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SURVEY ON KNOWLEDGE REPRESENTATION APPROACHES FOR NATURAL LANGUAGE PROCESSING

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Abstract: In artificial intelligence, knowledge representation is one of the fundamental concepts, which aim to transpose the information about the world in a way that allows the computers to "understand" it. This article briefly describes the most important formalisms used for natural language representation, along with their specific ways of reasoning. We also present (make) a comparative study, analyzing the characteristics of these methods, highlighting their advantages and disadvantages.

Keywords: natural language, knowledge representation, first-order logic, description logic, frame systems, semantic networks, conceptual graphs.

1. SEMANTIC PROCESSING IN NATURAL LANGUAGE

Semantic analysis is the process of studying the meaning of words, expressions, phrases, in relation to their surrounding context, thus facilitating the extraction of the commonsense knowledge. The next step is usually using this information for constructing a meaning representation of the target text, by employing the facilities of a metalanguage or an equivalent encoding system.

1.1. Difficult problems in semantic representation

In the field of linguistics, Fodor (1975) advocated the idea that, given the level of ambiguity specific to ordinary natural language, there must be an informational substrate in which concepts exist in a "clear" form that allows people to extract the fundamental meaning of word constructions. This intuition has been, almost unanimously, transposed in practice by using a terminal set of primitives. On the other hand, the characteristics of said primitives are still the object of debate because researchers have not yet agreed on their nature. Should they be elements of the natural language or should they be artificially created? Also, there is the question of them being language specific, or universal.

A major concern in semantic analysis, connected to the reasoning ability, is the *avoidance of circularity and infinite regression*, so, a lot of care must be put into the process of semantic representation, which involves a fair amount of insight. There is a fundamental question regarding the accuracy degree of semantic analysis that has, so far, remained without a definite answer because there is a multitude of approaches, none of which having sufficient influence to win against the others.

The traditional separation between lexical (word level) and supra-lexical (phrase level) semantic has proven to be quite counterproductive, because it increased the difficulty of guessing the sense of words. Knowing the true sense, helps reducing the word combinatorial potential, so the more recent works have been trying to integrate the two types of semantic analysis as much as possible.

Solving ambiguities is a frequent need in semantic analysis. From the perspective of an automated system, phrases can have more interpretations because: (1) words have multiple meanings - *lexical ambiguity*, (2) certain words (quantifiers, modal operators, negation) can be applied to more than one part of the text – *scope ambiguity*, (3) references to pronouns or other referential expressions may be unclear - *referential ambiguity*.

In the context of lexical ambiguities, *homonymy* (different words with the same form) and *polysemy* (different meanings of the same word) must be taken into account, the latter being more difficult to deal with because the differences in meaning are subtler.

2. THEORIES AND APPROACHES OF SEMANTIC REPRESENTATION

The knowledge representation involves the application of logic and ontological principles to build computational models in a particular field.

1. Logic provides formal structure and inference rules. Without logic, the knowledge representation is vague, with no criteria to determine whether statements are redundant or contradictory.

2. Ontology defines the types of things that exist in the application domain. Without using ontological principles, terms and symbols are incorrectly defined and ambiguous.

The theories and approaches that have been proposed so far can be placed on the following two axes:

formal $\rightarrow$ cognitive
compositional $\rightarrow$ lexical

Formal theories have emerged since the late 60s, their main purpose being to build artificial intelligence to help the computer "understand" the natural language, while the cognitive approaches gained momentum starting with the second half of the 80s and they usually aim to understand the way lexical elements fit together.

Compositional semantics is focused on the gradual construction of the sense starting from the basic lexical elements, whose meaning is usually taken as a given, without any sort of analysis. By contrast, lexical semantics specifically focuses these lexical elements (a) by analyzing their content and their internal structure - *decompositional approaches* and (b) by representing their relationship with other elements of the lexicon - *relational approaches*

2.1. Logic formalisms

Logical approaches are situated within the scope of compositional methods, and function on Frege's compositionality principle, which states that the meanings of the supra-lexical expressions are determined by the meanings of their parts and also by the way they are combined.

