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Model-Based Testing of Dynamic and Distributed Real-Time Systems

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Abstract

In this paper, we report on our main research contributions dealing with Model-Based Testing of Dynamic and Distributed Real-Time Systems, performed during the last ten years. Our first contribution deals with testing techniques for distributed and dynamically adaptable systems. In this context, we propose a standard-based test execution platform which affords a platform-independent test system for isolating and executing runtime tests. This platform uses the TTCN3 standard and considers both structural and behavioral adaptations. Moreover, our platform is equipped with a test isolation layer that reduces the risk of interference between testing processes and business processes. Besides, we compute a minimal subset of test cases to run and efficiently distribute them among the execution nodes while respecting resource and connectivity constraints. In addition, we validate the proposed techniques on two case studies, one in the healthcare domain and the other one in the fleet management domain. Our second contribution consists in proposing a model-based framework to combine Load and Functional Tests. This framework is based on the model of extended timed automata with inputs/outputs and shared integer variables. We present different modelling techniques aspects and we illustrate them by means of a case study. Moreover, we study BPEL compositions behaviors under various load conditions using the proposed framework. We introduce a taxonomy of the detected problems and we illustrate how test verdicts are assigned. Besides, we validate our approach using a Travel Agency case study. Furthermore, we consider several mutants of the corresponding BPEL process and we test them using our tool. Our third contribution consists in introducing a set of formal techniques for the determinization and off-line test selection for timed automata with inputs and outputs. With this respect, we propose a game-based approach between two players for the determinization of a given timed automaton and some fixed resources. Moreover, we present a complete formalization for the automatic off-line generation of test cases from non-deterministic timed automata with inputs and outputs. We also define a selection technique of test cases with expressive test purposes. Test cases are generated using a symbolic co-reachability analysis of the observable behaviors of the specification guided by the test purpose which is in turn defined as a special timed automaton.

1 Research Context and Motivation

In order to build and deliver quality assured software and avoid potential costs caused by unstable software, testing is a definitely essential step in software life cycle development. During the last few decades, very critical programming errors and accidents have been detected in different domains and in different corners of the world. Some of these errors were very dangerous and caused huge and dramatic human/financial/environmental damages. A first example of critical software errors we cite is related to the medical field. From 1985 to 1987, at least four patients died as a direct result of a radiation overdose received from the medical radiation therapy device Therac-25. In fact, the victims received up to 100 times the required dose. The accident was the result of a bug in the software powering the Therac-25 device. A second example concerns the European rocket Ariane 5 explosion in 1996 just 37 seconds after launch. The explosion was the result of a wrong reuse of code from Ariane 4. The financial loss caused by this accident was estimated to be about \$400 millions. A third example of software errors struck the very famous web service provider Google. This accident occurred in February 2009.

The important issue to emphasize here is that a good percentage of these errors could have been avoided by considering some more refined testing efforts. Yet, such efforts are still minimal in practice and the need for advanced testing solutions is still deep. Indeed, software companies are still not making enough efforts at this level.

Runtime Testing of Dynamically Adaptable and Distributed Systems: Nowadays, distributed component-based systems tend to evolve dynamically without stopping their execution. Known as *Dynamically Adaptable and Distributed Systems*, these systems are currently playing an important role in society's services. Indeed, the growing demand for such systems is obvious in several application domains such as crisis management, medical monitoring, fleet management, etc.

This demand is stressed by the complex, mobile and critical nature of these applications that also need to continue meeting their functional and non-functional requirements and to support advanced properties such as context awareness and mobility. Nevertheless, dynamic adaptations of component-based systems may generate new risks of bugs, unpredicted interactions (e.g., connections going down), unintended operation modes and performance degradation. This may cause system malfunctions and guide its execution to an unsafe state. Therefore, guaranteeing their high quality and their trustworthiness remains a crucial requirement to be considered.

One of the most promising ways of testing dynamic systems is the use of an emerging technique, called *Runtime Testing*. In this work, we propose a standard-based test execution platform which affords a platform-independent test system for isolating and executing runtime tests. We also compute a minimal subset of test cases to run and efficiently distribute them among the execution nodes.

Combining Load and Functional Tests: Many systems ranging from e-commerce websites to telecommunications must support concurrent access by hundreds or thousands of users. In order to assure the quality of these systems, load testing is a required testing process in addition to conventional functional testing

procedures, which focus on testing a system based on a small number of users. In fact, load testing is one of the testing types with high importance. It is usually accompanied by performance monitoring of the hosting environment.

