Possibilities for Formal Models of Smart Environments

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Abstract: - This paper is devoted to a recently running project description with a purpose to get some necessary feedback from the AmI community as to the project ambitions. The project intends to study possibilities of several formal approaches towards modeling intelligent environments based on principles of ambient intelligence. The main goal is in contributing towards theoretical foundations of ambient intelligence via modeling of intelligent environments functionality using three basic approaches: multi-agent systems of various kind, algebraic methods, and grammar systems and colonies, namely eco-grammar systems.

Key-Words: - Ambient intelligence, formal models, multiagent systems, process algebra, grammar systems, colonies.

1 Introduction

Although the area of ambient intelligence is studied broadly throughout the world, there are only few attempts to use formal approaches in studying as well as modeling basic principles or functionalities of intelligent environments based on ambient intelligence. Such formal approaches, well established in other area of informatics and/or mathematics could contribute towards theoretical foundations of this rapidly growing and applicable area.

In this paper we wish to present a recently running project description focused on certain formal approaches possibly usable for modeling and studying functionalities and perhaps also some basic principles (mainly complexity problems) of intelligent environments. The main aim of the described project is at contributing towards theoretical foundations of ambient intelligence via modeling of intelligent environments functionality using three different approaches: multi-agent systems, algebraic methods (namely process algebras), and approaches based on bio-inspired formal grammars paradigm (namely grammar systems and colonies, especially eco-grammar systems).

2 FORMAL APPROACHES

2.1 Multi-agent Systems

From the nature of the ambient intelligence ideas and principles it is straightforward, that the first and recently commonly used approach for modeling intelligent environments and processes in these environments are multi-agent systems or multi-agent architectures. There are a number of papers describing particular applications of multi-agent systems for this purpose. Let us mention, among others, e.g. [23], [26], [27], [28], [29], [31], [33], or [34]. A nice survey with a number of new research challenges appeared recently in [8].

As Cook [8] pointed out, only recently the related research has advanced to the point where the dream about smart environments can become a reality. Because the software architecture for smart environments is very complex, and because there may be multiple entities (e.g., residents) that the environment is serving, such a small environment can be naturally viewed as a multi-agent system.

However, there are also other approaches, which are already evolved and matured enough, and their modeling power seems to be usable also for modeling such problems, which are typical for ambient intelligence. Among others, these approaches are for instance algebraic methods – Algebra of Communicating Processes (ACP), see [1] or [3], or Ambient Calculus [6], and grammar systems – colonies (see, e.g., [9], [10], [11], [14], etc.) Our research intends to make use of these formalism for the sake of modeling basic principles and processes of ambient intelligence.

2.2 Algebraic Tools and Approaches

Ambient intelligence means dealing with processes; for that purpose, an algebraic approach has been developed, known as Algebra of Communicating Processes (ACP). ACP is focused on concurrent systems, and it provides a special mathematical theory known as process algebras or process calculi, initially developed by Bergstra and Klop in 1982 (see [1], [3] or [19]). A nice overview can be found also in [13]. ACP provides an abstract and generalized axiomatic system for processes; in fact, ACP is fundamentally an algebra in the sense of universal algebras. This principle in conclusion provides a way to

ISSN: 1792-6157

ISBN: 978-960-474-245-5

describe systems in terms of algebraic process expressions, defining compositions of other processes, clones of processes, starting from certain elements treated as primitives ones. For this purpose, ACP uses instantaneous, atomic actions as its primitives; some of them have a special meaning. Actions can be combined to form processes using a variety of defined operators. These operators can be roughly categorized as providing a basic process algebra, concurrency, and communication. ACP fundamentally adopts an axiomatic, algebraic approach to the formal definition of its various operators.

Ambient Calculus as a process calculus used in computer science has been devised by Cardelli and Gordon [6]. It is used to describe and theorize about concurrent systems that include mobility. Here mobility means both computation carried out on mobile devices, and mobile computation. The ambient calculus provides a unified framework for modeling both kinds of mobility. Since its inception, the ambient calculus has grown into a family of closely related ambient calculi.

The ambient calculus has been recently proposed as a modeling tool for mobility of agents in a dynamically changing hierarchy of domains. Its origins are based on formal concepts theory. In ambient calculus, properties of mobile computations could be described and studied on the base of a modal logic construction, dealing there about space as well as time.

