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REVIEW PAPER

Ontology Development Methods

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ABSTRACT

An ontology defines a common vocabulary for researchers who need to share information in a specific domain. It includes interoperability of basic concepts in the domain and relations among them. The present paper takes a brief overview of different tools and methods for developing ontologies, their relationship with artificial intelligence, followed by a review of literature on the same. Method for developing an ontology on energy amplifiers is discussed in brief.

Keywords: Ontology, artificial intelligence, accelerated driven systems, energy amplifiers

1. INTRODUCTION

In recent years the development of ontologies– explicit formal specifications of the terms in the domain and relations among them has been moving from the realm of artificial intelligence (AI) to the domain experts. They have become common in the World Wide Web (WWW), which range from large taxonomies categorising websites such as subject directories to categorising products for sale such as Amazon.com.

Traditionally, ontology as a subject was the focus of philosophers and logicians, who used the term to denote the study of what is what, i.e., what exists, the kind and structure of objects, properties, and other aspects of reality of the universe. Researchers in the field of AI used the term Ontologies to denote a theory, concerning the kinds of entities and specifically the kinds of abstract entities that are to be admitted to a language system. The concept was developed and implemented since the early 1990s. AI researchers use ontologies (in plural) for two basic purposes: Problem Solving Methods (PSMs) and Knowledge-based Systems (KBSs). Around the same time, tremendous developments in the WWW forced Web developers to find a solution to the problem of intelligent access to the vast resources available on the Internet. Thus, the semantic Web Activity was initiated by the WWW Consortium, towards the development of enabling technologies. This would allow data on the Web to be defined and linked in such a way, that it can be used for more effective automation, integration and reuse across various applications. This led to the development of standards and tools for effective information exchange such as the XML, SWAD, DAML+OIL and OWL. In the field of Library and Information Science (LIS), R&D on ontologies began in the late 1990s. The growth of digital information resources and their easy accessibility to clients have spurred the need for developing new tools and techniques. But the multi-dimensional nature of digital resources (both in terms of physical formats and interdisciplinary and multidisciplinary nature of subjects), posed a challenge to information specialists. Conventional knowledge organisation (KO) tools like classification schemes and thesauri resemble ontologies in a way that they define concepts and relationships in a systematic manner, but they are less expressive when it comes to machine language. Ontologies represent a domain of knowledge and permit relationships such as the definition of classes, relations, and functions. Despite their high level of specification, they allow a great deal of flexibility.

All library and information systems use two distinct schema for encoding information embodied in a document. One represents the subject contents of a document through the use of a classification scheme, a thesaurus or a subject heading list; the other provides descriptive information about a document like title, author, publisher, etc. These are handled by metadata schema such as cataloguing codes, MARC and other bibliographic description formats and more recently Dublin Core, FRBR, RDF, and XML. The main problem in the context of interoperability is a bibliographic description format that in one library may not be compatible with the format of another library. If a piece of information is downloaded from the Internet, it is represented in an entirely different format. Therefore, achieving homogeneity in heterogeneous digital information resources is a real challenge.

An ontology incorporates both a subject representational vocabulary and a bibliographic description format, and can be made compatible with any digital information resource in a library or any webpage from the Internet. Because at the syntactic level, it uses web-enabled bibliographic description formats and at the semantic level, apart from standard IS&R tools, an ontology also makes use of free index terms, to represent the subject contents of a document. In this way, interoperability is achieved both at the syntactic and semantic levels by applying principle of ontology. Some of the reasons for developing ontology are:

- To share common understanding of the structure of information among people or software developers
- To enable optimum use of domain knowledge in a specified subject area
- To differentiate domain knowledge from operational knowledge
- To do analysis of domain knowledge in the given area to make it explicit

2. ONTOLOGY DEVELOPMENT TOOLS

There are a number of tools available freely on the Internet, for developing new ontologies. The important ones are:

Ontolingua (http://ksl.stanford.edu/software/ontolingua): It is a set of tools written in Common LISP. It was one of the first tools to be developed in the 1990s at the Knowledge Systems Laboratory of Stanford University. It provides a repository of ontologies to assist the users in creating new ontologies and amending the existing ones collaboratively.

WebOnto (http://kmi.open.ac.uk/projects/webonto/): It was developed by the Knowledge Media Institute of the Open University, UK. It supports creation and editing of ontologies and collaborative browsing.

Cyc (http://cyc.com/): It is an AI project that attempts to assemble a comprehensive ontology and knowledge base of everyday common sense knowledge with the goal of enabling AI applications to perform human-like reasoning.