In the field of classical logic, there were two distinct directions of development. A small percentage of researchers worked on formalizing declarative knowledge, focusing primarily on mathematical rigor, but the resulting formal languages proved insufficiently expressive. On the other hand, in search of expressivity, the vast majority proposed languages having a large number of syntactical structures, thus making the use of automatic reasoning methods quite problematic.

The ***propositional logic*** is a mathematical model that can assign values of truth to logical expressions. In this context, a sentence (called proposition) is a possible state of the world that can be true or false (eg. It is sunny). The truth value of the analyzed sentence is determined based on the truths of other sentences. A sentence may be simple, in which case it is called propositional constant (eg. *snow*), or composed when it is formed from simple sentences connected by logical operators. These operators express the type of relationship between the component sentences: negation, conjunction, disjunction, implication, equivalence (biconditional relation) and the meaning of a logical expression is given by the way these simple sentences are combined and the operators that have been used.

eg. $mushroom \wedge red \Rightarrow \neg edible$ - Red mushrooms are not edible.

In ***first order logic***, the vocabulary consists of two types of symbols: functional constants and predicative constants, of positive arity. Being a fully formal language, the truth value of any expression can be automatically determined.

Unlike propositional logic which is very limited because it only allows for simple declarative sentences, their key point being expressing the facts that may or may not be true, first-order logic introduces variables and quantifiers, thus obtaining the ability to rationalize about the objects of the speech domain. Quantification is the ability to make reference to objects without the need for their explicit naming, like in propositional logic.

The first-order logic ontology includes: objects (terms), properties (single-term predicates), relations (multiple-order predicates), and functions (parameters are a series of terms, the result being another term). Terms can be variables, functions, or combinations of them. A sentence is a formula that has no free variables and can be true or false. The purpose of a formula with free variables is to describe the properties of those variables.

eg.
$x\exists y(Has"("John","x) \land Dog(x) \land Has(Mary,y) \land Cat(y))$
- John has a dog and Mary has a cat.

In an effort to increase the representational capacity of the first-order logic, many extensions were proposed. Among the most prominent ones we should mention the temporal logic, in which truth values and relationships change with time (McDermott, 1982; Allen, 1984) and fuzzy logic, which introduces uncertainty (Zadeh, 1983).

Description logic is a logic-based knowledge representation method, whereby the domain terminology of an application can be represented in a structured and formally defined manner. Concepts are described through expressions built from atomic concepts (unary predicates) and atomic roles (binary predicates) (Van Harmelen et al., 2008). Concepts are sets of individuals, roles are binary relationships between said individuals, and nominals refer to specific individuals of the domain. The semantic part is provided by a subset of the first-order logic that has the important property to be decidable. This feature involves finding a balance between the language expressivity and the reasoning complexity and is achieved by using various subsets of mathematical operators. The formal semantics allows accurate specification of the ontology meaning, eliminating ambiguities and making possible the use of logical deduction to infer information not explicitly mentioned in ontology (Krötzsch et al., 2012).

In description logic, the knowledge base is divided into two parts containing logical expressions called axioms. The first, called TBox, contains the terminology and describes the properties of concepts and roles, as well as the existing relationships between them. (eg. $Father \equiv Parent \sqcap Man$;). The second, ABox, is where specific situations are recorded by describing the properties of individual entities (eg. $human(ALLAN)$; $hasChild(ALLAN,\ SALLY)$).

eg. $Human \sqcap \exists hasChild.\exists gender.Male$ - a human that has a son

The basic syntax and semantics of description logic is called $\mathcal{ALC}$ (Attributive concept Language with Complements). As operators, it has only conjunction, disjunction, negation, existential restriction and value restriction. Some of its most common extensions, used to facilitate the ontology building, are:

(1) role hierarchy ($\mathcal{H}$) - subroles (eg. $hasParent$ is a subrole of $hasAncestor$)

(2) nominals ($\mathcal{O}$) - named entities (eg. $Allen \sqsubseteq \exists citizen_{of(USA)}$)

(3) inverse roles ($\mathcal{I}$) (eg. $isChild$ $_{-}$ $isParent$)

(4) cardinality restrictions ($\mathcal{N}$) - restricting the number of individuals that can be returned by a particular role (eg. $\leq 2\, hasParent$ - no more than two parents)

(5) qualified cardinality restrictions ($\mathcal{Q}$) - they also allow to specify the type of individuals (eg. $\geq 2\, hasChild.Student$ - more than two children which are students)

