A Fuzzy Integrated Ontology Model to Manage Uncertainty in Semantic Web: The FIOM

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Abstract— Semantic web, also known as next generation web, aims to provide context based information and services to the user. Although, ontologies play key role in implementation and exploitation of semantic web, however these fail to handle imprecision and uncertainty involved in user requests. Fuzzy logic provides a means to overcome the mentioned shortcoming and hence handles imprecise and vague knowledge quite decorously. This work proposes *F*uzzy *I*ntegrated *O*ntology *M*odel (*FIOM*) which aims to integrate fuzzy logic in design structure of ontology, so that it can handle vague and imprecise information.

Keywords- Semantic Web; Ontology design; Fuzzy Logic; Uncertainty

I. INTRODUCTION

Semantic web (SW) is a vision of next generation of World Wide Web (WWW) where information on web will be semantically annotated to be understandable by machines and crawlers. SW promises opportunities for exploitation of rich knowledge resources spread across WWW for processing, filtering and mining of knowledge by intelligent agents. The deployed agents require ontology not only for communication among themselves, but also for understanding the desires and hence deciding the line of action as well.

However traditional ontology development methods employ crisp logical structures only. But some domains of interest have subjective and inherently vague knowledge which can't be properly expressed using those structures. Thus exploitation of knowledge from such domains becomes difficult.

In order to accommodate uncertainty and vagueness in domain knowledge one possible solution is to incorporate ability of computation with words (i.e. fuzzy logic) in semantic web at ontology level. This need provided the motivation for this work and it aims to extend earlier work of authors which provided technique for ontology development [9]. Here the focus is to extend conventional ontology with fuzzy logic thus providing Fuzzy Integrated Ontology (FIO).

Section 2 provides an overview of Resource Description Framework (RDF), Ontologies and Extensible Markup Language (XML) as these as the vital components used while implementing semantic web. Section 3 discusses related work done so far. Section 4 explains how FIO manage uncertainty in semantic web and proves to be beneficial. Section 5 concludes the paper.

II. PRELIMINARIES

A. Resource Description Framework

RDF and Resource Description Framework Schema (RDFS) [15] are the basic knowledge representation formats employed in SW. RDF provides framework for representing concepts and statements as labeled directed graph. RDF requires every entity to be represented as a triplet of a subject, a predicate (property) and an object, where subject/resource is anything which can be retrieved from the web like web pages, emails, files etc. Also anything else that has a uniform resource identifier (URI) associated with it, is considered as a resource. Thus even a person can be a resource provided information about him/her is available through a URI. Predicates/Properties are specific aspects of a resource, where each property has its own meaning. Object provide values a property may acquire. Objects may be literal i.e. a self explanatory string or another resource i.e. subject of a statement can also be referred as object in some other statement. For example cost of a book can be specified using the following syntax:

<predicate> literal value </predicate>

<cost> 350</cost>

where cost is a constant value i.e. 350.
The same can also be specified using the link to that information, as given below
<feature:cost
<rdf:resource= “http://www.booksshop.com/cost # books/">

B. Ontology

Ontology basically refers to vocabulary of a domain. It can be defined as an explicit specification of a conceptualization which describes the objects, concepts and entities existing in a domain with their relationships [9]. It is used for standardizing terminology of knowledge exchange among various applications working on SW. Basically it involves taxonomy of class and subclass relations among entities in a domain coupled with definition of relations between them. Although RDF & RDFS allow representation of some ontological knowledge but still there is need for ontology development language, as major focus of RDF & RDFS is on organizing vocabularies in hierarchical fashion only. They lack flexibility and features desired in an ontology building language. For example RDFS allows defining range of a property on all classes of a schema but doesn’t support defining local scope of a property to a single class. For example consider the statement ‘Humans eat vegetables’ which applies to all humans in this case. But humans also eat meat, which is true for some humans only, thus it can’t be expressed in RDFS. Thus in addition to RDF & RDFS, SW requires ontology language richer than these.

