Fuzzy System Modeling and Representation Based on Linguistic Variable Ontology and SWRL

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Abstract

Ontology is an important tool on the semantic web, for ontology has a powerful expressive ability on knowledge representation. However, it has no ability to represent the imprecise information as well as the uncertainty. In order to share and deal with the fuzzy knowledge between homogeneous systems on the semantic web, in this paper, the concept of linguistic variable ontology is proposed as the basis of Fuzzy System. Taking a flu fuzzy diagnosis case for example, fuzzy system is modeled. For fuzzy knowledge representation and further inference, the fuzzy rule base is constructed, which constitutes a part of fuzzy system. A tool of protégé is used to realize the fuzzy system and a plugin of SWRLTab for the fuzzy rule. Also, SWRL/OWL is used to represent the rules formally for facilitating machine understanding and process. Comparisons are made between two fuzzy tools to illustrate the advantages of SWRLTab. The paper concludes that linguistic variable ontology-based diagnosis system can achieve the fuzzy knowledge sharing between homogeneous systems correctly.

Keywords: *fuzzy system, modeling and representation, linguistic variable ontology, SWRL*

1. Introduction

The Semantic Web is turning into a new generation web. And the ontology has been seen as a prerequisite for the Semantic web. The goal of ontology-based management is to improve the manage-ability of network resources through the application of formal ontologies [1]. Concepts are rather vague than precise in the context of semantic Web and multimedia applications. There are increasing 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 [2]. And fuzzy ontology is efficient in text and multimedia object representation and retrieval [3]. H. Ghorbel, *et al.*, [4] find the fuzzy aspect is not enough studied in many methods and tools for ontology building. So they present their fuzzy ontology building method "Fuzzy OntoMethodology". Abulaish, *et al*., [5] propose a fuzzy ontology framework in which a concept descriptor is represented as a fuzzy relation which encodes the degree of a property value using a fuzzy membership function. C. Silvia, *et al*., [6] show in their paper how a Fuzzy Ontology based approach can improve semantic documents retrieval. In the ontology-based CBR paradigm, A. Panos, *et al*., [7] present a novel CBR approach that manages and utilizes imprecise knowledge through the integration of Fuzzy M. W. Algebra, *et al.*, [8] present an integrated soft computing framework to provide users with more intuitive and efficient means of interaction with information bases. By analyzing the similar characteristics of malware, T. Tala, *et al*., [9] use fuzzy logic to represent malware relationships. W. Jinlin, *et al*., [10] propose an extension of OWL DL with fuzzy logic by giving the formal syntax and semantics, with which fuzzy information can be expressed well. Z. Jun, *et al*., [11] utilize fuzzy ontology and RDF to represent formally the fuzzy linguistic variables, which facilitates to incorporate fuzzy systems into the Semantic Web. W. Qi, *et al*., [12] build the knowledge base of catalogue concepts and rules on SWRL, which realizes the sharing of knowledge of audio-video material catalogue and the integration with relative information. J. M. Christopher [13] use SWRL to represent the complex knowledge needed to identify what is happening in an evolving situation awareness applications. Z. Jun, *et al*., [14] 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. Z. Jun, *et al*., [15] introduce data type of fuzzy linguistic variable into RDF data model. After constructing the semantic query expansion in SPARQL, they implement the semantic information retrieval for Electronic business on the semantic web. On the aspect of knowledge representation, Y. Soomi, *et al.*, [16] build an Area Profile Ontology and import other related ontology to annotate data from disparate sources, which promote the improvement of knowledge. Y. Mohd Kamir, *et al.*, [17] present an ontology and semantic approaches for using data from heterogeneous database. K. Harshit, *et al*., [18] share the development process of an ontology which is developed for knowledge management in an enterprise.

In this paper, for Section 2 we give the definitions of linguistic variable ontology. On the basis of that, in Section 3, we build the model of Flu Fuzzy Diagnosis System. In that section, a tool of SWRLTab (A plugin of protégé) is used to construct the fuzzy rule base and the rules are expressed in SWRL/OWL. In Section 4, we use another toolbox to construct the same fuzzy system, and make a comparison between the two tools, which showed the SWRLTab has many unique advantages. In Section 5, we give the conclusion.