Typically, industry software testing practice is to separate load testing from functional testing. Different teams with different expertise and skills execute their testing at different times, and each team evaluates the results against its own criteria. It is exceptional to get the two testing types together and to evaluate load test results for functional correctness or incorporate sustained load in the functional testing. In this work, we propose a formal model-based framework to combine functional and load tests. Moreover, we study BPEL (Business Process Execution Language) compositions behaviors under various load conditions using the proposed framework.

Determinization of Timed Automata: Timed automata (TA), introduced in (1), form a usual model for the specification of real-time embedded systems. Essentially TAs are an extension of automata with guards and resets of continuous clocks. They are extensively used in the context of many validation problems such as verification, control synthesis or model-based testing (2). Determinization is a key issue for several problems such as implementability, diagnosis or test generation, where the underlying analyses depend on the observable behavior.

Our method combines techniques from (3) and (4) and improves those two approaches. The core principle is the construction of a finite turn-based safety game between two players, Spoiler and Determinizator, where Spoiler chooses an action and the region of its occurrence, while Determinizator chooses which clocks to reset. Our main result states that if Determinizator has a winning strategy, then it yields a deterministic timed automaton accepting exactly the same timed language as the initial automaton, otherwise it produces a deterministic over-approximation.

Off-Line Test Selection for Timed Automata: Conformance testing is the process of testing whether an implementation behaves correctly with respect to a specification. Implementations are considered as *black boxes*, i.e. the source code is unknown, only their interface with the environment is known and used to interact with the tester. In *formal model-based conformance testing* models are used to describe testing artifacts (specifications, implementations, test cases, ...), conformance is formally defined and test cases with verdicts are generated automatically. Then, the quality of testing may be characterized by properties of test cases which relate the verdicts of their executions with conformance (e.g., soundness).

In this context, a very popular model is *timed automata with inputs and outputs* (TAIOs), a variant of *timed automata* (TAs) (5), in which observable actions are partitioned into inputs and outputs. We consider here partially observable and non-deterministic TAIOS with invariants for the modeling of urgency. In this work, we propose to generate test cases off-line for non-deterministic TAIOS, in the formal context of the tioco (4) conformance theory.

2 Contributions

The main research contributions presented in this work are the following (6).

1. Testing Techniques for Distributed and Dynamically Adaptable Systems:
 - (a) We designed a standard-based test execution platform which affords a platform-independent test system for isolating and executing runtime tests (7). This platform uses the TTCN3 standard and considers both structural and behavioral adaptations. Moreover, our platform is equipped with a test isolation layer that reduces the risk of interference between testing processes and business processes.
 - (b) We computed a minimal subset of test cases to run and efficiently distributed them among the execution nodes while respecting resource and connectivity constraints. The minimal subset of test cases is obtained using a smart generation algorithm which keeps old tests cases which are still valid and replaces invalid ones by new generated or updated test cases.
 - (c) We validated the proposed techniques on two case studies, one in the healthcare domain and the other one in the fleet management domain. Through several experiments, we showed the efficiency of our tool in reducing the cost of runtime testing and we measure the overhead introduced in case of dynamic structural or behavioral adaptations.
2. A Model-Based Approach to Combine Load and Functional Tests:
 - (a) We proposed a formal model-based framework to combine functional and load tests. The proposed framework is based on the model of extended timed automata with inputs/outputs and shared integer variables. In addition, we presented different modelling issues illustrating some methodological aspects of our framework and we illustrated them by means of a case study.
 - (b) We studied BPEL compositions behaviors under various load conditions using the proposed framework. We also proposed a taxonomy of the detected problems by our solution and we illustrated how test verdicts are assigned. Moreover, we validated our approach using a Travel Agency case study. We considered several mutants of the corresponding BPEL process and we tested them using our tool.
3. Formal Techniques for Determinization and Off-Line Test Selection for Timed Automata:
 - (a) We proposed a game-based approach for the determinization of timed automata. For a given timed automaton \mathcal{A} and some fixed resources, we build a finite turn-based safety game between two players Spoiler and Determinizer, such that any strategy for Determinizer yields a deterministic over-approximation of the language of \mathcal{A} and any winning strategy provides a deterministic equivalent for \mathcal{A} .

