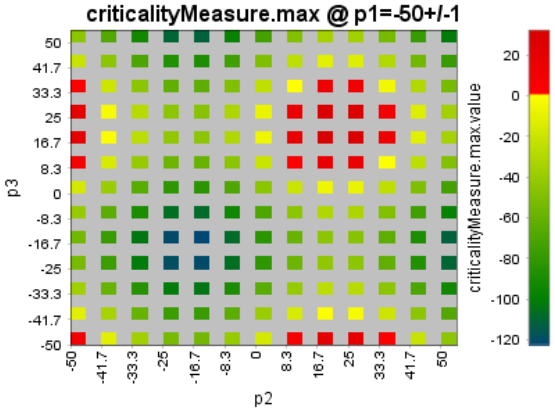
K=2, S=10	5 parameters	10 parameters	15 parameters	20 parameters
Scenarios	1000	4500	10.500	19.000
Simulation time	2,7 hours	12,5 hours	29 hours	2,2 days
K=3, S=5	**5 parameters**	**10 parameters**	**15 parameters**	**20 parameters**
Scenarios	1250	15000	56.875	142.500
Simulation time	3,5 hours	41,6 hours	6,6 days	16,5 days

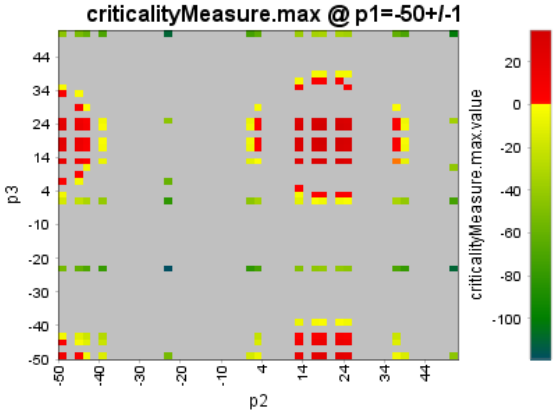
- For small K one can increase N. But when is it “safe” to reduce K?
- See also “Functional Decomposition: an approach to reduce the approval effort for highly automated driving”, Amersbach & Winner, *8. Tagung Fahrerassistenz*, 2017.

K-Combinations Adaptive Sampling

- Use KC with a smaller S and <u>increase the sampling rate around interesting spots</u>
- For instance near (a) safety violation border crosses (b) worst cases



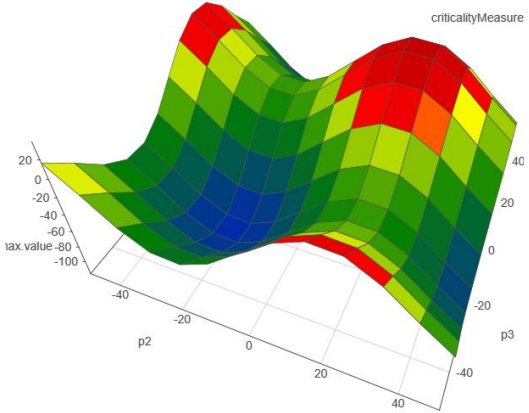


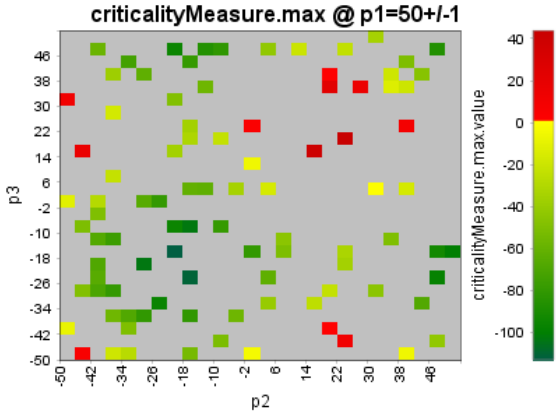


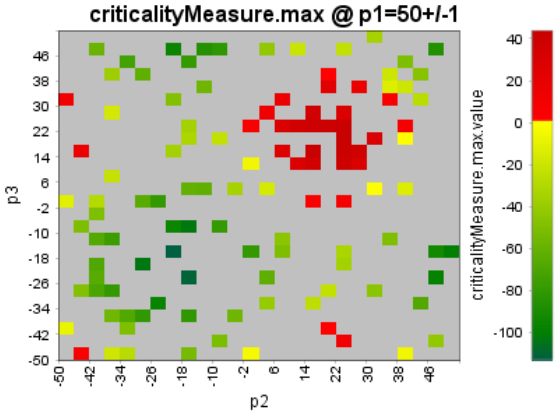
- Can be useful for characterization of areas with requirement violations
- Only applicable for small K
- What values take the unchanged N-K parameters? Better start with a good seed.