3. ONTOLOGY DEVELOPMENT METHODS

As stated earlier, in the field of AI, ontologies have been used in PSM and KBS. Hobbs[1] proposed a general structure for a different underlying conceptualisation of the world; one that would be particularly well-suited to language as opposed to philosophical ontology, which is independent of language. Reynaud and Tort[2], Heijst and Schreiber[3] and Gomez-Perez[4] developed ontologies for PSMs. O'Leary[5] discussed the role of ontology in knowledge bases and knowledge management and in another paper[6], he highlighted the problems in using ontologies for KBSs. Two pioneering papers described how to develop and build ontologies. One was by Noy and McGuinness[7] and another by Guarino[8].

A comparative review of the state-of-the-art in ontology design was described by Noy and Hafner[9]. The use of specific tools and services to develop collaborative ontologies was reported by Farquhar and Fikes[10] in their study on the "Ontolingua" server. Borst and Ackermann[11] described a formal ontology called PHYSSYS in the domain of Engineering. Visser[12] made a comparative study of four ontologies in the field of law. Valente and Russ[13] presented a case study in building and reusing an ontology in the field of air campaign planning. Lopez and Gomez-Perez[14], gave guidelines for developing a chemical Ontology using two ontology building tools: MethOntology and Ontology DEsign (ODE).

Duineveld and Stoter[15] compared various Ontology tools available on the Internet for engineering domain. Holsapple and Joshi[16], provided different approaches such as inspirational, inductive, deductive, synthetic and collaborative in the design of ontologies. Everett[17], *et al.*, described means to resolve issues of synonymy through the use of natural language in designing new ontologies. Kohler[18], *et al.* paved the way to bridge the gap between an HTML-based system and an RDF-based system, by linking words in texts to concepts in ontologies. Kim[19], *et al.* detailed the development of a methodology for an ontology management system, based on philosophical texts. Dahab[20], *et al.* described an automatic ontology construction method from natural language English text.

4. DIFFERENCES BETWEEN A THESAURUS AND AN ONTOLOGY

Differences between a thesaurus and an ontology are shown in Table 1.

5. CURRENT IS&R TOOLS: SOME PROBLEMS

The development of international databases, emergence of the Internet, and digital libraries as source of vast amount of information have stressed the need to

Table 1. Difference between a thesaurus and an ontology

Thesaurus	Ontology
It belongs to post-coordinate indexing era.	Its roots are in philosophy.
It is a controlled vocabulary tool with descriptors to reflect subject content of a source and a subject domain.	It is a controlled vocabulary tool using free-text terms to describe a specific subject domain.
It is somewhat rigid in its construction.	It is totally flexible allowing multiple choice of entries.
It has single dimension.	It is multidimensional in nature.
It can be manually created or machine generated.	It can be created only using high level software programs.
It is built on the principle of literary warrant.	Literary warrant concept as well as problem-solving methods and knowledge-based systems form its basis.
Only three kinds of relationships exist BT, RT, and NT.	The relationships are potentially poly-hierarchical in nature.
It does not provide definitions.	It can provide definitions, meanings, and relationships.
The relationships are exhibited in a vertical manner.	No fixed pattern of representing concepts can be interlinked as such.
The super-ordinate and sub-ordinate classes are determined solely in accordance with the knowledge domain.	The super-ordination and sub-ordination of classes are mostly decided by the ontology developer depending on the purpose.

reorganise information in a more effective way. The interdisciplinary and multidisciplinary areas cover several subject domains simultaneously, making it difficult to develop appropriate vocabulary, and control or indexing tools for organisation and dissemination of information. Construction of both classification schemes and thesauri is a highly skilled job. There is, therefore, a need to develop a new tool which can address these problems. Generally, libraries and information centres use a two-pronged approach to information encryption. One system for vocabulary control (using classification, and other indexing tools) and another for bibliographic data description (cataloguing codes, metadata systems, etc.). Heterogeneous sources of information, (both syntactically and semantically), available on the Internet, necessitate the development of a standard format for digital information exchange. Therefore, ontologies can be used for this purpose. An ontology incorporates both a vocabulary and a metadata format.

6. LIBRARY AND INFORMATION SCIENCE PERSPECTIVE

Dahlberg[21] was one of the first L&IS professionals to identify the link between classification structure and ontology. In her paper "Ontical Structures and Universal Classification", she described the Ontological foundations of modern classification systems. Gopinath and others reinforced and corroborated her theories. Hjorland[22] has delved into the ontological, epistemological, and sociological factors, affecting a domain of knowledge. According to him, all domains are dynamic, and any KO tool should be able to reflect the constant changes in any domain and incorporate them in the new ever-changing structure of knowledge. An experiment to convert a controlled vocabulary into ontology was reported by Qin and Poling[23]. They used the controlled vocabulary of ERIC descriptors to develop an ontology on education and educational materials. According to them, the major difference between the thesauri and ontologies, lies in the values added through deeper semantics, in describing digital objects, both conceptually and relationally. At the 7th International ISKO Conference on Knowledge Research and Organisation, the second session focused on epistemological foundations for knowledge structures and analysis. Silva and Rocha[24], suggested an alignment process at the ontological level for merging ontologies.

