Semantics in the Semantic Web: A Critical Evaluation†

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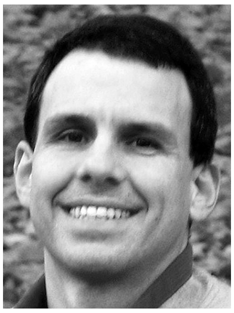

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Almeida, Mauricio, Souza, Renato, and Fonseca, Fred. **Semantics in the Semantic Web: A Critical Evaluation**. *Knowledge Organization, 38(3)*, 187-203. 44 references.

ABSTRACT: In recent years, the term "semantics" has been widely used in various fields of research and particularly in areas related to information technology. One of the motivators of such an appropriation is the vision of the Semantic Web, a set of developments underway, which might allow one to obtain better results when querying on the web. However, it is worth asking what kind of semantics we can find in the Semantic Web, considering that studying the subject is a complex and controversial endeavor. Working within this context, we present an account of semantics, relying on the main linguist approaches, in order to then analyze what semantics is within the scope of information technology. We critically evaluate a spectrum, which proposes the ordination of instruments (models, languages, taxonomic structures, to mention but a few) according to a semantic scale. In addition to proposing a new extended spectrum, we suggest alternative interpretations with the aim of clarifying the use of the term "semantics" in different contexts. Finally, we offer our conclusions regarding the semantic in the Semantic Web and mention future directions and complementary works.

Received 29 October 2009; Revision Accepted 1 July 2010

† Research developed during sabbatical leave funded by CAPES Foundation, Ministry of Education of Brazil, Caixa Postal 250, Brasília-DF 70359-970, Brazil.

1.0 Introduction

The term "semantics" comes from the Greek word semantiké, i.e., téchne semantiké, the art of signification. Definitions found in literature usually indicate that semantics is related to the study of meaning, or to the science that studies the meaning of words. In recent years, the term has been used in different fields of research, and its meaning varies according to distinct conceptions and constructs. Traditionally studied in Linguistics and Philosophy, the usage of the term "semantics" has grown in popularity in areas related to information technology, mainly pertaining to the vision known as the Semantic Web (Berners-Lee 1998).

The main goal of the Semantic Web (SW) is to improve the processes of knowledge representation (KR) and information retrieval (IR) on the Web. Since the 1990s, the Web has been characterized by the use of mark-up languages aimed at visualization by human beings, as well as by search mechanisms based on syntax-oriented algorithms. The impetus to improve IR processes on the Web arose from the expanded number of its functionalities and the significant increase in the volume of data available.

The SW proposes improvements on the mark-up languages used in the construction of Web pages in order to enhance the interaction between such pages and systems. With use of semantics, it is possible to increase the associations of documents to their meanings through descriptive metadata. The issue of meaning, and, therefore, of semantics, is thus essential to the intended purpose of the SW. The set of technologies involved in this proposition aims at solving problems related to the fact that "computers don't have a reliable way of processing semantics" (Berners-Lee 2001, 1).

Considering the complexity inherent in the study of semantics and the diversity of approaches taken over the years, not always exclusive but complementary, it is worth evaluating what kind of semantics is considered in the SW vision. The present article is presented within this context. After a brief survey of the existing approaches to the study of semantics in its original field of research, Linguistics, we present meanings for the term as it is used in the SW and in related areas. We propose an extension of the spectrum created by Obrst (2004) and Daconta (2005). They use a semantic scale to compare distinct instruments, such as taxonomies, thesauri, and databases, in addition to those used in the SW, such as ontologies and representation languages. We critically evaluate Obrst and Daconta's spectrum, clarify the acceptance of semantics in each case, and then we propose an extended spectrum.

The remaining part of the article is organized as follows. Section Two reviews the study of semantics in its most widely accepted sense, namely, the semantics of natural language, and describes the main lines of research in Linguistics. Section Three presents the semantics as used by information and computer science researchers working with the Semantic Web. Section Four discusses the semantic scale of the spectrum under evaluation and proposes the extended spectrum. Finally, Section Five presents final considerations and the possibilities for future research.

2.0 Semantics in Linguistics

Defining semantics is no trivial task, but there seems to be a consensus that semantics means the study of meaning. The difficulty is found in defining what meaning is. Indeed, the concept of meaning is neither clear nor consensual, appearing in variations ranging from realism to forms of relativism. The realistic approach is advocated by those who believe that language is overlaid as a nomenclature on a world in which things exist objectively. On the other hand, there are some forms of relativism according to which the structure of language determines the human capacity to perceive the world.

Indeed, semantics is a domain of investigation with fuzzy limits. Semanticists from different schools use concepts and jargons with no common measure, exploring in their analyses phenomena whose relationships are not always clear. Despite the difficulty in defining exactly what semantics is, Dowty (1979) specifies the main aspects that characterize semantics: i) compositionality; ii) semantic properties; iii) reference and representation.

Compositionality concerns the capacity of a semantic theory to attribute meaning to words and sentences, according to the language. Semantic properties concern the characterization of systematic relations between words and sentences of a language. The notions of reference and representation concern the nature of meaning: the notion of reference is explained as the connection between linguistic expressions and the world; the notion of representation concerns the association of meaning to a mental representation. These aspects guide the main trends in the study of semantics. Section 2.1 presents a brief history of semantic approaches and Section 2.2 emphasizes Formal Semantics due to its importance for the objectives of this article.

2.1 A Brief History and Main Approaches

The present section describes the approaches to semantics, from the first initiatives to the most recent ones. The intention is not to provide an exhaustive survey, which would not be possible due to the complexity and volume of the material on the subject. Thus, many authors and approaches are not mentioned. However, we hope to present some of the main aspects and possibilities in the study of semantics in order to contextualize the use of the term semantics by the SW community.

One of the first references in the study of meaning is the dialogue written by Plato, in which Socrates, Cratylus, and Hermogenes take part and whose subject was the origin of names. In this context, the term "names" refers to: i) a general term for words; ii) nouns or adjectives; and iii) proper names (Sedley 2006). Those Greek philosophers discussed whether names are conventional, i.e., language is an arbitrary system of signs, or whether names are natural, in other words, whether words are intrinsically related to the objects they represent.

According to Sowa (2000), the study of meaning, already established by Aristotle in his work *Categories*, has been developed over the centuries under the label of Logic or of the Theory of Signs. Only in the 19th century did Michel J. A. Bréal (French philologist, 1832-1915) suggest studying the laws governing meaning, naming this field semantics, a term derived from the Greek verb for to signify. In this context, semantics was a discipline of historical character. According to Noth (1995), Ferdinand de Saussure (Swiss linguist, 1857-1913) made the distinction between: i) diachronic linguistics, dealing with changes of meaning in a language over time; and ii) synchronic linguistics, concerning phenomena at a specific point in time. Modern semantics is of synchronic orientation.

Still in the 19th century, an important landmark in the study of meaning was the distinction demonstrated by Friedrich L. G. Frege (mathematician and philosopher, 1848-1925) between two elements present in the meaning of a sentence: sense and reference. According to Dummet (1981), the original German terms used by Frege were Sinn, for sense; and Bedeutung, a noun for the verb bedeuten, translated as meaning and as reference. Sense concerns only that which is important for determining the truth or falsity of a sentence. Any other characteristic that does not affect this determination belongs to its reference. According to Morris (2007), Frege's Theory of Reference explains the basic operations concerning categories of linguistic expressions when attributing to them things to which they refer, or rather their referents.

