A Survey on Ontological Organization of Data in the Semantic Web

Nikoletta E. Samaridi [1], Nikitas N. Karanikolas[2], Michail Papoutsidakis[3], and Evangelos C. Papakitsos[4]

[1] Department of Informatics and Computer Engineering, UNIWA, nsamaridi@uniwa.gr

[2] Department of Informatics and Computer Engineering, UNIWA, nnk@uniwa.gr

[3] Department of Industrial Design and Production Engineering, UNIWA, mipapou@uniwa.gr

[4] Department of Industrial Design and Production Engineering, UNIWA, papakitsev@uniwa.gr

Abstract. Given the scientifically certified usefulness of the ontological structure of data in the field of Semantic Web, it is deemed necessary to study in depth and record the existing approaches about the languages, the tools and the methodologies of ontology development, with the aim of expanding and extending the relevant technologies, which will in the future express the distributed semantics of information.

Keywords: *Semantic Web; knowledge representation; semantic networks; web languages; terminology; taxonomy; ontology;*

1. Introduction

Knowledge representation and modelling is an important area of Artificial Intelligence, which deals with how knowledge can be more efficiently represented around a field within a computer, with the ultimate goal of problem solving. However, in order for knowledge to be editable by a computer, it is necessary to choose the appropriate way of capturing it, through some method of representation, as well as a formalism, that is, an artificial language with its own syntax and semantics. Nowadays, the Semantic Web focuses on the ontological representation of knowledge

(Sheraz and Munir, 2018) and research on ontologies has gained a special role in Artificial Intelligence, computational linguistics, database theory, information systems science (Smith and Welty, 2001) and semantic data mining (Dou et al., 2015).

2. Methods of knowledge representation

The methodologies of knowledge representation and reasoning that have been proposed in the context of the development of knowledge-based systems can be distinguished in:

- the Schemes of Logical Representation of Knowledge (: propositional calculus, predicate calculus, first-order predicate calculus, clausal normal form of logic, conjunctive normal form of logic, higher order predicate logic, fuzzy logic, etc.) (Hisdal, 1998), and
- the Structured Forms of Knowledge Representation.

The last ones are distinguished in:

1. **Semantic Networks** (Collins and Quillian, 1969; Collins and Quillian, 1970): It is a graphical system of representation of knowledge in the form of connected nodes and arcs with labels, in order to capture the properties and relationships of objects, events, elements, situations and actions that constitute them. They are divided into six (6) categories: Definitional, Assertional, Implicational, Executable, Learning and Hybrid networks. Their feature is the property inheritance support, which allows conclusions to be drawn.
2. **Conceptual Dependency** (Schank and Rieger, 1974): According to this approach there are six basic primitive conceptual categories on which the interpretation can be based: (a) ACTs (Real world actions); (b) PPs (Real world objects); (c) AAs (Attributes of actions); (d) PAs (Attributes of objects); (e) T (Times); and (f) LOC (Locations), with the help of which relations between the concepts are defined with stable and well-defined semantics.
3. **Concept Maps** (Novak and Gowin, 1984; Novak, 1991): These maps combine the expression of concepts (in the form of images, shapes or words) with the connection of them as nodes, determining the hierarchical relationship between them.

4. **Conceptual Graphs** (Sowa, 1976): They are a language of knowledge representation rooted in linguistics, psychology, and philosophy. These are finite graphs consisting of interconnected nodes of interchangeable concepts and relationships. They create a hierarchy between concepts, which indicate the existence of inheritance and define generalization and specialization relations.
5. **Frames:** Frames are "data structures for the representation of stereotypical situations" (Minsky, 1975) and they are also called schemata. They mainly reflect declarative knowledge and are divided into: (a) class frames or classes and (b) instance frames. A frame system is essentially a representation corresponding to a semantic network, where the language of nodes and hierarchical connections has been replaced by that of frames and positions.
6. **Objects:** These are easy-to-understand models that lead to the decomposition of the entities of the physical world into objects, which are organized hierarchically into classes, which include all the properties of the methods and the messages or events to which they respond, and have as their main feature the multiple inheritance.
7. **Scripts** (Schank, 1975; Schank, 1991): A script describes a stereotypical situation, an expected sequence of events with specific content, and the related to them information through quoting frames in chronological order.
8. **Rules:** Rules are a method of representing procedural knowledge that corresponds to valid reasoning and it is in the form of IF-THEN. The rules are of three forms: deductive, productive, and active rules.
9. **Ontologies:** Ontologies have a lot in common with Semantic Networks and Frameworks. In them, there is a combination of logical and structured representations, and the modeling of their data is object-oriented.

