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Hierarchical Distributed Systems Based on Semantic Schemas

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Abstract. This paper synthesizes our work in the domain of distributed systems that use semantic schemas for knowledge representation and reasoning. The developed applications for this kind of systems are also summarized. The material for the present article gathers some results of my Ph.D. Thesis [Ghindeanu, 2009] obtained in the domain.

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1. Introduction

Most situations to be controlled are complex and uncertain and involve parallel processes. Thus, the applications developed to deal must be intelligent (to manage complexity and uncertainty) AND distributed (to handle parallelism) ([Dzitac, 2009]). In this article we resume our activity in the domain of developing new architectures for distributed system which benefit from the semantic schema representation and reasoning mechanism.

The concept of semantic schema was introduced in [Ţăndăreanu, 2004] in order to extend that of semantic network. A semantic schema is an abstract structure that can represent knowledge by considering a proper interpretation. Various interpretations can be used for the same semantic schema. This concept was applied successfully in various domains and we review such applications in a separate section of this paper.

The structure of the paper is as follows. In Section 1 the basic theoretical notions concerning the structure of semantic schema are presented. Section 2 shortly presents the distributed architectures of the two systems based on semantic schemas that we have constructed while Section 3 gives a short description of their implementations. Section 5 identifies the open problems associated to the development of such systems at this moment.

Consider a symbol θ of arity 2. A *semantic schema* ([Ţăndăreanu, 2004]) is a system $\mathcal{S} = (X, A_0, A, R)$, where:

• X is a finite non-empty set of symbols named object symbols
• A_0 is a finite non-empty set of elements named label symbols and $A_0 \subseteq A \subseteq \overline{A}_0$, where $\overline{A}_0$ is the Peano θ-algebra generated by A_0
• $R \subseteq X \times A \times X$ is a non-empty set of relations which fulfills the following conditions:
 – $(x, \theta(u, v), y) \in R \Rightarrow \exists z \in X : (x, u, z) \in R, (z, v, y) \in R$
 – $\theta(u, v) \in A, (x, u, z) \in R, (z, v, y) \in R \Rightarrow (x, \theta(u, v), y) \in R$
 – $pr_2 R = A$

An interpretation $\mathcal{I}$ of a semantic schema $\mathcal{S}$ is a system ([Ţăndăreanu, 2004], [Ţăndăreanu, 2005c]):

$$\mathcal{I} = (Ob, ob, \{Alg_u\}_{u \in A})$$

where:
• Ob is a finite set of elements which are called the objects of the interpretation
• $ob : X \longrightarrow Ob$ is a bijective function
• $\{Alg_u\}_{u \in A}$ is the set of algorithms corresponding to the labels of A

Every system constructed from a set of semantic schemas will also inherent the two aspects of these structures: the formal aspect which deals with the syntactic computations and the evaluation aspect described by means of an interpretation.

Using distributed and analogic calculus in such a system, the reasonings corresponding to the system's schemas of a certain level are extended at the upper levels of the system.

2. Hierarchical systems based on semantic schemas

We used semantic schemas as structures for knowledge representation and reasoning in several hierarchical and cooperating architectures as follows:

- Join semilatice of all semantic schemas was studied for modeling distributed knowledge representations and analogical reasoning ([Ţăndăreanu, 2005a]).
- In [Ţăndăreanu, 2005a] is given the use of semantic schemas in knowledge management where is defined a distributed system organized on three levels. Each level consists of some reasoning entities that represent and process information by means of semantic schemas. In this system, knowledge transfer, distributed and analogical computations are automatically implemented by constructing the supremum structure of the semantic schemas provided by the system's reasoning components.
- A new hierarchical architecture for a distributed reasoning system built upon the system's knowledge domain is proposed in [Ghindeanu, 2007a]. A study of the manner in which this architecture can be fitted on the system's inputs is given in [Ghindeanu, 2008a].
- Using a hierarchical method we defined new semantic schema structures: the *hyper-schemas*. By endowing the system presented in [Ghindeanu, 2007a] with these structures we obtained the *Hierarchical Distributed Resoning System* (shortly, HDR System). An HDR system is a directed graph organized on several levels such that each node of the level j is a hyper-schema of order j. For this kind of system we developed applications in computer graphics and image synthesis domains ([Ţăndăreanu, 2009], [Ţăndăreanu, 2008a], [Ghindeanu, 2008b]).

