Semantic Information Retrieval Based on Fuzzy Ontology for Electronic Commerce

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Abstract—**Information retrieval is the important work for Electronic Commerce. Ontology-based semantic retrieval is a hotspot of current research. In order to achieve fuzzy semantic retrieval, this paper applies a fuzzy ontology framework to information retrieval system in E-Commerce. The framework includes three parts: concepts, properties of concepts and values of properties, in which property's value can be either standard data types or linguistic values of fuzzy concepts. The semantic query expansions are constructed by order relation, equivalence relation, inclusion relation, reversion relation and complement relation between fuzzy concepts defined in linguistic variable ontologies with Resource Description Framework (RDF). The application to retrieve customer, product and supplier information shows that the framework can overcome the localization of other fuzzy ontology models, and this research facilitates the semantic retrieval of information through fuzzy concepts on the Semantic Web.**

Index Terms—**semantic information retrieval, fuzzy ontology, ontology, electronic commerce, the Semantic Web**

I. INTRODUCTION

Along with the Internet fast development, the electronic commerce based on the network displays the more huge than traditional business advantage, raises the performance and the efficiency of the traditional business activity biggest. Existing electronic commerce system will be hard to solve growing the business information explosion and the customer's characteristic need, so the customer who faces the amount of goods information hard to do a best choice, and lack to hand over with each other between the customer and the vender.

Therefore, information retrieval (IR) is very important to achieve E-Commerce in WWW. Current information retrieval on the web is based primarily on keywords which often cause problems in precision and recall. Ontology-based semantic retrieval is a hotspot of current research. Ontology is a conceptualization of a domain into a human understandable, machine-readable format consisting of entities, attributes, relationships, and axioms [1]. It is used as a standard knowledge representation for the Semantic Web [2]. The use of ontologies to overcome the limitations of keyword-based search has been put forward as one of the motivations of the Semantic Web [3]-[4].

However, the conceptual formalism supported by typical ontology may not be sufficient to represent uncertainty information commonly found in many application domains due to the lack of clear-cut boundaries between concepts of the domains. Moreover, fuzzy knowledge plays an important role in many domains that face a huge amount of imprecise and vague knowledge and information, such as text mining, multimedia information system, medical informatics, machine learning, and human natural language processing [5].

To handle uncertainty of information and knowledge, one possible solution is to incorporate fuzzy theory into ontology. Then we can generate fuzzy ontologies, which contain fuzzy concepts and fuzzy memberships. The fuzzy ontologies are capable of dealing with fuzzy knowledge [6], and are efficient in text and multimedia object representation and retrieval [7]. Lau [8] presented a fuzzy domain ontology for business knowledge management. Lee et al. [9] proposed an algorithm to create fuzzy ontology and applied it to news summarization. Tho et al. proposed a Fuzzy Ontology Generation Framework (FOGA) for fuzzy ontology generation on uncertainty information [10]. This framework is based on the idea of fuzzy theory and Formal Concept Analysis (FCA). Abulaish et al. [11]-[12] proposed 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. Calegari and Ciucci [13] presented the fuzzy OWL language.

But, current fuzzy ontology models have localization in expressing uncertainty derived from ordinary fuzzy set, and do not focus on essential semantic relationships between fuzzy concepts, which lead difficulty to search information at fuzzy semantic level. In order to achieve fuzzy semantic retrieval for E-Commerce, this paper applies a new kind of fuzzy ontology to information retrieval system in E-Commerce. The rest of this paper is organized as follows: Section 2 gives some basic definitions of intuitionistic fuzzy set. Section 3 introduces fuzzy domain ontology model. Section 4 proposes fuzzy linguistic variable ontology models and formal representation with RDF. Section 5 presents fuzzy

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ontology framework and section 6 applies the fuzzy ontology to information retrieval for E-Commerce. Finally, section 7 concludes the paper.

