An Approach to Computational Semiotics

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ABSTRACT

The aim of this paper is to introduce the theoretical foundations of an approach for intelligent systems development. Derived from semiotics, a classic discipline in human sciences, the theory developed provides a mathematical framework for the concept of knowledge and for knowledge processing. As a result, a new perspective to study and to develop intelligent systems emerges. A taxonomy of elementary types of knowledge is proposed based on the classification of types of signs in semiotics, followed by a another classification of knowledge from the point of view of application in cognitive systems. In addition, we propose the mathematical definition of objects, objects systems and objects networks, to model mathematically the different types of knowledge described. The symbiosis of such key concepts introduces a computational paradigm to develop and implement intelligent systems, called here computational semiotics.

KEYWORDS: *computational semiotics, theory of objects, intelligent systems, models of knowledge*

1. INTRODUCTION

Human intelligence has always been of interest and curiosity in the scientific world. In 1991, Albus published an outline for a theory of intelligence, and simultaneously Brooks [3] argued that for an intelligent behavior, there should not necessarily exist representation or inference. Additional aspects of intelligence, e.g. approximate reasoning (including fuzzy or incomplete concepts), learning, prediction, and adaptation are being studied in the fields of computational intelligence [14] and soft computing [13]. Considerable research effort on fuzzy set theory, neural networks and evolutive systems have and still are being pursued. The contribution of these fields in understanding the nature of human intelligence has been quite impressive.

Parallel to the developments in computer science and engineering, in human sciences there was a similar effort to model intelligence and intelligent behavior. Well known examples include the work of Piaget [2], and the development of semiotics by Peirce and Morris [12,9,10,11], just to mention a few. Semiotics deals with signs (representations), objects (phenomena) and interpretants (knowledge), that is, the main issues in cognition and communication. Semiotics has shown to be an useful tool especially when the basic ingredients of intelligence and their relationships are of concern.

Despite the challenges in discovering the formal mysteries behind human intelligence and the intrinsic difficulties in building machines and computer programs to emulate intelligent behavior, very few works analyzing intelligence in an integrated and organized manner have been done. Often, only particular aspects of intelligence are addressed. A notable exception comes from Albus' 1991 paper. In his work, Albus provides a systematic study of intelligence, and gives a description of the different parts composing the global phenomena. The integration of all parts should lead to intelligent behavior. Albus definitions and theorems are essentially linguistic due to the lack of a formal system to describe intelligence. In other words, currently there is no adequate mathematical model to describe intelligence as a whole. Most existing formalisms are closely tied to particular aspects, being unsuitable for a global, computational formalization of intelligent systems. Semiotic Modeling and Situation Analysis-SSA, developed by Pospelov and his team in Russia was another important attempt in this direction. A key feature of the SSA approach is extraction of knowledge from the descriptive information by its consistent analysis based upon well established algorithms [7]. From this point of view, mathematical tools of semiotics are considered to include those used in control science, pattern recognition, neural networks, artificial intelligence, cybernetics. But semiotic specific mathematical tools (for combining signs, symbols and extracting meaning) are still in the process of development [7].

In [8], the use of semiotics as a tool suitable for the analysis of intelligent systems was suggested. Concurrently, in [4] the computational view of semiotics for modeling, development and implementation of intelligent systems, the computational semiotics approach, was proposed. Computational semiotics is build upon a mathematical description of concepts from classic semiotics. Its formal contents can be regarded as a contribution towards the development of semiotic specific mathematical tools. Thus, it is in the very realm of the formal foundations of intelligent systems. The main purpose of this paper is to introduce the mathematical aspects which subsumes computational semiotics.

2. ELEMENTARY TYPES OF KNOWLEDGE

Based on the classification of types of signs in semiotics, we have derived a hierarchy of elementary types of knowledge, shown in figure 1.
Knowledge is divided in three main classes, the rhematic knowledge, dicent knowledge and argumentative knowledge. Strictly speaking, rhematic knowledge concerns the semantic of (linguistic) terms, dicent knowledge combines sequences of terms with truth values and analyses how rhematic knowledge relates to a real environment, and argumentative knowledge embodies the knowledge of how knowledge is transformed comprising reasoning, inference and learning.

3. APPLIED KNOWLEDGE

Based on its intended use, knowledge can be classified as designative, apraisive or prescriptive (figure 2), terms coined by Morris [9,10,11]. This classification is complementary to the elementary types of knowledge. In principle, any elementary type of knowledge can be used as designative, apraisive or prescriptive, i.e., this classification is orthogonal to the elementary classification.
Designative knowledge models the world. For this purpose it uses rhematic, dicent and argumentative knowledge, either specific or generic. Designative knowledge can also be viewed as descriptive knowledge. A cognitive system initially has just a few, or eventually no designative knowledge at all. Usually designative knowledge emerges from the interaction between the system and world.

