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Grammar Systems: Recent Results and Perspectives (Foreword)

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On July 26-27, 1996, a workshop with the title *Grammar Systems: Recent Results and Perspectives* was held in Budapest, at the Computer and Automation Research Institute of the Hungarian Academy of Sciences[1]. The aim of the meeting was to provide a forum for exchanging ideas about the state of the art of research in the area of grammar systems and preview the trends and perspectives. The presented talks and the fruitful informal discussions resulted in, among other things, the present volume.

" *Grammar systems*" is a recent active field of formal language theory, providing syntactic models, frameworks and tools for describing and studying (the behaviour of) multi-agent systems at the symbolic level. Several scientific areas have motivated and influenced the developments in this theory: *distributed and decentralized artificial intelligence, distributed and parallel computing, artificial life, molecular computing, robotics, ecology, sociology, etc.* Computer networks, parallel and distributed computer architectures, distributed and cooperative text processing, natural language processing are candidates for possible applications.

Roughly speaking, a *grammar system* (the term "grammar" is used here in a general sense) consists of several language identifying devices (language processors or linguistic agents) that jointly develop a common symbolic environment (usually, a string or a finite set of strings) by applying string manipulating operations to it. The symbolic environment can be shared by the components of the system, or it can be given in the form of a collection of separated sub-environments, each belonging to a language processor. At any moment in time, the state of the system is represented by the current string describing the environment (collection of strings of the sub-environments). The functioning of the system is realized by changes in its states. Depending on the variant of multi-agent systems that the actual grammar system represents, in addition to performing derivation steps, the language processors are allowed to communicate with each other. Usually, this is done by exchange of strings that can be data (for example, sentential forms in derivation)

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or programs (productions or coded form of some operation). The behaviour of the grammar system can be characterized by the set of sequences of environmental states following each other, starting from an initial state, or by the set of all environmental states originating from an initial state and satisfying some criteria (final states).

Grammar systems are both computational and language identifying devices, capturing several phenomena characteristic for multi-agent systems: *cooperation, distribution, communication, parallelism, emergent behaviour, etc.*

To give a picture about the research directions in the area, without the aim of completeness, we list some important frameworks and models. (The interested reader can find detailed information in [6], [21], [14]).

The theory started in 1988 by introducing *cooperating/distributed grammar systems* (CD grammar systems) for modelling syntactic aspects of the blackboard model of problem solving ([4],[5]). We should note, however, that the first appearance of the term *"cooperating grammars"* was in [20] as a notion for extending two-level substitution mechanism of grammars to a multi-level concept. A concept, based on modularity and related to cooperation of grammars, motivated by regulated rewriting, was introduced in [1].

In the basic form, a *CD grammar system* is a finite set of generative (usually context-free) grammars that cooperate in deriving words of a common language. At any moment in time there is exactly one sentential form in generation. The component grammars generate the string in turns, under some cooperation protocol. In this model the cooperating grammars represent independent cooperating problem solving agents that jointly solve a problem by modifying contents of a global database, called blackboard, that is for storing information on the problem solving process. In this architecture the agents communicate with each other only through the blackboard.

The main research directions in the field of CD grammar systems concentrate, among other things, on studying the question whether cooperation adds power to the derivational capacity of the individual grammars or not, and, if the answer is positive, how simple presentation of the components and the protocol is sufficient to reach this power. While the original model was introduced for generative mechanisms, the framework has been extended and applied also to other computational devices (accepting grammars ([2]), automata ([13]), tree processing devices ([16]), etc). Parallel with this kind of enhancement, properties characterizing the model have been studied in details: determinism in cooperation, comparison of systems with components using hybrid and homogenous cooperation strategies, variants of competence-based cooperation, systems with time limited activity of grammars, hierarchies among the components, similarity, uniformity, etc. The achieved results demonstrate the power of cooperation. Large language classes (ET0L, programmed with apperance checking, context-sensitive) can be described in terms of systems of a limited number of very simple cooperating language identifying devices.