Ontology Web Language (OWL) [17] is used for developing ontology. This is standard language accepted by World Wide Web Consortium (W3C). It comes in three different flavors namely

- OWL Full: It simply includes full OWL language primitives. It is fully compatible with RDF i.e. any legal RDF document is a valid OWL Full document.
- OWL DL (Description Logic)-it is a sublanguage of OWL full. It has the advantage of efficient reasoning support. However it losses full compatibility with RDF.
- OWL Lite- It is subset of OWL DL with advantages of easier understanding and easier implementation. However it has restricted expressivity.

Any one of these languages can be adopted by ontology developer, as per the requirement. Ontology works in the core of SW exploitation and thus has achieved widespread popularity. However the conceptual formalism supported by typical ontology is not able to handle uncertain information processed by many applications (such as search engines). The uncertainty arises due to lack of clear-cut boundaries of concepts and domains. This inherent uncertainty is focus of this work.

C. Extensible Markup Language (XML)

XML is the language used for presenting semantic web contents. Its purpose is to describe marked up electronic text. Basically it’s a meta language i.e. a language used for describing another language, which in this case is markup language. The purpose of markup is to explain how annotation or other marks with in a text should be printed or laid out. In other words markup is a means to make interpretation of a text explicit. XML is possessed with some special features which make it suitable for development of semantic web contents. Some the features are:

- It is extensible which means it is not restricted to fixed set of tags like HTML. User can freely create new tags as per their requirement. Rigid tag structure of HTML was severely limiting the exploitation of WWW.
- Its documents must be well formed according to a defined syntax and may be validated.
- Major focus of XML is on meaning of data and not on its presentation. Using XML it becomes possible to add information to web pages in such a way that it becomes easy for computers not simply to display it but also to process it in meaningful way[ ]. Since providing meaning of data to machines is underlying theme of SW, thus XML suits well for SW applications.

Example given in figure 1. below illustrates the exploitation of user defined tags in XML, compared to fixed tags in HTML.

HTML code for Book Catalogue

```
<ul>
<li><em> Computer Books</em>,
       <b> Data Structures</b>,
      <b> SEYMOUR LIPSCHUTZ</b>,
       USD15<br><p>
<b> New Order </b>
</ul>
```

XML code for Book Catalogue

```
<catalogue>
<product category= “Book”>
<subject category= “Computer Science”>
       <Title> Data Structures</Title>,
      <Author> SEYMOUR LIPSCHUTZ</Author>,
       <price= “USD”>15</price>
</subject category>
</product category>
</catalogue>
```

Figure 1. Comparison of fixed HTML tags with flexible XML tags

It is clear from this example that information becomes easily understandable using flexible XML tags.
Next section provides survey of literature, focusing on ontology development and fuzzy logic.

