Ontology of Imprecision and Fuzzy Ontology Applications

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Abstract: Dealing with uncertainty and vagueness is an important challenge for the Semantic Web. Ontologies are regularly used for structuring knowledge for the Semantic Web, however, the traditionally used ontologies are not suitable for all contexts. Introducing fuzzy logic offers new possibilities. In this paper an overview regarding ontology of imprecision is presented and a web application, based on the Fuzzy Wine Ontology is constructed. The paper provides some indications on how fuzzy ontologies can offer better and more reliable solutions. The web application opens the door for future developments in the knowledge mobilization field.

1 INTRODUCTION

Recently, the development of the Semantic Web has revealed that there is a demand for new methods. This observation becomes crucial especially regarding ontologies, as the current ontologies have limitations when dealing with uncertain and vague knowledge, which is present in most practical applications; but there is a tendency to forget about this resource. Tacit knowledge can exist in the form of linguistic information or historical data. In organizations, tacit knowledge disappears, for instance, when expert employees retire. Storing and thereby enabling for continuous use of this knowledge is therefore a key issue in organizations. There is also a challenge regarding the practicality of ontologies, as they might become difficult to maintain over time. Traditional methods are difficult to update and maintain in the long run, as they consist of a network of nodes (creating the ontology), which implies that even a small change on a low level results in numerous changes throughout the ontology.

The Semantic Web has traditionally been based on different types of crisp description logics (DL), which are not suitable for dealing with uncertainties. Fuzzy logic and fuzzy ontologies provide a solution to this issue. Machacha and Bhattacharya (2000) observe that fuzzy logic enables computers to imitate the human reasoning process, utilizing imprecise information but still making precise decisions.

In this paper, we provide an overview of ontologies of imprecision (also known as fuzzy ontologies) by shortly presenting the latest research in the field as well as some software and applications that have recently been developed.

A web application, combining the Fuzzy Wine Ontology (Carlsson et al., 2012b,a) with the *fuzzyDL* reasoner (Bobillo and Straccia, 2011) and web techniques is presented. The application shows that fuzzy ontology can be used for real-life problems, in the presence of tacit and vague knowledge / data. The Fuzzy Wine Ontology provides an appropriate tool to handle vagueness inherent in this context, as the description of wines naturally consists of a number of imprecise attributes, expert-based knowledge, the produced results are, however, precise.

This paper is structured as follows. Section 2 presents a short literature review regarding ontologies of imprecision. Section 3 presents the web application and, finally, Section 4 includes a conclusion and some discussion about future research.

2 LITERATURE REVIEW

This section presents a literature review regarding the main components of the proposed model.

2.1 Ontology

Ontologies have different roles depending on the context they function in for the Semantic Web; they represent the main technology for creating interoperability on the semantic level. This is achieved by creating a formal illustration of the data, which thanks to its

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formality can be shared and reused all over the Web. An ontology formulates and models the relationship between the concepts in a given domain (d'Aquin and Noy, 2012). An ontology could also be seen as a complex, domain specific vocabulary, that organizes and integrates data. In this way, it becomes possible to link together all the information available on the Web, as well as to include sources such as public libraries (Hebeler et al., 2011).

2.2 Fuzzy Logic

Fuzzy sets theory and fuzzy logic were originally proposed by Zadeh (1965), who points out that objects in the real world seldom have clearly-defined memberships to groups. In classical set theory, elements can exclusively belong to a set, or not, but with fuzzy set theory it becomes possible for elements to belong to different sets to some degree. This does not mean that the answers automatically are vague or imprecise. Fuzzy logic makes it possible to reason also in the grey areas, with the use of a simple numerical idea, dealing with ambiguity and still producing precise answers (Kordon, 2009).

Definition 1. *Let X be a nonempty set. A fuzzy subset A of X is characterized by its membership function*

$$\mu_A : X \to [0,1]$$

where $\mu_A(x)$ is interpreted as the degree of membership of element x in fuzzy set A for each $x \in X$.