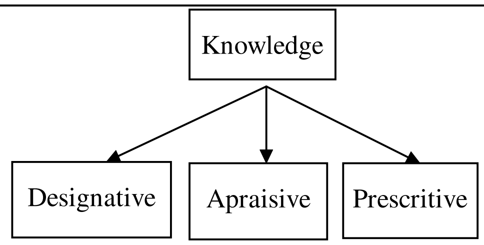

Figure 2 - Classification of Applied Knowledge

Apraisive knowledge is a type of knowledge used as an evaluation, a judgment, a criteria to measure the success in achieving goals. In natural systems, apraisive knowledge is closely related with the essential goals of a being; reproduction, survival of the individual, survival of the specie, increasing knowledge about the world, for example. Depending on the goal it assumes special forms like: desire, repulse, fear, anger, hate, love, pleasure, pain, confort, disconfort, etc. Essentially, apraisive knowledge evaluates if a given sensation, object, or occurrence is good or not, as far as goal achievement is concerned.
Prescriptive knowledge is intended to act on the world. Basically, prescriptive knowledge is used to establish and to implement plans through actuators. However, prescriptive knowledge will not necessarily end up with an action. Prescriptive knowledge may also be used to do predictions, but only one of them is selected to generate an action.

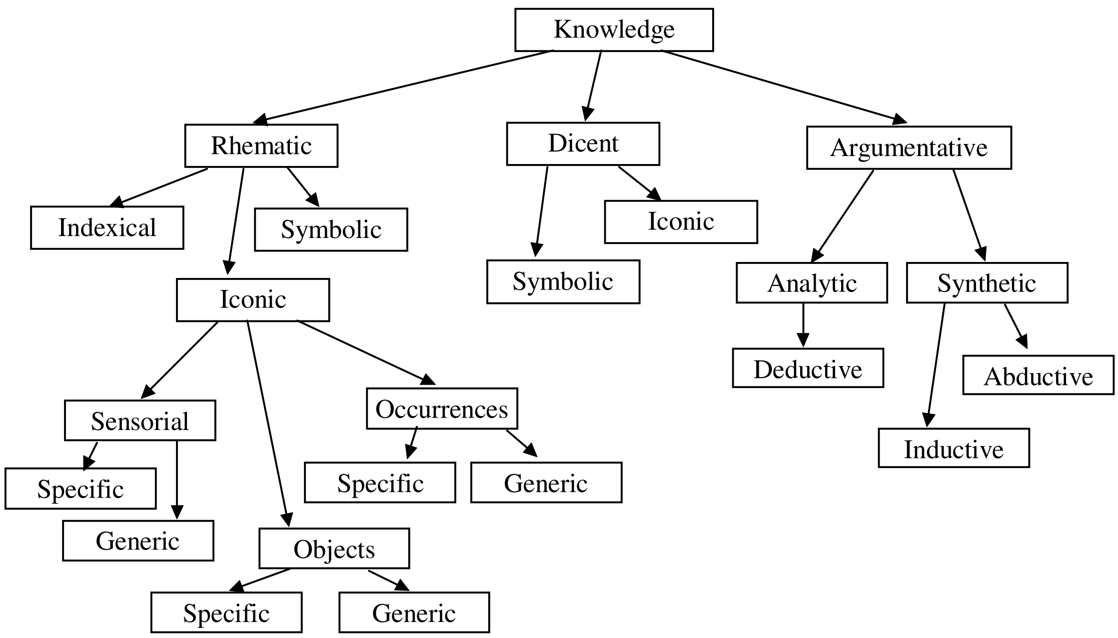

Figure 1 - Classification of the Elementary Knowledge Types

4. A MATHEMATICAL THEORY OF OBJECTS

This section introduces concepts and definitions as a formal background for computational semiotics. The focus here is on the main issues and definitions only. For a more in depth coverage the reader is referred to [4] or [5,6].

4.1. Variable

Let N be a countable set with a generic element n, and $X \subseteq U$. A variable x of type X is a function $x : N \to X$. Note that a function is also a relation and hence it can be expressed by a set. Thus, $x \subset N \times X$.

4.2. Class

A class C is a set whose elements c_i are tuples of the type:
$(v_1, v_2, \ldots, v_n, f_1, f_2, \ldots, f_m)$, $n \geq 0$, $m \geq 0$
where $v_i \in V_i$, and f_j are functions

$$f_j : \bigtimes_{p \in P_j} V_p \to \bigtimes_{q \in Q_j} V_q .$$

Here $\bigtimes$ means the cartesian product, $P_j \subseteq \{1, \ldots, n\}$ and $Q_j \subseteq \{1, \ldots, n\}$.