Nirenberg and Raskin (2004) noticed the existence of different solutions, which have been provided over the years, for the task of representing meaning. Then, the authors highlight: i) componential analysis; ii) semantic fields; and iii) use of metalanguage. Such approaches appear in the period between the establishment of the Theory of Reference and the initiatives considered as being contemporary.

The approach known as componential analysis is based on sets of semantic characteristics called components, which are used to describe related terms in different societies. The combination of these components allows the meaning of terms that are common to the majority of cultures to be obtained. Examples of representative authors related to this approach are Alfred L. Kroeber (American anthropologist, 1876-1960) and Ward H. Goodenough (American anthropologist (1919-?).

The approach known as semantic fields consists of the creation of groups of words with related meanings. Words are located close to one another through a combination of intuitive factors including, among others, paradigmatic relations and syntagmatic relations. Examples of authors representative of this approach are Jost Trier (German linguist, 1894-1970) and Leo Weisgerber (German linguist, 1899-1985).

The semantic fields approach explores semantics without using a metalanguage. The importance of using a metalanguage that is different from the language itself eliminates possible disturbances in linguistic analysis. An extension of componential analysis to encompass a whole lexicon might generate a metalanguage for describing the meaning of words. The use of a metalanguage for componential analysis based on First-Order Logic (FOL) resulted in the attribution of logical entities (predicates, arguments, functions) to the components. Examples of pioneering authors of this approach are Joseph H. Greenberg (American linguist and anthropologist, 1915-2001) and Yehoshua Bar-Hillel (mathematician and linguistic, 1915-1975).

Among contemporary approaches, three main trends are identified: i) the pragmatic approach; ii) the mentalist approach; and iii) the referential approach.

The pragmatic approach is represented by the argumentative semantics of Oswald Ducrot (French linguist and philosopher, born 1930) and by the Theory of Speech Acts-John L. Austin (English philosopher, 1911-1960). The Argumentative semantics approach, which originated in France, argues that sentences are pronounced as part of a speech in which the speaker tries to persuade his interlocutor to agree with his hypothesis. Language is not used to say something about the world, but to convince the listener to join in an argumentation game. The Theory of Speech Acts stresses the idea that part of the sense of a sentence has a social function.

According to the mentalist approach, the sense takes place at an intermediary level between the world and the words, which corresponds to the level of mental representation. The main initiatives within this approach are: i) the cognitive semantics represented, for example, by George P. Lakoff (cognitive linguistics researcher, 1941-); ii) the representational semantics represented by Ray Jackendoff (American linguist, 1945-); and iii) the lexical semantics represented, for example, by Beth Levin (Stanford University linguist).

Cognitive semantics presupposes the relation between the language and a representation through schemes and images, mapping distinct conceptual domains where the use of metaphors corresponds to an essential cognitive process. Representational semantics is concerned with the form of inner mental representations that constitute the conceptual structure, and with the formal relations between this level and other levels of representation (syntactic, phonologic, and visual). Lexical semantics explores the notion of thematic roles, which are semantic functions performed by the arguments of a verb (subject and complements) in a sentence. Other lexical semantics initiatives propose lexical studies in order to enable the application of linguistics in computational environments.

The Referential approach originates from the study of Logic and of Philosophy of Language, namely, from the distinction proposed by Frege. According to Portner (2005), Frege used as examples the expressions "Morning Star" and "Evening Star," which have different meanings, but refer to the same entity, the planet Venus. Sowa (2000) explains that Frege attributed the entities of his theory to the three vertices of a triangle, calling them symbol, sense, and reference. This same distinction was introduced in Linguistic Semantics by Ogden and Richards (1972, 32) through the triangle of meaning: "a diagram where the three factors involved, every time we declare that something is understood, are put on the vertices of the triangle, the existing relations among them being represented by the sides."

In the Triangle of Meaning (Figure 1), the edges connect the following entities: object and sign, sign and concept, object and concept. Culturally, there is a common agreement to identify a real world object by means of a sign (convention edge); such a sign, when perceived by a person, generates a concept in the mind (perception edge); the concept is formed in the mind of the person based on experience in the world,

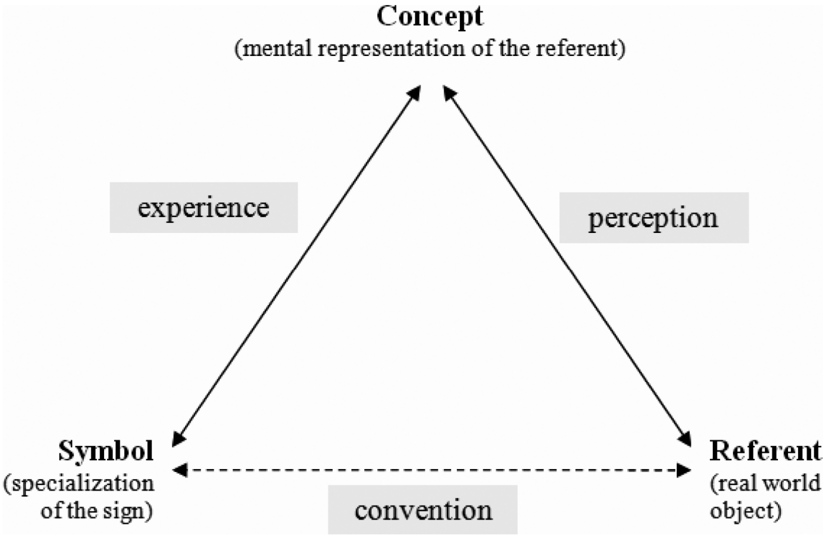

Figure 1. Triangle of meaning
Source: adapted from Ogden and Richards (1972)

because in that object another previously encountered object is recognized (experience edge). The convention edge is presented as a dotted line in order to emphasize that a symbol does not connect directly to its referent (an object of the world), but through a mental representation of this element in the world.

Dahlberg (1978) presents the Triangle of Concept, which is different from the Ogden and Richards´ triangle, in which the concept is one of the vertices of the triangle and its meaning might assume many possibilities. Dahlberg (1978) presents the concept as being the sum of the true and essential statements about a referent, and the term (lexicon) as being the communicable and representable form of the concept. In this representation, we can see that the meaning of a term, that is to say a verbal form, issues from the interpretation of a set of true statements (characteristics), which may be attributed to a referent, i.e., an object, phenomenon, process, or entity.

Writing on information retrieval, Blair (1990) presents a critical perspective regarding some developments in the semiotic field. Despite the enumerated useful aspects of semiotic theory, the author argues against what he calls the mentalistic semiotic approach, which focuses on the use of expressions instead of focusing on the meaning of expressions. According to him, there are at least two main problems with the mentalist theories of meaning: i) the content verifiability problem: the impossibility of a speaker verifying what the correct content is, in the sense of being culturally accepted, for the meaning of an expression; ii) the nature of an idea as content: the difficulty of directly ascribing a word meaning to a mental image that one can have when hearing or reading such a word. In addition to this, Blair (2006) continuously emphasizes the centrality of linguist-oriented studies of meaning, including Philosophy of Language, as an alternative to overcoming the limitations of the models for information retrieval that are prevalent nowadays.