2.3 Fuzzy Ontologies

In recent years, fuzzy ontologies have started to attract an increased interest from the academic world, although fuzzy logic was introduced already in the 1960's (Zadeh, 1965). However, research about fuzzy ontologies did barely exist before the start of this century, even though Peña (1984) already in the 1980's stated that using fuzzy logic in ontologies would be more suitable in certain cases, compared to classical logic. Lately, this statement has been supported several times; Sanchez (2006) argues that classical ontologies are not appropriate for dealing with imprecise and vague knowledge, which is a crucial problem for several real world domains.

Even though current knowledge representation formalisms for the Semantic Web rely on crisp logic, it does not mean that all knowledge is crisp. It has become evident that fuzzy ontologies could provide opportunities for new applications aimed for the Semantic Web, especially in fields where vague knowledge is imminent. It is clear that there is a lot of unexplored potential in this research field.

Recently, there has been some development regarding software and reasoners aimed at fuzzy ontology creation. The *fuzzyDL* reasoner by Bobillo and Straccia (2008) is a description logic reasoner, including support for fuzzy logic. *FuzzyDL* extends the DL SHIF with fuzzy concepts. For instance, it allows the user to define fuzzy concepts with left-shoulder, right-shoulder, triangular and trapezoidal membership functions. It also supports both Lukasiewicz logic and "Zadeh semantics" (Bobillo and Straccia, 2011).

Bobillo et al. (2012) have created a different reasoner with support for fuzzy logic, similar to the *fuzzyDL* reasoner. DeLorean (DEscription LOgic REasoner with vAgueNess) is a Description Logic reasoner which also supports fuzzy rough sets (fuzzy rough extensions of the fuzzy DLs SROIQ(D) and SHOIN(D), which are equivalent to OWL and OWL 2).

Stoilos et al. (2005) developed a fuzzy reasoning engine, FiRE, based on the fuzzy description logic f-SHIN. The engine has been used for several Semantic Web applications and there are plans to develop FiRE towards supporting also fuzzy OWL-DL.

Another relevant software is SoftFacts by Straccia (2010), an ontology mediated database system. Providing the possibility to include ontology layers in databases, SoftFacts supports MySQL, Postgres and RankSQL as well as several sets of OWL QL profile language expressions.

Calegari and Ciucci (2007) managed to enrich the KAON language, making it possible to express fuzzy ontologies with KAON. However, KAON ontologies are based on RDFS which have limitations in comparison with OWL. A solution presented for this problem is to convert the KAON file to an OWL file.

3 THE WEB APPLICATION

A web application has been developed based on the Fuzzy Wine Ontology. The goal of the web application is to show that it is possible to make use of tacit knowledge (available internally in organizations) and create usable applications for industrial purposes. This Section is a short presentation on how the application was structured and what results it produces.

Initially defined by Carlsson et al. (2012b,a), the Fuzzy Wine Ontology has now been applied to OWL by using Protégé. The data stored in the ontology is based on expert knowledge, retrieved from literature and forums written by wine connoisseurs. The structure of the fuzzy wine ontology makes it possible to combine both crisp values and fuzzy values;

Figure 1: Screen shot from the Web Application Front Page.

for instance, the crisp value "wine color"and the linguistics expressed "sweet"describing the wines taste. The wine characteristics are combined through aggregation, using the ordered weighted averaging operator. The wine combinations are used for selecting the best wine for specific scenarios. According the wine connoisseurs, different contexts, for instance, eating game together with your family, require a different kind of wine, compared to eating fish at a business dinner.

Definition 2 ((Yager, 1988)). *An OWA function is a mapping* $OWA_{\mathbf{w}} : [0,1]^N \rightarrow [0,1]$ *with an associated vector* $\mathbf{w} = (w_1, \ldots, w_N)$ *such that* $\sum_{i=1}^{N} w_i = 1$ *and* $w_i \in [0,1]\ \forall i$.

Furthermore,

$$OWA_{\mathbf{w}}(a_1, \ldots, a_N) = \sum_{i=1}^{N} w_i a_{(i)}$$

where $a_{(j)}$ *is the j-th largest element of the multiset* $A = \langle a_1, \ldots, a_N \rangle$.

3.1 Technology Framework

The technological framework for the web application consists of the *fuzzyDL* reasoner developed by Bobillo and Straccia (2011). The *fuzzyDL* reasoner uses the Gurobi optimizer for calculation purposes and the Java programming language for connecting the reasoner with the server. The server uses HTML and Glassfish for processing the users' requests.

