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Knowledge Representation using Fuzzy Ontologies – A Review

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Abstract--- Fuzzy ontologies are able to deal with imprecise and vague knowledge using fuzzy sets and its relations. Ontologies are currently emerging as a powerful knowledge representation technique on the semantic web. However, it doesn't have an ability to represent the fuzzy information as well as the uncertainty. This survey aims at giving a brief and comprehensible overview of the research directions practiced under the domain of ontology deal with the fuzzy knowledge, reconciling various definitions given in scientific literature and identifying some of the future research challenges in this domain. We hope this review will provide a useful resource for the fuzzy ontology learners' community.

Keywords--- Ontology, Fuzzy, Semantic web.

I INTRODUCTION

Ontologies are now central to many applications such as artificial intelligence, semantic web services, information management and integration systems, scientific knowledge portals and electronic commerce. Ontology is a systematic description of significant concepts in a particular domain, along with the description of the specific instances of each concept. In other words, ontology can be defined as a hierarchical description of part-of relationships and entity dependencies. It has a powerful expressive ability on knowledge representation. In recent times, it has been noted that classical ontologies and its languages are not appropriate to deal with vagueness and imprecise knowledge, which is fundamental to several real world domains [1]. To handle this problem, the use of fuzzy logics with ontology offers a solution. Fuzzy ontologies and its description logics for the semantic web can handle probabilistic or possibilistic uncertainties and vagueness. In our work, we provide in-depth discussion of these fuzzy ontologies in terms of fuzzy ontology generation, applications, languages, operators, tools and plug-ins.

The remaining paper is structured as follows: we describe knowledge representation using fuzzy ontology in section 2, fuzzy ontology generation framework in section 3, aggregation operators for fuzzy ontologies in section 4, applications using fuzzy ontologies in section 5, fuzzy ontology languages in section 6,fuzzy ontology tools and plugins in section 8, fuzzy rough ontologies in section 7, type-2 fuzzy in section 9. At last, the conclusion and future works are included in section 10.

II FUZZY ONTOLOGY

Surveying the literature, we can identify that there is no unique definition of fuzzy ontology. In the simplest way [2], a fuzzy ontology is a set of fuzzy concepts (C) and binary relations (R). In various methods, this can be extended in several ways:

- individuals (I), fuzzy axioms (A) [3],
- concept hierarchy (H) and axioms [4],
- attributes of a concept, concept hierarchy, fuzzy events of a concept [5].

Fuzzy ontology can be seen as extended domain ontology [6], which makes use of the precise domain and fuzzy information processing as follows:

(a) the input is unstructured data;
(b) the definition of related concepts in the particular domain,
e.g. instances, objects, and their relationships;
(c) the generation of domain ontology;
(d) the domain ontology extended as fuzzy ontology;
(e) applying the fuzzy ontology to the exact domain.

Though fuzzy logic was introduced in the 1960's [5], the research on fuzzy ontologies was approximately not present before 2000, so we can state that this is a quite new research field with a grand potential. This is even more astonishing that the fuzzy logic used already in the 1980's as the foundation for ontology building and it solved so many problems related to classical ontologies [7]. Following are important *advantages of fuzzy ontology*:

- fuzzy predicates consistently simplifies our theories in most advanced scientific fields
- fuzzy predicates are reasonable, and give us a attractive cohesive worldview, than their crisp matching part.

