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. Tomáš Masopust, Ph.D., DSc.**
Applicant's home unit, institution	Palacky University in Olomouc
Habilitation thesis	Partially Ordered Automata - Expressivity, Complexity, and Applications
Reviewer	**dr hab. Artur Jeż**
Reviewer's home unit, institution	Institute of Computer Science, University of Wrocław, Poland

The habilitation thesis investigates various aspects of partially ordered automata, their variants and generalizations. In such automata, which can be deterministic or not, cycles are always self-loops from a state to the same state and thus they recognize a strict subclass of regular languages; as said, variants of this definition are also considered. These notions are to be connected to classic notions in formal language theory: piece-wise testable languages, ST-hierarchy of regular languages as well as classes defined by algebraic properties of their syntactic monoid.

More specifically, the following problems are investigated:

Descriptional complexity of operations on the languages, so how much the number of states of an automaton changes where some operations (here: reverse) are performed on its language. Close upper and lower bounds were shown, using standard approach. Such research topics are well-established, however, the most specialized one, as the one presented here, often are in a niche. I think that this is also the case here, mostly because the reason behind studying this particular operation is not clear. While reasonable, I find this to be perhaps the most standard part of the habilitation thesis.

Separability of languages, so is it possible to find for two languages K, L (here: regular) a simpler language (here: defined by variant of partially ordered automaton) that contains one of them and is disjoint from the other and how to construct the respective automaton. The algorithms presented here improve the state of the art ones, using much simpler and natural approach. Both the decidability and the construction of the appropriate separator are investigated. I find this part to be of large importance, also the technical contents is impressive, the proof techniques, while used before, are demanding. To me this is clearly the best part of the habilitation. Moreover, it seems that this was one of the works the started a renewal of interest in the separation problems, which also marks it as important.

Universality, so the question, whether the automaton accepts every word. When the set the notion of partially ordered automata, this is the natural question to investigate. The presented constructions are based on traditional combinatorics of automata, sometimes the arguments use standard approaches, yet sometimes there are new ways to encode computation

in such automata. I think that the most important is the introduction of the restricted partially ordered NFA, which is another characterization of R-trivial languages. In general, I find this to be part to be very good.

Complexity of translating from automaton recognizing piece-wise testable languages to characterization via boolean combinations of appropriate languages. This follows a natural approach in the translation, which was investigated earlier. As a result, the translation splits into three natural steps, which leads to a couple of questions, again most of them were studied before. The presented work gives a detailed and precise bounds for the above mentioned questions, in some cases closing some open ends left by earlier research. This is a natural problem to consider, also it has some practical motivation. The arguments are both combinatorial and algebraic, I find this part to be good.

Applications Lastly, some problems resulting from applications (deterministic regular expressions and discrete event systems) were investigated, where the underlying automata are partially ordered. The notion of DREs comes from real-world application and its study here is interesting and important. Concerning the latter problem, while I see the technical quality, I know little of the area, so it is hard for me to evaluate it.

It is worth mentioning and praising, that all investigated topics have a common theme of partially ordered automata, in many cases habilitation theses are collections of much more loosely connected works grouped under some very general title. Here this is not the case. This is especially good, taking into the account that the sheer volume of work in the habilitation thesis is large.

Overall, I find the scientific level of the habilitation thesis to be good, for the following reasons. The field of study is classic in computer science, even though it sadly is no longer in the core of currently most investigated areas. The investigated class is defined naturally and it links to studied areas (ST hierarchy, *etc*.). The investigated problems are also natural and interesting, many of them are classic (like descriptional complexity or universality), on the other hand the separability questions seem to be gaining popularity recently. Some of them seem purely theoretical, but yet other are very well motivated by practice, as say, study of deterministic regular expressions or different formalisms for piece-wise testable languages. There are various proof techniques, while most resort to rather classic combinatorics of finite automata, there are also arguments using algebraic approach as well as those using well-quasi orders. The technical level varies from average to high (for instance in case of separability). In most cases the obtained results are tight or almost tight, which is always welcomed.
I personally liked most the results concerning the separability, mainly due to their technical involvement and deep understanding of the problem as well as the definition and results on restricted partially ordered NFAs, as they gave another, non-obvious and nice characterization of a well-known classic class of languages, which is not so common.

Around three fourth of the papers in the habilitation thesis are joint work, mostly by 2-3 authors. In each case the input from the Tomas Masopust was at least proportional, often he was the leading author (in terms of scientific input). The remaining papers had single author. Even taking into the account the average input to the papers, I still value it as good.

Concerning the impact of the work, there are ways how to evaluate it. First, the scientific quality. I believe that it is good, as the obtained results are non-trivial and interesting. Secondly, how much the work fits into the current trends and how much does it the directions of research — some of the research had follow-up work, in particular the work on separability gained much attention, though some other seem to fit a rather narrow niche. Lastly, the bibliometrics. Here I would like to disclaim that I do believe that it should be viewed as one

of the indicators, not the unique one. The paper forming the habilitation thesis were on average well-published, with the best ones in top venue (ICALP) through good (MFCS) to reasonable (CIAA, DCFS); some papers were only published in journals, which are harder to judge in this respect, nevertheless the picture is similar. The citations, while not particularly high, are acceptable.

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

1. Is there any operation or a candidate for an operation, such that the state complexity of this operation grows with each level of the ST hierarchy or that it reaches the maximal values somewhere relatively high in the hierarchy?
2. Your construction of sets L_i and K_i that in the limit are the separator of languages L and K seems much more natural than the one using towers between languages. Do you think that framing the proofs in this setting would simplify the existing proofs?
3. For the universality, you consider the three cases, when the alphabet has one letter, a constant number of letters and grows with the number of states of the automaton. However, in the last case you consider mostly alphabets that are linear in the number of states of the automaton. Do you have any conjecture, what happens with some intermediate growth functions?
4. Do you have any non-trivial upper bound on the increase of size of translation from rpoNFA to poDFA?
5. When you translate the automaton defining a Piecewise Testable language to a boolean combination of simple languages, you do not consider the size of the description of such languages. Have you considered trying to obtain the minimal one (according to some reasonable size function), what about the computational complexity of such problems?

Conclusion

The habilitation thesis entitled “Partially Ordered Automata - Expressivity, Complexity, and Applications” by Tomáš Masopust ***fulfils*** requirements expected of a habilitation thesis in the field of Informatics.

In Wrocław, Poland on 08.03.2021

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