(6) concrete domains (($\mathcal{D}$)) - the integration into description logic of numerical or other type of domains (real numbers, integers, strings) by using datatype properties, data values or data types (eg. $\exists age. \leq 21$)

(7) transitive roles ($\mathcal{S}$ – the abbreviation of $\mathcal{ALC}$ + transitive roles) – allow for the description of aggregated objects by means of their component parts, without specifying the decomposition level (Horrocks and Ulrike, 1999) (eg. $Transitor \sqsubseteq Device \sqcap is_{part_{of}}.CPU$, $CPU \sqsubseteq Device \sqcap is_{part_{of}}.Computer$

In order to express the uncertainty, various forms of probabilistic extensions were proposed, some based on Bayesian networks (Ding and Peng, 2004, Ceylan and Penaloza, 2014), others on statistical axioms (Ochoa-Luna et al., 2011). For the temporal information modeling, point-based (Schild, 1993) or interval based (Halpern and Shoham,1991; Artale and Franconi, 2011) extensions were formulated.

2.2. Semantic networks

Semantic networks are graphs that represent knowledge through certain patters of nodes interconnected by arcs. Objects are represented as nodes in the graph and the relations between objects are represented by links, each being assigned a label (Jurafsky and Martin, 2009). The common denominator of all semantic networks is their graphical declarative representation used for knowledge modeling.

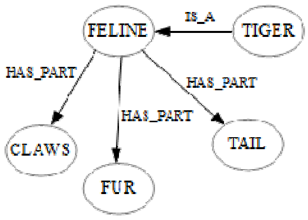

Fig.1. "A tiger is a feline with fur, claws and a tail."

Initially, semantic networks were very limited by their extremely general formalism, due to the fact that knowledge was structured in terms of fixed relations such as object/property, class, subclass, and agent/verb/object. For this reason, researchers have been trying to identify the fundamental relations of natural language, in order to integrate them as primitives in the network formalism. The advantage of using primitives is that the interpreter is programmed in advance to understand and work them. In this respect, it is worth mentioning Fillmore (1968) effort in the field of linguistics which was the first to develop a list of deep case relations, expressed through various speech constructions, specific to natural language. A special research direction, led by Schank, called conceptual dependency (Schank, 1972) was directed towards reducing the number of relations as much as possible, in order to be able to formulate the meaning of sentences in a canonical form.

Currently, semantic networks can represent both specific relations of a particular problem (eg. weight, distance, etc.) as well as general relations, among which the most used are *isa* (instance-class), *ako* (class-subclass) and also *subset-of, has-parts, agent, object, attribute*.

2.3. Conceptual graphs

The language of conceptual graphs introduced by Sowa (1984) is part of the network representation type of languages, created for modeling natural language semantics by mapping questions and assertions to a relational database (Van Harmelen et al., 2008). Its graphical representation formalism is slightly different from ordinary semantic networks in that both concepts and relations are represented by rectangular and, respectively, circle-like nodes, none of the arcs having being named. Such a graph is called a bipartite graph, in which the concepts nodes will always be connected exclusively to relation nodes and vice versa. The advantage of using bipartite graphs is the considerably simplified way of representing relations of any arity. The way of drawing the connecting arcs depends on the arguments number of each relation: (1) one argument – the connector arc is simple, (2) two arguments – an arc having the arrow pointing to the first argument and a second arc having the arrow coming in from the second argument, (3) n arguments – each arc is marked with an integer number. Operators are represented by framing their area of influence with a rectangle. The implicit operator, in case none other is specified, is the negation.

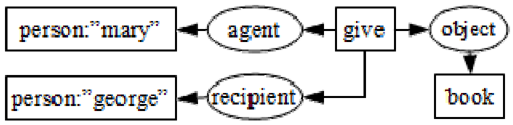

Fig.2. "Mary gave George the book."

2.4. Frame theory

Frame-based systems were introduced by Minski (1974) as an alternative to logic-based approaches. The knowledge represented through record-like data structures includes archetypal knowledge about situations, implicit values, multiple perspectives, and analogies (Baader, 2003). Although the frames were initially provided with reasoning mechanisms, most of the subsequent work, concentrated mainly on the structural representation. Information stored in the frames was often treated as the database of the system, the reasoning engine being implemented using other techniques, usually variants of predicate logic (Fikes and Kehler, 1985).

