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. Kim G. Larsen**
Reviewer's home unit, institution	Department of Computer Science, Aalborg University, Denmark

This thesis collects a large number of results related to stochastic real time systems. In particular the thesis considers several stochastic models ranging from (continuous and discrete time) Markov chains to generalized semi-Markov processes, decision processes and games, and with focus on several subclasses. The commentary part of the thesis provides a clear overview of theses models as well as a number of related models (queuing systems, stochastic Petri nets, stochastic timed automata and stochastic process algebra).

The thesis is based on a collection of 11 peer-reviewed papers published in the period 2010-2017 with clear indications of the (in all cases significant) contribution of Vojtěch Řehák. The majority of the papers has appear in top outlets including CONCUR, HSCC, FSTTCS, QEST and ATVA witnessing the high quality of the underlying research.

The papers in the collection make significant contributions to a number fundamental and hard problems within the area of stochastic real time systems.

Analysis of Generalized Semi-Markov Processes [P3,P2,P5,P6]
Within this area the papers [P3] provides truly remarkable results concerning the well-definedness of long-run properties. In particular it is shown that for GSMP in general, the so-called property of "decisiveness" (i.e. bottom strongly components will be reach with probability one) does not hold, and that important notions of frequencies are not stable. In fact the result of this papers disproves the correctness of a 25 year old result by Alur, Coucourbetis and Dill. The problem lies in allowing arbitrary fixed-delay events: restricting to so-called *one-ticking* GSMPs the property of "decisiveness" does hold and frequencies become stable. This important negative result is reformulated in [P5] in a Petri Net setting.

Generalized Semi-Markov Games [P1]
In the paper [P1] the problem of winning strategies for Generalized Semi-Markov Games is considered in a setting where all event-time distributions are continuous with positive density on a single interval (this ruling out fixed-delay events considered in [P3]. The paper provides

an exponential time algorithm for deciding (and constructing) the existence if an *almost sure* for objectives given as deterministic timed automata.

Interactive Markov Chains [P4]
In the previous papers, the stochastic models considered are monolithic. In paper [P4] the considered modelling formalism is that of Interactive Markov Chains, allowing for composition of models to be considered. In particular, the paper considers open IMC (essentially 2½ player games), and introduce the problem of synthesizing optimal control for time-bounded reachability. The paper provides a algorithm for computing an ϵ-optimal scheduler (using discretization).

Synthesis of Delays [P7,P8,P9,P10]
In this line of research fixed-delay events are reconsidered (in the safe setting of 1-fdCTMC), but now being specified by parameters rather than concrete values. The problem considered is to synthesize the values of these that will optimized a given objective. In [P7] an algorithm obtaining ϵ-optimal solutions for expected reachability-reward by (a non-trivial) discretization is given and experimentally evaluated in PRISM [P8]. A symbolic-based near-optimal synthesis algorithm was provided in [P9] including experimental evaluation in PRIMS (using MAPLE) demonstrating significant improvements. In [P10] the more challenging problem of long-run average reward optimization was considered. This line of research is highly interesting and with recent follow-up work.

MDP with resilient Control [P11]
In [P11] the problem of synthesizing resilient repair strategies for MDP.

In conclusion, I find the research addressed in the Habilitation of Vojtěch Řehák to be of very high quality, providing highly original and elegant solutions to a several important and non-trivial problems. I also, appreciate the significant effort that has been made towards integration into tools (e.g. PRISM) and experimental evaluation of the developed algorithms.

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

Q: On page 18 it is stated that "STA roughly corresponds to GSMP". The statement is backed up by an example. However, is there a general construction that will transform a STA into an equivalent GSMP? And what does "correspond to" mean: isomorphic? Probabilistic bisimilar?

Q: Can you comment more on the relationship of the results in [P3] and the later publication [BBBC18].

Q: how does the stochastic models considered in the thesis relate to the stochastic semantics of *networks* of stochastic timed automata used in UPPAAL SMC (see STTT publication)? Does some of the results of the thesis carry over to this setting?

Q: could you clarify in which settings memoryless strategies suffices in the sense that the use of history-dependent strategies will give the same results.

Q: on page 20 references to several probabilistic process algebras are made. How does the formalism Markov Automata (by Katoen, Hermanns, Timmer ao) relate to the stochastic models considered in the thesis.

Conclusion

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

In Aalborg on 20/3/19