Fuzzy Reasoning with Ontology: Towards Truly Autonomic Semantic Web Service Consumption

Petr Musilek, Marek Reformat, Yifan Li, Cuong Ly
Department of Electrical and Computer Engineering,
University of Alberta, Edmonton, AB, Canada
{*musilek, reform, yifan, cly*}*@ece.ualberta.ca*

Abstract

To ensure autonomous consumption of services by software agents, Web Services have to be represented in a machine-understandable form. With this infrastructure in place, agents acting on behalf of their human users can automatically locate, discover, compose, and execute required services. Such scenario is based on the recently introduced concept of Semantic Web: an agent should know personal preferences of its user, and use them to find and engage services providing the best match to these preferences.

User preferences can be represented using ontologies. Conventional ontologies, however, do not provide means for representing concepts that are vague or approximate, as typical for humans. Similarly, conventional matching mechanisms may not provide the best match as perceived by users. In this paper, ontology is extended by concepts of fuzziness and matching mechanism by methods of approximate reasoning. Such approach aims at providing capability to mimic human performance in multi-criteria decision-making, as illustrated in a simple application.

1. Introduction

The semantic web [1, 2] has promised a new lifestyle in which software user agents act on behalf of their human owners to discover, compare, and ultimately consume various services on the web. Based on the concepts of semantic web, semantic web services greatly enhance the interoperabilities of services on the web. Using ontologies for specification, these services are no longer tied to the inflexible interaction protocols and human-oriented advertising mechanisms, making autonomous consumption possible.

However, expressive and flexible as they are, the semantic web concepts do not address the need for approximate reasoning, which is an essential element of human reasoning. This negligence greatly affect the Semantic Web Agents' ability to reason on behalf of their human users since imprecise preferences of the users cannot be effectively reflected in the agents' reasoning process.

In this paper, a new approach is proposed to apply concepts of fuzziness and approximate reasoning to ontologies to close the aforementioned gap. The concept of ontology with fuzziness is proposed to represent preferences and acceptance of semantic web services from the perspective of human users, in a form that is suitable for software agents. To properly handle imprecise information during decision-making processes concepts of approximate reasoning are used.

The paper is organized as follows. Section 2 provides brief introduction of main concepts used in the paper: semantic web, semantic web service, and approximate reasoning. Section 3 describes a fuzzy extension to ontologies and how approximate reasoning can be incorporated into semantic web services, with a sample hotel service application. Finally, Section 4 presents main conclusions and directions of future work.

2. Background

2.1. Semantic Web and Semantic Web Service

Advances in Artificial Intelligence in the area of knowledge representation [10] have led to the conception of semantic web. Introduced by Tim Berners-Lee et al in 2001 [1], semantic web is a complex engineering structure [3] (c.f. Figure 1) for representing resources on the World Wide Web in a way that is easily accessible to computer programs such as software agents.

While adopting existing technologies as data exchange and security infrastructure, at the core of the layered cake are various standards related to knowledge representation and reasoning. Resource Description Framework (RDF) provides a universal way of expressing web resources in the form of triples {`resource, subject, property`}.

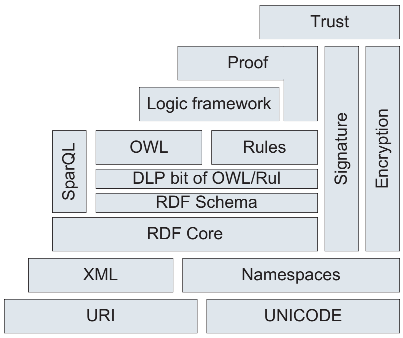

Figure 1. Structure of Semantic Web.

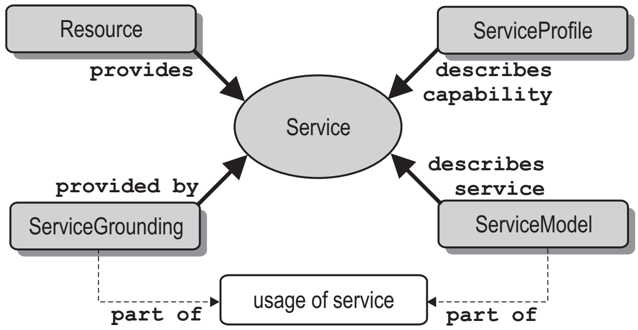

Figure 2. Semantic Web Service

Resource Description Framework Schema (RDFS) is then used as an ontology language supporting exchange of knowledge over the web. Rooted in description logic, the higher level ontology languages such as DAML+OIL [1] and its successor, OWL [9], provide significantly more expressive power and reasoning capabilities. Used together, RDF and ontology languages provide a method to represent knowledge in a structured, interchangeable, and deductable form, which makes possible further processing and query.