In [Ţăndăreanu, 2005a] we identify for semantic schema some important properties that lead us to the defining of the supremum structure for a finite number of semantic schemas. We prove that the supremum obtained in this manner is also a semantic schema in which distributed and analogic computations can be implemented. We applied this concept in a *distributed reasoning system on three levels*

$$DS = (L_1, L_2, L_3, SDB, G)$$

organized as follows:

(1) on the first level L_1 there are the *observers* or the *agents* of the system which send phrases in a natural language to the second level of the system.

(2) the second level L_2 includes the *primary knowledge managers* (PKM) of the system. Each PKM receives phrases from some observers, has an own semantic schema and identifies a useful part of it in order to represent the received information.
(3) on the third level L_3 we find the *general knowledge manager* (GKM). It processes the structures of the second level of the system by constructing the supremum of these structures and obtaining its corresponding interpretation. The supremum construction permits GKM to perform distributed computations.
(4) the component SDB is a database, by means of which correspondences between the names of the objects and of the binary relations with their internal representation can be defined.
(5) G is a grammar for natural language

We applied the system in the domain of geometrical image generation. The proposed method can be used in order to store semantic schemas instead of geometrical images.

The system introduced in [Ţăndăreanu, 2005a] is reconsider in [Ţăndăreanu, 2008a] but with other reasoning mechanism. It uses hyper-schemas of various orders instead of semantic schemas and has a hierarchical architecture that is not restricted to a certain number of levels. We obtain a Hierarchical Distributed Reasoning System (HDR System) in which distributed reasonings, a new method for knowledge transfer and reasoning by analogy are implemented.

In order to prepare the definintion of an HDR system several new theoretical concepts were needed to be introduced:

(1) the concept of *ordered path* and based on it, the *deductive path*. By means of deductive paths, a new kind of reasoning is formalized in a semantic schema: the *path-driven reasoning mechanism* ([Ţăndăreanu, 2008b]).
(2) the need of a new semantic schema structure in which distributed and analogic computations can be implemented is claimed in [Ghindeanu, 2007b] and formalized in [Ţăndăreanu, 2008a]. The new structure is named *hyper-schema*. A semantic schema with path-driven reasoning mechanism becomes a hyper-schema of order 0. By means of a recursive and hierarchical method hyper-schemas of higher orders can be constructed.
(3) the definition of the HDR system is prepared in [Ghindeanu, 2007a] and finalized in [Ţăndăreanu, 2008a]. In [Ţăndăreanu, 2009] the reader can find the syntactic and semantic computations corresponding to this reasoning system detailed on several examples.

An HDR system ([Ţăndăreanu, 2008a]) is the tuple $H = (Q_1, Q_2, \ldots, Q_k)$ where $k \geq 2$ and

- $Q_1 = \{\mathcal{S}_1, \ldots, \mathcal{S}_{n_1}\}$, $n_1 > 1$, constitutes the first level of the system. The entities $\{\mathcal{S}_1, \ldots, \mathcal{S}_{n_1}\}$ are hyper-schemas of order zero.
- $Q_2 = \{\mathcal{S}_{n_1+1}, \ldots, \mathcal{S}_{n_2}\}$, $n_2 \geq n_1 + 1$, gives the second level of the system and $\mathcal{S}_{n_1+1}, \ldots, \mathcal{S}_{n_2}$ are hyper-schemas of order 1. More precisely, for every $m \in \{n_1 + 1, \ldots, n_2\}$ there are $m_1, m_2 \in \{1, \ldots, n_1\}$, $m_1 \neq m_2$ such that $\mathcal{S}_m \in Hyp_1(\{\mathcal{S}_{m_1}, \mathcal{S}_{m_2}\})$.
- For $j \in \{3, \ldots, k\}$, $Q_j = \{\mathcal{S}_{n_{j-1}+1}, \ldots, \mathcal{S}_{n_j}\}$ represents the j-th level of the system, where $n_j \geq n_{j-1} + 1$. For every $m \in \{n_{j-1} + 1, \ldots, n_j\}$ there is $m_1 \in \{n_{j-2}, \ldots, n_{j-1}\}$, $m_2 \in \{1, \ldots, n_{j-1}\}$ such that $\mathcal{S}_m \in Hyp_{j-1}(\{\mathcal{S}_{m_1}, \mathcal{S}_{m_2}\})$.