The evaluation of knowledge representation models has shown that logical representations, despite the simplicity of their semantics, are very strict in their formalism. On the other hand, structured forms of representation are distinguished for the ease with which conclusions are drawn, due to the hierarchical structure of concepts and semantic correlations that are created, allowing the achievement of inheritance. Ontologies, however, are superior to the above representations, because they are based on Descriptive Logics, based on which terminology supported by reasoning algorithms with good computational features are developed (Stamou, 2015).

3. Ontologies

"Ontology is a formal, explicit specification of a conceptualization" (Gruber, 1993). According to the W3C[1], ontology is a formal description of a domain. It includes a set of terms and the semantic correlations between them. These terms describe object classes, that is, standard concepts related to objects, and the correlations usually refer to hierarchical dependencies between terms. Ontology supports taxonomy for dealing with large volumes of objects, defining subcategories, hierarchical structure of categories and subcategories, and inheritance. The instances of a subcategory inherit the properties of the parent category and may have additional properties, structuring in this way and through a framework of constraints, rules and axioms, a semantic network with relations A_K_O and IS_A. Started by Aristotle who divided the "Existence" into ten categories (Substance, Quantity, Quality, Relatives, Somewhere, Sometime, Being in a position, Having, Acting and Being Acted Upon), leading to the conclusion that everything must be studied through relationships between cause and effect, be divided and categorized, so as to prove, up to the present time, ontologies are in essence theories of logic.

Various schemata are considered as ontologies, such as glossaries and data dictionaries, thesauri and taxonomies, metadata and data models, formal ontologies (Uschold and Grüninger, 2004), while their types are varied:

- content ontologies, communication ontologies, indexing ontologies, meta-ontologies (Mizoguchi et al., 1995);
- highly informal, semi-informal, semi-formal, rigorously formal (Uschold and Grüninger, 1996);
- terminological ontologies, information ontologies, knowledge modeling ontologies and representation ontologies, generic ontologies, domain ontologies (Van Heijst et al., 1997);
- top-level ontologies, domain ontologies, task ontologies, application ontologies (Guarino, 1998);
- generic or common-sense ontologies, top-level ontologies, domain ontologies, metadata ontologies, knowledge representational ontologies,

[1] W3C Semantic Web Activity, available at https://www.w3.org/2001/sw/

method or task ontologies (Gómez-Pérez, 1998), (Benjamins et al., 1998);

controlled vocabularies, glossaries, thesauri, informal is-a hierarchies, formal is-a hierarchies, frames, value restrictions, general logical constraints (Lassila and McGuiness, 2001).

3.1 Ontology Representation Languages

Ontology Representation languages are divided into three categories:

- **Traditional languages:** (a) First-Order Predicate Logic (Prolog); (b) Frame-Based Logic; (c) Description Logic. Examples: Loom (MacGregor, 1991), KIF (Genesereth-Fikes et al., 1992), F-logic (Kifer et al., 1995), Ontolingua (Farquhar et al., 1996), OKBC (Chaudhri et al., 1998), Carin (Levy and Rousset, 1998) και OCML (Motta, 1999).
- **Web - based languages:** XML (Raggett et al., 1999), (Bray et al., 2006), XOL (Karp et al., 1999), SHOE (Luke and Heflin, 2000), OML/CKML (Kent, 1998), RDF (Lassila and Swick, 1999)-RDFS (Amann and Fundulaki, 1999), OIL (Horrocks et al., 00), DAML+OIL (Horrocks et al., 2002), OWL (McGuinness and Van Harmelen, 2004).
- **Languages for specific ontologies and applications**, such as: CycL (Lenat and Guha, 1989), NKRL (Zarri, 1996), GRAIL (Rector et al., 1997), Gellish (Van Renssen, 2005).