- (b) We introduced a complete formalization for the automatic off-line generation of test cases from non-deterministic timed automata with inputs and outputs. We proposed an approximate determination procedure and a selection technique of test cases with expressive test purposes. Test cases are generated using a symbolic co-reachability analysis of the observable behaviors of the specification guided by the test purpose.

3 Future Works

Many possible extensions for our work are possible. Next we list some possible directions to investigate in the future.

- **Meta-heuristic techniques for the constrained test placement problem:** The major problem that we faced while applying RTF4ADS on large-scale environments comes from the constrained test placement module. In fact, this module requires a long time to compute an exact optimal solution fitting the resource and connectivity constraints. Therefore, we intend to use the *Tabu Search* (TS) meta-heuristic as a resolution algorithm and performing a parallel exploration of the solution domain.
- **Extension of the distributed TTCN-3 Test System:** The current version of RTF4ADS focuses only on distributing TTCN-3 test cases. Each one is managed by a *Main Test Component* (MTC) and may create several Parallel Test Components (PTC) in order to execute integration tests. To gain more performance and to alleviate the test workload on the execution environment, we should also distribute PTC Components over the execution nodes in order to avoid the communication overhead introduced by the centralized execution architecture.
- **Runtime testing of autonomous systems:** We intend to enhance our test framework in order to support autonomous systems which are able generate emergent behaviors in response to changing environmental conditions. To do so, we should include our test system into *Monitor-Analyze-Plan-Execute* (MAPE-K) loops with the purpose of automating not only the adaptation process but also the runtime testing process.
- **Test generation based on probabilistic model-checking:** The key idea here is to apply runtime testing before the occurrence of dynamic proactive adaptations which consist in making predictions of how the environment or the system is going to evolve in the near future. To do so, tests have to be generated from behavioral models that are augmented with probabilities to describe the unpredictable system's behavior. Formalisms like *Probabilistic Timed Automata* can be used to specify the system behavior.
- **Distributed and resource-aware load testing of WS-BPEL compositions:** Recognizing problems under load is a challenging and time-consuming activity due to the large amount of generated data

and the long running time of load tests. For this reason, we intend to extend our previous approach dealing with functional and load testing of BPEL compositions by distribution and resource awareness capabilities. Indeed, supporting test distribution over the network may alleviate considerably the test workload at runtime, especially when the SUT is running on a cluster of BPEL servers.

- **Developping heuristics to determinize timed automata:** The determinization of timed automata is a complex problem and our proposed algorithms run in time doubly exponential in the size of the input. Given the difficulty of the problem, it would be of interest to develop some heuristics. For instance, the resources and other features of our algorithms could be optimized online. During the on-the-fly construction of the game while searching for a winning strategy, resource clocks could be added if necessary, or the precision of the guards and relations could be increased.
- **Combining coverage with on-line test execution for real-time systems:** The topic of coverage needs to be studied in more depth in a real-time context. In particular, combining coverage with on-line test execution is another aspect that seems to be little studied. The problem is related to choosing online tester outputs and output times. Many heuristics can be applied to resolve such choices, but an additional problem is how to manage these choices across the execution of the entire test suite, using some appropriate book-keeping techniques.

4 List of Publications

Journals

- Moez Krichen, Afef Jmal Maâlej, Mariam Lahami. A model-based approach to combine conformance and load tests: an eHealth case study. In *International Journal of Critical Computer-Based Systems, IJCCBS 8(3/4): 282-310 (2018)*. (8)
- Mariam Lahami, Moez Krichen. Safe and Efficient Runtime Testing Framework Applied in Dynamic and Distributed Systems. In *Science of Computer Programming Journal. 122: 1-28 (2016)*. (9)
- Afef Jmal Maâlej, Moez Krichen, Mohamed Jmaiel. A Comparative Evaluation of State-of-the-Art Load and Stress Testing Approaches. In *International Journal of Computer Applications in Technology IJCAT 51(4): 283-293 (2015)*. (10)
- Mariam Lahami, Moez Krichen, Mohamed Jmaiel. Runtime Testing Approach of Structural Adaptations for Dynamic and Distributed Systems. In *International Journal of Computer Applications in Technology. IJCAT 51(4): 259-272 (2015)*. (11)
- Afef Jmal Maâlej, Moez Krichen. Study on the Limitations of WS-BPEL Compositions Under Load Conditions. In *The Computer Journal (2015) 58 (3): 385-402* (12)