Web services also benefit from adopting the semantic web concepts. Traditional web service standards, such as WSDL and SOAP, are not capable to provide means of automated service discovery and invocation, mandating the interference of human programmers. However, by semantically encoding the key elements of services, i.e. resources, properties, objects and interaction processes, this gap can be eventually closed. As shown in Figure 2, a Semantic Web Service addresses the composition of description (ServiceProfile) and process (ServiceModel), and grounding of Web Services that makes the services available for exploitation by software agents [7]. The key technology that combines web services with knowledge representation is web service ontology, an ontology specific to web services that provides a common foundation for expressing their core elements in machine-understandable form. The current work in this field is the OWL-based Web Service Ontology (OWL-S), a service ontology expressed in OWL.

2.2. Approximate Reasoning

Imprecision and approximation is an intrinsic part of human reasoning. In natural languages that serve as our communication and reasoning media, the definitions of categorical labels, such as ”tall” in reference to a person’s height, often depend upon the context where they are used. The concepts of fuzzy theory and approximate reasoning were resulted from efforts to enable computers to cope with such imprecision.

With the fuzzy theory in place, contexts of a categorical label can be precisely defined using linguistic variable. For example, Figure 3 illustrates hotel room rate defined as linguistic variable with four categorical labels (terms) $\{very\, cheap, cheap, moderate, expensive\}$. In this context, a nightly rate of \$80 maches $verycheap$ with degree of 0.4, $cheap$ with degree of 0.8, and the rest with degree of 0. Similarly, a corresponding degree of match can be calculated between arbitray prices and categories.

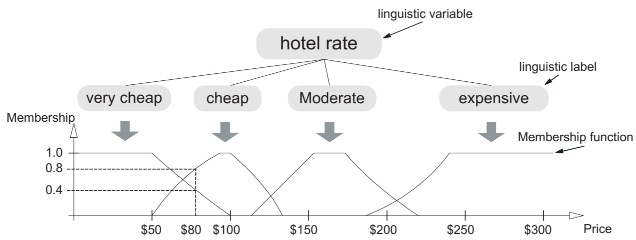

Figure 3. Hotel Rate as Linguistic Variable

Basic principles of approximate reasoning have been formulated by Zadeh in 1979 [8]. Based on Generalized Modus Ponens, approximate reasoning provides mechanisms for knowledge representation and reasoning in presence of incomplete or inaccurate information. An inference engine based on the principles of approximate reasoning is able to process meanings rather then symbols. This scenario can be applied to model human reasoning. In such case, response to a given request can be not only *yes* or *no* but also an approximation lying anywhere between the two extremes. Clearly, approximate answers can often be more meaningful than exact but coarse answers [6].

Approximate reasoning methodology is applied in this paper as the fundamental part of reasoning service described in Section 3.2.

3. Approximate Reasoning in Semantic Web Services

3.1. Fuzziness in Ontologies

At a first glance, it seems that ontology and fuzziness contradict each other: ontology is designed to articulate explicit and precise relations among entities, while fuzziness is applied to represent imprecise, vague information. However, combining these two allows better expression of human belief, preference, and other aspects that are important for successful human-service interaction.

To illustrate this, consider representing the degree of acceptance related to some available resource according to specific user preferences. The verb accept is defined as "to make a favorable response to <*accept* an offer>" [11], suggesting the act of accepting as a result of decision based on belief. For example, consider the case of a user's acceptance of the location of a hotel: Is 1.5 km from hotel to beach *close* or *far*? The answer clearly depends on individual user. If a user likes walking, such hotel location would be convenient; other users would probably consider the distance too large. Even when considering a single person, determination of what "close" means is quite vague: If 1.5 km is close, what about 1.6 km? As shown in Figure 4, fuzzy approaches allow beliefs to be modeled with better reflection of reality and human nature.