The above distinction of ontology languages is mainly based on syntax, terminology, expressiveness, and semantics. The difference between traditional and web-based languages is that the last ones have well-defined syntax and semantics and satisfactory reasoning support. They also provide power and flexibility in their expressiveness and syntax that is compatible with existing web templates (XML, RDF, RDFS). Classes, relationships, and objects are defined as well as relationships and classifications are created within almost all web-based ontology languages. In particular, XML and RDFS schemes use the same syntax and are preferred for data modeling and ontology representation. XML has well-defined and compact syntax, ease of parsing, good readability, easy scalability, and, thus, is the basis for all other web-based languages, except SHOE. RDF(S) is compatible with HTML, but because it does not support any kind of logical contributions, efforts have been made to implement a Reasoning Machine (based on Flogic) that works directly on RDF(S) (Decker et al., 1999). The expressiveness of DAML + OIL is much richer than that of its predecessors, as it supports different natural languages, is quite easy to use, and supports the full range of XML structure data types, since it is based on XML and RDF schemes. However, OWL is superior to other languages, because it is compatible with DAML + OIL and RDF(S), can express complex relationships, offers reasoning possibilities and has been proposed as the official ontology language by the W3C. Finally, as far as the languages designed for specific ontologies are concerned, it is worth noting that Gellish is a language that has the advantage of including its own English dictionary that is both a taxonomy and an ontology, and includes a large and extensible set of standardized types of relations, without a distinction made between a meta-language and a user language.

At the end, it should be noted that the most important query languages for ontological knowledge extraction are RQL (RQL, SeRQL, eRQL), SPARQL (SPARQL, SquishQL, RDQL, TriQL) and OWL-S. SPARQL is the W3C suggested language for queries on the Semantic Web (Prud'hommeaux and Seaborne, 2008).

3.2 Ontology development tools

In recent years, several tools have been developed, known as ontology management systems, which provide a framework for building ontologies through a Graphical User Interface (GUI) or for reusing existing ontologies. These tools usually include options of ontology documentation, ontology export and input from different schemes, ontology graphic representations, ontology libraries, and built-in inference engines. There are also tools for assembling and aligning ontologies, tools for content documentation using ontologies, as well as tools for query execution and ontology storage, evaluation and learning.

The most well-known ontology development tools are: Apollo (Matousek et al., 2004), LinKFactory (Ceusters et al., 2001), OilEd (Bechhofer et aI., 2001), Ontolingua Server (Farquhar et al., 1996), Ontosaurus (Swartout et al., 1996), Protégé 2000 (Noy et al., 2001), OpenKnoME (Rogers, 2002), IsaViz (Pietriga, 2002), OntoEdit (Sure et al., 2002), SymOntoX (Missikoff and Taglino, 2003), WebODE (Arpírez et al., 2001), WebOnto (Domingue, 1998), SMORE (Kalyanpur et al., 2005), Swoop (Kalyanpur et al., 2006). Evaluating these tools, Protégé is currently the most complete solution for writing and managing ontologies, as it is a modular and open system, its meta-model is an ontology itself, which makes it scalable and extendable, supports ontology visualization, has SWRL (Semantic Web Rule Language) (SWRL, 2004) interface used to draw logical conclusions, provides the ability to import-export data in a number of languages (FLogic, OIL, XML, Prolog, OWL etc.) and is the only environment which is constantly evolving and has new software versions.

In addition, useful tools that serve various other purposes are: (a) the Chimaera and Protégé-PROMPT for merging ontologies; (b) the Ontomorph for converting an ontology from one language to another; (c) the COHSE, OntoMat and SHOE Knowledge Annotator for commenting ontologies in web environment; and (d) the OntoAnalyser, ONE-T and ODEClean for evaluating ontologies.

Finally, there are effective reasoners of Descriptive Logic, such as: Algernon (Crawford and Kuipers, 1991), FACT (Horrocks and Sattler, 2002), RACER (Haarslev and Möller, 2003), JTP (Fikes et al., 2003), KAON2 (Hustadt et al., 2004), FACT++ (Tsarkov and Horrocks, 2006), Pellet (Sirin et al., 2007), Hermit (Shearer et al., 2008), OWLJessKB (Ludwig and Rana, 2008).