- Nathalie Bertrand, Amélie Stainer, Thierry Jéron, Moez Krichen. A game approach to determinize timed automata. In *Formal Methods in System Design 46(1): 42-80 (2015)*. (13)
- Nathalie Bertrand, Thierry Jéron, Amélie Stainer, Moez Krichen: Off-line test selection with test purposes for non-deterministic timed automata. In *Logical Methods in Computer Science 8(4) (2012)*. (14)
- Moez Krichen: A formal framework for black-box conformance testing of distributed real-time systems. In *International Journal of Critical Computer-Based Systems, IJCCBS 3(1/2): 26-43. 2012*. (15) [Arabic version available (16)]
- Mariam Lahami, Moez Krichen and Mohamed Jmaiel. A distributed Test Architecture For Adaptable and Distributed Real-Time Systems. In *the Journal of New technologies of Information. 2012*. (17)

Conferences

- Mariam Lahami, Moez Krichen, Roobaea Alroobaea. Towards a Test Execution Platform As-A-Service: Application in the E-Health Domain. In *Proceedings of the 2nd International Conference on Control, Automation and Diagnosis (ICCAD 2018), Marrakech, Morocco, March 19-21, 2018. IEEE, 2018*. (18)
- Moez Krichen, Afef Jmal Maâlej, Mariam Lahami, Mohamed Jmaiel. A Resource-Aware Model-Based Framework for Load Testing of WS-BPEL Compositions. In *Enterprise Information Systems - 20th International Conference, ICEIS 2018, Funchal, Madeira, Portugal, March 21-24, 2018, Revised Selected Papers, pages 130-157, LNBIP, volume 363. Springer, 2018*. (19)
- Afef Jmal Maâlej, Mariam Lahami, Moez Krichen, Mohamed Jmaiel. Distributed and Resource-Aware Load Testing of WS-BPEL Compositions. In *Proceedings of the 20th International Conference on Enterprise Information Systems (ICEIS 2018), Funchal, Madeira, Portugal, March 21-24, 2018, Volume 2. SciTePress 2018*. (20)
- Moez Krichen, Omar Cheikhrouhou, Mariam Lahami, Roobaea Alroobaea, Afef Jmal Maâlej. Towards a Model-Based Testing Framework for the Security of Internet of Things for Smart City Applications. In *Proceedings of the 1st EAI International Conference on Smart Societies Infrastructure, Technologies, and Applications (SCITA 2017), Jeddah, Saudi Arabia, November 27-29, 2017. Springer, 2017*. (21)
- Afef Jmal Maâlej, Moez Krichen. WSCLim: A Tool for Model-Based Testing of WS-BPEL Compositions Under Load Conditions. In *Proceedings of the 11th International Conference on Tests and Proofs (TAP 2017), pages 139-151, Marburg, Germany, July 19-20, 2017. Springer, 2017*. (22)
- Mariam Lahami, Moez Krichen, Hajer Barhoumi, Mohamed Jmaiel. Selective Test Generation Approach for Testing Dynamic Behavioral Adaptations. In *Proceedings of the 27th IFIP International Conference of Testing Software and Systems (ICTSS 2015), pages 224-239, Sharjah and Dubai, United Arab Emirates, November 23-25, 2015. Springer, 2015*. (23)