2. Definitions of Linguistic Variable Ontology

The linguistic variables proposed by Zadeh are the basic of fuzzy knowledge and fuzzy system [19]. The linguistic variables and their membership functions support fuzzy logic to perform the imprecise and non-numerical reasoning. To achieve the fuzzy knowledge representation and inference on the Semantic Web, it is essential to combine the linguistic variables with ontology. Definitions of linguistic variable ontology are as following [20].

2.1. Fuzzy linguistic variable

Fuzzy linguistic variable is the variable whose value is term or concept in natural language. A fuzzy linguistic variable is a 4-tuple (X,T,M,U), where:

(1) X is the name of fuzzy linguistic variable.

(2) T is the set of terms which is the value of fuzzy linguistic variable.

(3) M is the mapping rules which map every term of T to fuzzy set at U.

(4) U is the universe of discourse.

Introducing semantic relationships between concepts, we obtain the ontology model.

2.2. Fuzzy linguistic variable ontology

A fuzzy linguistic variable ontology is a 6-tuple $O_F = (c_a, C_F, R, F, S, U)$, where:

(1) c_a is a concept on the abstract level. The corresponding element of c_a is X in definition 2.1.

(2) C_F is the set of fuzzy concepts which describes all values of c_a. The corresponding element of C_F is T in definition 2.1, but C_F has certain structure or relations R.

(3) $R = \{r \mid r \subseteq C_F \times C_F\}$ is a set of binary relations between concepts in C_F. A kind of relation is set relation R_S ={inclusion, intersection, disjointness, complement}, and the other relations are the order relation and equivalence relation $R_O = \{\leq, \geq, =\}$.

(4) F is the set of membership functions at U, which is isomorphic to C_F. The corresponding element of F is M in definition 2.1, but F has also certain structure or relations.

(5) $S = \{s \mid s : C_F \times C_F \to C_F\}$ is a set of binary operators at C_F. These binary operators form the mechanism of generating new fuzzy concepts. Basic operators are the "union", "intersection" and "complement".

(6) U is the universe of discourse.

Modeling the linguistic qualifiers, we extend the fuzzy linguistic variable ontology as follows.

2.3. Extended ontology

An extended fuzzy ontology is a 9-tuple $O_F = (c_a, C_F, R, F, S, Q, O, I, U)$, where:

(1) c_a, C_F, R, F, S, U have same interpretations as defined in definition 2.2.

(2) Q is the set of the linguistic qualifiers, e.g. Q={very, little, close to, …}. An qualifier $q \in Q$ and a fuzzy concept $c_F \in C_F$ compose a composition fuzzy concept that can be the value of c_a.

(3) O is the set of fuzzy operators at U, which is isomorphic to Q.

(4) $I \subseteq Q \times C_F$ is a binary relation from Q to C_F. $< q, c_F > \in I$ means that $q \in Q$ and $c_F \in C_F$ can compose a composition fuzzy concept.

To simplify the transform from fuzzy linguistic variables to fuzzy ontology, we introduce the basic fuzzy ontology model as follows.

2.4. Basic fuzzy ontology

A basic fuzzy ontology is a 4-tuple $O_F = (c_a, C_F, F, U)$, where c_a, C_F, F, U have same interpretations as defined in definition 2.1, which satisfy the following conditions.

(1) $C_F = \{c_1, c_2, \cdots, c_n\}$ is a limited set.

(2) Only one relation of set, the relation of disjointness, exists in C_F, and C_F is complete at U.

(3) C_F has an ordered relation $\leq$, and $< C_F, \leq >$ is a complete ordered set.

(4) F is optional element of ontology.

3. Modeling of Fuzzy System

3.1. Building Flu Fuzzy Diagnosis System model

Through the investigation and analysis on the features of flu patients, we summarize the following fuzzy rules that constitute the basis of the Flu Fuzzy Diagnosis System.

