

Review of Ph.D. thesis
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New Parallel and Regulated Automata and Grammars

The topic of this Ph.D. thesis belongs to the area of the theory of formal languages and automata where different formalisms that can be used to represent formal languages are studied, such as different kinds of automata, different kinds of grammars, and other more general kinds of rewriting systems. The thesis introduces several new formalisms of each of these types and studies their properties. The introduced formalisms include several new types of automata, grammars, and rewriting systems, and the thesis concentrates mainly on the questions concerning the expressive power of these formalism, i.e., on the classes of languages represented by these formalisms and relations between these classes, and on transformations between these formalisms.

All the results presented in the thesis are theoretical and most of them were already published in several journal and conference papers where the author of the thesis is a co-author. Some of these topics are extended in the thesis with some additional new results that were not published previously. For some of the results that were published but without full versions of proofs due to space limitations, the thesis presents complete detailed versions of these proofs.

Overview of the results

The results can be divided into four main topics where each of these topics is covered by one chapter in Chapters 4–7 of the thesis. These chapters are based on publications [53, 54, 49, 48] of the author.

The first of these topics are *state-synchronized automata systems*. These automata systems are discussed in Chapter 4. The content of this chapter is based mainly on the paper by the author published in journal *Schedae Informaticae* in 2016 (reference [53] in the thesis). The co-author of this paper is A. Meduna.

State-synchronized automata systems consist of several pushdown or finite automata running in parallel with synchronization achieved by requiring that allowed combinations of control states of these automata in configurations are specified by a language, which is given as a part of the definition of such system.

It is shown that different variants of state-synchronized automata systems with two pushdown automata accept exactly the class of recursively enumerable languages. (This is not so surprising, given that it is well known that pushdown automata with two stacks, and in fact already counter machines with two counters, are Turing powerful.) It is more surprising that for all variants of state-synchronized automata systems this holds already for one-turn pushdown automata, i.e., pushdown automata that can change their behaviour from pushing to popping only once. In the case that the number of turns is not bounded, this holds also when the pushdown automata are required to be deterministic.

Another result, which is also not much surprising, is that systems that consist of just one pushdown automaton and an arbitrary number of finite automata recognize precisely context-free languages, and linear languages if the pushdown automaton is required to be one-turn.

The second topic are *unlimited pushdown automata*. They are discussed in Chapter 5 of the thesis. Two variants of these automata are considered — *absolutely unlimited* (in

Section 5.1) and *relatively unlimited* (in Section 5.2).

Section 5.1 that deals with absolutely unlimited pushdown automata is based on a paper by the author presented at conference *MEMICS 2015* (reference [54] in the thesis). The co-authors of this paper are A. Meduna and O. Soukup. Section 5.2 that deals with relatively unlimited pushdown automata is new and presents notions and results that were not published previously.

Both absolutely and relatively unlimited pushdown automata are variants of pushdown automata that allow rewriting deeper in the stack of the automaton, not only on the top.

It is shown that absolutely unlimited pushdown automata recognize exactly the class of recursively enumerable languages, and that they recognize exactly context-sensitive languages when they are restricted to so called “propagating” variant. Similar results hold also for the relatively unlimited variant of pushdown automata.

The third topic are *jumping pure grammars*. They are discussed in Chapter 6, which is based mainly on the paper by the author published in *The Computer Journal* in 2019 (reference [49] in the thesis). The co-authors of this paper are Z. Křivka and A. Meduna.

Pure grammars are grammars where is no distinction between terminal and non-terminal symbols, and so every sentential form represents a word in the generated language. Jumping grammars are grammars that allow certain types of permutations of symbols in sentential form in addition to usual rewriting. There are several variants of them depending on, which kind of permutations is allowed. Both pure grammars and jumping grammars were previously studied in the literature. Jumping pure grammars combine these two features.

The thesis introduces 16 different variants of jumping pure grammars and studies how the classes of languages generated by these variants are related to each other and also to some standard classes such as context-free and context-sensitive languages. For many combinations of these variants, the thesis presents examples of languages that belong to some of them and at the same time do not belong to the other. For some of these combinations it remains an open question whether such language exists or not.

The fourth topic are *$k\#\text{\$}$ -rewriting systems*. They are discussed in Chapter 7, which is based on the paper by the author published in *Romanian Journal of Information Science and Technology (ROMJIST)* in 2018 (reference [48] in the thesis). The co-authors of this paper are Z. Křivka and A. Meduna.