- Mariam Lahami, Moez Krichen. Test Isolation Policy for Safe Runtime Validation of Evolvable Software Systems. In *Proceedings of the 22nd IEEE International Conference on Enabling Technologies: Infrastructures for Collaborative Enterprises (WETICE 2013)*, pages 377-382, Hammamet, Tunisia, June 17-20, 2013, IEEE Computer Society. (23)
- Afef Jmal Maâlej, Manel Hamza, Moez Krichen. WSCLT: A Tool for WS-BPEL Compositions Load Testing. In *Proceedings of the 22nd IEEE International Conference on Enabling Technologies: Infrastructures for Collaborative Enterprises (WETICE 2013)*, pages 272-277, Hammamet, Tunisia, June 17-20, 2013, IEEE Computer Society. (24)
- Mariam Lahami, Fairouz Fakhfakh, Moez Krichen, Mohamed Jmaiel. Towards a TTCN-3 Test System for Runtime Testing of Adaptable and Distributed Systems. In *Proceedings of the 23rd IFIP International Conference of Testing Software and Systems, ICTSS 2012, Aalborg, Denmark, November 19 - 21, 2012*. Springer, 2012. (25)
- Mariam Lahami, Moez Krichen, Mariam Bouchakwa, Mohamed Jmaiel. Using Knapsack Problem Model to Design a Resource Aware Test Architecture for Adaptable and Distributed Systems. In *Proceedings of the 23rd IFIP International Conference of Testing Software and Systems, ICTSS 2012, Aalborg, Denmark, November 19 - 21, 2012*. Springer, 2012 (26)
- Mariam Lahami, Moez Krichen, Mohamed Jmaiel. A distributed Test Architecture For Adaptable and Distributed Real-Time Systems. In *Proceedings of 'Conférence sur les Architectures Logicielles', CAL 2011, Lille, France, June 2011*. (17)
- Nathalie Bertrand, Amélie Stainer, Thierry Jéron, Moez Krichen. A Game Approach to Determinize Timed Automata. In *Proceedings of the 14th International Conference on Foundations of Software Science and Computation Structures, FoSSaCS'11, Saarbrücken, Germany, April 2011*. LNCS 6604, pages 245-259. Springer, 2011. (27)
- Nathalie Bertrand, Amélie Stainer, Thierry Jéron, Moez Krichen. Off-line Test Selection with Test Purposes for Non-Deterministic Timed Automata. In *Proceedings of the 17th International Conference on Tools and Algorithms for the Construction and Analysis of Systems (TACAS'11), Saarbrücken, Germany, April 2011*. LNCS 6605, pages 96-111. Springer, 2011. (28)
- Moez Krichen. A Formal Framework for Conformance Testing of Distributed Real-Time Systems. In *Proceedings of the 14th International Conference On Principles Of Distributed Systems, OPODIS 2010, Tozeur, Tunisia, December 14-17, 2010*. LNCS 6490, pages 139-142. Springer, 2010. (29)
- Mariam Lahami, Moez Krichen, Akram Idani, Mohamed Jmaiel. A generic process to build reliable distributed software components from early to late stages of software development. In *Sixth International Conference on Computer Engineering and Systems, ICCES 2010, Cairo, Egypt, November 30 - December 2, 2010, Proceedings*. (30)

- Moez Krichen, Monika Solanki. Automatic Generation of Real-Time Observers for Monitoring Web Services. In *Second International Conference on Web and Information Technologies, ICWIT 2009, Kerkennah Islands, Sfax, Tunisia, June 12 - 14, 2009, Proceedings*. (31)
- Matthieu Gallien, Fahmi Gargouri, Imen Kahloul, Moez Krichen, Thanh Hung Nguyen, Saddek Bensalem, Félix Ingrand. D'une approche modulaire à une approche orientée composant pour le développement de systèmes autonomes : défis et principes. In *3rd National Conference on Control Architectures of Robots, CAR 2008, Bourges, France, May 29 - 30, 2008, Proceedings*. Invited paper. (32)
- Saddek Bensalem, Marius Bozga, Matthieu Gallien, Félix Ingrand, Moez Krichen, Stavros Tripakis. Automatic generation of observers for the dala robot with ttg. In *1st Mediterranean Conference on Intelligent Systems and Automation, CISA 2008, Annaba, Algeria, June 30 - July 02, 2008, Proceedings, volume 1019 of American Institute of Physics*, pages 487–492. AIP, 2008. (33)
- Saddek Bensalem, Moez Krichen, Stavros Tripakis. Generating Analog-Clock Real-Time Testers Using Action Refinement Techniques. Dans les *Actes de la Conférence Internationale sur les Relations, Ordres et Graphes: Interaction avec l'Informatique, ROGICS 2008, Mahdia, Tunisie, 12-17 Mai 2008*.

