MASARYKOVA UNIVERZITA

Annex No. 11 to the MU Directive on Habilitation Procedures and Professor Appointment Procedures

Habilitation Thesis Reviewer's Report

Masaryk University	
Faculty	Faculty of Informatics
Procedure field	Informatics
Applicant	RNDr. Vojtěch Řehák, Ph.D.
Applicant's home unit, institution	Faculty informatics, Masaryk University
Habilitation thesis	Stochastic Real-Time Systems: Parameter Synthesis and Games
Reviewer	**Prof. Patricia Bouyer-Decitre**
Reviewer's home unit, institution	LSV, CNRS & ENS de Cachan, France

The Habilitation thesis of Vojtěch Řehák is a collection of 11 articles preceded by 4 chapters giving a unified perspective to these articles. These 11 articles are only a part of the scientific production of Vojtěch Řehák.

The topic of the thesis is the analysis of stochastic real-time systems, which are systems where delays are randomized. Discrete decisions can either be randomized or agent-based.

The document starts with a short introduction giving the motivation for the research topic.
Chapter 2 then informally presents the models of interest, starting with the general fully stochastic model of generalized semi-Markov processes (GSMP). Various subclasses are then presented. Several measures of performance are then discussed, together with the important concept of instability. Extensions of these fully stochastic models are then provided. These extensions either allow non-deterministic or agent-based decisions (so they are Markov decision processes or games), or synthesis of distributions.
In chapter 3, Vojtěch Řehák explains the relations between the models he will study and other known models of the literature.
Chapter 4 comments on the contributions of the 11 papers he provides in his thesis. I have chosen to comment the contributions using the logical blocks highlighted in this chapter.

Analysis of GSMPs. In [P3] (CONCUR'11), it is shown that finite GSMPs are not stable in general. A counter-example is provided, where instable behaviours almost-surely happen. This phenomenon is due to fixed-delay events, and it is also shown in this paper that if we restrict the use of those fixed-delay events, then all behaviours are almost-surely stable. To me, this result is a major result, for (at least) two reasons: first, as consequences, standard analysis or approximation technics cannot be applied; then, this issue had been mostly ignored in earlier literature. A similar counter-example was provided in [P5] (ICPE'13) for stochastic Petri nets, showing the important impact of the former result. Paper [P2] (HSCC'11) was an earlier paper showing the stability, hence the decidability, of the model of semi-Markov processes with properties expressed as deterministic timed automata. The proof in this paper goes via a proof of stability of the system, and is related to the stability proof of [P3].

Another problem that is considered here is that of the approximation GSMPs using the approximation of continuous distributions with phase-type distributions. While this is theoretically possible to use such approximations to analyse finite GSMPs, it requires the construction of huge continuous-time Markov chains. This makes the analysis almost infeasible in practice. In [P6] (EPEW'14), a new approximation algorithm using d-CTMCs (that is, CTMCs with fixed delays) are provided, which are experimentally proven feasible.

Generalized semi-Markov games. Those are games with stochastic states (like in GSMPs), and player-1 as well as player-2 states. The winning condition is expressed with a deterministic timed automata with a reachability condition. While the existence of a value can be obtained quickly via standard results, it is proven via an example that there might not exist optimal strategies. Then, it is shown how to decide the existence of almost-sure winning strategies via a region automaton construction. Note that the instability problems mentioned previously are not relevant here since a reachability condition is considered. Those results have appeared in [P1] (CONCUR'10), and form the first (chronologically) work in this thread of research. I realize here that this paper contains the first fruits of the reflexion on the stability of stochastic real-time systems we have mentioned earlier, and is, as such, a very important contribution to the field.

Interactive Markov chains. Interactive Markov chains (IMCs) are somehow open continuous-time Markov chains, which can be conveniently composed. In [P4] (FSTTCS'12), the first algorithm is proposed to analyse these open systems (for time-bounded reachability properties). The algorithm goes through the definition of a two-player game, and then via a discretization step (that we can control). This is correct under some hypotheses on the IMCs. Proving the correctness of such an algorithm is really technical and requires to be made with much care. There are a couple of follow-up papers to this work, but they are not works by Vojtěch Řehák.

Synthesis of delays in fdCTMC. The model of fdCTMC is the one of CTMCs enhanced with parameterized fixed-delay events, that is, there are some timeouts in the states, after which no more delay can happen. Values of these delays are assumed to be parameters, and the considered problem consists in synthesizing parameter values that optimize some reward function. It is shown that optimal parameter values can be arbitrarily approximated both for optimal reachability [P7] (QEST'15) and for mean-payoff [P10] (QEST'17). While these two works share the same structure, it requires different technicalities. The general idea is to transform the problem into an optimization problem in a non-denumerable (semi-)Markov decision process, and to discretize the set of actions to get approximations with an arbitrary precision of the original optimization problem. Practical considerations and implementations, as well as alternative algorithms (based on policy iteration) are given as [P8] (IFM'16) and [P9] (MASCOTS'16).

MDP with resilient control. Markov decision processes (MDPs) with repairs are specific MDPs where some states are considered as normal behaviours whereas some states are error states, and which structurally satisfy some conditions. The aim is to study resilient schedulers that operate safely with high probability within a certain cost amount. In [P11] (ATVA'17), the existence of resilient schedulers is proven to be decidable. The proof uses recent results on multidimensional MDPs.

Conclusion. The contributions of Vojtěch Řehák presented in this thesis cover a large spectrum, from inspiring fundamental results on stochastic real-time systems to practical algorithms and implementations. In this research topics, proofs have to be made in a very careful manner, as witnessed by some mistakes found in the earlier literature, and those proofs are always very technical and require strong mathematical skills and rigor. I knew some (actually many) of the papers before reviewing the thesis, and I have been very much impressed by the quality of the papers, both in terms of clarity and of technical strength.

Reviewer's questions for the habilitation thesis defence (number of questions up to the reviewer)

1. The notion of instability of GSMPs that you consider (based on the definition of the frequency functions) seems to be linked with that of `fairness' (and that I have looked at in my works). I can see that technically, it seems it corresponds to the same properties (unfair region automaton construction), but is there a more direct formal link between the two notions?
2. In [DHS09] (reference below), a specification language CSL^{TA} is presented and an algorithm for analysing CTMCs is given. How would you compare your approach in [P2] and their approach? Could we get both expressiveness (SMPs on one side and CSL^{TA} on the other side) while preserving decidability?
   [DHS09] S. Donatelli, S. Haddad, and J. Sproston. Model Checking Timed and Stochastic Properties with CSL^{TA}. IEEE Transactions on Software Engineering, 35(2):224--240, March-April 2009.
3. In [P6], it is unclear to me what are the hypotheses that you need to have on the distributions? Are fixed-delay events allowed? I understand that you require that probability density functions exist, but is that really required? Could the Radon-Nikodym theorem not help getting rid of this hypothesis?
4. In your work about fdCTMCs, you devise approximation algorithms. But what is the decidability status of the problem?
5. In [P11], if you turn the decision problem into an optimization problem, will the Pareto frontier be computable? Also, specification and synthesis of those MDPs where resilient controllers exist (by construction), would be interesting for the system designer.
6. What are the next big challenges in your research plan?

Conclusion

The habilitation thesis entitled "*Stochastic Real-Time Systems: Parameter Synthesis and Games*" by Vojtěch Řehák ***fulfils*** requirements expected of a habilitation thesis in the field of Informatics.

In Cachan on March 19, 2019

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