It is important to note that most of the definitions in the literature are quite restrictive and are mostly anchored to a specific application area. The fuzzy ontology has been introduced to represent the fuzzy concepts and relationships, with a degree of membership μ ($0 \leq \mu \leq 1$) assigned to this relationship. In general, the Fuzzy ontology is a hierarchical relationship between concepts within a particular domain, which can be viewed as a graph. It is well developed based on the ontology graph and fuzzy logic. Fuzzy ontology captures wealthier semantics than traditional domain knowledge representations by allowing half-done belonging of one item to another. The Semantic Web is turning into a new generation web. And the ontology has been seen as a prerequisite for the Semantic web. Concepts are rather vague than precise in the context of semantic web applications. There are rising needs to deal with vague knowledge. So it is important to cope with the inexact concepts on the Semantic Web. The goal of the research of fuzzy ontology is to integrate these characteristics. The fuzzy ontology is capable of dealing with fuzzy knowledge [8]. In the ontology-based CBR paradigm, Alexopoulos et al., [9] propose a new CBR approach that manages and utilizes imprecise knowledge through the integration of Fuzzy. Mohd Kamir et al., [10] present an ontology and semantic approaches for using data from various database. Harshit [11] share the development process of an ontology which is used for knowledge management in an enterprise. Hamani et al., [12] propose a new approach for patterns ranking according to their unexpectedness and background knowledge represented by domain fuzzy ontology organized as DAG (Directed Acyclic Graph) hierarchy. Ghorbel et al., [13] find the fuzzy aspect is not enough studied in many methods and tools for building ontology. Therefore, they present a new fuzzy ontology building method called "FuzzyOntoMethodology".

III Fuzzy Ontology Generation

Fuzzy logic can be integrated to ontology to represent ambiguity or uncertainty information. Though construct a concept hierarchy for a particular domain can be a tedious and difficult task, fuzzy ontology is constructed from a predefined concept hierarchy. Quan et al., [14] proposes the FOGA (Fuzzy Ontology Generation framework) for automatic generation of fuzzy ontology on uncertainty information. The FOGA framework consists of the following components: Concept Hierarchy Generation, Fuzzy Formal Concept Analysis, and Fuzzy Ontology Generation. They also discuss about approximating reasoning for incremental enhancement of the ontology with new forthcoming data and also proposed a fuzzy-based technique for incorporating other attributes of database to the ontology. Recently, some papers combine fuzzy ontologies with fuzzy Formal Concept Analysis to elicit conceptualizations from datasets and generate a hierarchy-based representation of extracted knowledge [15]. Most of the current fuzzy ontologies are domain specific and doesn't support reasoning on fuzzy descriptions.

By surveying the uncertainty knowledge in the real world, Huamao et al., [16] discover three widely existing general fuzzy relations. Based on such survey and motivated by the desire to support reasoning and guide fuzzy ontology construction, they propose a reasoning-enabled general fuzzy ontology including these general fuzzy relations, which play major roles in modeling domain knowledge. It should be noted that the classical ontology is limited to crisp concepts and may not be sufficient for handling imprecise information that is commonly found in many application domains. More recently some efforts have been made to propose fuzzy ontology. Lam [17] introduces a fuzzy ontology map (FOM) based on fuzzy theory and graph theory for fuzzy extension of the hard-constraint ontology. Abulaish and Dey [18] present a fuzzy ontology framework in which a concept descriptor encodes the degree of a property value using a fuzzy membership function. In addition, Sanchez and Yamanoi [4] introduce a fuzzy ontology structure from the aspects of lexicon and knowledge base. Just like the generation of traditional ontology, fuzzy ontology can be generated from heterogenous fuzzy data resources. In Quan et al., [14], a fuzzy ontology generation framework (FOGA) is proposed for fuzzy ontology generation on uncertainty information. The framework is based on the concept of fuzzy theory and formal concept analysis. Nevertheless, fewer researches have been done in the construction of fuzzy ontology. It is particularly true in using the fuzzy databases for generating fuzzy ontology. To the best of our knowledge, up to now, there are not any reports on fuzzy ontology generation from fuzzy databases. Pan [19] presents a framework for the construction of fuzzy ontology from fuzzy relational databases.