Frames could be linked to one another by two types of inheritance relations. The subclass-class inclusion relationship between generic frames is an *ako* relation, and is specified by two special attributes, that could refer to superclasses (SuperClass) or to subclasses (SubClass). The other type is an instantiation relation (*isa*) and is specified by MemberOf attribute.

In a frame, there are two types of slots: (1) member slots (MemberSlot) - specifies the attributes of a particular class and (2) global slots (GlobalSlot) - describe class-specific global attributes.

Each slot may have attached some constraints for the occupying data. Simple conditions specify only the type of data required, but more complex conditions can establish conditional relations with values assigned to other slots. If possible, default values for the slots may be specified.

Frame Child
SuperClass: LivingBeing
MemberOf: Person
MemberSlot: Name
Value: unknown
Type: string
MemberSlot: Sex
Value: unknown
Type: (*one-of* male female)
MemberSlot: Parents
Value: unknown
Type: Person
Cardinality: 2

Fig.3. Child frame

Inheritance systems formalize the hierarchical organization of knowledge specific to human beings. Information is stored at the highest possible level of abstraction, thus reducing the size of the database and preventing inconsistencies.

2.5. Reasoning methods

In ***propositional logic*** a collection of sentences Γ entails another sentence p if all truth assignments for which Γ is true, also make p true. In practice, (1) the inference (deduction) – a procedure for deriving a sentence given the collection Γ – is used as a reasoning method.

An inference algorithm is sound if it derives only sentences that are entailed by Γ and complete if it can derive all the sentences entailed by Γ. Examples of sound inference rules are (a) modus ponens (if $p \rightarrow q$ and p then q), (b) modus tollens (if $p \rightarrow q$ and $\neg q$ then $\neg p$), (c) hypothetical syllogism (if $p \rightarrow q$ and $q \rightarrow r$ then $p \rightarrow r$), (d) disjunctive syllogism (if $p \vee q$ and $\neg p$ then q), (e) simplification (if $p \wedge q$ then p), (f) conjunction (if p and q then $p \wedge q$), resolution (if $\neg p \vee r$ and $p \vee q$ then $q \vee r$). Resolution is a very important rule, because it is used in automatic theorem proving.

In ***first-order logic***, the reasoning is also made through (1) inference. In addition to the rules used in propositional logic, there are specific rules concerning the use of variables and quantifiers: (a) universal instantiation (if $\forall x P(x)$ then $P(c)$) , (b) existential instantiation (if $\exists x P(x)$ then $P(c)$ for some element c), (c) existential generalization (if $P(c)$ for some element c then $\exists x P(x)$), (d) universal modus ponens (if $\forall x P(x) \rightarrow Q(x)$ and $P(c)$, where c is an element of the domain, then $Q(c)$).

The main type of reasoning in ***semantic networks*** is (1) the property inheritance – the process by which it can be inferred that a child object has a certain property because the parent object has also that property. The child-parent relationship is specified by *isa* and *ako* type of relations, both having the transitivity characteristic.

In ***frame systems*** the reasoning is made through (1) partial matching – to determine the supraconcepts and (2) value and type inheritance for slots – for learning new information about a particular object (situation).

Attribute inheritance is the specific type of inference for frames. A complication that usually occurs in this process is the difficulty of choosing the most specific information when dealing with multiple incoming paths of inheritance. For this it is usually employed an algorithm of minimum inference distance which stipulates that a subclass (C3) is closer to the superclass C2 than the superclass C1 if there is an inferential path from C3 to C1 passing through C2.

The reasoning power of ***description logic*** has been used in many inferential engines for ontology-based applications, the most well-known example being OWL and OWL 2.0 within the Semantic Web.

The basic inference problems for description logic reasoning are: (1) subsumption – verifying the correctness of knowledge, (2) equivalence - detection of redundant knowledge, (3) consistency (satisfiability) – checking knowledge validity, (4) instancing – determining whether an individual is an instance of a class or not. All of them are reducible to determining the knowledge base satisfiability.