Table 1. Descriptions of Fuzzy Rules

Rules	Part of IF	Part of THEN
Rule-1	temperature is high and cough is frequent	comfort is terrible
Rule-2	temperature is low and cough is slight	comfort is bad
Rule-3	temperature is normal and cough is little	comfort is good

Facilitating the formal representation of fuzzy rules, we use RDF graph to describe the rules. Results are showed in Figure 1 to Figure 3.

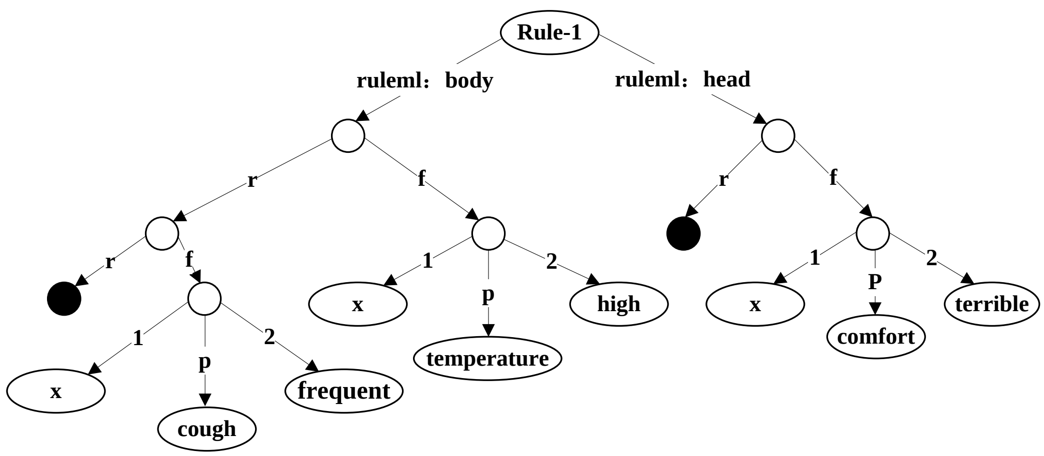

Figure 1. Fuzzy Rule-1 in RDF Graph

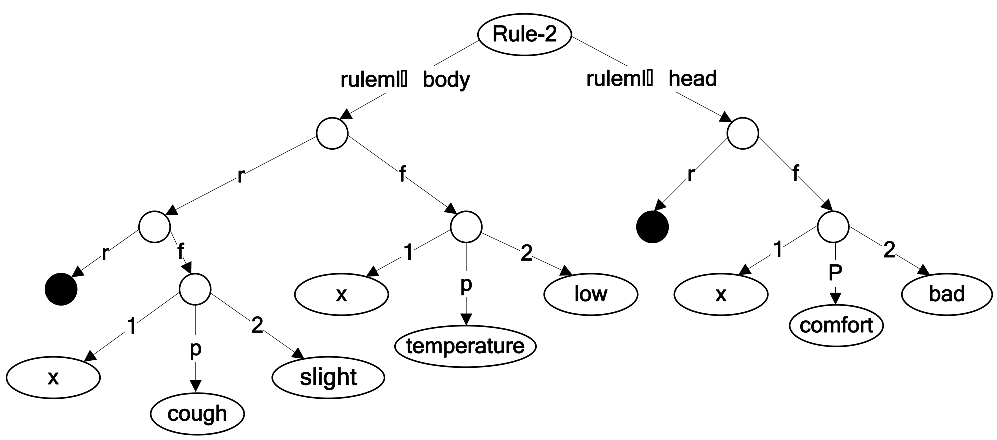

Figure 2. Fuzzy Rule-2 in RDF Graph

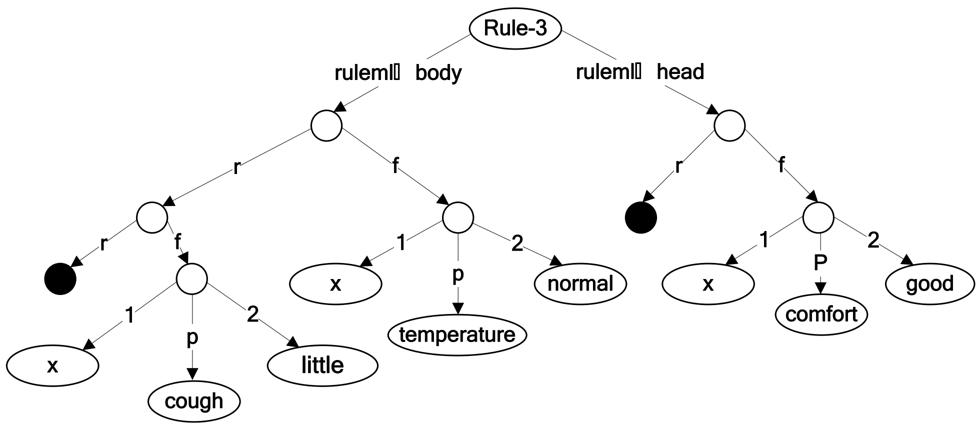

Figure 3. Fuzzy Rule-3 in RDF Graph

The symbols and its interpretations are as following in Table 2.

Table 2. Symbols and its Interpretations

Symbols	Interpretations
—f→	**rdf:first**
—r→	**rdf:rest**
●	**rdf:nil**
—p→	**swrl：propertyPredicate**
—1→	**swrl：argument1**
—2→	**swrl：argument2**

Abstracting linguistic variables and its values in the rules, we build the linguistic variable ontology model for the fuzzy rule base.

O_{F1} (temperature) =
(
c_a = temperature,
C_F = {low, normal, high},
R = {low $\leq$ normal $\leq$ high},
F = {$F_{low}(x)$, $F_{normal}(x)$, $F_{high}(x)$},
