Chasing critical situations in large parameter spaces

Mugur Tatar, QTronic GmbH
Acknowledgements

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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

- Sensor models
- 3D World model
- Vehicle models
- Actuator models
- Current world states
- Future world states
- Action planning
- Action control
- Vehicle dynamics and traffic simulation

Scenario description e.g. OSC
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 Exploratory 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. $v_{\text{Start}_e} > v_{\text{Start}_A}$

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

- **Search** for safety violations / worst case(s)
- **Characterize** 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”?

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.

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

<table>
<thead>
<tr>
<th>S=5</th>
<th>5 parameters</th>
<th>10 parameters</th>
<th>15 parameters</th>
</tr>
</thead>
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<tr>
<td>Scenarios</td>
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<td>9.765.625</td>
<td>30.517.578.125</td>
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<tr>
<td>Simulation time</td>
<td>8.7 Hours</td>
<td>3 Years</td>
<td>9677 Years</td>
</tr>
</tbody>
</table>

- 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 combinations of K parameters $C(N,K)$, do the K-cross products: $C(N,K) \times S^K$

<table>
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<table>
<thead>
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</thead>
<tbody>
<tr>
<td>Scenarios</td>
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<td>Simulation time</td>
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<td>41.6 hours</td>
<td>6.6 days</td>
<td>16.5 days</td>
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</table>

- 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 increase the sampling rate around interesting spots
- 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

![Graphs showing criticalityMeasure.max at different p1 values](image-url)
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 useful and accepted coverage measures
Testing with TestWeaver

All presented exploration strategies available in

- **TestWeaver 3.6**
- release expected later this year
Thank you for the attention.

mugur.tatar(at)qtronic.de

See you in the AV Expo @ AV10002