Requirements Coverage as an Adequacy Measure for Conformance Testing*

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Abstract. Conformance testing in model-based development refers to the testing activity that verifies whether the code generated (manually or automatically) from the model is behaviorally equivalent to the model. Presently the adequacy of conformance testing is inferred by measuring structural coverage achieved over the model. We hypothesize that adequacy metrics for conformance testing should consider structural coverage over the requirements either in place of or in addition to structural coverage over the model. Measuring structural coverage over the requirements gives a notion of how well the conformance tests exercise the required behavior of the system.

We conducted an experiment to investigate the hypothesis stating structural coverage over formal requirements is more effective than structural coverage over the model as an adequacy measure for conformance testing. We found that the hypothesis was rejected at 5% statistical significance on three of the four case examples in our experiment. Nevertheless, we found that the tests providing requirements coverage found several faults that remained undetected by tests providing model coverage. We thus formed a second hypothesis stating that complementing model coverage with requirements coverage will prove more effective as an adequacy measure than solely using model coverage for conformance testing. In our experiment, we found test suites providing both requirements coverage and model coverage to be more effective at finding faults than test suites providing model coverage alone, at 5% statistical significance. Based on our results, we believe existing adequacy measures for conformance testing that only consider model coverage can be strengthened by combining them with rigorous requirements coverage metrics.

1 Introduction

In critical avionics applications, the validation and verification phase (V&V) is particularly costly and consumes a disproportionally large share of the development resources. Thus, if the process of deriving test cases for V&V can be

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automated to provide test suites that satisfy the most stringent standards (such as DO-178B in civil avionics [20]), dramatic time and cost savings can be realized. The current trend towards model-based development is one attempt to address this problem. In model-based software development, the traditional testing process is split into two distinct activities: one activity that tests the model to validate that it accurately captures the customers’ high-level requirements, and another testing activity that verifies whether the code generated (manually or automatically) from the model is behaviorally equivalent to (or conforms to) the model. (Note that by “model”, we are referring specifically to a high level formal model written in a language such as Simulink or Lustre. Throughout this paper, we refer to this simply as a “model”.) In this paper, we focus on the second testing activity—verification through conformance testing. There are currently several tools, such as model checkers, that provide the capability to automatically generate conformance tests [19,7] from formal models. In this paper, we examine the effectiveness of metrics used in measuring the adequacy of the generated conformance tests.

For critical avionics software, DO-178B necessitates test cases used in verification to achieve requirements coverage in addition to structural coverage over the code. However, there is no direct and objective measure of requirements coverage, and adequacy of tests is instead inferred by examining structural coverage achieved over the model. The Modified Condition and Decision Coverage (MC/DC) used when testing highly critical software [20] in the avionics industry has been a natural choice to measure structural coverage for the most critical models. In our work [21], however, we have defined coverage metrics that provide direct and objective measures of how well a test suite exercises a set of high-level formal software requirements. We examined using requirements coverage metrics, in particular the Unique First Cause (UFC) coverage metric, to measure adequacy of tests used in model validation (or black-box testing) and found them to be useful. To save time and effort, we would like to re-use validation tests providing requirements coverage for verification of code through conformance testing as well. This paper examines the suitability of using tests providing requirements UFC coverage for conformance testing as opposed to tests providing MC/DC over the model.

We believe requirements coverage will be useful as an adequacy measure for conformance testing for several reasons. First, measuring structural coverage over the requirements gives a direct assessment of how well the conformance tests exercise the required behavior of the system. Second, if a model is missing functionality, measuring structural coverage over the model will not expose such defects of omission. Third, obligations for requirements coverage describe satisfying scenarios (paths) in the model as opposed to satisfying states defined by common model coverage obligations (such as MC/DC). We believe coverage obligations that define satisfying paths will necessitate longer and more effective test cases than those defining satisfying states in the model. Finally, we found in [16] that structural coverage metrics over the model, in particular MC/DC, are sensitive to the structure of the model used in coverage measurement. Therefore,