Achieving Weight Coverage for an Autonomous Driving System with Search-based Test Generation (HOP Track at GECCO 2021)

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ABSTRACT

Autonomous Driving Systems (ADSs) are complex critical systems that must be thoroughly tested. Still, assessing the strength of tests for ADSs is an open and complex problem. Weight Coverage is a test criterion targeting ADSs which are based on a weighted cost function. It measures how much each weight, related to different aspects of the ADS's decision process, is involved in the decisions taken in a test scenario. All weights/aspects should be involved for a strong test suite. Although weight coverage can measure the quality of a test suite, it does not provide clear guidance for test generation. This work proposes weight coverage-driven search-based test generation for ADSs. It describes and compares three designs of the search process: a single-objective search aiming at generating a test covering a single weight; a multi-objective search where each objective targets a different weight; and a single-objective search where the fitness function is an aggregate function representing the coverage over multiple weights. Experiments using an ADS system provided by our industry partner show the validity of the method and provide insights into the benefits of each search design.

This Hot-off-the-Press paper summarises the paper [2]: T. Laurent, P. Arcaini, F. Ishikawa and A. Ventresque, "Achieving Weight Coverage for an Autonomous Driving System with Search-based Test Generation", 25th International Conference on Engineering of Complex Computer Systems (ICECCS 2020).

CCS CONCEPTS

• **Computer systems organization** → **Embedded and cyber-physical systems**; • **Software and its engineering** → **Search-based software engineering**.

KEYWORDS

search-based testing, autonomous driving, weight coverage

ACM Reference Format:

Thomas Laurent, Paolo Arcaini, Fuyuki Ishikawa, and Anthony Ventresque. 2021. Achieving Weight Coverage for an Autonomous Driving System with Search-based Test Generation (HOP Track at GECCO 2021). In *2021 Genetic and Evolutionary Computation Conference Companion (GECCO '21 Companion)*, July 10–14, 2021, Lille, France. ACM, New York, NY, USA, 2 pages. <https://doi.org/10.1145/3449726.3462723>

1 BACKGROUND AND PROPOSED METHOD

Autonomous Driving Systems (ADSs) represent a complex and active area of research, which promises to have a large impact on society. As such, they have recently been the focus of a lot of work. As they are eventually deployed on the streets, they must be thoroughly tested in order to avoid possibly fatal consequences.

Assessing whether a set of driving scenarios tests the ADS thoroughly enough, or if more testing is needed, is an open problem. To address this problem, some *coverage criteria* have been defined, such as identifying diverse *scenario types* to include in the test suite, or evaluating scenarios that trigger all the possible "types of decisions" of the ADS, as required by *weight coverage* [1]. This work focuses on the use of weight coverage to drive the testing effort.

Weight coverage is computed using a mutation-based approach. It creates several mutated ADSs having a different value than the original system for one of the weights. The approach then runs the original and mutant ADS on the test scenarios and compares the results. If the mutated ADS produces a different result, then the weight is *covered*. The smaller the difference between the mutated and original value of the weight, i.e., the *mutation level*, the better the coverage. Comparison of the results is performed using a delta function Δ . Three delta functions can be used: Δ^P that compares the paths produced by both systems, Δ^S that compares the safety of the paths, and Δ^C that compares the comfort of the paths.

Although weight coverage assesses how well a set of scenarios tests the ADS, it does not give clues towards the missing scenarios to increase coverage. If a weight is not (or badly) covered, it is unclear what scenario would cover it. Thus, the testing process remains based on manual and costly exploration, hence the need for automated test generation.

This work proposes weight coverage-driven search-based generation for ADS. In the search *individuals* represent scenarios. In particular, we define a *baseline scenario* $S_{\bar{v}}$ in which some fields $\bar{v}$

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GECCO '21 Companion, July 10–14, 2021, Lille, France

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ACM ISBN 978-1-4503-8351-6/21/07.

<https://doi.org/10.1145/3449726.3462723>

(e.g., initial position, speed, direction, acceleration of a given scenario car) are not specified: these are the *search variables*. Given some values $\bar{v}'$ for the searched variables, we will indicate with $S_{\bar{v}'}$ the scenario $S_{\bar{v}}$ with the new values $\bar{v}'$.

This work describes and compares three designs of the search process, SWA, MWA_{M0} , and MWA_{S0} , detailed as follows.