IV Aggregation Operators For Fuzzy Ontologies

Fuzzy ontologies are able to handle represent imprecise and vague knowledge. Bobillo and Straccia [20] provide the syntax and semantics of fuzzy description logic with fuzzy aggregation operators and provide a reasoning algorithm for the family of operators by Mixed Integer Linear Programming optimization problem and also show how to encode aggregation operators using the language Fuzzy OWL 2. Some examples of aggregation operators are Ordered Weighting Averaging operators, weighted sums and fuzzy integrals. Sánchez and Tettamanzi (2006), considers fuzzy ontologies with fuzzy quantifiers that could be used for some kind of quantifier-guided aggregation. Carlsson et al., [21] developed a recommender system composed of a fuzzy ontology encoding real data which can be used to select a data given a specific context and reasoning using OWA operators. Lee et al., [22] apply fuzzy ontologies to personal diabetic-diet recommendations, with several experts taking part of the process and having to aggregate their different opinions. Bobillo and Straccia [23] show how to support fuzzy integrals in fuzzy ontologies.

V Applications Using Fuzzy Ontologies

There are two very nice applications of fuzzy ontologies solving real-world problems. By analyzing the similar characteristics of malware, Tala and Seyed [24] use fuzzy logic to represent malware relationships. Qi et al., [25] build the knowledge base of rules and catalogue concepts on SWRL, which realizes the knowledge sharing of audio-video material catalogue and the incorporation with relative information. Jun et al., [26] construct the fuzzy ontology for product knowledge and establish the semantic query expansion, facilitating the semantic retrieval for the fuzzy product information on the semantic web. Jun et al., [27] introduce data type of fuzzy linguistic variable into RDF data model. In addition to that, after constructing the semantic query expansion in SPARQL, they implement the semantic information retrieval for E-business on the semantic web. And fuzzy ontology is efficient in text and multimedia object representation and retrieval [28]. Huang et al., [29] design an Interval Type-2 Fuzzy Ontology model and propose a methodology for a malware analysis system and model.

VI Fuzzy Ontology Languages

Knowledge in the Semantic Web is usually structured in the form of ontologies [30]. This has led to considerable efforts to develop a suitable ontology language, concluding in the design of the OWL Web Ontology Language [31]. The OWL language consists of three sub-languages of increasing expressive power, namely OWL Lite, OWL DL (Description Logic) and OWL Full. OWL Lite and OWL DL are, fundamentally very expressive description logics; they are nearly equivalent to the SHIF (D +) and SHOIN (D +) DLs. OWL Full is clearly undecidable because it does not impose restrictions on the use of transitive properties. Though the OWL DL languages are very expressive, they provide expressive drawbacks concerning their ability to represent vague and imprecise knowledge. Pan et al., [32] , extend the OWL web ontology language with fuzzy set theory [33], which is a mathematical framework for covering vagueness, thus getting fuzzy OWL (f-OWL). DL-based fuzzy ontology languages have attracted much attention during the last decades. That is mainly due to the fact that compared to other formalisms, fuzzy ontology languages provide an expressive and yet efficient way to perform reasoning over a fuzzy knowledge. In particular, Straccia [34] extended the DL-Lite ontology language, which enables highly efficient query answering procedures, to fuzzy DL-Lite.

Apart from that, the description logic behind the reasoning, the most familiar is fuzzy SHOIN(D), a fuzzy generalization of SHOIN(D) which is one of the classical logic schemes used in the Semantic Web. This approach permits concrete datatypes to be represented by fuzzy sets. In addition to that, it introduces fuzzy RBoxes, fuzzy TBoxes, fuzzy ABoxes, fuzzy modifiers and fuzzy axioms. The fuzzy SHOIN(D) was formerly proposed for logic-based information retrieval in a document management system [35]. Bobillo and Straccia [36] developed a procedure to represent imprecise information in current standard languages and tools by recognizing the syntactic differences that a fuzzy ontology language has to cope with, and by proposing a appropriate methodology to represent fuzzy ontologies using OWL 2 annotation properties. FuzzyOWL2 allows a developer to encode (1) linear and triangular fuzzy modifiers (2) fuzzy data types such as left - shoulder, right - shoulder, triangular and trapezoidal (3) fuzzy concepts (4) fuzzy roles and (5) fuzzy axioms.

