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Abstract:

This deliverable describes the basic work in the QUASIMODO project on quantitative testing theory

Keyword list: Timed testing.

Contents

Abbreviations

AAU: Aalborg University, DK

CFV: Centre Fèdèrè en Vèrification, B

CNRS: National Center for Scientific Research, FR

ESI: Embedded Systems Institute, NL

ESI/RU: Radboud University Nijmegen, NL

RWTH: RWTH Aachen University, D

SU: Saarland University, D

1 RWTH Aachen: Quantitative testing theory

1.1 Timed Testing

Participants:

- Henrik Bohnenkamp, RWTH Aachen.
- Ed Brinksma, ESI

In [3], a timed testing theory is developed which attempts to generalises the *ioco* theory [9]. The conformance relation $tioco_M$ describes a correctness criterion of implementations with respect to specifications. The theory is developed using *timed transition systems*, which makes an effective implementation of the developed test-case derivation algorithm impossible (due to several undecidable problems on timed transition systems).

In [1], an on-the-fly timed testing algorithm is developed which uses timed automata as specification formalism. The algorithm has been implemented in the testing tool TorX. Albeit developed independently from [3], the motivation behind the developed algorithm is to provide a practically usable instance of the $tioco_M$ theory.

Our current work is aimed at combining [3] and [1], in particular, proving that [1] is sound and complete with respect to the $tioco_M$ theory. This proof does exist now and will be published in a short while.

1.2 Dealing with Imprecisions in Quantitative Testing

Participants:

- Henrik Bohnenkamp, RWTH Aachen.
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Quantitative testing theories handle numerical values contained within the requirement specification and the IUT quite commonly with an infinite precision. That is, they do not take into account deviations from these values due to measurement errors, numerical instability or noisy channels: e.g., if the specification requires a response time of 1 second, but the IUT responds in 1.01 second, a fail verdict is generated, even though the deviation might be tolerable.

We work on a model-driven test theory in the presence of imprecisions: rather than concentrating on one particular area like timed or hybrid testing, we present a general theory for testing quantitative systems that works for systems containing numerical information, no matter how the numbers are interpreted. This allows us to focus on the essentials of testing with imprecise information; one can always specialise our theory to deal with the particularities of a concrete (real-time, hybrid, probabilistic) data domain.

We set our theory in the context of *quantitative transition systems* (QTS) [4]. These are an extension of input/output transition systems with continuous information: Each action in a QTS carries also a value $x \in [0, 1]$. Based on this model class, we define conformance relations

$qioco_\varepsilon$, a conservative extension of the well-known *ioco* relation [9] and parameterised with a tolerance value ε. An implementation conforms to a specification as long as it is functionally correct (i.e. delivers only outputs that are expected) and deviates in the quantitative part by at most ε. We are however more interested to find out by testing which ε is the smallest such that the IUT conforms to the specification with respect to $qioco_\varepsilon$. We present two testing algorithms that estimate this smallest distance. The first approach is on-line, and interleaves the test derivation and test execution phase. The second one is a batch or off-line approach, where test cases are first generated, and subsequently executed against the IUT. Both approaches are sound and complete with respect to $qioco_\varepsilon$, up to the perturbations of ε. This theory is described in detail in [2].

2 ESI: Quantitative Testing Theory: Timed Model-Based Testing

Participants:

- Julien Schmaltz, ESI
- Jan Tretmans, ESI

Conformance testing for labelled transition systems starts with defining when an implementation conforms to its specification. One of the formal theories for model-based testing uses the implementation relation $\mathbf{ioco}$ for this purpose. A peculiar aspect of $\mathbf{ioco}$ is to consider the absence of outputs as an observable action, named *quiescence*. Recently a number of real-time extensions of $\mathbf{ioco}$ have been proposed in the literature. Quiescence and the observation of arbitrary delays are issues when defining such extensions. In a recent paper [7], we presented two new timed implementation relations and show their relation with existing ones. Based on these new definitions and using several examples, we show the subtle differences, and the consequences that small modifications in the definitions can have on the resulting relations. Moreover, we presented conditions under which some of these implementation relations coincide. The notion of *M-quiescence*, i.e., if outputs occur in a system they occur before a delay M, turns out to be important in these conditions.

We generalized this preliminary work to a complete classification of conformance relations for real-time systems [8]. Many relations have been defined. We identified a subset of relations which are equivalent, i.e., they have exactly the same discrimination power. We refer to these relations simply as $\mathbf{tioco}$. One issue with $\mathbf{tioco}$ is that it can observe an unbounded set of delays. An important contribution of our work is the definition of a new relation – named $\mathbf{tioco}_\eta$ – which bounds the set of observable delays by η. We proved that $\mathbf{tioco}_\eta$ and $\mathbf{tioco}$ are equivalent. In the family of timed conformance relations, we proved that the last two members are not equivalent to $\mathbf{tioco}_\eta$. They are stronger in the sense that they imply $\mathbf{tioco}_\eta$. We also proved that these last two relations are not equivalent to each other, i.e., one is stronger than the other.

Our work consitutes a precise formalisation of conformance relations for model-based testing of real-time systems. We clearly identified for each one of them, the hypotheses made on the possible observations of the system under test. By showing their differences and the conditions under which they are equivalent, we built a strong basis to develop efficient algorithms and tools for testing real-time systems.

3 AAU: Timed Testing and UPPAAL TRON

AAU: AAU has in previous work [6] extended the classical untimed ioco-testing relation with real-time behavior and explicit environment assumptions. This relation is called relativised real-time input output conformance, denoted $Irt - ioco_E S$ for an implementation I, specification S and environment E. The main differences are that it compares the timing of the implementation and specification (allowed and required upper/lower bounds on actions), and that this judgement (and test generation) is done relative to the behavior specified in the environment assumptions - an essential feature for embedded systems. Uppaal-TRON is a tool for online real-time test generation which is continually being developed and improved, and will be applied to the Quasimodo case studies (to be reported in future deliverables). Similarly we are working on offline test generation using the strategy synthesis feature of Uppaal-Tiga. Both approaches are based on rt-ioco. Obviously the generalised quantivative testing theory developed in Section 2 will be considered for adoptation in these testing tools.

In [5] the potential of applying a real-time model checker like UPPAAL for automatic test generation is described in detail. In particular, the applied techniques for on-line vs. off-line testing are presented. In the coming periods of Quasimodo, it is planned to apply both techniques on the industrial case studies.

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