At the same Conference, Negrini and Zozi[25], focused on the way ontological structures can aid the understanding and modelling of works of art. In the Networked Knowledge Organisation Systems (NKOS) group, Mai[26] held a series of workshops in conjunction with the Digital Libraries Conference and ACM+IEEE joint conference on digital libraries since 2001. At their 6th workshop, "Building a Meaningful Web from Traditional KO Systems to New Semantic Tools", all the seven presentations focused on how traditional systems for KO can be transformed into Ontologies. In another study, Gnoli and Poli[27], investigated the meaning of ontology as a model for KO, in the current Internet scenario, Ding[28] reviewed the importance of ontologies in the development of the semantic Web. He discussed the definition of ontologies, kinds of ontologies, ontology tools, ontology language and some important ontology projects. Ding and Foo, in another study, presented a two-part review. In the first part of the review[29], state-of-the-art techniques on semi-automatic and automatic Ontology generation were detailed. The second part of the review[30] dealt with ontology mapping and evolving. McGuinness[31] and Kim[32] summarised their comments on the development of ontologies and the Web's growing dependence on them.

As far as methodologies for developing ontologies is concerned, an important study by Poli[33], highlights ontological sub-theories and the use of domain analysis for developing an ontology. Ironically, this methodology in the field of AI, utilises domain analysis, an integral part of L&IS. Similarly, Prieto-Diaz[34] also used a domain analysis and a faceted approach to build ontologies with a software tool called 'DARE'. Most of the current ontological projects, use readily-available ontology tools for developing new ontologies. Charlet[35], *et al*. describe a methodology to build a medical ontology from textual reports, using a natural language processing tool; the SYNTEX software. Sanchez and Moreno[36] described an automatic and unsupervised methodology that addresses the non-taxonomic learning process for constructing domain ontologies. Roche and Kodratoff[37] presented a text-mining approach, to extract candidate terms from a corpus.

A clustering-based approach for developing cultural ontologies, was reported by Srinivasan[38], *et al*. The study concluded that a semi-automated method was useful in resolving the twin problems of scalability and interoperability in developing ontology. Another study by He and Hou[39], substantiated Srinivasan's view that semi-automatic construction of a domain ontology was more fruitful. They used a statistical NLP technique for mining of the concepts, developing the taxonomic as well as the non-taxonomic relationships and formalising the ontology. Ziyu and Lei[40] reported the development of a domain ontology on high-speed railway, combining terms from a thesaurus with other key concepts suggested by subject experts. The Unified Software Development Process**,** a widely used standard in software engineering, formed the basis for developing a methodology for an ontology in the e-business domain[41]. The UMLS meta thesaurus was used by Zeng[42], to develop an ontology on traditional Chinese medicine. Hjorland[43] addressed the theoretical problem in developing ontologies.

According to him, a basic knowledge of concept theory was essential for information scientists as well as KO experts. The best understanding and classification of theories of concepts, is to view and classify them in accordance with epistemological theories (empiricism, rationalism, historicism and pragmatism). The strength of an ontology lies in the use of both standard vocabulary terms as well as free index terms.

Dotsika[44] reinforced this view, by reconciling an ontology with a folksonomy and also proposed a common framework for reconciling both a formal descriptive system as represented by an ontology and an informal descriptive system, represented by a folksonomy. An automatic domain ontology construction method based on FCA, was reported by Lei Wang[45], *et al*. Using Content analysis, facet analysis, and clustering Deokattey[46], *et al*., described a method for developing a domain ontology in the multidisciplinary area of accelerator driven systems in nuclear physics.

7. ACCELERATOR-DRIVEN SYSTEMS

Accelerator-driven systems is an interdisciplinary and multidisciplinary subject domain. It is a part of the broad area of physics, particularly particle physics, atomic and nuclear physics, and nuclear and reactor engineering. Accelerators are huge electromagnetic devices that give high energy to subatomic particles, which then collide with targets. Particles are being used in a variety of ways for the benefit of mankind. Cancer therapy, medical and industrial imaging, radiation processing, electronics, measuring instruments, new manufacturing processes, and materials are some of the areas where accelerated particles are being used. Another promising use of particle accelerators is in producing clean, safe and almost inexhaustible amount of nuclear energy. The amount of energy produced is much more than energy utilised, hence they are called energy amplifiers (EA).

Accelerator-driven systems are used for several purposes. Some of the important applications of ADS are for R&D in Particle Physics, for generating nuclear energy, for destruction of high-level radioactive waste and for breeding or producing additional nuclear fuel.