$k\#\text{\$}$ -rewriting systems are a variant of rewrite systems resembling a context-free grammar with just one non-terminal (denoted $\#$), which is in addition equipped with a finite control state and a stack. The number k restricts, which occurrences of $\#$ can be rewritten. Other occurrences of $\#$ can be “pushed” on the stack (where they can be replaced with different symbols) and “popped” from the stack (by popping a specified symbol from the stack and changing it into $\#$).

It is shown that depending on the value of k these systems form a strict hierarchy of classes of languages, which is related to the hierarchy of so called state grammars. It is also shown that for each k , $k\#\text{\$}$ -rewriting systems generate a strict superclass of languages generated by $k\#$ -rewriting systems.

Organization of the thesis

The thesis is organized into three parts, denoted Part I – Part III.

Part I consists of Chapters 1, 2, and 3. Chapter 1 is an introduction. Chapter 2 recalls standard mathematical definitions and standard definitions concerning automata and grammars, it introduces mainly the used notation and terminology. Chapter 3 gives an overview

of the state of the art and recalls some less known and more specialized types of automata, grammars, and rewrite systems, which are used as the starting points for the formal systems discussed later in the thesis, and to which these newly introduced systems are related.

Part II consists of Chapters 4, 5, 6, and 7, and forms the main core of the thesis where different new kinds of formal systems are introduced and where their properties are proved. The content of these chapters was described above in the overview of the main results of the thesis.

Part III consists only of Chapter 8, which is a conclusion.

At the end, the thesis also contains a detailed list of all language families discussed in the thesis with references to particular pages where the given families are discussed. It also contains an index of used notation and an index of used notions.

Evaluation of the thesis

The studied problems and formalism seem interesting from the theoretical point of view. On the other hand, from the practical point of view, they may seem a little bit artificial and a possible motivation and/or application of them is not always clear and is not much discussed in the thesis. Most of the studied formalisms are generalizations or variants of formal systems (automata, grammars, rewriting systems, ...) studied previously in the literature. It clearly makes sense to study their expressive power and classes of languages represented by them.

In fact, the thesis concentrates mainly on questions concerning the expressive power and relations between corresponding classes of languages. The other related questions that are traditionally studied with respect to such formalisms (automata, grammars, ...) like closure properties of studied classes of languages with respect to different operations on languages (complement, intersection, union, concatenation, Kleene star, ...), or questions concerning decidability and complexity of algorithmic problems dealing with such formalisms (membership, emptiness, universality, ...) are not discussed in the thesis. Other type of questions, which is not discussed in the thesis, is how the size of representations is changed when one type of system is transformed to another type of system, and whether some of these formalisms can allow more succinct representations of languages than the other.

I see the main contribution of thesis in the introduction of the new formalisms. The proofs of properties of these systems and of transformations between them are presented very carefully and with all technical details, which is something I appreciate. On the other hand, it seems to me that most of these proofs are rather straightforward. They typically do not require some ingenious new idea and they usually proceed by using standard techniques, although sometimes it is necessary to deal with some technicalities. All proofs in the thesis seem correct and I have not found any errors in them.

The text of the thesis is written very carefully. I have spotted almost no typos. Also the quality of English, in which it is written, and the quality of typography are very good.

The quality of publications, on which the thesis is based, is very good, and the quality of thesis itself is high, so, in my opinion, it is clearly defensible as a Ph.D. thesis.

Typos:

- pp. v–vi (“Rozšířený abstrakt” in Czech): missing spaces in front of citations (e.g., “Chomského klasifikace[9]”, “komplexnosti použití[88]”, ...)
- pp. 81: “a configuration of a $k\#\$$ -rewriting system is consist of two parts” should be “a configuration of a $k\#\$$ -rewriting system consists of two parts”

Questions

- Are there some interesting results or questions concerning closure properties of classes of languages generated by the formal systems studied in this thesis? (I.e., the questions whether particular classes are closed with respect to different operations like complement, intersection, union, concatenation, Kleene star, etc.)
- Are there some interesting results or questions concerning decidability and complexity of some standard algorithmic problems concerning formal systems studied in this thesis? I.e., the problems like testing membership (whether a given word is accepted by a given automaton, resp. generated by a given grammar), emptiness (whether the language generated by a given system is empty), universality (whether the language generated by a given system contains all words), etc.

Overall evaluation

In my opinion, the topic of the thesis is interesting and relevant. Most of the results were already presented in several journals and conferences, which shows their relevance. The quality of the thesis is high and it is written very carefully. So in my opinion, the thesis clearly satisfies all requirements for a Ph.D. thesis, and **I do recommend the Ph.D. thesis for the defense.**

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