An important initiative within the scope of the referential approach is the one known as formal semantics. Examples of important authors who worked in this area are Rudolf Carnap (German philosopher, 1891-1970), Alfred Tarski (Polish mathematician and logician, 1901-1983), Saul Aaron Kripke (American logician and philosopher, born 1940), and Richard Merett Montague (American mathematician and logician, 1930-1971). Due to the importance of formal semantics in relation to the goals of the present article, Section 2.2 is dedicated to describing its main characteristics.

2.2 Formal Semantics

The field of Formal Semantics was concerned mainly with three aspects during its evolution: i) emphasis on the principle of compositionality; ii) use of the truth-conditions in order to explain meaning; iii) conception of models in semantics. These three lines of study are described in the present section.

The principle of compositionality establishes that the meaning of sentences depends on the meanings of words that compose it. Thus, the meaning of the whole is dictated by the meaning of the parts and the syntactic combination among them. In order to deduce the meaning of a sentence, one needs to know the meaning of its parts, as well as the rules which define how to combine such parts.

The use of the condition of truth in order to explain the meaning concerns the determination of the conditions under which such a sentence is true. According to Morris (2007), this vision originates from Tarski's Theory of Semantic Truth: a set of rules governing the application of the concept of truth to formal logic-based system sentences without the risk of ambiguity inherent to natural language. Once the notion of truth is central in Logic, the question then becomes one of explaining how formal system sentences are stated as being true or false. In this context, to know the meaning of a sentence is the equivalent of knowing its truth-conditions, which is not the same as knowing its truth-value, that is to say, whether the fact is true or false.

In order to clarify what are the conditions for a sentence to be true or false, Portner (2005) presents, as an example, the following sentence: the circle is inside the square. According to the author, once one knows the sentence, a simple inspection of Figure 2 allows him to say under what conditions the sentence is true. In Formal Semantics, such situations are called possible situations or state of affairs.

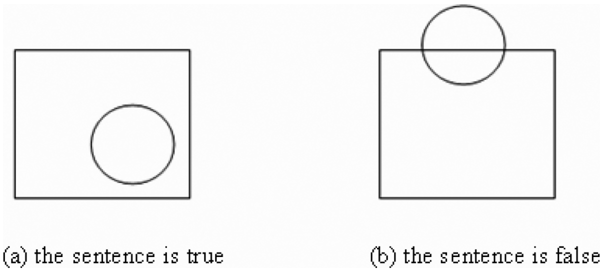

Figure 2. Truth conditions for the sentence "The circle is inside the square."
Source: adapted from Portner (2005)

The existence of a set of scenarios, like the ones shown in Figure 2, allows one to identify a true set and a false set. Such sets are called possible worlds. In this context, the term "situation" refers to an incomplete scenario, a part of the universe limited by space and time boundaries. The term "world," on the other hand, is used when people have a complete idea of what the world must be with all its components, which do not change over time.

According to Nirenberg and Raskin (2004), the use of logic in the scope of Formal Semantics allows for the application of the notion of proposition to the study of a sentence. The meaning of a sentence thus corresponds to a proposition, and there then occurs a shift in the triangle of meaning from the level of a word to the level of a sentence (Figure 3a). Logicians renamed the vertices of the triangle according to terms used in their systems (Figure 3b). Hence, none of the elements of the triangle (b) is directly related to natural language, since a proposition is the translation of a declarative sentence into a logic-based meta-language.

In the semantic models approach, a simpler system is built as a model for the study of another more complex system. Then, a theory is built for the model, usually a logical theory. If results are found to be reasonably representative of the complex system, the simple system is said to be a good model. If this is not the case, the system is abandoned. Studying the semantics of formal languages is helpful in the study of natural languages, because both share common characteristics, and formal language is simpler than natural language. Hence, a common procedure undertaken by formal semanticists has been to propose simple models in formal languages and to then interpret through them as many natural language sentences as possible.

According to Jech (2002), a simple model for interpreting a language is the Set Theory. The procedure consists of associating set theory expressions to objects of the world. Thus, no model for interpreting reality could ignore objects. In this case, objects that comprise models of natural language interpretation are called the theoretical objects of the model.

Portner (2005) explains that Model-Theoretic Semantics, an instance of Tarsky's Theory of Semantic Truth, makes use of elements that supply models of reality that are useful for semantic purposes. Such models are composed of: i) a set of possible worlds; ii) a set of individuals; iii) a set of periods of time; iv) a description of which individuals inhabit which worlds; v) a description of which periods are prior to the other periods.

Besides the elements mentioned, there is an interpretation, which describes the meaning of each word, phrase, or sentence according to a specific model. Considering a specific model, the meaning of a name must belong to an individual from that model, and the meaning of a sentence must correspond to a set of possible worlds within that model. A semantic interpretation may or may not say something about what reality is like. In fact, statements are made about the model and the model is assessed in terms of how it is connected to reality. Models that represent reality in a precise way are called intended models. The interpretation connecting parts of the language to intended models, in the same way that natural language is connected to reality, is called intended interpretation.

Finally, it is worth mentioning that the importance of the formal perspective resides in the fact that other semantic theories were established from formal se-

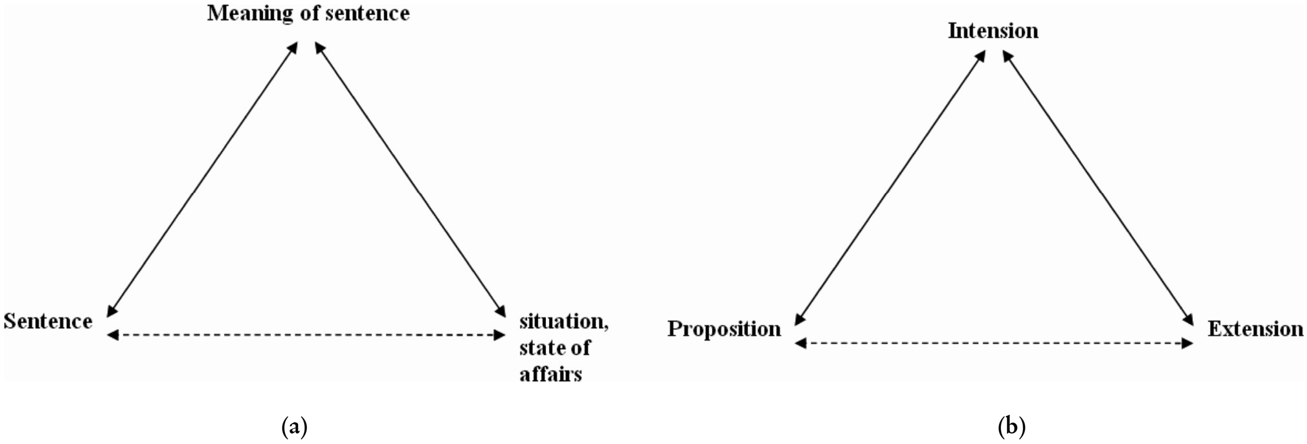

Figure 3. Triangle of meaning (a) for sentences and (b) using logical terms
Source: Adapted from Nirenberg and Raskin (2004)

Evolution	Approach	Brief description
Ancient times	Platonic	Origin of names
	Aristotelian	Categories
19th Century	Dyachronic	Semantics as historical discipline
	Synchronic	Origins of modern linguistic approach
	Referential	Sense, meaning and reference
19th and 20th Century	Semantic fields	Words with related meanings
	Componential analysis	Sets of semantic characteristics
	Metalanguage	Components as logical entities
20th Century	Pragmatic	Use of argumentation game
		Sentence has a social function
	Mentalist	Language and mental schemes
		Other levels of mental representation
		Thematic roles of the arguments of a verb
	Referential	Triangle of meaning
	Formal semantics	Theories originated from Philosophical Logic

Table 1. Synoptic table of semantic approaches in Linguistics

mantics when trying to solve problems that that model was not able to solve. Moreover, alternative models might be proposed. Table 1 shows a synoptic table of semantic approaches as presented in Section Two.

