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SOME QUESTIONS INSPIRED BY (MEMBRANE COMPUTING MOTIVATED) LANGUAGE-THEORETIC MODELS

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Abstract. This contribution argues for the proposition that formal models based on the theory of formal grammars and languages are adequate for the study of some computationally relevant properties of agents and multi-agent systems. Some questions are formulated concerning the possibilities to enlarge the universality and realism of such models by considering the possibilities to go with their computing abilities beyond the traditional Turing-computability, and by considering very natural properties of any real (multi-)agent system such as the partially predictable functioning (behavior) of agents, their unreliability, dysfunctions, etc.

Keywords: Agent, multi-agent system, formal language, formal grammar, membrane system, grammar system, computability, randomness, fuzziness

1 INTRODUCTION

Checking the hypothesized list of different areas of the use of different types of formal language-theoretic framework we easily realize that the language-theoretic paradigm works well. However, on the other side of the coin, from the methodology of science we know that each modeling framework is in certain sense limited by its own descriptive and predictive boundaries. So, the question of limitations emerges also in the case of language-theoretic models.

An actual, and challenging field for constructing predictively productive formal models is the field of agents and multi-agent systems (agencies). The reason of the increased interest consists in the fact that the agent perspective seems to be very effective for the study of a very large spectrum of systems. Another reason consists perhaps in the fact that good, really applicable formal models of agents and agencies are very rare up to now. Moreover, we must consider the appeals from the practice very seriously, like the one formulated by a recognized specialist in advanced robotics and artificial intelligence, Rodney Brooks: *We have become very good at modeling fluids, materials, planetary dynamics, nuclear explosions and all manner of physical systems. Put some parameters into the program, let it crank, and out come accurate predictions of the physical character of modeled system. But we are not good at modeling living systems, at small or large scales. Something is wrong. What is wrong? There are a number of possibilities: (1) we might just be getting a few parameters wrong; (2) we might be building models that are below some complexity threshold; (3) perhaps it is still a lack of computing power; and (4) we might be missing something fundamental and currently unimaginable in our models* [1]. OK, but: *What of "fundamental" we have missing? And why? And how to build better models?*

We must be also sensitive to the scepticism of some of our other respected colleagues. It is, e.g., necessary to take seriously the opinion of Marvin Minsky, one among the founders of theoretical computer science and artificial intelligence research, who said: *If a theory is very simple, you can use mathematics to predict what it'll do. If it's very complicated, you have to do a simulation* [12]. That's true, but we must ask: *What to do when the problems are somewhere in between?*

This contribution focuses on two among the number of different language-theoretic models developed during the decades of efforts. Namely, it focuses to the bio-chemically inspired models built up on the idea of membrane activities in living structures, and to the sort of models inspired by distributed and multi-agent systems, which have the form of systems of traditional formal grammars which work together (cooperate, compete...) during the process of derivations. We will sketch the close relation of the membrane and multi-grammar models to the field of agents and agencies first, and then we will sketch some questions on the universality and realism of the models.

2 AGENTS AND AGENCIES

In the broadest meaning agent is any active entity, which is able to sense its environment, and to act in it according to the sensed pattern; cf., e.g., [8]. In [10] we provide a taxonomy of different types of agents created according to the different levels of complicatedness of the generation of appropriate actions on the basis of patterns sensed by them in the moment of action (this is the case of the so-called purely reactive agents) or sequences of patterns sensed during the history of their activities and processed by specific inference procedures (deliberations) inside the agents' structures (this is the case of the so-called deliberative agents).

Considering any active thing as an agent it is a very general understanding. From this perspective, agents at different levels of complexity are human beings, computer programs, living cells, social or economic organizations, etc. So, to find a universal theoretical framework for dealing with such a large spectrum of active entities is really a hard problem. However, we have some appealing approaches at hand. Let us mention at least two of them.