Lot of papers are devoted to the study of methods, algorithms and their applications in intelligent environments; however, only a minor part of the research uses approaches based on or derived from algebraic structures working tools. A number of papers by Ichiro Satoh are devoted to the study of mobile agents. In [32] he presents a theoretical and practical framework for constructing and reasoning about mobile agents. The framework is formulated as a process calculus, like join calculus and ambient calculus. Due to the author‘s conviction, the calculus constructed and presented in the paper can provide a theoretical base for the mobile agent system, in particular it leads to the construction of a security mechanism in that system. Further on, algebraic methods derived and applied in universal algebra enable to involve the order into the hierarchy of agents. The special order relation defined on the set of agents, with its specific properties, enables the study of functionality in spaces, based on introduction of algebraic systems concepts, such as relational systems, and operational systems as well, with specific aspects on mobility. The research has to be concentrated on the ordered set of states, on the study of properties of the order and their conclusions. The search for generators, possibly finite sets of generators, bases of the functional agent system, homomorphisms of functionality spaces leads to a simultaneous study of structured classes of ambient intelligence environments, and enables to presume and to derive their common or comparable properties, provided constraining conditions are fulfilled. Research based on universal algebra methods has to be devoted for design, implementation, interaction possibilities, testing and controlling reasons, and security purpose of ambient intelligence environments.

2.3 Grammar Systems

Another conceptual and methodical approach which devotes our attention as suitable for modeling smart environments will be based on grammar systems and their variants and generalizations.

Nearly all the approaches mentioned in this chapter were inspired with the distributed Artificial Intelligence for which it is typical that deals with the cooperative solution of problems. Several agents here interact with each other, following a given strategy; the communication and interaction protocols of the agents are well-defined in advance.

First models of grammar systems theory are mainly motivated by distributed AI. According to [2] the theory of Grammar Systems was developed as a grammatical model for distributed computation (see [10] as the most general source). Briefly, a grammar system is a finite set of grammars working together according to a specified protocol of cooperation, to generate one language. Many variants of grammar systems have been developed and studied as language generators, simulators of natural or artificial environments, problem solvers and conversational models. For instance, the concept of cooperating distributed grammar systems (abbrev. CD grammar systems) was proposed as a syntactic model of the blackboard architecture of problem solving where several independent agents work together on the solution of a problem by cooperating with each other only by modifying the common blackboard representing the current state of problem solving.

In a CD grammar system the agents are generative grammars and the global data base is represented by a string, called sentential form. The agents take turns in rewriting the sentential form according to a cooperation strategy, called derivation mode. The successful problem solving is achieved by generating a terminal word. CD grammar systems were the first formal language theoretical models formalizing distributed computation. It demonstrated that complex behavior, i.e. complex languages can be generated by simple grammars using a simple cooperation strategy [9]. For an overview about CD grammar systems see [10].

In accordance with general trends in computer science the development of generative models of computations proceeds from grammars with linguistic motivation and grammars motivated by sequential computing, to grammars motivated by parallel computational processes typical for biological development and/or computation of biological structures. Typical representative of such parallel grammars are Lindenmayer systems and different variant of parallel grammars. On the more structured level, the level of grammar systems, there are eco-grammar systems, eco-colonies, colonies and membrane systems, etc. These are topics investigated for several years by a number of research teams, see e.g., the monograph on grammar systems [10] by J. Kelemen and his coauthors or the Handbook of Formal Languages [30] with quite a lot of further interesting references.

Colonies firstly appeared in [15] and after basic sequential models also PM colonies [20], colonies with time bounds [16], structural colonies [11] and some others were introduced and investigated. Colonies represent the simplest architecture reflecting the idea of total decentralization and completely emergent behavior of systems set up from purely reactive components [15]. Particular experiences prove the practical usability of the architecture, e.g. in real-world robotic systems design. The formalized concept of colonies proposed first in [16] offers a formal framework for description and study of the behaviors of systems set up according this architecture principles from purely reactive (non-iterating) components.

In connection with the study of membrane systems (P systems), also P colonies as special P systems [18] are studied.

Other interesting variant, eco-grammar systems came up from biological motivation [7], [11]. Eco-grammar systems represent a grammar-theoretic framework for describing systems which consist of a community of agents acting in a shared environment, and provide a formal framework for describing systems of agents formalized as simple entities which generate strings of symbols and act through rewriting symbols in a shared simple environment of the form of string of symbols. The ability of systems to evolve is very closely related to life. In [17] the evolution in eco-grammar systems as a mechanism of change (growth) of the complexity of systems (structure, behavior) during systems functioning (over time) is characterized. Conditions in the environment of the eco-grammar systems and conditions in the agents of the systems which lead to the artificial evolution are of a special interest.