8. METHODOLOGY

For the purpose of developing a sample domain ontology on EA, INIS database was used for picking up keywords. Steps followed were as under:

8.1 Process of Conceptualisation

This process was initiated through the preparation of the final list of keywords and descriptors, which formed the basis for developing the ontology. Six hundred seventy nine descriptors were downloaded from the bibliographic records of the INIS database and saved as an Excel file.

8.2 Grouping and Interlinking of the Descriptors

In the first step, each descriptor was linked to the other through a one-to-one or one-to-many correspondence between the descriptors depending on the type of the descriptor. Table 2 depicts a sample of such an interlinked file of descriptors. Among these descriptors, 10 descriptors with highest frequency of occurrence were identified as core clusters around which several minor or smaller clusters were developed. Thus, each descriptor was a part of a basic semantic unit, consisting of a minimum of three descriptors. These descriptors were:

81 transmutation

73 accelerators

Table 2. A sample display of one of the main clusters on accelerators

Cyclic accelerators	Beams	Targets	Neutrons
Quadrupole linacs	Beam dynamics	Target chambers	Neutron beams
Synchrotrons	Neutron beams	Thorium 232 target	Multiplication factors
ECR ion sources	Beam emittance	Lead 208 target	Neutron transport
Cyclotrons	Beam injection	Eutectics	Ultra cold neutrons

59 nuclear-reactions

56 reactors

55 elements

50 beams

50 metals

49 nucleon-beams

49 particle-beams

49 proton-beams

Under these core clusters, other descriptors identified and downloaded from the INIS database, were grouped to form smaller clusters, on the basis of Facet analysis and semantic similarity. Each of the descriptors under any of the core groups, could belong to more than one core group (Table 2).

8.3 Software for Designing the Ontology

A special program was written to develop the ontology, in a web-based environment. The following three-tier architecture was used to develop the domain ontology.

- Active server pages
- Web server (IIS)
- MS Access

8.4 Organising the Keywords/Descriptors File

In the first step, the interlinked Excel file (the semantic network) of all descriptors on EA was fully updated.

8.5 Organising the Bibliographic Data File

The bibliographic records on EA (129) downloaded from INIS database formed the core data for the domain ontology on EA. These records were downloaded and saved as a separate text file. Only certain mandatory fields for each bibliographic record were downloaded from the INIS database. These fields were Author, Corporate Author, Title (both original and translated), Publisher, Year of Publication, Language, Collation, Report No. (in case of technical reports), Source, Descriptors, and Abstract. This edited text file of bibliographic data input was then saved as an HTML file.

8.6 Uploading Data onto the Web-enabled Platform

Both the keywords/descriptors file and the bibliographic file were uploaded onto the Web-based platform developed for the domain ontology. The methodology for the present domain ontology on EA was thus developed using facet analysis techniques, which are an integral part of LIS studies. This methodology can be used to develop a domain ontology both for pure subject domains as well as for interdisciplinary subject domains.

9. CONCLUSION

The focus of much of the research in AI is on the emulation of problem solving behaviour. AI applications include medical diagnosis, natural language interpretation, robotics, programming, game playing, vision, speech, pattern recognition, and fact retrieval. Therefore, most of the work on the design and development of ontologies was carried out in the late 1990s and in the beginning of early 2000s. Apart from domain knowledge, ontologies in the field of AI have to incorporate operational knowledge, to simulate real-life problems and function as Expert Systems.

Semantic Web initiatives by the W3C, saw a number of Web developers designing ontologies for interoperability among various systems. Ontologies form an integral part of the semantic Web architecture. The ontology layer represents the semantic Web's central metadata artery, where simple descriptive to complex classificatory schemas are created and registered so that agents can intelligently interpret data, make inferences, and perform tasks. Ontologies are metadata systems. In the context of information science, ontologies are still at a nascent stage. There is as yet no consensus on the definition of ontology. If an ontology has to be developed, the first requirement would be, that it should be based on the concept of literary warrant; which means that only domain knowledge would be utilised to develop an ontology. Secondly, in the present era of reusable modules of ontologies for various applications, interoperability is a major issue, which means an ontology should be flexible and yet be Web-enabled.

Third and the most important area is vocabulary control. Information Scientists need to think beyond classes, keywords and descriptors to represent information, embodied in any document. The basic idea or the concept as envisaged by Hjorland, would be the key to effective organisation and retrieval of information. A concept encompasses keywords, descriptors, and their corresponding linkages. These linkages should also take into account, institutional, cultural, and national warrants. The complexity of evolving subject domains is another problem area and innovative methods, including webometric techniques, need to be used to harness concepts, for developing ontologies in interdisciplinary domains. The theoretical foundations of classification, rooted in logic and cognitive psychology, would form the ideal basis for developing techniques and methods for creating new domain ontologies.

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