4.3. Object

Let C be an non-empty class and c be a variable of type C. Thus c is an object of class C.

4.4. Object System

A set of objects c_i is an object system if the c_i's are related to each other in the sense that each instance of such objects in a given instant is a function of the instances of all objects in the previous time instant:

$$c_k (t+1) = f (c_1(t), \ldots, c_n(t)).$$

This is only a concise definition of an object system. The complete definition is far more involved. The reader is referred to [4] or [5,6] for details.

4.5. Object Network

An object system is a too generic approach for modeling elementary knowledge types. An object network is a special type of object system in which additional restrictions concerning interactions are included. To distinguish object network and object system let us assume places and arcs whose roles are similar to those in Petri nets. Objects in places can only interact with objects in places connected through arcs. Thus, at each instant, the objects defined should be at one place. For each place there is a set of places connected with through of input arcs. These places are called the input gates of the place. Analogously, each place has a set of places connected with it by means of output arcs, called output gates.

4.6. Additional Definitions

Other definitions, important for the particular aspects of some of the knowledge types, may be found in [4] and [5,6]. They include the temporal restriction for objects, set variable, generic objects, fuzzy objects, meta-objects, instances of meta-objects, occurrences of meta-objects in objects, generic objects and fuzzy objects, generic meta-objects, occurrences of generic meta-objects in objects, generic objects and fuzzy objects, fuzzy meta-objects, occurrences of fuzzy meta-objects in objects, generic objects and fuzzy objects.

5. MODELS OF KNOWLEDGE TYPES

Using the mathematical definitions given above, we are able to model the elementary types of knowledge and use them to build intelligent systems, mainly concerning the applied aspects of knowledge, i.e., their property of being designative, apraisive or prescriptive.
Basically, sensorial and object rhematic iconic knowledges can be modeled by passive objects, i.e., objects that do not have functions in its image tuples. Occurrence rhematic knowledge can be modeled by meta-objects (standard, generic or fuzzy). Those meta-objects can be reduced, however, to objects by means of appropriated techniques. Dicent knowledge can also be modeled by objects. Argumentative knowledge must be modeled by active objects, i.e., objects that have working functions in its image tuples. The complete description of such modeling representations can be found in [4] or [6].
This leads to a scenario where a whole intelligent system may be modeled by an object network. The representation by means of an object network has many advantages. An object network is more powerful than a Petri net in the sense that it allows modifications in its active parts, what is not possible in Petri nets. This is important for systems that have learning and adaptive capabilities, which can not be represented by Petri nets, including there colored Petri nets. The possibility of representing an intelligent system by a formal computational tool allows for a more in depth study of phenomena involving intelligent behavior. Some properties that were targeted linguistically in early studies of intelligent systems (e.g. [1]), may be translated into a mathematical framework, allowing for a more solid foundation. In this sense, the tools provided by computational semiotics seems to be a very promising set of mechanisms for building a future theory of intelligence.

6. CONCLUSIONS

In this paper we briefly introduced a new approach for the study of intelligent systems. This approach, called computational semiotics, uses the concepts brought from semiotics to propose a hierarchy of elementary types of knowledge, and based on a mathematical framework, models such knowledges in a mathematical way. Due to its object oriented nature, the mathematical model is very suitable for computational implementation, providing in addition, a mathematical description of intelligent systems.

It is very important to stress, though, that such an approach is in its very beginning. The presented taxonomy of types of knowledge, despite significant, is only partial. In his works, Peirce identifies more than 100 different types of signs, eventually implying in different types of knowledge. These are not included in the presented taxonomy. But, the presented taxonomy provides an elaboration of rather sophisticated intelligent systems. More than that, it creates an organization that is not usually found in literature, concerning the differences among the knowledge used when building intelligent systems. The formalism presented for objects in this paper, does not aim to be a general theory for objects, but simply put foundations for a future grow of such a theory. Some extensions are actually needed, mainly to consider asynchronous interaction among objects. But, the formalism, in its current form, is suitable to represent intelligent systems, what is a very important characteristic. Despite its representation power, the object networks developed upon the mathematical concept for objects still have many limitations. For example, analysis tools are still incipient, when compared with other modeling tools, e.g., Petri Nets. Indeed, very few systems have been modeled by the object network formalism. In addition, there is a lack of a formal representation for the types of knowledge not covered by our elementary knowledge hierarchy. As new types of knowledge are included in the hierarchy, new formal definitions would be demanded. Very few intelligent systems were built so far using the computational formalism. To consolidate object networks as a valid and general tool for modeling intelligent systems, it is still necessary to solve a broad class of problems to emphasize its virtues and to precisely identify the extensions needed.

An application example concerning the control of an autonomous vehicle was successfully developed and implemented using the computational semiotics approach [4,6].

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