3.0 Semantics in SW

Within the scope of SW, something is considered as having semantics when it can be processed and understood by a computer. This idea does not appear to take into account the origins of the term. Despite the clearly technological bias, the idea does not reach the level of consensus even when considered solely within the scope of Computer Science (Sheth et al. 2005). In Section Two, we described the main approaches to semantics from the point of view of Linguistics, Logic, and Philosophy. Next, we describe the different usages for the term within the Information Technology field. There are a variety of meanings and dubious interpretations that overlap with the theories presented in Section Two.

Sowa (2004) lists the models proposed in the second half of the 20th century for the understanding of language and its implementation on computers: the statistical model, the syntactic model, the logical model, the lexical model, and the neural model. According to Sowa, every approach is based on a specific theory—statistics, mathematics, grammar rules—while ignoring aspects of language to which technology is not able to adapt. The logical models based on Philosophical Logic produced formal semantic theories of superior quality when compared to concurrent approaches. Such theories have been widely used in ontology research in the context of the SW. However, as with formal semantic theory, these models suffer from the inability to deal with an ordinary text written by people for the purpose of communication. Language thus remains restricted to sentences deliberately written in a notation that is merely similar to natural language.

Charles Peirce's Semiotic Theory (American logician and mathematician, 1839-1914) defines the three main components of a language: syntax, semantics, and pragmatics (Sowa 2000). This notion of language is used in Knowledge Representation (KR), a field of Artificial Intelligence associated with the development of expert systems. In this context, language usually corresponds to a type of logic. Branchman and Levesque (2004) define the semantics of a language as the specification of the meaning presumed for syntactically well-formed expressions. Hence, the semantic specification does not correspond precisely to the meaning of the terms, but only to the meaning of the sentences according to an interpretation function. This function leads to the notion of interpretation mentioned in Section 2.1. Nevertheless, in order to obtain specifications for the meaning of sentences, a simplistic world view needs to be adopted. This view should only consider that: i) there are objects in the world; ii) for each predicate P, of arity one, some objects satisfy P and others don't, with the decision being obtained through the interpretation function; iii) other aspects of the world are not of interest.

Uschold (2001) distinguishes and defines the types of semantics present in the world of computer systems, classifying them as real world semantics, axiomatic semantics, and Model-Theoretic Semantics. According to the author, semantics on the SW identifies itself mainly with real world semantics, an expression used to indicate the mapping of objects from the world to a computational model.

Axiomatic semantics is a rather specific approach defined within the scope of languages and standards used on the SW, specifically the Resource Description Framework Schema (RDFS). According to Fikes and McGuinness (2001), the goal of axiomatic semantics is to enable the translation of RDFS descriptions into logic, or rather, to establish rules for mapping RDFS in FOL. This mapping is performed specifically to provide automatic inference capacity to the representation language considered.

Model-Theoretic Semantics is related to the Theory of Models and according to W3C (2004a, 2):

> It assumes that language refers to the 'world' and describes the minimum conditions the world must satisfy in order to attribute proper meaning to language expressions. A particular world is called interpretation and thus the theory of models is also known as the theory of interpretation.

This definition is similar to the one presented in Section Two concerning Formal Semantics. However, the continuation of this same W3C definition clarifies the goals of semantics in that context:

> The main use of formal semantics theory is not to provide deep analysis of the nature of things described by language ... but to offer a technical way of determining when inference processes are valid, or rather, to preserve truth.

It is important to observe that the definition however appropriate for W3C propositions has its origins in Formal Semantics, as the institution, itself, admits: "the Theory of Models is a Formal Semantics theory which relates expressions to interpretations" (W3C 2004a, 44). This is also clear in the "preserving the truth" proposition which leads to Tarski's Theory of Semantic Truth, also mentioned in Section Two. Hodges (2005) corroborates this vision and explains the notion of truth embedded in the Theory of Models: when we say that statement D is true according to interpretation I, we are really saying that D, when interpreted from I, is true. According to the author, in its broader sense, the Theory of Models has points in common with Philosophy and with the studies of semantics in Linguistics. Consequently, there is a possibility for ambiguous interpretation regarding semantics as defined by W3C (formal language) and the semantics of natural language.

Uschold (2001) presents another classification for semantics, which sheds light on misinterpretations regarding the term, since it is related to the way semantics is expressed and to whom it is directed. The author distinguishes four types of semantics sequentially aligned in a semantic continuum, stressing that, among these types mentioned, the first three are not appropriate for machine processing.

- Implicit semantics: meaning is communicated from the common understanding reached by people, for instance, definitions of eXtensible Markup Language (XML) tags reached through consensus in a community using some system;
- Informal semantics: meaning is explicit and informally expressed, for instance, as in glossaries and in specifications for system requirements; it is worth noting that the author does not clearly define what he calls "explicit meaning," or even "explicit semantics," unless as opposed to "implicit semantics;"
- Formal semantics for human processing: this is a type of explicit semantics expressed in a formal language but used in human communication and not in systems, for instance, semantics research in ontological categories;
- Formal semantics for machine processing: a type of explicit semantics, formally specified, which might be used by computers for direct processing via inference engines in order to derive new data from existing data.

Even in the case of identical terms, there is no consensus among authors about some definitions. The definition established by Uschold (2001) for implicit semantics considers semantics in a language and differs from the definition developed by Sheth, Ramakrishnan and Thomas (2005), which considers implicit semantics present in all types of data sets, not only in language. Authors distinguish two additional categories for semantics, which they call soft semantics and powerful semantics:

– Implicit semantics: refers to the meaning inserted in non-explicit data patterns in computer-readable language; it is present in non-structured texts and in repositories of semi-structured documents; IR and Computational Linguistic techniques are used for analyzing these sources;
– Soft semantics: data are represented by a formal language based on established syntactical structures and by rules defining the possible combinations, associated to semantic interpretations; it expresses statements for systems used in KR, Artificial Intelligence and databases; and,
– Powerful semantics: corresponds to statistical implementations, which allow for the exploration of relations not explicitly established; the possibility of hierarchical composition associated to statistical analysis is advantageous because it allows the formalization of the languages subject to use in inference engines; in cases in which information is not precise or is incomplete, the extension of database and KR models might be applied.