III. Related Work

This section explores the literature to find applicability of fuzzy logic in semantic web at ontology level.
Stoilos et. al in [1] proposed a fuzzy extension of Ontology Web Language called Fuzzy OWL for capturing imprecise and vague knowledge. But fuzzy OWL still needs extension on fuzzy component’s expressiveness. Tho et. al in [2] proposed Fuzzy ontology generation framework (FOGA) for automatically generating fuzzy ontology from uncertain information. Zadeh in [3, 8] emphasized that fuzzy logic plays key role in computing with words and vice-versa. The work in [8] highlighted that Computing with words is a necessity when information available is too imprecise and also the application has a tolerance for imprecision. Thus computing with words suits well to SW applications.
Klinov et. al in [4] illustrated that rough set theory can be used to complement fuzzy set theory for managing imprecision in ontologies. However their work concluded that having only certainty values as indicator of confidence in description logic axioms might not be enough for ontologies since it can not entertain vague terminology such as mostly, very, quite etc. to capture this kind of terminology linguistic variables should be incorporated in the frameworks.
Lukasiewicz in [5] presented an approach to fuzzy description logic programs under the answer set semantics. Although, integration of expressive fuzzy description logic into description logic program is left as future work. Song et. al in [6] provided an overview on the basic concepts of fuzzy logic and elaborated how this technique can be applied to solve complex power system problems.
Zhai et. al in [7] presented fuzzy ontology and RDF to represent formally the fuzzy linguistic variables. Singh et.al in [9] presented a design structure for the development of ontological database in general.
Chandrasekaran et. al in [10] provided a conceptual introduction of ontologies and their role in information systems and artificial intelligence. In their survey paper they also discussed how ontologies clarify the domain structure of knowledge and enable knowledge sharing. They emphasized gap between knowledge based problem solving and knowledge representation community and indicated that ontologies can serve as sharable knowledge resource. But the actual implementation of this idea is left for future research. Kitamura et. al in [11] discussed the concept of functional ontology including the functional concepts of fluid related systems only. The evaluation and extension of ontology is left as future work.
Fensel et. al [12] provides an ontology based tool environment to speed up knowledge management, dealing with large number of heterogeneous, distributed and semi-structured documents. Uschold in [13] identified two methods for ontology development and presented a framework for comparing and unifying them. Extension of their method and also refinement in level of granularity for different methods is left as future work. Maedche et. al in[9] proposed a framework for ontology learning from legacy ontologies, from free text or from dictionaries or even from existing XML documents. However the usage semantics for imported ontologies are not clear. Refinement of methods for importing legacy ontologies is left for the future.
Critical analysis of above literature highlighted that researchers have made attempts for incorporating fuzzy logic in ontology, but yet there is no standard way of developing such ontologies. Thus it’s worth attempting research in this direction. The next section provides a broad view of the proposed model.

IV. The Proposed Fuzzy Integrated Ontology Model (FIOM)

Fuzzy logic has already been applied in wide range of applications and this technique has returned impressive results across large variety of domains where human like reasoning and behavior is required. This technology promises capacity of implementing machine intelligence. Thus it makes sense to embed this crucial technology into ontology which bridges the gap between human understandable soft logic and machine understandable hard logic in SW. The next section provides the basics of Fuzzy set theory.

A. Introduction of Fuzzy set theory

Fuzzy logic mainly focuses on quantifying vague or uncertain terms that appear in our natural language conversations. These terms are known as linguistic variables [8], or fuzzy variables. Zedeh [3,8], "Father of fuzzy logic theory" highlighted that these linguistic variable which are building blocks of Computing with words(CW) methodology, might allow machines to work with perception based rational decision making in environments of imprecision, uncertainty and partial truth. Imprecision and uncertainty are key features of user exploitation of WWW. For example query 'Biodata of persons who are experienced' is a fuzzy statement. As who can be considered as experienced is not clear. Here biodata is a linguistic variable having value experienced. The range of all values that a linguistic variable can acquire makes its Universe of Discourse (UoD). Major thrust of fuzzy logic is use of linguistic variable in contrast to quantitative variables for representing imprecise concepts.

Fuzzy set and membership values

Conventional set theory allows the members of sets to have only one of two possible values either true or false, i.e. either the member belongs to a set or they don't, but there may not be partial membership. This can be mathematically stated by using a membership function $m_A(x) = 1$ if $x \in A$ and $m_A(x) = 0$ otherwise.
Fuzzy set theory extends conventional set theory by allowing the members to have degrees of membership or truth. A fuzzy set is characterized by a membership function which defines range of possible values for a variable. Capability of associating fuzzy variables with membership values is the major thrust of fuzzy logic which makes it suitable for handling uncertainty in SW.

B. About FIOM

This work extends the authors previous works where general design structure for ontology database was laid down. Now to provide general ontology with capability of processing linguistic variables, new sets of fuzzy concepts as well as fuzzy qualifiers have to be included. The extended ontology called as Fuzzy Integrated Ontology (FIO) is expressed as a six tuple (C ,R ,CH ,C_F ,Q ,U) where:

- C is set of concepts
- R is set of relations among the concepts defined in set C like { $\subseteq$, $\supseteq$, $\leq$, $\geq$, $\neq$, =}
- CH $\subseteq$ C x C is concept hierarchy or taxonomy for the domain of interest.
- C_F is the set of fuzzy concepts over the concepts defined in C. For e.g. In Ontology for employees , set C will contain descriptions for concepts like employee, manager, salary, designation etc. whereas C_F will contain description for terms like experienced, fresher, young, old , teenager etc.
- Q_F is set of qualifiers for the fuzzy terms which help in mapping fuzzy terms with membership values. For eg. The employee ontology stated above will have Q_F values as {less, more, high, very, not very …..}
- U denotes the UoD for the domain under consideration.