3.2 The Fuzzy Wine Ontology

Figure 1 shows a screenshot from front-page with the different alternatives available. The user chooses the context and the specific food. In this example, the user prefers a wine that suites a candle dinner where the user plans to serve game. The query is then submitted to the server, where it is processed by *fuzzyDL*. The result is then displayed as an HTML page.

The OWA operators for this example are defined in the following way:

Candle: 0.4 MediumPrice, 0.3 LowAcidity, 0.3 HighAlcohol

Game: 0.25 HighAlcohol, 0.25 HighAcidity, 0.25 Red (color), 0.25 Full (body)

OWA combining Candle and Game: 0.5 Candle 0.5 Game

The following example presents how one membership value is calculated for one wine. First, all the membership values for different concepts are calculated, this example shows Fenocchio Barolo membership value for HighAlcohol:

Wine: Fenocchio Barolo. Full bodied red wine. Alcohol level: 14 Acidity level: 5.4 Price: 26,5 € Concept: HighAlcohol, Rightshoulder function

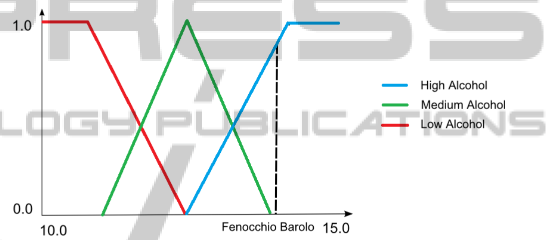

Figure 2: Defining the membership value of Fenocchio Barolo.

Fenocchio Barolo's membership value to HighAlcohol = 0.75

Then, all the different membership values are combined:

*(0.4 * 0.0) + (0.3 * 0.09) + (0.3 * 0.75) = 0.252*
*(0.25 * 0.75) + (0.25 * 0.14) +*
*(0.25 * 1.0) + (0.25 * 1.0) = 0.7225*
*(0.5 * 0.252) + (0.5 * 0.7225) = 0.48725*

Fenocchio Barolo membership value for the candle/game context is: 0.48725

In this case, the top 5 most suitable wines turned out to be: Villages Cuvee 3 Fleurs (membership value of 0.883), Abadal Cabernet Sauvignon Reserva (0.881), Domaine Depeyre (0.823), Belleruche (0.717), Baron de Ley Reserva (0.713).

With this approach, also a wine that is far from suitable, regarding a specific property, can be situated in a top spot. If one would use an approach based on crisp logic only, it would filter out wines that are almost perfect, but do not fulfil a certain property. For instance, if one requires that the wine should be from year 2009, among other properties, it automatically would filter out wines from 2008 and 2010, even if they would full-fill all the other demands. By using

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fuzzy logic, a wine produced in year 2008 or 2010 would still be considered and not be eliminated from the search already in an early stage.

4 CONCLUSIONS

In this article, we present a short literature review about fuzzy ontologies. In recent years, there have been several successful applications of fuzzy logic and ontologies. The fact that fuzzy logic can deal with uncertain and imprecise knowledge in a more efficient way, compared to traditional methods, is a key factor for encouraging future development. Research results prove that applications and systems based on fuzzy logic and ontologies have the possibility to capture and model tacit knowledge. This could limit the loss of expert knowledge, for instance, as employees disappear from organizations.

A web application, based on the techniques and methods developed by Bobillo and Straccia (2011) and Bobillo and Straccia (2008) in combination with Java, Gurobi, HTML and Protégé, is also presented. The application can be accessed and used through a web browser. As the need for accessing relevant information wherever and whenever one needs it is increasing, the mobility issues will certainly be important factors for future applications. This web application shows that fuzzy ontologies and fuzzy reasoners can be accessed and used through web browser; in other words, the application is made platform independent.

Future directions for the fuzzy ontology fields seem to be centred around the combination between fuzzy logic and the Web Ontology Language (OWL). The latest research and findings on type-2 fuzzy logic together with ontologies should spark future research about type-2 fuzzy logic based ontologies, as this combination improves the possibilities to model uncertainty (Lee et al., 2010). Exploring how this recent development could facilitate future knowledge mobilization applications and systems is therefore the central theme for future research.

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