Table 2 summarizes the approaches to semantics for computational systems and for those used in SW described in this section. It is worth mentioning that there is some overlap between the approaches presented.

The last column (Table 2), named "Linguistic semantics," classifies approaches to SW in relation to the type of semantics in its field of origin (according to Table 1, Section Two). The majority of interpretations for semantics described within the scope of the SW are nothing more than types of Formal Semantics, except in some cases. Such exceptions are undetermined because their descriptions do not allow for their origin to be verified nor for their classification. However, there are some considerations:

– Real world semantics: the practice of mapping real world objects for a system originated in database research, when data models became known as semantic models (Peckham and Maryanski 1988); in this case, semantics concerns the improvement of the understanding of models, since the previous ones were implementation-oriented;
– Implicit semantics: this is not necessarily a formal semantics, and what seems to characterize it is the existence of a consensus among a group of people in order to establish a standard; in digital libraries, for instance, this approach is called federation (Fox, 2002); and,
– In addition to exceptions, we can still highlight in Table 2 the "Formal for humans" semantics item in order to clarify that Formal Semantics is not exclusively used in computer-based information system contexts, but is also used by people.

Before describing the spectrum evaluation, it is worth mentioning that, for the purposes of this article, the semantics in ontologies is considered solely within the context of SW, that is, a matter of formal semantics.

Approach	Brief description	Linguistic semantics
KR	Semantics is formal and based on logical-philosophical theories	Formal
KR	Semantics is the meaning of sentences through an interpretation	Formal
Web semantics	Semantics enables an interpretation by a computer system	Formal
Real world semantics	Semantics maps objects from the world to a system	Undetermined
Axyomatic semantics	Semantics maps SW languages for Logic	Formal
Theory of models	Semantics validates automatic inference processes	Formal
Implicit semantics	Semantics transmits consensus reached between people	Undetermined
	Semantics inserted in data patterns not readable by machines	Undetermined
Informal semantics	Semantics is explicit and informal	Undetermined
Formal for humans	Explicit semantics expressed in formal language for people	Formal
Formal for machines (soft semantics)	Explicit semantics expressed in formal language for machines	Formal
	Semantics defined by syntactic rules plus interpretations	Formal
Powerful semantics	Semantics based on statistics	Formal

Table 2. Synoptic table of approaches to semantics in SW

Admitting the complexity of that subject, we understand that a suitable approach to it is beyond of the scope of this article. It will be considered for future work.

4.0 Spectrum Evaluation

As the main approaches to natural language semantics were described in Section Two and the ways the term appears in SW research were dealt with in Section Three, it is now time to critically analyze the proposition of a spectrum. A new spectrum based on the considerations in this article is also presented.

Different versions of spectra and semantic continuums can be found through a simple search on the Web; however, most of them are variations on the same theme. We consider here the version (Figure 4) presented in Daconta (2005) and in Obrst (2004).

We can observe that the spectrum is a type of scale beginning at one end named "weak semantics" and reaching another one named "strong semantics." The instruments are located between the weak and strong ends, with some having stronger semantics than others according to their position in the scale. Strong semantics and weak semantics are characterizations of greater or lower expressiveness of an instrument, which makes it able to better represent reality so as to allow for the functioning of a computer-based information system.

However, the instruments presented in the spectrum are distinct and varied including thesauri, database schemes, modeling languages, and Web-oriented declarative languages. Considering all these instruments together hinders their evaluation and correct localization in a new spectrum. We propose to separate them into groups, according to their use. Figures 5 through 8 present, accordingly, the instruments organized into groups using the following orientations: i) those related to the SW (and to KR); ii) those related to Web-based systems; iii) those related to computer-based information systems; iv) those related to the organization of information in documents and in bibliographic data.

These groups also reflect representation possibilities from those directed at human use (Figure 8) to those directed at representation in computer-based information systems. In the case of systems, the groups reflect three evolutionary phases: i) the procedural information systems based on databases (Figure 7); ii) the Web-oriented systems (Figure 6); iii) the SW-oriented systems (Figure 5). It is worth mentioning that the list of instruments is not exhaustive and that many instruments present in the spectrum do not belong to the SW set. In the remainder of the present section, we describe the instruments of the spectrum, underlining their relation with semantics and finally, offering a new spectrum.

The expression Modal Logic designates a family of logics (modal logic, deontic logic, temporal logic, among others), which contain similar rules, but a distinct variety of symbols. According to Garson (2008), Modal Logic studies deductions involving the expressions "necessarily" and "possibly," as well as its operators called "probability," "possibility," and "necessity."