One important step in FIO is to associate Q_F terms with membership values. UoD can be defined with different values for different terms.
Reconsidering the example taken earlier 'Biodata of all experienced persons' can be defined over UoD= [0, 50] i.e. range of experience value is taken between 0 to 50 years.

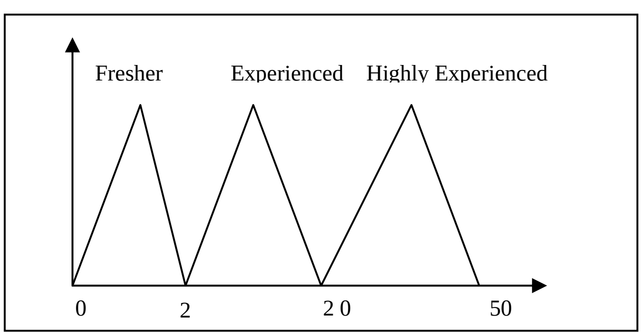

Figure 2. Defining Linguistic Variables using Fuzzy Logic

Fuzzy qualifiers like less, more etc. have been defined taking same UoD, as follows:

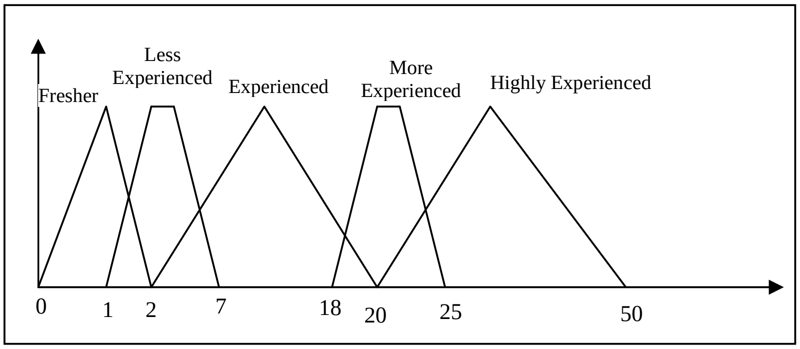

Figure 3. Associating Fuzzy Qualifiers with Membership Values

Now for implementing this ontology, the domain concepts, fuzzy concepts and qualifiers are to be defined using RDF. Values of the qualifiers will be associated with numbers using membership functions. For the example taken earlier i.e. the biodata of experienced persons, attributes of persons are defined using RDF as shown in figure 4 below.

```
<rdf: RDF XMLns:rdf= "http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns.biodata= " http://www.employement.com/person#">
<rdf: Description
        Rdf:about= http://www.employement.com/person#attribute>
        <attribute:name> Smith</attribute:name>
        <attribute:age> 25</attribute:age>
        <attribute:experience> 3</attribute:experience>
        -    ----------------------

</rdf:Description>
</rdf:RDF>
```

Figure 4. Defining Person's Attributes in RDF

Value of experience tag can be fetched and then associated with corresponding membership value from the fuzzy ontology, which will result in whether the person is fresher or less experienced, experienced or much experienced etc. Thus using FIOM uncertainty in user queries and requests can be handled, leading to user satisfaction and better exploitation of knowledge available on web.

V. CONCLUSIONS

This work proposed fuzzy integrated ontology, which can handle uncertain and vague information provided by the user in web exploitation. Ontologies are backbone of semantic web. For SW to be implemented in its full swing, it must handle imprecision and uncertainty, inherent in user requests. For that ontologies must be designed in such a way to cope up with imprecise and vague information.

Fuzzy integrated ontology exploits fuzzy logic to handle these requirements. It can work well with perceptions and linguistic variables. It can help equip machines with human like reasoning mechanism.

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