While CD grammar systems realize sequential computing devices, *team grammar systems* with simultaneous actions of some grammars (teams) on the sentential form, introduce parallelism in the model ([19],[23]). These systems demonstrate an equivalence between programming the sequence of actions and computation under some kind of competence-based cooperation of freely chosen grammar teams with a very limited number of components (pairs of grammars).

Colonies, motivated by subsumption architectures of R. Brooks, describe language classes in terms of behaviour of collections of very simple, purely reactive, situated agents with emergent behaviour ([17],[18]). In this model the agents are represented by very simple regular grammars (each grammar generates a finite language) that operate on a common sentential form. The basic variant of colonies determines the context-free language class, while the more sophisticated models (competition among the agents, timing, etc.) lead to considerably enhanced computational power ([12],[22]).

Eco-grammar systems form a language theoretic framework for modelling ecosystems: developing linguistic agents, represented by L systems, in a dynamically changing population, interact with each other and with their shared evolving symbolic environment ([9],[10]). Eco-grammar systems provide tools for describing life-like phenomena (birth, death, hybernation, overpopulation, pollution, etc.) in terms of formal grammars and languages.

Networks of language processors (this general term was introduced in [11] and [3]) form an essential part of the area. In this case language processors are located in nodes of a network (a virtual graph). Each processor works on its own sentential form (on its own collection of sentential forms) and informs the others about its activity by communicating strings that can be data and/or programs. Rewriting and communication take place alternately, the system is functioning (usually) in a synchronized manner. *Parallel communicating grammar systems,* a highly elaborated field, with Chomsky and Lindenmayer grammars at the nodes, studies networks with components communicating data strings by request ([24],[25]). *Test tube distributed systems based on splicing* and on *cutting and recombination* are particular cases of the model with components using variants of DNA recombination and realize computationally complete and universal machines (in some cases with a limited number of components) ([8],[15]). Ideas of the *WAVE paradigm* of active knowledge networks are implemented in [7] and *networks of parallel language processors,* where the nodes are represented by L systems, are studied in [11].

In addition to the above mentioned areas, investigations have been started for applications in related scientific areas, as natural language processing.

Recent developments that can be observed in grammar systems theory, are trends

- from *cooperating/distributed grammar systems* to **cooperating/distributed systems of language processors,**
- from *parallel communicating grammar systems* to **networks of language processors,**
- from *simple communities (colonies) of grammars* to **societies of linguistic agents,**
- from *computing* to **nature-motivated computing,**

- from (applications in) *natural language processing* to **natural processing of languages**.

Contributions to the present volume fit into the above trends, by providing a better understanding of cooperation and distribution through a deeper study of the existing models and enhancing the concept to further computational phenomena. The papers are clustered in the volume according to the subfield of grammar systems they represent.

The first three articles are devoted to the study of cooperating/ distributed language processors. Jürgen Dassow and Victor Mitrana studied fairness in CD grammar systems, Henning Bordihn and Erzsébet Csuhaj-Varjú dealt with competence and completeness of component grammars both in the case of generative CD grammar systems and in the case of accepting ones. Henning Fernau and Markus Holzer discussed accepting CD grammar systems in details, in comparison with the generating ones, taking new variants of cooperation protocols into account. They also considered team behaviour of accepting CD grammar systems. Networks of language processors are investigated in the next three papers. The first is the survey of Gheorghe Păun on parallel communicating grammar systems. It also studies new variants and raises several open problems in the area. Valeria Mihalache examined parallel communicating grammar systems with components having own nonterminal alphabets and terminal alphabets, Lucian Ilie and Arto Salomaa provided important characterizations of recursively enumerable languages in terms of parallel communicating grammar systems with WAVE-like communication. Societies of grammars, nature-motivated computing and natural language processing are represented by the last three papers. Maurice H. ter Beek investigated team grammar systems with teams using different cooperation strategies and a new variant of derivation mode, called weak rewriting. A framework motivated by DNA computing, a generalization of test tube systems, is introduced and studied in the paper of Rudolf Freund and Franziska Freund. The last paper in the volume is about the challenge that natural language understanding means for grammar systems, by Carlos Martin-Vide.

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