In fact, SHOIN(D) is correspondent of OWL DL, and from this follows that fuzzy SHOIN(D) is convenient as a formal basis for bringing uncertainty into OWL. There are several proposals to encode imprecise information into OWL, such as using transforming fuzzy DL into classical DL, OWL extension and at last using OWL2 annotations. Jinlin et al., [37] propose an extension of OWL DL with fuzzy logic by giving the formal syntax and semantics, with which fuzzy knowledge can be expressed well. Jun et al., [38] utilize fuzzy ontology and RDF to represent properly the fuzzy linguistic variables, which facilitates to incorporate fuzzy systems into the Semantic Web.

The conceptual formalism supported by ontology is not sufficient for handling vague information that is commonly found in many application domains. Bibillo and Straccia [20] describe how to introduce fuzziness in ontology. To this aim they define a framework based on Fuzzy DL and Fuzzy OWL. The main differences between the fuzzy ontology and crisp ontology are as shown in Table 1.

VII FUZZY ONTOLOGY TOOLS AND PLUG-INS

Ontology is a vital tool on the Semantic Web. Although, Ontology has no ability to represent the imprecise information as well as the uncertainty, it has a powerful expressive ability on knowledge representation. In order to share and deal with the fuzzy knowledge several tools are proposed.

A. Protégé

A tool of protégé is used to realize the fuzzy system. Protégé-2000 is a very popular knowledge-modeling tool developed at Stanford University. Protégé can be extended with various pluggable components to add new features, functionalities and services. There exists an increasing number of plug-ins offering a variety of features, such as multimedia support, extra ontology management tools, problem solving methods, querying and reasoning engines, etc. Protégé implements an effective set of knowledge-modeling constructions and actions that support the creation, manipulation and visualization of ontologies in several representation formats. A frame based Open Knowledge Base Connectivity protocol (OKBC) which is emerging in ontology is supported by the protégé tool. There are various forms such as RDF (Resource Description Framework), OWL (Ontology Web Language) and XML Schema in which protégé ontology can be exported. Characteristic features of fuzzy ontology tools and plug-ins are shown in Table 2.

B. Fuzzy OWL2

Fuzzy OWL2 plugin provides an appropriate way to represent fuzzy ontologies using OWL 2 annotation properties. It is able to use in present OWL 2 editors (example protege). Moreover, it supports the two fuzzy DL reasoners such as fuzzyDL and DeLorean.

C. SWRLTab

SWRLTab is a plugin of protégé. SWRL/OWL is used to represent the fuzzy knowledge in terms of rules properly for facilitating machine understanding and process correctly. It is an environment for working with *SWRL* rules in Protege - OWL and it supports the editing and execution of SWRL rules. The principle of *SWRLTab* is to recognize fuzzy rule. It also provides mechanisms to allow interoperation with various rule engines and the integration of user-defined libraries of methods that can be used in rules. Moreover, A tool of *SWRLTab* is used to create the fuzzy rule base and the rules are expressed in SWRL/OWL [39].

TABLE I MAIN DIFFERENCES BETWEEN FUZZY AND CRISP ONTOLOGY

Aspect	Fuzzy Ontology	Crisp Ontology
Multiply-Located terms	Does not occur	Issue for disambiguation
Query expansion	Depends on membership value	Depends on location only
Customisation	Simple, based on modification of membership values	Review new ontology and/or ontology sharing
Intermediate locations for grouping	Unnecessary	Needed for construction – may be useful
Storage required	Depends on the number of terms in the ontology and the membership values of the relations, can be smaller or larger than crisp	Depends on the number of terms in the ontology
Knowledge representation	Relted to use	Relted to structure