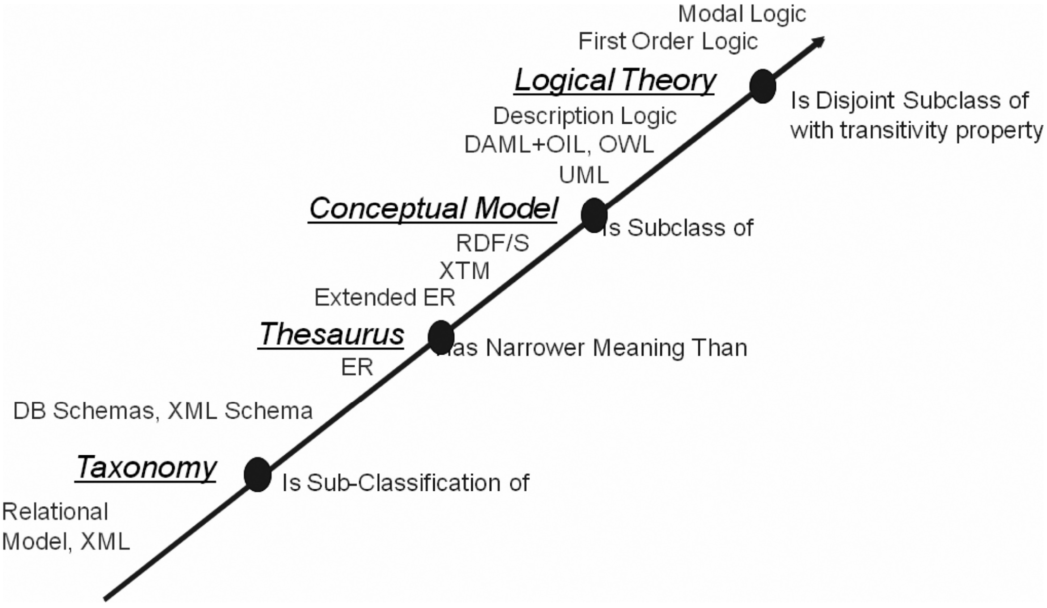

Figure 4. The spectrum under analysis

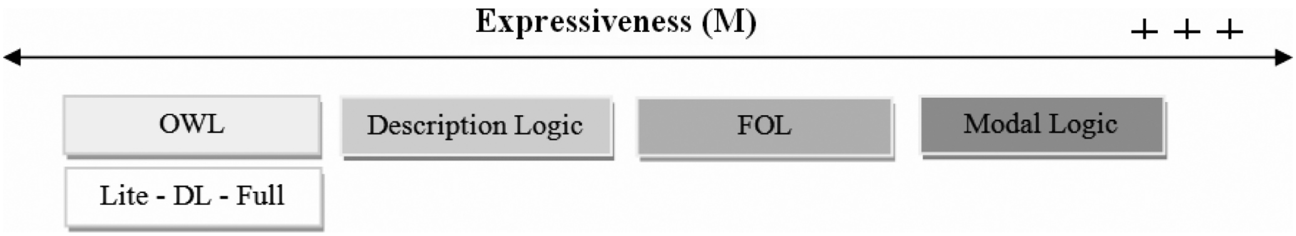

Figure 5. SW and KR, (M) = machines

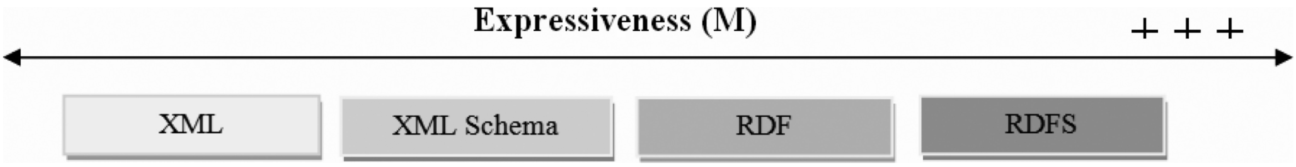

Figure 6. Web oriented, (M) = machines

Semantics in Modal Logic is defined through the notion of possible worlds. FOL is a language for expressing knowledge in which syntax establishes the rules for the formation of statements and semantics is captured by interpretations. Both Modal Logic and FOL are not efficient from the standpoint of inferences, and are thus called undecidable (Branchman and Levesque 2004).

The origins of Description Logic are found at the end of the 1980s, when conceptual or terminological languages appeared (Baader et al. 1992) in order to represent relations between concepts, and relations between concepts and individuals. As stated by Baader et al. (2003), Description Logic is a logic family based on hierarchical structures presenting good balance between expressiveness and treatability. It has been used in the field of Databases and in the SW. The Ontology Web Language (OWL), largely adopted in SW initiatives, is, in fact, a type of Descriptive Logic.

In order to improve the possibilities for Web usage, the SW uses resources such as metadata, ontologies, logics, and protocols. Hence, OWL is an attempt to standardize languages for ontology building (Antoniu and Van Harlemen 2004). The division of language into three dialects is an attempt to meet the needs of expressiveness – in the case of OWL Full – and of inferences – in the case of OWL Lite (Horridge et al. 2004). OWL was designed using the RDFS metadata standard in such a way that it is not easy to distinguish the exact point where SW languages begin. The criterion used here is the possibility of inference. Hence, RDFS was classified as a Web-oriented language and not as an SW language.

RDFS makes use of XML syntax and was designed for the solution of RDF limitations (Ahmed et al. 2001). RDFS proposes the definitions of class and sub-class as primitives, besides containing the notion of data-types. It also has resources for determining the properties fit for a class (domain tag) and the values fit for a property (range tag). RDF is a metadata standard, which evolved from XML, defining a data model based on resources, properties, and values. This model reduces the ambiguity of statements when specifying a place for the definition of each element considered, through the XML implementation called namespace. W3C immediately clarifies the type of semantics involved in the introduction of RDF specification: "this document uses a technique named theory of models in order to specify the semantics of a formal language" (W3Cb 2004, 1).

XML corresponds to a first attempt to reduce the problems verified in the 1990s with the use of HTML, which is based on fixed tags for data presentation. In XML, the structure of the document is expressed by flexible tags making the content accessible to systems. The XML is rooted in the Standard Generalized Markup Language (SGML), an international standard for electronic text mark-up. SGML defines a Document Type Definition (DTD) whose goal is to structure documents through tags, that is to say, it defines how these tags will be distributed in the text. It is worth noting that W3C presents specifications for RDF and RDFS semantics, but it does not present a similar document for XML.

Web-oriented mark-up languages and metadata standards corresponded to a change of paradigm in the field of information systems in which emphasis shifted from a structured data model (databases) to a semi-structured data model characteristic of the Web (Abiteboul et al. 2000).

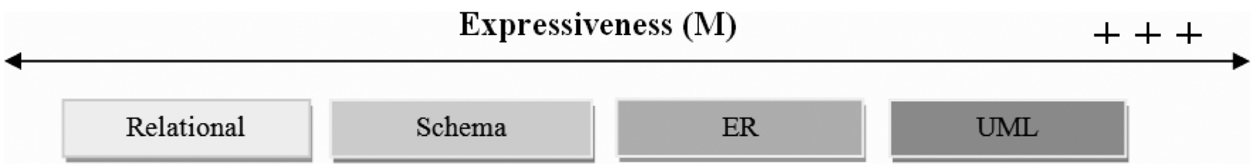

Figure 7. Information-system-oriented, (M) = machines

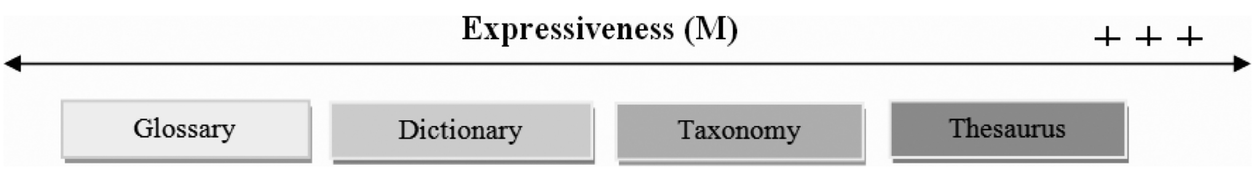

Figure 8. Information-organization-oriented, (H) = humans

The Relational Model (Codd 1970) was one of the first instruments for conceptual modeling; however, in this model, the construct relation is used to represent both entities and relationships among entities (Peckham and Maryanski 1988). This fact creates misunderstandings, makes the mapping of world concepts difficult and leads to modeling errors. In the Relational Model, a relation corresponds to a table, with lines called tuples and columns called attributes. According to Kroenke (1998), these terms originate in Relational Algebra, a branch of FOL. The concept of table is similar to the concept of relation in mathematics. The semantics of the Relational Model concerns Formal Semantics.

Silberchatz et al. (1997), explain that a database schema corresponds to its logical scheme or, rather, the conceptual model after the application of normal forms (rules for database standardization). For example, they explain that a similar idea would be that of a variable, to which instances may be attributed. The semantics related to schema is Formal Semantics, too.

Because of problems in the relational model, the Entity-Relationship Model (ER) was developed (Chen 1976), which offers extra terms for modeling used as primitives. Furthermore, ER eliminates the overload of the relation construct. According to Silberchatz et al. (1997, 25), the higher expressiveness of ER concerns the attempt to represent the meaning of data through the mapping of reality in a conceptual model. ER is a semantic model in which, however, semantics is referred to as Formal Semantics, because a relationship "is the mathematical relation with n □ 2 sets of entities."

The Object Orientation approaches are concerned with the conceptual modeling of information systems, offering new ways of dealing with events, which define the state of a model (Olivé 2007). In fact, the Object Orientation proposals present almost the same theory, but different notations. An attempt to standardize these notations is the Unified Modeling Language (UML). The definition of semantics in UML is a little vague, because the term is mentioned in many contexts, and its specifications state that "there are, of course, other relevant semantics for UML" (OMG 2007, 10). Two specific situations are worth noting.