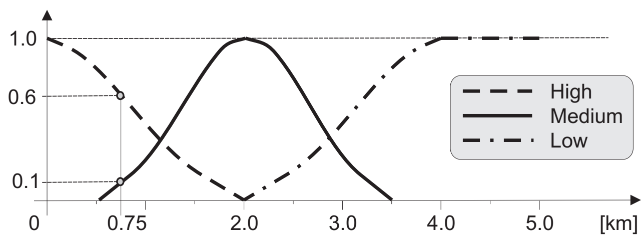

Figure 4. Fuzzy Representation of Acceptance Based on Hotel Location

Unlike many other efforts attempting to integrate fuzziness into the very foundations of ontology, i.e. description logic [4, 5], a simpler and more application-oriented approach is chosen for this project: a special ontology is constructed to represent fuzzy elements. This approach has its disadvantages when compared to the former, especially in its expressive power, due to the lack of instruments to naturally represent fuzzy relationship between concepts (e.g. a *third-world country* is a country with *low* per capita GDP). However, many of the disadvantages are circumventable by taking special design considerations (e.g. using parameterization in place of subclassing). On the other hand, in many real-world situations it is enough to work only with fuzzy properties, which is well handled by the simpler approach. Further more, in the chosen approach approximate reasoning and description logic based reasoning are processed independently, which not only simplifies the implementation but also presents computational advantages.

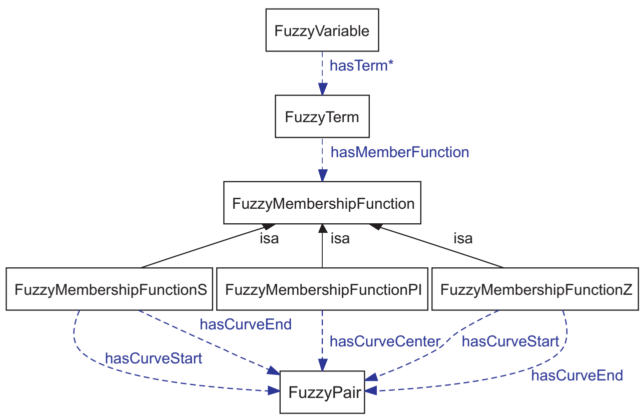

Figure 5. Fuzzy Ontology (Partial)

As illustrated in Figure 5, core fuzzy logic concepts that are related to fuzzy information expression, such as fuzzy variable, fuzzy terms, membership functions, as well as their relationships, are captured in the fuzzy ontology in order to provide a uniform and structured means of fuzzy knowledge representation. It is also worth noting that, since the fuzzy ontology is ultimately consumed by the fuzzy reasoner, it is beneficial to design its concepts and properties in a manner that closely resembles those of the selected fuzzy inference engine. In this respect, there is probably no single best ontology for fuzziness.

3.2. Hotel Service Selection Application

A lightweight hotel reservation system has been built to illustrate the use of approximate reasoning in the semantic web environment. For the sake of simplicity, the discovery process of hotel services is omitted and the user service works directly with service responses from hotel services. The user service compares these responses against user preferences by loading ontologies and instances related to the user and hotels into an approximate reasoner. Additionally, a set of rules describing the user's acceptance of a service based on different degrees of price and location acceptances is also loaded to the reasoner. After evaluation, the approximate reasoner rates each hotel service according to its degree of match against the user preferences and returns the ratings to the user.

The architecture of the system is represented in Figure 6. Its major components are as follows:

- Reasoning Unit: contains the semantic model of reasoning services, includes fuzzy inference reasoner; it matches responses obtained from service providers with user's preferences;
- Knowledge Base: includes user related ontologies, their instances and fuzzy rules;
- Knowledge Base Parser: transforms user related ontologies (local to the User Service), hotel related ontologies (remote) and their instances to facts and rules;
- Grounding Component: performs actual message and parameter passing.

Also shown in Figure 6 are three ontologies designed for the system:

- User Information Ontology (UIO) defines terms and concepts regarding users and their preferences. This ontology is used to express information about user's requirements regarding location of a hotel, its services, rooms and facilities.
- User Acceptance Ontology (UAO) contains specifications of terms needed to perform approximate reasoning about compliance of responses of service providers with users needs. It refers to the fuzzy ontology mentioned earlier for the basic constructs of fuzzy logic. Its instances contain information regarding what users "thinks" about discrepancy between their requirements and responses from service providers and how they "treat" these differences.
- Hotel Information Ontology (HIO) is a partially ordered set of all terms and concepts describing a hotel. Its instances contain every piece of information that is needed to reason about the fitness of a given hotel: its location, its services and facilities, and prices for different rooms.