The most popular method for determining the database's consistency (satisfiability) is based on a *tableau based algorithm*, which aims to construct a database model by structurally decomposing concepts and determining new constraints between the elements of the model (Van Harmelen et al., 2008).

Conceptual graphs have an expressive graphical formalism that can be translated to first order logical formulas. Their reasoning capacities include: (1) verifying the validity of a graph - based on the corresponding logical formula and (2) determining whether a graph can be subsumed to another.

Sowa (2000) introduced series of six graph specific operators, called canonical formation rules. They have an important semantic role, and their combinations are used in reasoning: (1) *copy* and (2) *simplify* are equivalence operations, generating a graph equivalent to the original one, (3) *join* and (4) *restrict* are specialization operations which create a graph that implies the original, and finally (5) *detach* and (6) *unrestrict*, as generalization operations, generate a graph that is implied by the original one.

To solve the problem of undecidability, which is inherited from first-order logic, researchers tried to identify the decidable fragments of the graphs. Simple conceptual graphs are a well-known such fragment, corresponding to conjunctive, positive and existential fragment (the conjunction of existentially quantified atoms) in the first-order predicate logic (Baader, 2003).

3. COMPARATIVE SURVEY OF MAIN KNOWLEDGE REPRESENTATION METHODS

The logic formalism as we know it has been around, evolving, since the ancient times of Aristotle, and scholars have had ample time to study and write about it extensively. It is undoubtedly the formalism that exerted the greatest influence in the field of artificial intelligence, especially in the knowledge representation area. Lots of formalisms have directly inherited their features from classical logic, and many others have been formulated as a "revolt" to its constrictive character and rigid rules.

Logical representations have been developed due to the desire of philosophers and mathematicians to follow the principles of correct reasoning. The use of a formal language, able to represent and process in a mathematical way the logical thinking, has always been considered attractive, being a solid way to derive new knowledge based on existing ones using logical deduction. The main interest in this area is the development of formal representation languages with complete and solid inference rules. Consequently, the semantics of formal logic emphasizes the truth value preservation of well-formed expressions.

The suitability of representing knowledge through formal logic has been debated since its inception. The supporters believe that first-order logic along with its extensions is well suited to reasoning, due to the expressiveness of its well-defined semantics and inferential power. The favorable arguments mainly emphasize the need for a formal declarative semantic, paired with appropriate inference methods. On the other hand, its opponents have been complaining that it actually does not have enough reasoning capacity to represent the full spectrum of human cognition, and that it is fundamentally different from human way of thinking (Goddard and Schalley, 2010). Practical implementations of reasoning are also very costly from a computational point of view and correct representation of knowledge is very difficult (Van Harmelen, et al., 2008). In addition, classical logic did not have specialized mechanisms for representing time, beliefs and uncertainty, which are very important components of natural language.

Concerning the reasoning aspect, it was emphasized that besides deduction, which is the only method used in formal logic, people also use abduction for explaining the causes of a situation, as well as the induction to transition from a particular aspect (instance) to its general counterpart (class).

Generally, human experts, working with knowledge represented in classical logic, had difficulties in using and understanding it, due to the fact that the language had a high specificity, aggravated by the fact that it did not have adequate mechanisms for defining more complex constructions. Also, the generality of the language was a significant barrier to the development of deductive facilities that could effectively use the modeled knowledge (Fikes and Kehler, 1985).

A problem that comes up fairly often, related to the logic formalisms, is that they are very costly from a computational point of view, and there is no guarantee that a certain inference process will complete (Goddard and Schalley, 2010). For this reason, efforts have been made to develop simplified, decidable logics, for which reasoning time is reasonable. In turn, these have also been criticized by linguistic researchers, for whom the computational processing is secondary, their main interest being the ability to express the many nuances of natural language.

In logical-based rule systems, the information is stored in any number of separate axioms, which can make examining the data related to a certain object quite difficult (Coppin, 2004).

By contrast, frame-based languages emulate the way human experts usually organize their knowledge, providing a concise structural representation of useful relations and a easy to use technique of definition by specialization. This depart from the logical representation format comes at cost, namely that expressing the quantifiers, disjunction and negation is more difficult to achieve.