II. BASIC DEFINITIONS OF INTUITIONISTIC FUZZY SET

In this section, we review some fundamental knowledge of fuzzy theory [14].

Definition 1 (Intuitionistic fuzzy set) – An intuitionistic fuzzy set A on a universe U is defined as an object of the following form: $A = \{(u, \mu_A(u), \nu_A(u)) \mid u \in U\}$, where the functions $\mu_A(u): U \to [0,1]$ and $\nu_A(u): U \to [0,1]$ define the degree of membership and the degree of non-membership of the element $u \in U$ in A, respectively, and for every $u \in U: \mu_A(u) + \nu_A(u) \le 1$.

The intuitionistic fuzzy set has an equivalent form of interval value: $A = \{(u, [\mu_A(u), 1-\nu_A(u)]) \mid u \in U\}$, where $[\mu_A(u), 1-\nu_A(u)] \subseteq [0,1]$. Obviously, when $\mu_A(u) + \nu_A(u) = 1$, the intuitionistic fuzzy set is an ordinary fuzzy set.

Definition 2 (Intuitionistic fuzzy relation) – An intuitionistic fuzzy relation from U to V is an intuitionistic fuzzy set on $U \times V$: $R = \{< (u,v), \mu_R(u,v), \nu_R(u,v) > \mid (u,v) \in U \times V\}$, where $\mu_R(u,v): U \times V \to [0,1]$, $\nu_R(u,v): U \times V \to [0,1]$, $\mu_R(u,v) + \nu_R(u,v) \le 1$.

The intuitionistic fuzzy relation has also an equivalent form of interval value: $R = \{< (u,v), [a,b] > \mid (u,v) \in U \times V\}$, where $[a,b] \subseteq [0,1]$.

Because an intuitionistic fuzzy set provides more choices for the attribute description of an object and has stronger ability to express uncertainty than an ordinary fuzzy set, it has gained extensive attention from the academic circles and the circles of engineering and technology. Presently, some science branches based on intuitionistic fuzzy set have appeared, such as intuitionistic fuzzy set topology, intuitionistic fuzzy set logic etc. The intuitionistic fuzzy set has applied to lots of fields such as artificial intelligence, decision-making analysis, pattern recognition, handling intelligence information and so on.

III. FUZZY DOMAIN ONTOLOGY MODEL

Gruber defines ontology as an explicit specification of a conceptualization, i.e. an abstract and simplified representation of real-world entities [15]. An ontology organizes domain knowledge in terms of concepts, properties, relations and axioms.

Definition 3 (Ontology) – An ontology is a 4-tuple $O = (C, P, R, A)$, where:

(1) C is a set of concepts defined for the domain. A concept is often considered as a class in an ontology.

(2) P is a set of concept properties. A property $p \in P$ is defined as an instance of a ternary relation of the form $p(c, v, f)$, where $c \in C$ is an ontology concept, v is a property value associated with c and f defines restriction facets on v. Some of the restriction facets are type (f_t), cardinality (f_c), and range (f_r). The type facet f_t may be any one from the standard data types supported by ontology editors, i.e. $f_t \in$ {boolean, integer, float, string, symbol, instance, class, …}. The cardinality facet f_c defines the upper and lower limits on the number of values for the property. The range facet f_r specifies a range of values that can be assigned to the property.

(3) $R = \{r \mid r \subseteq C \times C\}$ is a set of binary semantic relations defined between concepts in C. Basic relations are defined as {synonym of, kind of, part of, instance of, property of} $\subset R$.

(4) A is a set of axioms. An axiom is a real fact or reasoning rule.

Fuzzy ontology is created as an extension to the standard ontology.

Definition 4 (Fuzzy domain ontology) – A fuzzy domain ontology is a 6-tuple $O_F = (I, C, P^C, R, P^R, A_F)$, where:

(1) I is the set of individuals, also called instances of the concepts.