U = [0, 50]
)
O_{F2} (cough) =
(
c_a = cough,
C_F = {little, slight, frequent},
R = {little $\leq$ slight $\leq$ frequent},
F = {$F_{little}(x)$, $F_{slight}(x)$, $F_{frequent}(x)$},
U = [0, 100]
)

O_{F3} (comfort) =
(
c_a = comfort,
C_F = {terrible, bad, good},
R = {terrible $\leq$ bad $\leq$ good},
F = {$F_{terrible}(x)$, $F_{bad}(x)$, $F_{good}(x)$},
U = [0, 30]
)

3.2. Using protégé to realize the fuzzy system

Using protégé to represent the model above, there are three enumeration classes, namely: EnumOfTemperature, EnumOfCough and EnumOfComfort. Each enumeration class consists of several individuals representing fuzzy linguistic terms. Linguistic variables are mapped into object properties whose ranges are individuals belonging to enumeration classes. Figure 4 shows structure of these enumeration classes and its individuals. Figure 5 shows the structure of object properties and its ranges.

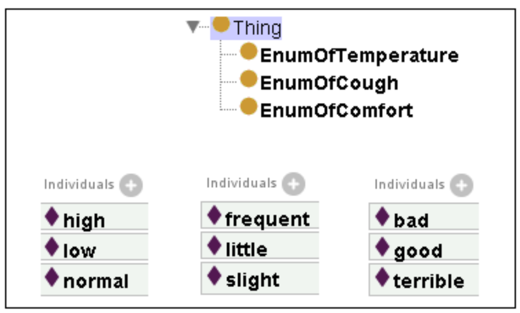

Figure 4. Enumeration Classes and its Individuals

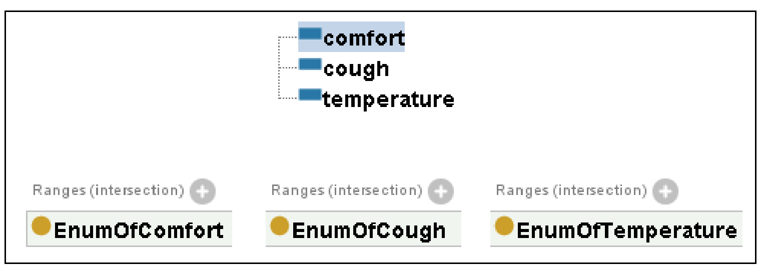

Figure 5. Object Properties and its Ranges

Using SWRL to describe rules of flu fuzzy diagnosis system, we obtain the following fuzzy rule expressions.