The object-centered representation of frames provides a natural way of organizing knowledge about (a) *physical objects* (eg. a *desk* has *material*, *drawer number*, *length*, *width*, *height*, *color*, etc.) and (b) *situations* (eg. a *class* has a *room*, *participants*, *teacher*, *day*, *duration*, etc.). Information indexing, based on important objects, facilitates the quick retrieval of both them and the relevant facts related to them. It is also worth mentioning that this declarative, monotonic component of frames can be expressed through the logic of first-order predicates.

The property of being able to present the knowledge in an organized and structured way based on existing relationships between objects is also characteristic to approaches based on semantic networks.

Although, in essence, semantic networks and frameworks are part of the same family of formalisms, there are still some important differences between them. The first is related to their particular point of interest: if in semantic networks the arcs are more important than the nodes, encoding the relations, in a frame system, the nodes are the main aspect, because the information is centered around them. The second is related to information processing mechanisms. In the case of frame systems, the procedural power is distributed and it is specific to each frame, whereas in semantic networks it has a global characteristic by being located in the inferential engine, the network itself, being used only to store the data. It can also be mentioned that, in the initial form, the properties of the semantic networks were restricted to using only primitives, while the frame properties were allowed to be complex concepts like other frames (Baader, 2003).

An alternative direction of research, a category that encompasses the systems of the cognitive domain, was born from the efforts of psychologists and linguists, trying to define the nature of human understanding. This work was less concerned with establishing a representation based on sound reasoning, instead seeking to describe the way people acquire, associate and use commonsense knowledge (Luger, 2008). This approach has been proven particularly useful in the understanding of natural language and commonsense reasoning.

Depending on research orientation, two categories can be distinguished:

- *structural theories* – include frames and semantic networks and correspond to "weak structures" because their model does not contain information about the actual knowledge they are supposed to encode, specifying only the method of representing and organizing it. They are associated with uninformed search strategies, the searching technique being independent of any particular characteristic of the problem to solve.
- *content theories* – borrow a certain type of representation (usually semantic network), thereby inheriting a number of specific structural properties, but additionally provide the informational content of the domain, and so they are considered to be "strong structures". They can be associated with cognitive theories, which are specifically tailored to represent natural language and include specific information about the type of objects in the world and the existing relationships between them. They are characterized by informed search strategies, based on algorithms that use accurate heuristic information. Conceptual Dependency theory is part of this category.

4. CONCLUSIONS

In this article we presented the difficult problems that have to be taken into consideration in order to have a good representation method for the natural language. A point is made about the fine balance between language expressivity and reasoning capability, because straying too much in any one direction results in making potential unacceptable sacrifices for the opposite side. Next, we presented the most used representation methods: logical, frame systems and semantic networks formalisms.

Finally, it is presented a comparative study of their characteristics, starting with formal methods, by talking about the suitability of logical formalisms in representing the natural language and their drive for complete and solid reasoning methods. Among them, first order logic is an expressive language, but the high specificity of the language makes it difficult to describing complex constructions. This specificity is also the cause of a high computational cost, so, many other simplified decidable logic formalisms, like description logic, have been proposed in order to deal with this problem. The primary mode of inference is deduction, lacking abduction and induction methods of which humans usually make use of.

Frames were introduced as an alternative method of representation, complete with specific reasoning techniques, but ultimately, only the concise representation form was kept as a mean to organize the knowledge, due to its resemblance with the human way of structuring the knowledge. In the same family of formalisms, semantic networks are a graphical representation that puts more emphasis on expressing the relations between concepts, in contrast to object centered orientation of the frames. Both these methods were constructed with inheritance relation in mind, this being their primary mode of reasoning. Speaking of reasoning one important difference between them is that the frames have specific processing mechanisms incorporated inside them, while semantic networks have a global inference engine. Due to their focus on representation, they have difficulties in expressing quantifiers, disjunction and negation, for which logic is natively equipped.

In contrast to formal methods of representation, cognitive approaches were mainly concentrated on describing the way humans gain, associate and use commonsense knowledge, reasoning capabilities taking the back seat.

Comparing this difference of orientation, we can consider that the formal methods are mainly structural theories, as they are focused on describing the way of representing and organizing the knowledge, while cognitive methods are mostly content theories being based on structural formalisms but also adding the content (objects, relations and specialized strategies of inference) of the domain they are trying to model.

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