Workshops

- Afef Jmal Maâlej, Moez Krichen, Mohamed Jmaiel. A Model Based Approach to Combine Load and Functional Tests for Service Oriented Architectures. In *Proceedings of the 10th Workshop on Verification and Evaluation of Computer and Communication System (VECoS 2016), Tunis, Tunisia, October 6-7, 2016. CEUR-WS.org 2016*. (34)
- Mariam Lahami, Moez Krichen, Mohamed Jmaiel. Runtime Testing Framework for Improving Quality in Dynamic Service-based Systems. In *Proceedings of the 2nd International Workshop on Quality Assurance for Service-Based Applications (QASBA 2013) in conjunction with the International Symposium in Software Testing and Analysis (ISSTA 2013), pages 17-24, Lugano, Switzerland, July 2013*. ACM. (35)
- Afef Jmal Maâlej, Zeineb Ben Makhlof, Moez Krichen, Mohamed Jmaiel. Conformance Testing for Quality Assurance of Clustering Architectures. In *Proceedings of the 2nd International Workshop on Quality Assurance for Service-Based Applications (QASBA 2013) in conjunction with the International Symposium in Software Testing and Analysis (ISSTA 2013), pages 9-16, Lugano, Switzerland, July 2013*. ACM. (36)
- Afef Jmal Maâlej, Manel Hamza, Moez Krichen, Mohamed Jmaiel. Automated Significant Load Testing for WS-BPEL Compositions. In *Proceedings of the 6th IEEE International Conference on Software Testing, Verification and Validation Workshops (ICSTW 2013), pages 144-153, Luxembourg, March 18-22, 2013, IEEE Computer Society*. (37)

- Afef Jmal Maâlej, Moez Krichen, Mohamed Jmaiel. WSCCT: A Tool for WS-BPEL Compositions Conformance Testing. *In Proceedings of the 28th Annual ACM Symposium on Applied Computing (SAC 2013), pages 1055-1061, Coimbra, Portugal, March 18-22, 2013, ACM.* (38)
- Afef Jmal Maâlej, Moez Krichen, Mohamed Jmaiel. Model-based Conformance Testing of WS-BPEL Compositions. *In Proceedings of the IEEE 36th International Conference on Computer Software and Applications Workshops, COMPSAC 2012, pages 452-457, Izmir, Turkey, July 16-20, 2012. IEEE Computer Society.* (39)
- Saddek Bensalem, Moez Krichen, Stavros Tripakis. State Identification Problems for Input/Output Transition Systems. *In 9th International Workshop on Discrete Event Systems, WODES 2008, Göteborg, Sweden, May 28 - 30 2008 , Proceedings, pages 225-230. IEEE, 2008.* (40)

References

- [1] R. Alur and D. L. Dill, “A theory of timed automata,” *Theoretical Computer Science*, vol. 126, no. 2, pp. 183–235, 1994.
- [2] M. Krichen, “Model-based testing for real-time systems,” Ph.D. dissertation, PhD thesis, University of Joseph Fourier (December 2007), 2007.
- [3] C. Baier, N. Bertrand, P. Bouyer, and T. Brihaye, “When are timed automata determinizable?” in *ICALP’09*, ser. LNCS, vol. 5556, 2009, pp. 43–54.
- [4] M. Krichen and S. Tripakis, “Conformance testing for real-time systems,” *Formal Methods in System Design*, vol. 34, no. 3, pp. 238–304, 2009.
- [5] R. Alur and D. Dill, “A theory of timed automata,” *Theoretical Computer Science*, vol. 126, pp. 183–235, 1994.
- [6] M. Krichen, “Contributions to model-based testing of dynamic and distributed real-time systems,” Ph.D. dissertation, École Nationale d’Ingénieurs de Sfax (Tunisie), 2018.
- [7] M. Lahami, “Runtime testing of dynamically adaptable and distributed component based Systems,” Theses, Ecole Nationale d’Ingénieurs de Sfax, Apr. 2017. [Online]. Available: <https://hal.archives-ouvertes.fr/tel-02469999>
- [8] M. Krichen, A. J. Maâlej, and M. Lahami, “A model-based approach to combine conformance and load tests: an ehealth case study.” *IJCCBS*, vol. 8, no. 3/4, pp. 282–310, 2018.
- [9] M. Lahami, M. Krichen, and M. Jmaïel, “Safe and Efficient Runtime Testing Framework Applied in Dynamic and Distributed Systems,” *Science of Computer Programming (SCP)*, vol. 122, no. C, pp. 1–28, 2016.