Rule-1: temperature(?x, high) $\wedge$ cough(?x, frequent) $\rightarrow$ comfort(?x, terrible).

Rule-2: temperature(?x, low) $\wedge$ cough(?x, slight) $\rightarrow$ comfort(?x, bad).

Rule-3: temperature(?x, normal) $\wedge$ cough(?x, little) $\rightarrow$ comfort(?x, good).

where x is either variables or OWL individuals.

SWRLTab is a plugin of protégé. Figure 6 shows the expressions of fuzzy rules in SWRLTab of protégé.

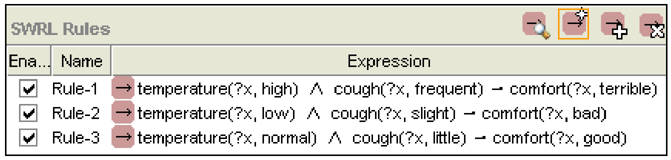

Figure 6. Expressions of fuzzy rules in SWRLTab

3.3. Fuzzy rule representation in SWRL/OWL

In order to product representations accessible and understandable by machines, we use SWRL/OWL to represent the fuzzy rules above. The results are as following.

3.3.1. Rule-1 in SWRL/OWL

```
<swrl:head>
  <swrl:AtomList>
    <owl:first>
      <swrl:IndividualPropertyAtom>
        <swrl:propertyPredicate rdf:resource=“comfort”/>
          <swrl:argument1>
            <swrl:Variable rdf:about=“x”/>
          </swrl:argument1>
          <swrl:argument2 rdf:resource=“terrible”/>
      </swrl:IndividualPropertyAtom>
    </owl:first>
    <owl:rest rdf:resource=“&rdf;nil”/>
  </swrl:AtomList>
</swrl:head>
<swrl:body>
  <swrl:AtomList>
    <owl:first>
      <swrl:IndividualPropertyAtom>
        <swrl:propertyPredicate rdf:resource=“temperature”/>
          <swrl:argument1 rdf:resource=“x”/>
          <swrl:argument2 rdf:resource=“high”/>
      </swrl:IndividualPropertyAtom>
    </owl:first>
    <owl:rest>
      <swrl:AtomList>
        <owl:first>
          <swrl:IndividualPropertyAtom>
            <swrl:propertyPredicate rdf:resource=“cough”/>
              <swrl:argument1 rdf:resource=“x”/>
              <swrl:argument2 rdf:resource=“frequent”/>
            </swrl:IndividualPropertyAtom>
        </rdf:first>
        <rdf:rest rdf:resource=“&rdf;nil”/>
      </swrl:AtomList>
    </rdf:rest>
  </swrl:AtomList>
</swrl:body>
```

3.3.2. Rule-2 in SWRL/OWL

```
<swrl:head>
   <swrl:AtomList>
      <owl:first>
         <swrl:IndividualPropertyAtom>
            <swrl:propertyPredicate rdf:resource="comfort"/>
              <swrl:argument1>
                 <swrl:Variable rdf:about="x"/>
               </swrl:argument1>
               <swrl:argument2 rdf:resource="bad"/>
         </swrl:IndividualPropertyAtom>
      </owl:first>
      <owl:rest rdf:resource="&rdf;nil"/>
   </swrl:AtomList>
</swrl:head>
<swrl:body>
   <swrl:AtomList>
      <owl:first>
         <swrl:IndividualPropertyAtom>
            <swrl:propertyPredicate rdf:resource="temperature"/>
               <swrl:argument1 rdf:resource="x"/>
               <swrl:argument2 rdf:resource="low"/>
         </swrl:IndividualPropertyAtom>
      </owl:first>
      <owl:rest>
         <swrl:AtomList>
            <owl:first>
              <swrl:IndividualPropertyAtom>
                 <swrl:propertyPredicate rdf:resource="cough"/>
                   <swrl:argument1 rdf:resource="x"/>
                   <swrl:argument2 rdf:resource="slight"/>
                 </swrl:IndividualPropertyAtom>
            </rdf:first>
            <rdf:rest rdf:resource="&rdf;nil"/>
         </swrl:AtomList>
      </rdf:rest>
   </swrl:AtomList>
</swrl:body>
```