Basically, a distributed system on three levels $DS = (L_1, L_2, L_3, SDB, G)$ and a hierarchical distributed system $H = (Q_1, Q_2, \ldots, Q_k)$, $k \geq 2$ are two distributed reasoning systems that use semantic schemas for knowledge representation and reasoning. Still, between these two kinds of systems are important differences as it can be seen in Table 1.

3. Applications of DS and HDRS

In [Ţăndăreanu, 2005a] we defined for semantic schemas interpretations such that the algorithms' outputs are 2D images consisting of some geometrical figures. We endow a distributed system with this kind of interpretations. The result is an image generation system where the images of the last level of the system are constructed using distributed and analogic computations.

In [Ghindeanu, 2008b] is described an HDR system for image synthesis. The proposed synthesis mechanism takes descriptions of images consisting of some objects arranged in a spatial area and provides at output the grid representation of the image. By this implementation results a HDR system for spatial reasonings with the following properties:

- the agents of the system start the processing of spatial linguistic descriptions, each agent being specialized on a certain set of spatial relations
- at the upper levels the knowledge managers perform distributed computations in order to enrich the deductions already obtained in the system at the previous levels

The maner in which the reasonings are implemented in HDR systems lead to an inference mechanism based on which grid-representations can be constructed without using any artithemtical operations.

In [Ţăndăreanu, 2008a] is presented another use of HDR system, this time in the field of cumputer graphics. More precisely, we defined a new mechanism for image generation by means of hyper-schemas similar with the edge rewriting operation mode of Lindenmayer-systems (shortly, L-systems).

The mechanism is implemented in an HDR system as follows. Each leaf of the system is given by a semantic schema. The other nodes are hyper-schemas. The leaves represent the input of the system in semantic schemas and, by appending proper interpretations, the graphical illustrations of the received inputs can be obtained. In this manner the leaves obtain the initial images of the generation mechanism. Then, at the upper levels, these images are constructed using a combination process formalized by means of the path-driven reasoning mechanism defined for hyper-schemas. Thus, a *bottom-up generation method*, based on some initiators, results.

We have implemented this geometrical image generating mechanism by means of an HDR system in a Java application as it can be found in [Ţăndăreanu, 2009]. We apreciate that the application can draw maximum 1000 images with maximum 50 geometrical objects per image.

Another applicability of HDR systems which was not fully investigated and remains as an open problem can be found in the domain of the natural language processing. In [Ţăndăreanu, 2009] we show how the abtract components of the system can be evaluated as sentences in a natural language (in English). Summarizing, we defined an interpretation for this kind of systm by means of some *sentential forms*. Such a structure is a sentence containing two variables. In we substitute each variable by an object then the sentential form becomes a sentence in a natural language.

Table 1. The differences between DS and $HDRS$

	$DS = (L_1, L_2, L_3, SDB, G)$	$H = (Q_1, Q_2, \ldots, Q_k)_{k \geq 2}$
Reasoning components	A DS has two levels of reasoning entities, because the agents are used only to collect information for the managers.	In an HDR system all the components are reasoning entities organized on levels based on the order of their hyper-schemas.
Knowledge transfer	In a DS all the θ-schemas generated by the managers of 2^{nd} level are transmitted to the 3^{th} level where the general manager, GKM constructs the supremum of them.	In an HDR system only paths are transmitted. More precisely, only the paths that can generate new deductions at the upper levels are transmitted.
Structure	It is restricted to three levels, no matter the system's knowledge domain.	The number of the system's levels, k, depends on the maximum order of the hyper-schemas that are generated in the system starting from the agents' schemas

4. Conclusions

Even if we obtain good results, the HDR systems' applications are not restricted to these generating mechanisms. An HDR system is a proper structure for implementing recursive and distributed reasoning mechanisms that allow representations by means of semantic schemas. Each level of the system corresponds to a certain step of iteration and the system can grow as long as new iterations can be performed.

5. Open problems

Over the last decade, agent technology has shown great potential for solving problems in large scale distributed systems. We consider that the mobile agents are advantageous for being used as reasoning components in HDR systems.

Also, the use of the HDR systems in e-learning promises new development directions. The basic idea comes from the fact that a link in an HTML document gives a reference to another document of a similar structure.

HDR systems can be used for natural language processing. The architecture of these systems allows processing of the phrases on pieces. One important advantage relies in a easy shift from one language to another while the semantics of the phrases can be preserved.

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