- [10] A. J. Maâlej, M. Krichen, and M. Jmaïel, “A comparative evaluation of state-of-the-art load and stress testing approaches,” *Int. J. Comput. Appl. Technol.*, vol. 51, no. 4, pp. 283–293, Jul. 2015.
- [11] M. Lahami, M. Krichen, and M. Jmaïel, “Runtime testing approach of structural adaptations for dynamic and distributed systems,” *International Journal of Computer Applications in Technology*, vol. 51, no. 4, pp. 259–272, 2015.
- [12] A. J. Maâlej and M. Krichen, “Study on the limitations of ws-bpel compositions under load conditions,” *The Computer Journal*, vol. 58, no. 3, pp. 385–402, 2015.
- [13] N. Bertrand, A. Stainer, T. Jérón, and M. Krichen, “A game approach to determinize timed automata,” *Formal Methods in System Design*, vol. 46, no. 1, pp. 42–80, 2015.
- [14] N. Bertrand, T. Jérón, A. Stainer, and M. Krichen, “Off-line test selection with test purposes for non-deterministic timed automata,” *Logical Methods in Computer Science*, vol. 8, no. 4, 2012. [Online]. Available: [https://doi.org/10.2168/LMCS-8\(4:8\)2012](https://doi.org/10.2168/LMCS-8(4:8)2012)
- [15] M. Krichen, “A formal framework for black-box conformance testing of distributed real-time systems,” *International Journal of Critical Computer-Based Systems*, vol. 3, no. 1-2, pp. 26–43, 2012.
- [16] Moez Krichen, “A black-box model-based framework for conformance testing of real-time distributed systems (in arabic),” 2018. [Online]. Available: <http://rgdoi.net/10.13140/RG.2.2.22391.57764>
- [17] M. Lahami, M. Krichen, and M. Jmaïel, “A distributed test architecture for adaptable and distributed real-time systems,” in *Avancées récentes dans le domaine des Architectures Logicielles : articles sélectionnés et étendus de CAL’2011, Lille, France, 7-8 Juin 2011*, ser. Revue des Nouvelles Technologies de l’Information, P. Aniorté, Ed., vol. L-6. Hermann, 2011, pp. 73–92. [Online]. Available: <http://editions-rnti.fr/?inprocid=1001804>
- [18] M. Lahami, M. Krichen, and R. Alroobaea, “Towards a test execution platform as-a-service: Application in the e-health domain,” in *2018 International Conference on Control, Automation and Diagnosis (ICCAD)*. IEEE, 2018, pp. 1–6.
- [19] M. Krichen, A. J. Maâlej, M. Lahami, and M. Jmaïel, “A resource-aware model-based framework for load testing of ws-bpel compositions,” in *International Conference on Enterprise Information Systems*. Springer, Cham, 2018, pp. 130–157.
- [20] A. J. Maâlej, M. Lahami, M. Krichen, and M. Jmaïel, “Distributed and resource-aware load testing of ws-bpel compositions,” in *ICEIS (2)*, 2018, pp. 29–38.
- [21] M. Krichen, O. Cheikhrouhou, M. Lahami, R. Alroobaea, and A. J. Maâlej, “Towards a model-based testing framework for the security of internet of things for smart city applications,” in *International*