3.2.1 Modeling Acceptance Criteria

User preferences of hotel acceptance are modeled with five contributing factors: $Convenience\ (location)\ Acceptance$, $Price\ Acceptance$, $Facility\ Acceptance$, $Service\ Acceptance$, and $Willingness\ to\ Take\ Risk$, as shown in Figure 7.

Each criterion is defined as a linguistic variable with three linguistic labels $high\ acceptance$, $moderate\ acceptance$ and $low\ acceptance$. Although definition of linguistic labels is a rather subjective matter and users may have different ideas in this subject, a uniform definition simplifies design and development of the application. Instead of defining their own linguistic labels, end users focus on initializing the variables, i.e.

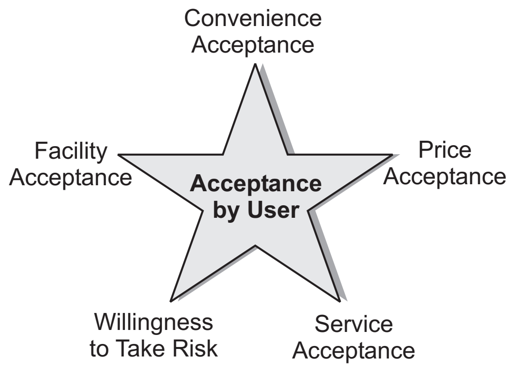

Figure 7. User Acceptance Model

designing the membership functions of the linguistic labels. The initialized criteria variables are stored in accordance to the structures prescribed by the aforementioned fuzzy ontology; and the collection of user preferences is modeled after the user acceptance ontology.

Depending on the type of criterion, initialization of the linguistic variables are approached differently. For criteria defined on a continuous universe of discourse, such as location and price, direct input from user is required to define the fuzzy membership function of each linguistic label (c.f. Figure 8). End users specify a set of four parameters for each linguistic variable to determine the shapes of the membership functions of its three linguistic labels. Once the linguistic variable is defined, the system is then able to interpret user preferences such as "close to the beach", or even more complex situations like "not too expensive". Other criteria, such as facility and service, are composed of many discrete individual items. For example, facility is a collection of mini bar, satellite TV, safe box, and swimming pool etc. Initialization of such variables involves a process of calculating membership functions from user preferences of the related individual items. End users classify each relative individual item as $must\ have$, $nice\ to\ have$ or $don't\ care$ (c.f. Figure 9, which is then translated into numeric weight. The system collects all individual weights of the specific criterion and builds its member functions based on the weights.

Another key aspect of user preference is the user's reasoning about the relative importance of the five contributing factors, which is represented by a fuzzy rule matrix. Each rule in the rule matrix covers one combination of acceptance levels of individual factors and yields an overall acceptance level. For example, if location acceptance is $moderate$ and price acceptance is $high$ and facility acceptance is low and ... $then$ overall acceptance is $moderate$.

Introduction of the concepts of user acceptance ontology and fuzzy ontology endows the system capabilities to model