Random Generation and Local Optimization

- Figures below illustrate RND and RND+LO
- Local optimization algorithms: hill-climbing (gradient based), simulated annealing



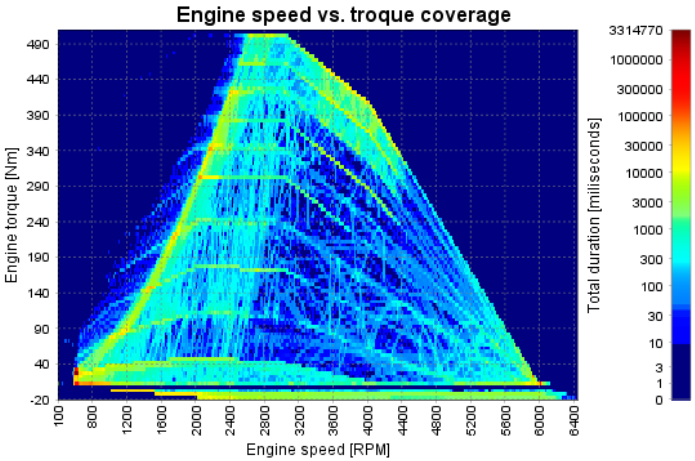


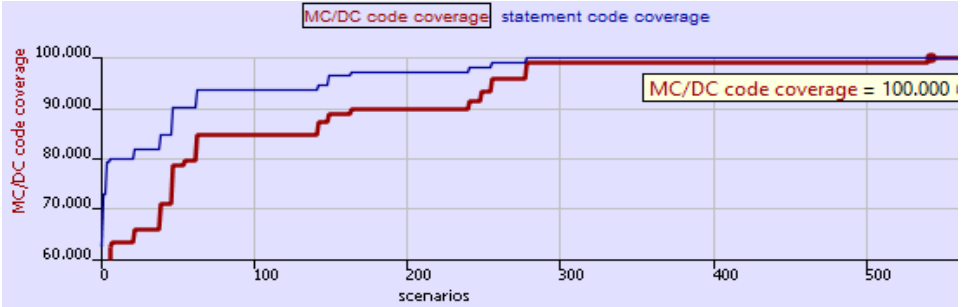


- Good to find hot-spots, but not so good for system characterization
- Restarts with differing seeds may find spots from differing regions with safety violations

Coverage Driven Generation

- Useful for search spaces with dynamic input changes and alternative coverage measures
  - operational state coverage, requirement coverage, code coverage

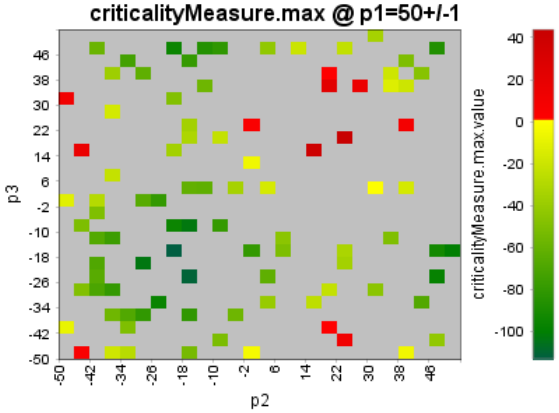


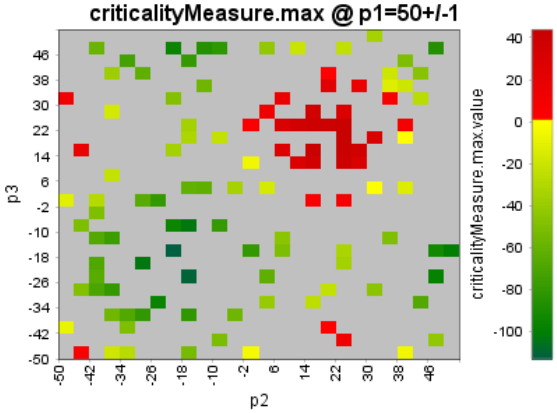


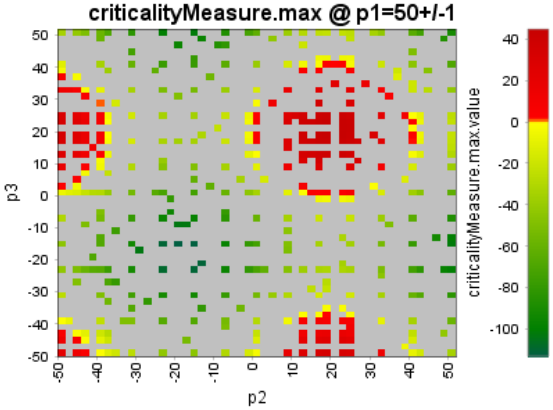
- Applications so far: powertrain and vehicle stability (ESP, ABC)
- Typical problem size, naïve translation to a static parameter space: 10^{300}
  https://youtu.be/EawgRnTAQxE