- Conference on Smart Cities, Infrastructure, Technologies and Applications*. Springer, 2017, pp. 360–365.
- [22] A. J. Maâlej, M. Krichen, and M. Jmaïel, “Wscim: A tool for model-based testing of ws-bpel compositions under load conditions,” in *International Conference on Tests and Proofs*. Springer, 2017, pp. 139–151.
- [23] M. Lahami, M. Krichen, H. Barhoumi, and M. Jmaïel, “Selective test generation approach for testing dynamic behavioral adaptations,” in *IFIP International Conference on Testing Software and Systems*. Springer, 2015, pp. 224–239.
- [24] A. J. Maâlej, M. Hamza, and M. Krichen, “Wscit: a tool for ws-bpel compositions load testing,” in *2013 Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises*. IEEE, 2013, pp. 272–277.
- [25] M. Lahami, F. Fakhfakh, M. Krichen, and M. Jmaïel, “Towards a TTCN-3 Test System for Runtime Testing of Adaptable and Distributed Systems,” in *Proceedings of the 24th IFIP WG 6.1 International Conference Testing Software and Systems (ICTSS’12)*, 2012, pp. 71–86.
- [26] M. Lahami, M. Krichen, M. Bouchakwa, and M. Jmaïel, “Using Knapsack Problem Model to Design a Resource Aware Test Architecture for Adaptable and Distributed Systems,” in *Proceedings of the 24th IFIP WG 6.1 International Conference Testing Software and Systems (ICTSS’12)*, 2012, pp. 103–118.
- [27] N. Bertrand, A. Stainer, T. Jérón, and M. Krichen, “A game approach to determinize timed automata,” in *FOSSACS’11*, 2011, to appear. Extended version as INRIA report 7381, <http://hal.inria.fr/inria-00524830>.
- [28] N. Bertrand, A. Stainer, T. Jérón, and M. Krichen, “A game approach to determinize timed automata,” in *Foundations of Software Science and Computational Structures - 14th International Conference, FOSSACS 2011, Held as Part of the Joint European Conferences on Theory and Practice of Software, ETAPS 2011, Saarbrücken, Germany, March 26-April 3, 2011. Proceedings*, ser. Lecture Notes in Computer Science, M. Hofmann, Ed., vol. 6604. Springer, 2011, pp. 245–259. [Online]. Available: https://doi.org/10.1007/978-3-642-19805-2_17
- [29] M. Krichen, “A Formal Framework for Conformance Testing of Distributed Real-Time Systems,” in *Proceedings of the 14th International Conference On Principles Of Distributed Systems, (OPODIS’10)*, 2010.
- [30] M. Lahami, M. Krichen, M. Jmaïel, and A. Idani, “A generic process to build reliable distributed software components from early to late stages of software development,” in *The 2010 International Conference on Computer Engineering & Systems*. IEEE, 2010, pp. 287–292.

- [31] M. Krichen and M. Solanki, “Automatic generation of realtime observers for monitoring web services,” in *Proceedings of the Second International Conference on Web and Information Technologies (ICWIT’09)*, 2009.
- [32] M. Gallien, F. Gargouri, I. Kahloul, M. Krichen, T.-H. Nguyen, S. Bensalem, and F. Ingrand, “D’une approche modulaire à une approche orientée composant pour le développement de systemes autonomes: Défis et principes,” *Proceedings of Control Architectures of Robots, CAR*, 2008.
- [33] S. Bensalem, M. Bozga, M. Gallien, F. F. Ingrand, M. Krichen, and S. Tripakis, “Automatic generation of observers for the dala robot with ttg,” in *AIP Conference Proceedings*, vol. 1019, no. 1. American Institute of Physics, 2008, pp. 487–492.
- [34] A. J. Maâlej and M. Krichen, “A model based approach to combine load and functional tests for service oriented architectures.” in *VECoS*, 2016, pp. 123–140.
- [35] M. Lahami, M. Krichen, and M. Jmaïel, “Runtime Testing Framework for Improving Quality in Dynamic Service-based Systems,” in *Proceedings of the 2nd International Workshop on Quality Assurance for Service-based Applications (QASBA ’13), in conjunction with (ISSTA ’13)*, 2013, pp. 17–24.
- [36] A. J. Maâlej, Z. B. Makhoulf, M. Krichen, and M. Jmaïel, “Conformance testing for quality assurance of clustering architectures,” in *Proceedings of the 2013 International Workshop on Quality Assurance for Service-based Applications*, 2013, pp. 9–16.
- [37] A. J. Maâlej, M. Hamza, M. Krichen, and M. Jmaïel, “Automated significant load testing for ws-bpel compositions,” in *Proceedings of the 6th IEEE International Conference on Software Testing, Verification and Validation*. Luxembourg: IEEE Computer Society, March 18-22 2013, pp. 144–153.
- [38] A. J. Maâlej, M. Krichen, and M. Jmaïel, “Wscet: A tool for ws-bpel compositions conformance testing,” in *Proceedings of the 28th Annual ACM Symposium on Applied Computing*, 2013, pp. 1055–1061.
- [39] A. J. Maâlej, M. Krichen, and M. Jmaïel, “Model-Based Conformance Testing of WS-BPEL Compositions,” in *Proceeding of the 4th IEEE International Workshop on Software Test Automation (STA ’12) in conjunction with (COMPSAC ’12)*, 2012, pp. 452–457.
- [40] S. Bensalem, M. Krichen, and S. Tripakis, “State identification problems for input/output transition systems,” in *2008 9th International Workshop on Discrete Event Systems*. IEEE, 2008, pp. 225–230.