3.3.3. Rule-3 in SWRL/OWL

```
<swrl:head>
   <swrl:AtomList>
      <owl:first>
         <swrl:IndividualPropertyAtom>
            <swrl:propertyPredicate rdf:resource="comfort"/>
              <swrl:argument1>
                 <swrl:Variable rdf:about="x"/>
               </swrl:argument1>
```

```
            <swrl:argument2 rdf:resource=“good”/>
        </swrl:IndividualPropertyAtom>
      </owl:first>
      <owl:rest rdf:resource=“&rdf;nil”/>
   </swrl:AtomList>
</swrl:head>
<swrl:body>
   <swrl:AtomList>
      <owl:first>
         <swrl:IndividualPropertyAtom>
            <swrl:propertyPredicate rdf:resource=“temperature”/>
              <swrl:argument1 rdf:resource=“x”/>
              <swrl:argument2 rdf:resource=“normal”/>
         </swrl:IndividualPropertyAtom>
      </owl:first>
      <owl:rest>
         <swrl:AtomList>
            <owl:first>
               <swrl:IndividualPropertyAtom>
                  <swrl:propertyPredicate rdf:resource=“cough”/>
                     <swrl:argument1 rdf:resource=“x”/>
                     <swrl:argument2 rdf:resource=“little”/>
                  </swrl:IndividualPropertyAtom>
            </rdf:first>
            <rdf:rest rdf:resource=“&rdf;nil”/>
         </swrl:AtomList>
      </rdf:rest>
   </swrl:AtomList>
</swrl:body>
```

4. Experiment comparison and analysis

The Fuzzy Logic Toolbox is a collection of functions built on the matlab, which provides tools to create and edit fuzzy inference system. In this part, we use the toolbox to describe the same fuzzy rules mentioned above, and give a comparison between the two tools, Fuzzy Logic Toolbox and SWRLTab. The description result is showed in Figure 7.

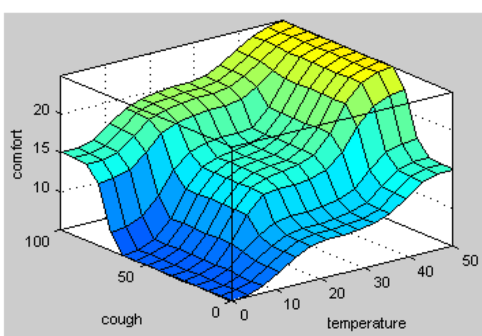

Figure 7. Fuzzy description in Fuzzy Logic Toolbox

We make a comparison between the two tools from three aspects, which is showed in Table 3.

Table 3. Characteristic Comparison

Characteristic	SWRLTab	Fuzzy Logic Toolbox
Visualization	Dealing with the reasoning process by inference engine automatically	Manual operation and observing the reasoning process at any time
Scalability	Open Source for code and many third class libraries for choice	Function and scalability limited
Integration	Realizing the fuzzy knowledge sharing between heterogeneous systems	Realizing the fuzzy inference in a single system

5. Conclusion

In the paper, we combine the ontology with the linguistic variable which is called linguistic variable ontology. Then we illustrate modeling scenarios to demonstrate the practical feasibility of our modeling approach. Protégé is employed as a tool for the pictorial representation of our formal model. An instance of fuzzy flu diagnosis is showed that fuzzy information can be expressed well with the proposed model. Finally, we make a comparison between the Fuzzy Logic Toolbox and SWRLTab to show that the linguistic variable ontology-based model has many advantages in visualization, scalability and integration. The paper shows that linguistic variable ontology model provide a well-defined model basis for the fuzzy inference system.

Our further researches lay on the exchange and integration of fuzzy knowledge among heterogeneous systems, and also the inference based on the model of linguistic variable ontology.

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