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Evaluation of Artur Męski's PhD thesis manuscript

I was recently contacted by the Institute of Computer Science of the Polish Academy of Sciences with a request to evaluate Artur Męski's PhD thesis. I followed Męski's work for several years already, as his research field partially overlaps with my own. I thus feel qualified to write this evaluation and I have the first-hand evidence to base it on.

Męski's background is firmly rooted in formal methods, specifically model checking. This is an area of research with long traditions and spectacular results, especially in software engineering. Model checking has found in the last couple of decades remarkable new applications in, among others, autonomous systems, cyber-physical systems, in systems and synthetic biology. Męski focused in his PhD project on model checking for reaction systems, a recent computational framework inspired by the functioning of (and biochemistry of) the living cell.

Męski's high level objective was to demonstrate that model checking can be successfully applied to reaction system. Some work on this topic had been done prior to, and during the early phases of his project, by my group and others. Męski embarked on a systematic investigation of the potential of model checking for reaction systems, and designed it with the firm grasp of a fundamental, logic-based approach. He managed to extend significantly the current state-of-the-art in this field in several different respects. I discuss below in details his contributions and their significance to the field.

The first set of contributions (in the order they are presented in his thesis manuscript) is on extending the reaction systems framework with the capability of specifying the context sequences driving their dynamics (in terms of interactive processes). The reason for this extension was so that temporal properties of reaction systems could be specified formally and verified through model checking. Męski introduced the so-called initialized context restricted reaction systems, as well as their interactive processes. A branching time logic, rsCTL, was then introduced to specify properties of such systems. Męski demonstrated the usefulness of this logic on several examples and introduced several algorithms for model checking in this logic. He also demonstrated that the general model checking problem in this logic is PSPACE-complete. He also showed that this remains true also for the symbolic modelc checking problem.

The second set of contributions is on extending reaction systems to allow the modeling of multi-agent systems, a topic on which his research group has made many significant research contributions over the years. He refined his earlier idea of specifying context sequences and defined so-called context automata, defining suitable context sequences for the interactive processes of a reaction system. He also introduced the so-called multi-agent reaction systems, a distributed form of the reaction system framework. To specify and verify logical properties of such systems, he introduced the rsCTLK, a logic for temporal-epistemic properties of reaction systems. He then showed that the model checking problem in this logic is PSPACE-complete. He also described a symbolic model checking method based on binary decision diagrams.

The third set of contributions is on model checking for reaction systems with discrete concentrations. He introduces this notion of reaction systems, by extending the basic formalism from a set-based framework to a multiset-based one, an elegant idea with independent merits of its own. Similarly as in his other contributions, he then introduced a suitable logic for this new framework, the rsLTL, and showed that the model checking problem is PSPACE-complete also in this case.

The fourth set of contributions concerns another bold extension of the reaction systems: that of having a parametric formulation. Following the same pattern of investigation, he proves that model checking remains PSPACE-complete also in this case. He also discusses a translation of the parameter synthesis problem into the satisfiability modulo theory.

The fifth set of contributions concerns the implementation of all the algorithms proposed in his thesis, and the experimental exploration of each of them on several case studies. This includes a dedicated specification language for reaction systems, and a Python-based, open-source toolkit of software methods for model checking for reaction systems.

The contributions brought by Męski's PhD thesis manuscript are unusually broad. He successfully managed to drive a systematic investigation of several different ways in which logical properties of reaction systems may be useful to specify and verify. In each case he extended in a natural way the basic formalism of reaction systems, introduced a suitable logic, clarified the computational complexity of the model checking problem, introduced some algorithms, implemented them, and demonstrated them experimentally. The definitions he proposed are natural and elegant, the proofs are correct, and the software implementations convincingly demonstrated experimentally. In driving his project to completion, Męski demonstrated deep skills of logic, formal methods, computational complexity, computational modeling, and software engineering. Such a broad set of skills is very unusual for a young PhD student, and worthy of special praise. His results extend significantly the current state-of-the-art in model checking for reaction system and provide the new baseline for any further research in this field.

Based on the arguments outlined above, I strongly recommend to the Institute of Computer Science of the Polish Academy of Sciences to approve Artur Męski's PhD thesis manuscript. Furthermore, I think the breadth and the depth of his contributions are unusual for a PhD thesis. His work has been well received by the international community, as evident in the quality of the forums where he published, as well as by the good number of citations his work has received (he has an h-index of 6 and over 100 citations, a very good achievement

for a PhD candidate). Because of this, I strongly support awarding him his degree with honors.

Sincerely yours,

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