Single-weight approach (SWA) In this variant of the approach, given a weight w_i , we search for a scenario that achieves weight coverage for w_i . The search is a single-objective search and the fitness function is simply the coverage achieved by a scenario, i.e. scenarios detecting small levels of mutation for weight w_i have better fitness. The single weight approach should be run for each weight in the system in order to produce a test suite with full coverage, and would produce one scenario for each weight. As a single scenario could cover multiple weights, this work also explores approaches targeting multiple weights. Although computing the fitness in these approaches is more expensive (weight coverage must be computed for multiple weights instead of one), they should produce smaller test suites with less specialised scenarios.

Multi-weight multi-objective approach (MWA_{M0}) In this variant, given n weights $w_1, \dots, w_n$ that we want to cover, we search for a scenario that achieves weight coverage on all weights. The search is a multi-objective search with n fitness functions, each function fit_i being the coverage achieved on weight w_i .

Multi-weight single-objective approach (MWA_{S0}) In this variant, like in MWA_{M0} , given n weights $w_1, \dots, w_n$ that we want to cover, we search for a scenario that achieves weight coverage on all weights. Similarly to SWA, the search is single-objective, but the fitness function *aggregates* the coverage achieved on the different weights. The aggregation function is designed so that a scenario covering more weights is always preferred to one covering fewer weights, and a scenario covering one of the weights with a smaller mutation level is preferred if it covers the other weights as well.

2 SUMMARY OF THE RESULTS

All three methods were applied to an ADS provided by our industry partner. The experiments targeted 4 of the system's weights, and used 3 search spaces (i.e., baseline scenarios and field intervals). All experiments were repeated 5 times. This section presents the main results from these experiments, first on the performance of each method, and then on the comparison between methods.

2.1 Coverage of each method

Single-weight approach (SWA) Results show that this method reliably finds scenarios achieving coverage, often detecting the smallest mutation level for the targeted weight. They also show that, although the scenarios the method produces are specialised to cover the target weight, they can also cover other weights, although most scenarios only detect higher levels of mutation for non-target weights. This shows that scenarios can cover multiple weights, although SWA does not find scenarios both covering multiple weights *and detecting small mutation levels for all weights*, further motivating the inquiry into the two multi-weight approaches.

Multi-weight multi-objective approach (MWA_{M0}) Results show that this method finds scenarios that cover the 4 weights considered

during the search, often detecting small mutation levels. It can thus produce small test suites achieving good coverage.

Multi-weight single-objective approach (MWA_{S0}) Results show that this method finds scenarios that cover the 4 weights considered during the search, although the mutation levels detected are higher than with scenarios produced by MWA_{M0} .

2.2 Comparison between the three approaches

The non-parametric Wilcoxon test and the $\hat{A}_{12}$ statistic provided a way to compare the approaches. These tests let us compare the overall coverage achieved by the set of 4 scenarios produced by SWA, each targeting one of the weights used in the experiments, with the best scenario (covering the most weights and detecting the lowest mutation levels) produced by each of MWA_{M0} and MWA_{S0} .

These results show that SWA performs best out of the three methods in terms of coverage, which is expected as it produces four scenarios while the other approaches produce one. Still, as mentioned above, MWA_{M0} and MWA_{S0} produce scenarios covering all weights, leading to smaller test suite size. Privileging test suite size over optimal coverage could be desirable. Of the two multi-weight approaches, MWA_{M0} systematically performs better, thus the “true” multi-objective approach should be preferred over the combined objectives approach. Interestingly, when considering the comfort coverage objective (Δ^C), a much harder problem, all three approaches perform similarly, as the main issue becomes finding a covering scenario, rather than a scenario detecting smaller levels of mutation.

3 CONCLUSIONS

The main theoretical challenge of this work was to obtain scalability. To this aim, in the fitness function (which is time costly, being based on simulation), the mutants are evaluated in a given order. In the same spirit, in the design of the fitness function of MWA_{S0} , we prioritised the different levels of coverage of the different weights. We believe that future works on search-based testing for ADSs should tackle the problem of scalability as main challenge.

ACKNOWLEDGMENTS

This work was supported supported, in part, by Science Foundation Ireland grant 13/RC/2094_P2. T. Laurent is supported by an Irish Research Council grant (GOIPG/2017/1829). P. Arcaini and F. Ishikawa are supported by ERATO HASUO Metamathematics for Systems Design Project (No. JPMJER1603), JST. We thank our industry partner Mazda for providing the software used as target in our work and discussing principles in testing and improving real-world automotive systems: the software is a prototype constructed for the purpose of evaluating new testing methods, and its quality has no relation with the quality of Mazda products.

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