Systems consisting of biochemical membranes and active entities inside the regions bounded by these membranes can be considered as agencies. From this perspective, the active entities inside are the agents belonging to the agency. The agents, (bio-)chemical structures in their substance, act in their unstructured environments (acting means (bio)-chemical reactions in real situations, and the unstructured nature of the environment is modeled by the multi-set of symbols instead of the strings of symbols), and through the membranes the results of their activities change the environment in neighboring regions (it can define a structure in the environment in certain sense and certain extent because of generating strings of symbols in the environment from previously isolated symbols), where other agents react to the chemical conditions in their environment, etc. Note two important points in this context. The first point is that in this case the environment in which agents act is unstructured, and the activities of agents contribute to the emergence of some (local) structures of the environment. The second point is that environments can be hierarchically structured, so organized like (semi-)Chinese boxes or (semi-)Russian dolls.

These changes of the environment(s) caused by activities of such kind of agents might be interpreted in the computational framework as a computation, and, in the consequence, the membrane structures might be considered as a specific type of computing device. The systematic study of this type of computation using the language-theoretic framework is presented in the form of a monograph in [15]. In the model, there exist two types of communication between regions isolated by membranes: The first type is the communication between the hierarchically "sibling" regions. The second type of the communication is the "cross-hierarchic" communication.

Another example of the use of the agent paradigm is the view of the mind from the perspective of Marvin Minsky's society theory of mind [13]. In this case, the components of the brain/mind machinery are considered as agents and agencies. At the lowest level of the hierarchy are perhaps the neurons. In this case the agencies formed from neurons (as some anatomical parts of the brain structure) are considered as agents. It is then, step-by-step, possible to define other agents as agencies, e.g. those appearing as psycho-physiological regions of the brain as agents playing roles in the formation of psychic activities, etc. Note, however, that the neurons might be considered as membrane structures in this way. In such a simple way, the two above-mentioned models – the Păun's membrane model, and the Minsky's agent model – are in fact interconnected and the agent paradigm works as a unifying framework for the whole spectra of structures and activities starting somewhere down by the (bio-)chemical ones up to the psychic ones on the top. To provide a unifying formal framework for theoretical study with respect to the needs of practice seems to be a great appeal, and the multi-grammar models as the membrane system ([15]) or (eco-)grammar system ([4]) approaches are promising candidates for such framework.

From the architectural point of view the agents are in the case of the society theory of mind organized in pseudo-pyramidal hierarchies. Some parts of such hierarchies might be considered – from an outside observers point of view, or from the point of view of their functioning – as agents. The interactions between agents are changeable, what enables to consider in the framework of the society of mind phenomena like learning, remembering, evolution, and similar cognitive processes. Moreover, the theory connects, as it is presented in [14], the cognitive and the emotive parts of the functioning of mind in an interesting and inspiring way.

The above-sketched concepts of agents might be described in different formalisms and then studied in different formalizations. Each formalization emphasizes some of the aspects of the real systems, and suppresses others. In our context, the most interesting are the formal models of agents and agencies constructed in the framework of the theory of formal languages and formal grammars, as presented, e.g., in [3] or [15]. In the case of grammar-systems, comparing them with membrane systems, the model of environment is supposed to be strictly structured, it is modeled by a string of symbols instead of the model of environment as a multi-set of symbols, as it is in the case of membrane systems. As documented, e.g., in [16], there are many results concerning the formal language or the grammar-systems-like models. The situation is similar in relation to other models, too.

In the prevailing majority of formal models, however, the answers to the questions appearing very naturally inside the framework used for modeling have values first of all inside the conceptual framework of the model formalism. In the case of grammar systems there are questions inherent in the theory of formal grammars and languages concerning the relation of language hierarchies to the traditional Chomsky hierarchy, and questions generated then with respect to the number of components sufficient or necessary to generate some given (and theoretically important) families of languages, etc. In such a way, the models built originally for studying multi-agent systems contribute to the enlargement and further development of the traditional formal language theory. This is important for the development of this theory, first of all. But: *How to proceed in order to help with results of such theoretical model to the better understanding of the field of real multi-agent systems?*

3 UNIVERSALITY

Before starting with search of the related questions to that formulated at the end of the previous section, and looking for the appropriate from of answers, we will deal in short with the question of the universality of multi-agent approaches to describe the different parts of the reality of some processes and phenomena. According to [7], agents offer an abstraction tool, or a metaphor, for the design and construction of complex systems with multiple distinct and independent components. These abstractions can be used in the design and development of large systems, of individual agents, of ways in which agents may interact to support these concepts, and in the consideration of societal or macro-level issues such as organizations and their computational counterparts. They also enable the aggregation of different functionalities that have previously been distinct in a conceptually embodied and situated whole. So, we may ask why the multi-agent approach is an adequate point of view, and where are the limits of its successful use.