Multi-Stage Experiments / Strategy Mix

- No best algorithm for all test objectives and larger N
- Iterative approach: **Decompose → Experiment → Learn → Repeat**. For instance:
  - Use RND + LS to find a hot spot
  - Use KC to sample on 2D / 3D projections around the hot spot
  - Repeat or apply KC-AS for better characterization of worst case / safety borders

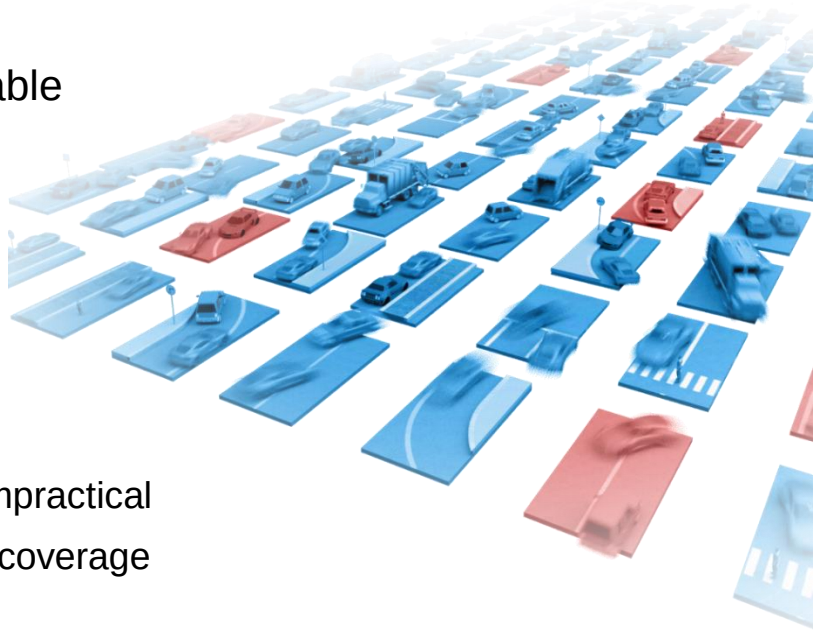




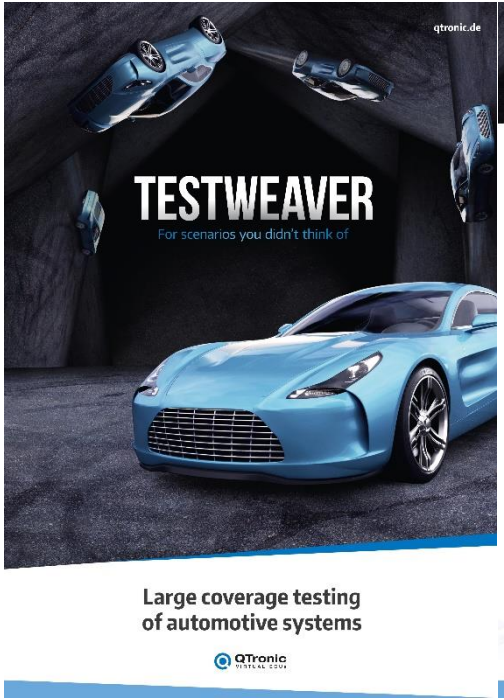


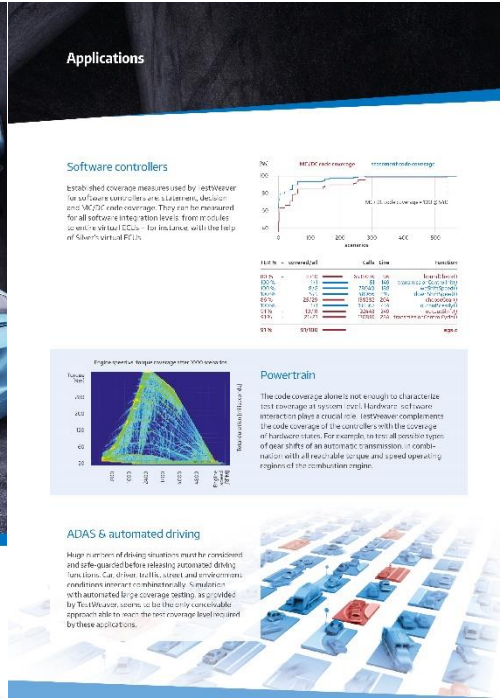
Future Work and Conclusion

- Problem dimensionality is a huge challenge
- No satisfying solutions that are generally applicable
- Future work:
  - Dimensionality reduction: sensitivity analysis, feature extraction, principal component analysis
  - Use of surrogate (learned) models for speed-up and characterization
- Nevertheless:
  - Focusing on the combinatorial coverage (S^N) is impractical
  - Need to come up with other <u>useful and accepted</u> coverage measures



Testing with TestWeaver





All presented exploration strategies available in

- **TestWeaver 3.6**
- release expected later this year

Thank you for the attention.

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See you in the AV Expo @ **AV10002**