3.3 Ontology development methodologies

Most ontology development methodologies are geared towards building an ontology from scratch or reusing ontologies without change. The main ones are: the Cyc Based Methodology (Lenat and Guha, 1990), the Uschold and King's methodology implemented for the development of the Enterprise Ontology (Uschold and King, 1995), the Grüninger and Fox's methodology implemented for the project TOVE (Toronto Virtual Enterprise) (Grüninger and Fox, 1995), the Kactus-Based Methodology (KACTUS, 1996), the METHONTOLOGY (Fernández-López et al., 1997), the SENSUS-Based (Swartout et al., 1997), the On–To–Knowledge (Sure, et al., 2004), the DILIGENT (Pinto et al., 2004). In the end, there was a proposal for an ontology redesign methodology (Gómez-Pérez and Rojas, 1999), the aim of which was to retrieve and transform the conceptual model of an existing and implemented ontology, in order to produce a new concept that could be re-implemented. The most mature of the above methodologies so far is METHONTOLOGY, proposed for the development of ontologies by the Foundation for Intelligent Physical Agents (FIPA)[2], although some specifications of its procedures and techniques are lacking in detail.

[2] http://www.fipa.org/

4. Usefulness of Ontologies – Applications

Ontologies, having a formality with great expressive power, contribute substantially to the processing and utilization of semantic information. They are the fundamental element of modeling the Semantic Web, as:

1. they are readable and understandable by computers;
2. they provide a semantic description in the contents of the Internet;
3. they make possible by simple reasoning mechanisms the concept-based search instead of keyword-based search, allowing in this way the semantic focus of questions, the questions and answers to more than one term and the use of text transformation operators;
4. they enable automated reasoning and inference services;
5. they are useful for sharing a common information comprehension structure (Musen 1992; Gruber 1993) and for the reuse of knowledge, allowing the integration of heterogeneous sources of information;
6. they are a powerful tool for completing databases and understanding natural language (Dahlgren, 1995), and
7. they participate in the use of different sources of information in a variety of applications.

Consequently, the value of ontologies has been recognized in different areas of research, such as: knowledge representation (Artale et al., 1996), knowledge engineering (Gruber, 1993), (Uschold et Grϋninger, 1996), (Gaines, 1997), (Gómez-Pérez, 1998), language technology (Lang, 1991), (Bateman, 1995), database design (Burg, 1997), (Van de Riet et al, 1998), information modeling (Ashenhurst, 1996), information integration (Wiederhold, 1996), (Bergamaschi et al., 1998), (Mena et al., 1998), object-oriented analysis (Wand, 1989), (Pazzi, 1998), information retrieval and extraction (Benjamins and Fensel, 1998), (Guarino, 1997), (McGuinness, 1998), knowledge management and organization (Poli, 1996) and in particular, in e-commerce (Fensel et al., 2001), medicine (Pisanelli, 2004), the digital libraries (Antonakis et al., 2006), the Geographic Information Systems (Fonseca et al., 2002).

5. Conclusion

Since ontologies have proven to be so useful in a variety of knowledge management applications, it is imperative that we extend their use to any area, in which they may seem effective. In particular, in the promising field of Artificial Intelligence and Natural Language Processing, the design and development of a Knowledge Based System is a common requirement, which will use ontologies as a basis to offer possibilities of semantic integration and interoperability in an automatic and secure way, connecting heterogeneous systems and approaches in engineering and technology (De Giacomo et al, 2018). Since this requirement is even greater in the field of Computational Lexicography (which is of interest to the authors of this paper), it is aimed at initiating the development of an electronic conceptual dictionary of the Modern Greek language, which will achieve the export and production of sound knowledge, through the connection with hierarchical-ontological correlations of morphological, syntactic and semantic information. Undoubtedly, ontologies can be the most effective means of achieving this goal, as they are the most appropriate way of representing linguistic knowledge, by allowing the definition of relationships between words, something that does not exist in a standard dictionary (Markantonatou and Fotopoulou, 2007).

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