UML uses a formal language, the Object Constraint Language (OCL), to describe expressions in UML models, in which semantics is defined as "the mapping of OCL expressions for semantic domain values" (OMG 2006, 95). In this context, a semantic domain is the set of values, which may be produced by the expressions. The specification also has an appendix about semantics, in which one can find a formal definition of what is called an object model in OCL, issued from definitions of the Set Theory and its interpretation. In Section Two, these elements were described as pertaining to Formal Semantics.

Figure 8 presents a set of instruments that are different from those prior. The expressiveness in these types of instruments is human-oriented and not system-oriented. In this context, semantics is the semantics of natural language. A thesaurus is a tool for vocabulary control, which allows for the relation terms representative of the content of documents, according to three types of relations: broader term, narrower term, and related term. A taxonomy corresponds to a basic structure of information organization based on subsumption relations. A dictionary is an alphabetically ordered list of terms in a specific language, presenting, in addition to definitions, information such as pictures, pronunciation, etymology of terms, among other features. A glossary is a list of terms related to a specialized domain and their definitions.

After considerations about the instruments, we present now the proposal for a new spectrum, which gathers all instruments (Figure 9). A use-oriented axis divides the spectrum into two quadrants: i) use of semantics by humans or ii) use by machines. In each quadrant, the semantic expressiveness of the instrument is considered according to the case, as natural language semantics or as formal semantics.

5.0 Discussion

At the end of Section 2.1, the importance of the Linguistic approach of Formal Semantics for the goals of this article was mentioned. Such importance is demonstrated by verifying that all approaches related to information technology are, in fact, types of Formal Semantics. Keeping this in mind, it becomes simpler to understand the use of the term. This understanding is important within the scope of information science in order to avoid any confusion between semantics used in thesauri and semantics used in an ontology, for example. In the remainder of this section, some additional questions related to the new spectrum are discussed.

Among the possibilities for misinterpretation, which the present article intends to reduce, one deserves to be given special attention: the confusion between semantics, or the definition of the meaning, in the planning of a system, and the semantics used by the system. In many cases, as in semantic models and in UML, specifications mention how to define the meaning of objects in order to represent them. A typical case is a data dictionary in databases and in XML attributes, where entities are defined, such as: author is the person intellectually responsible for a work; student is the person enrolled in an educational institution. Actually, in this case, what is defined is what one really understands by author and by student in a given

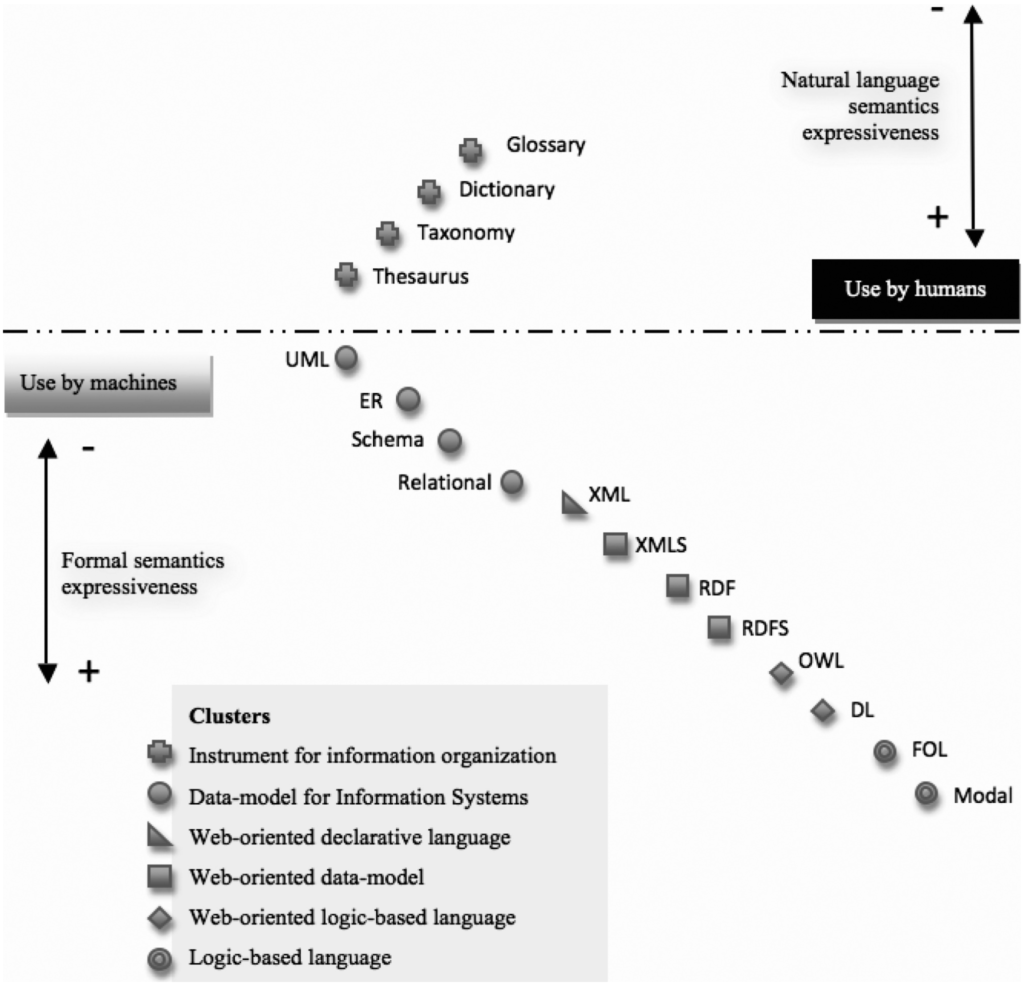

Figure 9. Proposal for a new spectrum

context, by people, something close to the meaning in natural language.

However, the relevant issue here is not exactly the meaning of things in the world. This definition is important whether systems are procedural, web-oriented, or SW-oriented. There is always a phase when people define what the system is going to encompass; such a phase is known as business modeling, conceptual modeling, systems analysis, or knowledge acquisition, among other denominations. The emphasis of the spectrum is not on this phase, but on semantics from the standpoint of use by the system in the computer. Based on this consideration, the spectrum was organized, or that is, the instrument presenting inference capabilities was considered the most expressive. Due to this characteristic, the system is considered more evolved than others, an expert system, and the type of system that the SW looks for.

Other possibilities for misinterpretation are the result of the lack of distinction among the kinds of semantics, as well as of the direct comparison among the semantic of spectrum components which are diverse in origin and in function. Regarding the lack of distinction among different semantics, a horizontal axis divides the new spectrum into two quadrants (as mentioned at the end of Section Four, Figure 9) whether the semantic considered is used by humans or by machines. This distinction may seem obvious, but that misunderstanding is present in several similar versions of spectra found in literature, leading to dubious interpretations.

In order to distinguish between the components according to a functional criterion, the components of the new spectrum are depicted by different geometrical forms (diamond, circle, square, etc., see Figure 9). In this sense, we considered six kinds of characterizations, which cluster the components as follows: i) instrument for information organization; ii) data model for procedural-oriented systems; iii) Web-based declarative language; iv) data model for web-based declarative-oriented system; v) web-based logic language; vi) logic language. The comparison of the expressiveness of the components of the respective semantics only makes sense within a cluster.