Typical research area studied for above mentioned types of generative systems are their generative power, structural complexity (number of components) and the corresponding hierarchy of languages, and also an attempt to express quantitatively the emergence. Overviews of these topics can be found in [7], [12], or [20].

The environment as special component plays important role in these models. While passive environment is typical for colonies, the eco-grammar systems represent large variety of models, where activity of the environment plays a substantial role [9]. Therefore these systems can be considered as most promising also for modeling and further investigation of interesting features of multi-agent architectures of intelligent environments of various kinds. Actually, eco-grammar systems were introduced to formalize the concept of ecosystems consisting of several agents living together in a common environment. The model assumes that both the agents and also the environment evolve; the environment evolves independently of the agents, while the agents dependently on the environment. Moreover the agents can sense the environment and can change it. According to [9], the original model was based on the following six postulates:

1. An ecosystem consists of an environment and a set of agents. Both the state of the environment and the states of the agents are described by strings of symbols.
2. In an ecosystem there is a synchronized universal clock, which divides the time in units. In each time unit the environment and the agents together perform a derivation step.
3. Both the environment and the agents have evolution rules, which are rules of Lindenmayer systems, hence are applied in a parallel manner to all the symbols describing the states of the agents and of the environment; such a (rewriting) step is done in each time unit.
4. The evolution rules of the environment are independent of the agents and of the state of the environment itself. The evolution rules of the agents depend on the state of the environment (at a given moment, a subset of the rules is chosen from a general set associated to each agent).
5. The agents act on the environment according to action rules, which are rewriting rules used in context-free manner. In each time unit, each agent uses one action rule, chosen from a set depending on the current state of the agent.
6. The action (of agents on the environment) has priority over the evolution of the environment; in a given time unit, those symbols of the environment which are not affected by the actions of the agents are rewritten (in parallel manner) by the evolution rules.

Although the eco-grammar systems seem to be relatively too simple for modeling ambient intelligent environments, the postulates just mentioned give us quite interesting possibilities for further research in the area.

3 Further Works

The research focuses on several interesting goals in the systematic investigation of grammar structures reflecting their motivation as modeling tools for intelligent environments based on suitable multi-agent architecture. One of the most interesting research questions is focused on dealing with the relations of the component of the system to its environment, where the environment can be treated as one special component of the system. Interactivity between individual components of systems and interactivity between environment and components of the systems are basic features of grammar systems, P systems and their variants. Structure of the environment determines hierarchy and generative power of respective grammar systems. It is reflected in many results obtained in the area of grammar systems and colonies during the last decade. It seems to be necessary to concentrate further research to the effect and consequences of the interactivity on the form of the changes in the environment or in individual components, which were influenced by changes of the behavior of another individual component(s). There could be direct relations found to structure and functionality of intelligent environments based on multi-agent architectures. The eco-grammar systems, for instance, possess large variety of open problems in connection with inbuilt mechanisms for influencing agents by the state of the environment and vice versa. In this connection a possible classification of the interactivity can be formulated and studied further on as well.

4 Conclusion

There is a real "boom" of the activities in the area of ambient intelligence or related areas of smart environments, pervasive computing or ubiquitous computing. These activities are very often ad hoc, without properly established theoretical foundations. We are convinced that there is highest time to start with research a priori focused on possibilities of establishing sound theoretical foundations for this area. Such theoretical results could be interesting also for other theoretical areas, e.g. achievement of new complexity results via grammar systems or colonies can contribute also to further evolution of young but already established theory of grammar systems. Certainly among rather new and inspiring (maybe also promising) directions in this effort we can count also usage of algebraic approaches, which we intend to apply.

The expected results should contribute towards theoretical background of ambient intelligence area, namely they will present new possibilities of modeling smart environments not only via multi-agent architectures but also using other formal approaches as grammar systems or selected algebraic approaches. We expect to achieve also new results on complexity of processes performed in an environment with ambient intelligence (smart environment). The results will be published largely; a monographic elaboration of results in a leading world publishing house is expected as well.

This research has been partially supported by the *Czech Scientific Foundation Project No. P403/10/1310 SMEW - Smart Environments at Workplaces* as well as by the UHK FIM *IPSV Project 2101/10 AmIRRA - Ambient Intelligence Research Related Activities.* The author is also indebted to Tatiana Gavalcová and Alica Kelemenová for submitting valuable related materials and ideas.

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