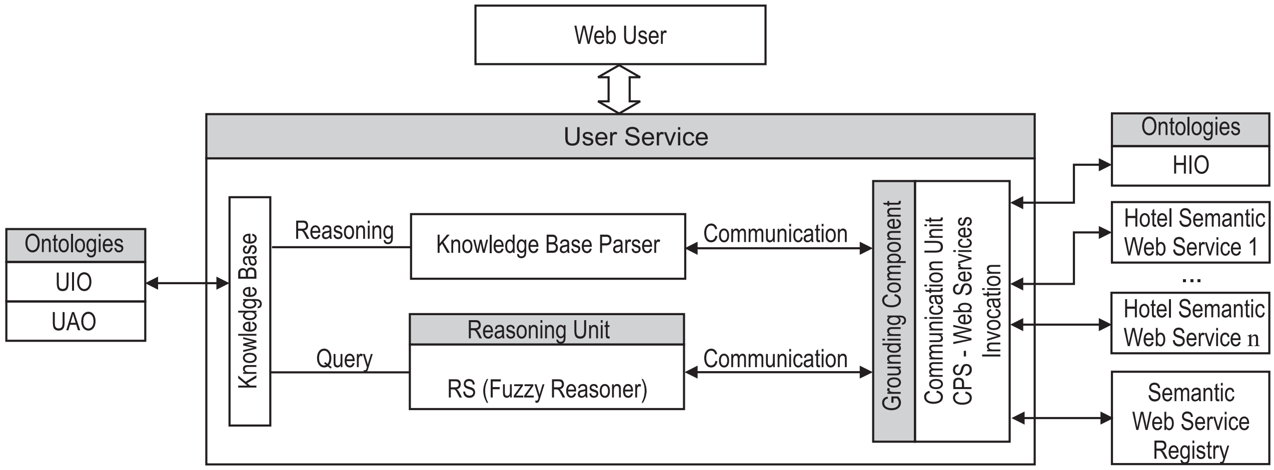

Figure 6. User Service Architecture

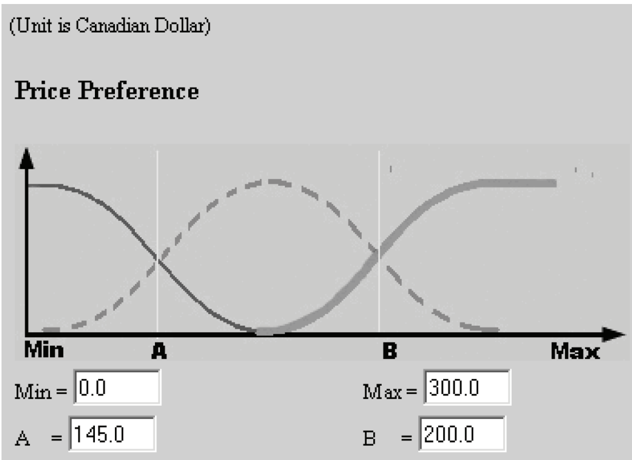

Figure 8. User Input for Price Acceptance

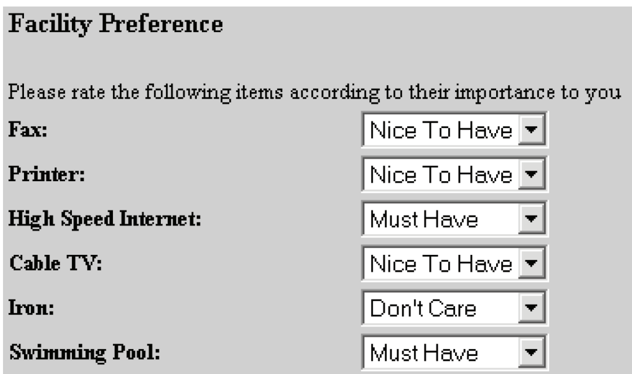

Figure 9. User Input for Facility Acceptance

vague user preferences. At a glance, it may seem burdensome to the end users because they need to provide more information than they used to. However, considering the fact that a user's preferences seldom change, acceptance criteria specified by users should become part of their profiles and remain relatively constant across service sessions. Except for the first time, users of the system are only expected to provide their requirements of the hotel, as prescribed by the user information ontology.

3.2.2 Third Party Utilities

The fuzzy reasoner used in this system is implemented with Jess and FuzzyJ. Created and supported by Sandia Labs, Jess is a very efficient Java rule engine for rule-based systems. FuzzyJ is an extension of Jess introducing fuzzy concepts to the inference engine. FuzzyJ is developed by the Institute for Information Technology, National Research Council of Canada's Institute for Information Technology.

OWLJessKB, which is developed and maintained at Drexel University, is used to transfer ontologies and knowledge instances into the Jess knowledge base.

4. Conclusions

This paper introduces an easy-to-implement method for structured expression of imprecise knowledge with ontologies. This is particularly useful for software agents designed to represent their human users in a semantic web environment, for whom the ability to represent and reason about their masters' vague preferences can be extremely important. In order to present vague preferences, fundamental changes to the structure of knowledge are mandated. Compared to the existing requirement-search-output application model, a new model of preference-requirement-search-output is proposed, in which the new element of user preference takes an equally important position in the knowledge structure as that of user requirement. Modeled by the user acceptance ontology, the preference knowledge functions as meta-information that facilitates the interpretation of user requirements presented in vague terms.

As shown in the given sample hotel selection service, the introduction of fuzziness eliminates the ”mind gap” between human users and machines by allowing users to express their preferences in a natural manner. Benefits of this improvement should not be underestimated: increased comfortableness felt by the users not only increases the perceived quality of service but also increases the willingness of them to delegate the decision-making process to such services, which is the purpose of the semantic web.

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