As we have mentioned in the previous section, the agent-based approach is interesting and attractive, because it provides a unifying view to the processes running in the (bio-)chemical level through many interesting branches of the human scientific and engineering interests, e.g., up to the reflection of (some parts of) processes running at the level of (human) consciousness. Moreover, this view unifies in an appropriate way the biological, psychic, social, and technical systems. All the mentioned types (and many other ones) of systems might be considered as systems composed of a (smaller or larger) number of active, effectively isolable components with their own specific behaviors. The behaviors of the whole systems then emerge (in a more or less predictable way) from the behaviors (often not coordinated, not centrally governed or managed) of the component agents; cf. [9].

However, there also exist and are intensively studied some alternative formalizations of phenomena appearing in living systems, esp. also of the membrane functioning. On the basis of some of such kind of models, computer simulation models are developed, too; see, for example, the review of a mathematical model and its simulator presented in [18] and the formalization proposed in [20]. *What about comparing different approaches and models or simulators, and perhaps trying to set up some combination of them?*

In the cases of the above-mentioned-language theoretic formal models of membrane computing, of grammar systems, and of eco-grammar systems, and more generally, in all the cases when the models are built on the conceptual basis of formal grammars and languages, the rules governing the dynamics of the behavior of agent-like entities are described in the form of rewriting rules. This is an advantage, because this formulation of the rules is, in fact, a formulation which defines (trivially simple, but it is not a disadvantage!) agents (in the meaning we have accepted at the beginning): Each rule has its own sensor capacity (to sense the appearance of its left-hand side string), and an action capacity to make a change in its environment (to rewrite the sensed pattern by the rule's right hand side). The ways of rules interactions are specified by different derivation modes and rewriting regulations.

This is, at least from the methodological point of view, a fundamental advantage. We know very well that some specific multi-agent systems (formal grammars) define very well-specified behaviors (formal languages) with very interesting relation to different models of computation (to different types of automata) which have very important relations to real engineered (computing) machines. What we do not know is the question of the universality of the approach accepted for describing languages (behaviors). *What kind of behaviors are we able to describe using the just sketched framework behind the Turing-computable ones?*

The second question follows from inclusion of the dynamics of the environments in which our agents act. In the traditional formal language theory we do not consider any dynamics of the strings under rewriting. The only changes are those executed as rewriting activities of (some of) the rules. In the case of eco-grammar systems, however, the situation is slightly modified, because of providing an "independent" dynamics of the environment changes using a specific parallel rewriting mechanism (modeled by L-systems) working independently on the agents activities. *What will happen when more complicated mechanisms of changes will be included into the models? What do we know on the situation, for instance, when some finite subsequences (belonging to a language with specific Turing-computability properties) will be randomly replaced by words from another set of words (of known Turing-computability property)? How to proceed in the case of multi-sets used as models of the environments in the case of membrane systems? For instance, does the number of (certain) symbols change as the result of applying a non-computable function to generate the changes?*

Of course, many more similar questions can be formulated in a more or less formal way. We provide some examples only, but related to very actual themes in present-day theoretical computer science, too, as documented in [2], for instance. An overview of some proposals to development of formal computing models with hyper-computational power – the power going beyond the traditional Turing machine – is provided, e.g., in [19].

The most fundamental question, according to our meaning, is the following one: *Is it possible, and if yes, in what cases, and under which condition, to receive (define) some stabilized (well defined in the framework of Turing-computability, for instance) behavior in the hardly-predictable behavior of the environment in which the agents act?* From the standpoint of the practice, this question is very important! The design of such stabilizing multi-agent systems working in unstable environments is often the main goal of many engineering activities. *What we are able to say about the possibility of such design in our theoretical framework?*

The last question leads us from speculations about universality of our models to the question of their realism.