TABLE II CHARACTERISTIC FEATURES OF FUZZY ONTOLOGY TOOLS AND PLUGINS

Features	Type	Availability	Extensibility	Version	Knowledge Representation
Protege	Tool	Open Source	Plug-in	Protégé 3.0, 4.0, 5.0 (latest)	Realize the fuzzy system
FuzzyOWL2	Plugin	Open Source	Tab Widget	Fuzzy OWL2 1.1	Represent fuzzy knowledge using OWL annotation properties.
SWRL	Plug-in	Open Source	Tab Widget	SWRL 1.1	Realizing the fuzzy knowledge sharing between heterogeneous systems
KAON	Tool	Open Source	Application Server	KAON 1 KAON 2	Managing OWL – DL and F – Logic (Fuzzy Logic)

D. KAON 2

KAON is an ontology management infrastructure targeted for business applications. It contains a comprehensive tool suite permitting easy ontology creation and management.

Calegari and Ciucci [3] develops a suited plug-in of the KAON Project in order to introduce fuzziness in ontology. KAON2 is a descendant to the KAON project (often referred to as KAON1). KAON2 is an infrastructure for overseeing OWL-DL, F-Logic and SWRL ontologies. KAON1 is based on RDFS, whereas KAON2 is based on F-Logic and OWL-DL.

VIII FUZZY ROUGH ONTOLOGY REPRESENTATION

Ontology is largely used in the areas of web based data mining, knowledge engineering, etc. Since the last decades, several domains in the Semantic Web engage different sorts of imprecision, ontologies must be significant and expressive enough to handle imperfect information. Most of approaches to handle imprecision in ontologies deal either with probability or use fuzzy set and fuzzy logic methods for representing ontologies for intrinsically vague domains. Klinov et al., [40] show how they can be balanced by rough set techniques to capture another type of vagueness caused by approximation spaces. Ishizu et al., [41] formulate a concept of rough ontology, define upper and lower approximation, approximation accuracy of preference, granularity concept of preference. Bobillo [42] represent generalized fuzzy rough description logics to handle uncertainty.

IX TYPE-2 FUZZY ONTOLOGIES

We know very well, it has been widely pointed out that classical ontology is not sufficient to deal with imprecise and vague knowledge for some real-world applications like personal diabetic-diet recommendation. Apart from that, fuzzy ontology can powerfully help to handle and process imprecise data and knowledge. A recent development in the field is the appearance of type-2 fuzzy ontologies (T2FO). Lee et al., [22] introduced a T2FO, which is composed of (i) a type-2 fuzzy personal profile ontology (ii) a type-2 fuzzy food ontology and (iii) a type-2 fuzzy-personal food ontology. Li et al., [43] newly represent a type-2 fuzzy version of *ALC* and express its syntax, semantics and reasoning algorithms. In addition to that Li et al., [43] specify an implementation of the logic with type-2 fuzzy OWL. Lee et al., [22] represent the computer Go knowledge with the extension of a Fuzzy Markup Language (FML)-based type-2 fuzzy ontology. It consists of an FML transformation mechanism, a type-2 fuzzy set inference mechanism and a type-2 fuzzy set construction. Bukhari and Kim [44] provide an integrated secure type-2 fuzzy ontology multi-agent platform to completely automate the process of manual air ticket booking. Interval Type-2 Fuzzy Set (IT2FS), a special case of T2FS, is currently the most widely used because of reduced computational cost [45].

X CONCLUSION

Ontology has a powerful expressive ability on knowledge representation. But classical ontologies are not suitable to handle vague and imprecise knowledge. So, this paper has presented an overview of the research directions practised under the domain of ontology deal with the fuzzy knowledge. Even if there are several researches revolve around handling imprecise knowledge, there are still some new tools and extended fuzzy languages are required to automatizing the fuzzy ontology by means of both quantitative and qualitative approach. We hope that this review will be useful for researchers and practitioners interested in the area of fuzzy ontology.

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