Such characterizations are described in Table 3, in an ad hoc manner, from a compilation of the information about each component presented in Section Four. It is worth emphasizing that the adoption of ad hoc criteria to characterize the components aims only to differentiate them, rather than define them. The definition of such components in a suitable way is a non-trivial task and is beyond the goals of this article.

It also can be seen that, in the new spectrum, the space between instruments does not follow a scale that expresses semantic differences in a quantitative way; however, it is possible to observe qualitative distinctions. The data compiled in Table 3 allow for some qualitative analyses, such as: a dictionary has more resources that a glossary to aid one in finding information regarding some subject; a thesaurus contains more relations available to represent a certain subject than a taxonomy; an ER model has more primitives than a relational model to represent the part of the reality of interest for an information system; modal logic has more operators than FOL; and so forth. The additional distinctions possessed by a component grant it more expressiveness, once the appropriate context has been observed (humans or machines).

The new spectrum and the defined clusters allow for reasoning about some other possible comparisons involving the semantics notion. For example: is a thesaurus constructed using FOL more expressive than the same thesaurus constructed using OWL? In the new spectrum, a thesaurus was characterized as an instrument for information organization in which the expressiveness concerns natural language semantics. Then, in the case of such an instrument conceived for human use, whether OWL or FOL is used is of little importance. However, if one is concerned with computational implementation, a thesaurus constructed using FOL may me more efficient than the same one constructed using OWL, considering only the topic expressiveness for machines.

Indeed, such a question could be also explained by another similar question posed in a wider context, within the scope of Philosophy. For example: consider a representation R1 of a scientific theory via axiomatization developed with a language L1 and the representation R2 of the same scientific theory developed with a language L2. Could R1, in any sense, be considered better or worse than R2? Rosenberg (2005, 97), for example, poses the question "is Euclidean geometry correctly axiomatized in Greek, with its alphabet, or German with its gothic letters, its verbs at end of the sentences and nouns inflected, or in English?"

The author himself answers the question stating "Euclidean geometry is indifferently axiomatized in any language." Likewise, Munn and Smith (2009, 75) explain that

> The fact that your mother language has no ready-made term for a given entity or kind of entity does not prevent you from using or understanding a corresponding concept or talking

Component	Characterization of the component	Distinctions (ad-hoc) for each component
Glossary	Instrument for information organization …	… which contains terms of a specialized domain, as well as its definitions
Dictionary		… which contains a list of alphabetically ordered terms and definitions, in addition to figures, pronunciation, etymology, and so forth
Taxonomy		… which contains terms organized hierarchically (only subsumption relations)
Thesaurus		… which contains terms representative of related documents for up to three relations, namely, NT, RT, BT
UML	Data model for procedural-oriented system…	… which contains a formal constraint language, in addition to diagrammatical elements to be used in modeling
ER		… which contains entities and relations established via a relational algebra, primitives and diagrammatical elements to be used in modeling
Schema		…. which contains standardization rules (normal forms) and diagrammatical elements to be used in modeling
Relational		… which contains entities and relations established via a relational algebra, a few primitives and diagrammatical elements to be used in modeling
XML	Web-based declarative language …	… which contains textual structural elements delimited by tags and defined by a grammar
XMLS	Data model for web-based declarative-oriented system …	… which contains textual structural elements delimited by tags and defined by a grammar, in addition to elements defining basic data types (i.e. data, integer, string, etc)
RDF		… which contains elements called resources and properties, as well as their values
RDFS		… which contains elements called resources and properties, as well as their values, in addition to elements defining types and constraints
OWL	Web-based logic language	… which contains DL fragments
DL	Logic language …	… which contains FOL decidable fragments
FOL		… which contains rules for creating statements and the respective interpretations
Modal Logic		… which contains rules for creating statements and the respective interpretations, in addition to probability, possibility and necessity operators

Table 3. The six clusters in which the semantic comparison makes sense

about an entity in question, by means of some more complex word formation.

Indeed, the question relating the construction of information organization instruments to one or another language seems to be meaningless, insofar as a certain theory representing a domain would be expressed using different languages. Nevertheless, one could argue that an artificial language might have a limited number of constructs (as in the case of the relational model), and, even considering some combination of them, it is not possible to obtain a suitable representation of a domain. In this case, the better alternative would be to find another language to perform the task.

6.0 Summary and Conclusions

We have presented a survey about semantics in Linguistics and worked on clarifying the understanding of the term semantics in the field of information technology, emphasizing the SW point of view. A semantic spectrum was discussed, and a new proposal was presented that takes into account the use of each component element of the spectrum (by computers or by human beings). We stress that the survey was not exhaustive, and there are certainly important researchers of Philosophy and Linguistics who were not cited. Furthermore, the brief explanation about elements of the spectrum for human usage does not indicate that those elements are of minor importance, we simply remained focused on the objectives of the article, that is, to present semantics in its various contexts of usage and a critical view about its use in the SW field.

The SW seems to be a promising initiative, and the possibilities it has brought in its developments are innovative. However, there is no consensus as to the validity of those developments. The SW prioritizes research for improvements in the capacity of inference of logic, specifically, of Description Logics. This engagement becomes clear in the emphasis given to research into representation languages such as OWL, for example. In fact, semantics and meaning are much more complex and comprehensive subjects than the implementations that the SW promotes in FOL and in the Theory of Models. This verification leads to some discredit in relation to the related developments. Gärdenfors (2004, 2), for example, reckons that "SW is not semantics."

It is important to admit that researchers in the SW field make the use of Formal Semantics clear, but, in some cases, offer too simplistic an explanation to define it. Antoniu and Van Harmelen (2004, 110) define Formal Semantics as a semantics that "precisely describes the meaning of knowledge. By 'precisely' we understand here that semantics does not refer to subjective intuitions, nor is it open to different interpretations by people (or machines)." Definitions of W3C mentioned in Section Three follow the same pattern.

Finally, we conclude the use of term "semantics" in the realm of SW is a particular case of the semantics, namely, formal semantics. It seems that the field of semantic has much more to offer, insofar as one is willing to address it deeply. It is worth mentioning that the main contribution of this paper is represented by the initiative to re-order the instruments according to a semantic orientation, which results in an extension to the original spectrum. Concerning the new spectrum, it can be observed that its organization is not so different in relation to what was evaluated. One conclusion is that the evaluated spectrum provides a reasonable vision of the semantics related to its component elements, but at least three essential details are missing: i) the context of use and the orientation of the semantics used; ii) the proper clustering of the kinds of elements under comparison; and iii) the comprehensiveness of the elements considered in its scope. Bearing in mind these enquiries, one may avoid erroneous interpretations.

We thus hope, in future work, to find the necessary adjustments in order for the spectrum to become more representative of the semantic of the component elements of the spectrum. In order to achieve this, it is urgent that at least two other subjects complementary to the analysis conducted here be dealt with. One of them, mentioned in Section Three, is the relevant issue of semantics in the realm of ontologies. The other one relates to the use of ontology, in its broad sense, as a meta-theory to compare a more expressive account of Knowledge Organization Systems. These issues are going to be addressed in future papers.

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