4 REALISM

In this section we will continue the provocations contained in [6]. However, our intention is not to continue in the development of inspiring ideas contained in it. We are much more modest – we try to enlarge, if we will be successful, the number of motivations for some questions connected with the study of realism of grammar-theoretic models of real systems. We note that systems are in our context composed from agents. We construct conceptual models in order to better understand the studied real systems. We formalize our conceptual models in order to receive rigorously predictive power of our conceptual models, and, as a consequence of that, to have models with rigorous predictive power. The answers derived logically and in formally (logically) correct ways with mathematical rigor are truthful. OK! But: *Are we able to formulate practically interesting questions in our theoretical formalized models? Are our models realistic in this sense?* If yes, then: *What are the inherently interesting questions for any multi-agent systems theory?*

In this section we will concentrate on the problem of the broad-sense reliability of multi-agent systems. Real (embodied or software) multi-agent systems are, naturally, not perfectly reliable. To be more particular, let us mention some of really often appearing in multi-agent systems, and because of that practically interesting, phenomena related with reliability of (multi-agent) systems.

One among the most frequent is the phenomenon of disfunction of (some of the) agents which form parts of the whole system. Suppose that some of the components of a complicated machine go down. *Will the whole machine work after this reduction of its components? What kind of changes will appear in its behavior after this change? How to preserve some appropriate level of the functionality of the machine (its resistance with respect to the "small" changes in its architecture)?* We see that the parts and the reliability (in weaker sense) of the parts are in very close relation to the whole system functioning.

In other type of systems, despite of the reliability of the agents, their involvement into the work of the whole system is important. In the society of ants, for instance, it is practically impossible to organize the work of any particular agent. Some ants work in some time period, some do not, and, moreover, we have absolutely no predictive power to know exactly what an ant will or will not do in the next time period. I will call this problem the *problem of randomness* in multi-agent systems.

Let us stress that both of the sketched types of problems are imaginable in the context of membrane computing and in the case of (eco-)grammar systems as well, and that they are perhaps expressible also in some mathematically not very complicated ways. *How to do that?*

Consider first the problem of reliability. An approach to incorporating reliability into the multi-grammar models (like the membrane computing and the (eco-)grammar frameworks) may be inspired by the incorporation of the fuzzy-approaches into the traditional grammar-theoretic models. It seems to be possible to fuzzify the rewriting rules, and consequently the derived strings, and to receive formal languages as fuzzy sets, in such a way. It is also possible to fuzzify the components of grammar systems, or the regions of membrane systems, and then to propagate the fuzziness toward the generated sets of behaviors, etc. It is then possible to compare the behaviors of such models with the behavior (generative capacity) of the unfuzzified models. *How to define the necessary notions, and what will be the results derived from the resulting model?*

Concerning the randomness of the impact of particular components of multi-grammar models to the derivative capacity of the whole systems, we mention [21] as an example of an interesting approach. The participation of the components in each derivation step is defined by a function defined on the number of derivation step with values in the superset of the components. In such a form, for each derivation step, a team – similar to that introduced in [5] – is created from all of the components, which execute the derivation. The relation of particular forms of this team-forming function and their computational properties considerably influence the behavior of the multi-grammar models. *In what ways exactly, and to what extent?*

Another way of incorporating the dynamics of components behaviors in the models may consist in timing, as defined in [11] for colonies, but defined also for other models, e.g., by functions defined of the length of the derivation chains. Note that similar approaches are also incorporable into the fuzzified models; thus, the ability to combine different models of reliability and randomness into one theoretical model also seems to be realistic. *What is the most promising way of doing that?*

5 CONCLUSION

The language-theoretic models seem to be well inspired by large spectrum of multi-agent systems, and the agent and multi-agent paradigm seems to be promising for better understanding of events and processes appearing in the real world in which different individually more or less autonomous entities (agents, in our terminology) cooperate, compete, or simply cohabitate, but inevitably participate in generation of the dynamics of the whole. We have argued that the language-theoretic models form a suitable formal framework form study of systems of the above mentioned type, and we have posed maybe too many questions the answers to which will contribute to the better understanding of at least some multi-agent phenomena. But almost no answers yet! However, let us hope that, as Marcel Proust wrote, *each ... reader reads only what is inside himself. A text is only a sort of optical instrument which the writer offers to let the reader discover in himself...* So, be successful! And remember: *If you "understand" something in only one way, then you scarcely understand it at all – because when you get stuck, you'll have nowhere to go. But if you represent something in several ways, then when you get frustrated enough, you can switch among different points of view, until you find one that works for you!* [14].

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