(2) C is a set of concepts. Every concept here has some properties whose value is fuzzy concept or fuzzy set. And, every concept can have the degree of membership $\mu_C(i): I \to [0,1]$ and the degree of non-membership $\nu_C(i): I \to [0,1]$ of the $i \in I$ in C.

(3) P^C is a set of concepts properties. A property $p^C \in P^C$ is defined as a 5-tuple of the form $p^C(c, v_F, q_F, f, U)$, where $c \in C$ is an ontology concept, v_F represents property values, q_F models linguistic qualifiers, which can control or alter the strength of a property value v_F, f is the restriction facets on v_F, and U is the universe of discourse. Both v_F and q_F are the fuzzy concepts on U, but q_F changes the fuzzy degree of v_F. For example, "price" is a property of concept "service". The value of "price" may be either fuzzy concept "cheap" or fuzzy number "around 50", and the linguistic qualifiers may be "very", "little", "close to" etc. Therefore, the final value of "price" may be "very cheap" or "little expensive". At the same time, the property $p^C \in P^C$ has also the non-fuzzy form $p^C(c, v, f)$.

(4) R is a set of inter-concept relations between concepts. The relation type is not only the ordinary binary relation of $r \subseteq C \times C$, but also is the fuzzy relation and the intuitionistic fuzzy relation from C to C.

(5) P^R is a set of relations properties. Like concept properties, $p^R \in P^R$ is defined as a 4-tuple of the form $p^R(c_1, c_2, r, s_F)$, where $c_1, c_2 \in C$ are ontology concepts, r represents relation, and $s_F \in [0,1]$ or $s_F \subseteq [0,1]$ models relation strengths and has meaning of fuzzy set or intuitionistic fuzzy set on $C \times C$, which can represent the strength of association between concept-pairs $< c_1, c_2 >$. For instance, there is a relation of "loyalty" between "customer" and "brand". The strength of "loyalty" can be 0.7, a fuzzy value, and can be [0.6,0.8], a interval value, i.e. intuitionistic fuzzy value, which express more abundant information about uncertainty.

(6) A_F is a set of fuzzy rules. In a fuzzy system the set of fuzzy rules is used as knowledge base.

The fuzzy domain ontology is used to model domain expert knowledge. But, due to the lack of relationships between fuzzy concepts that can be the value of properties, it is difficult to search information at semantic level. Consequently, we propose the fuzzy linguistic variables ontology models.

IV. Fuzzy Linguistic Variable Ontology

The fuzzy linguistic variables proposed by Zadeh are the basic of fuzzy knowledge and fuzzy system.

Definition 5 (Fuzzy linguistic variable) – A fuzzy linguistic variable is a 4-tuple (X, T, M, U), where:

(1) X is the name of fuzzy linguistic variable, e.g. "price" or "speed" etc.

(2) T is the set of terms which is the value of fuzzy linguistic variable, e.g. T ={ cheap, appropriate, expensive, …} or T ={fast, middle, slow,…}.

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

(4) U is the universe of discourse.

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

Definition 6 (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, e.g. "price", "speed" etc. The corresponding element of c_a is X in definition 5.

(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 5, 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 (i.e. $\subseteq$), intersection, disjointness, complement (i.e. $\neg$)}, and the other relations are the order relation and equivalence relation $R_O = \{\leq, \geq, =\}$. C_F and an order relation r compose the ordered structure $< C_F, r >$. There are other semantic relations between concepts, such as semantic distance relation, semantic proximity relation and semantic association relation etc.

(4) F is the set of membership functions on U, which is isomorphic to C_F. The corresponding element of F is M in definition 5, 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" etc., i.e. $S = \{\vee, \wedge, \neg, \cdots\}$. C_F and S compose the algebra structure $< C_F, S >$.

(6) U is the universe of discourse.

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

Definition 7 (Extended fuzzy ontology) – An extended fuzzy ontology is a 9-tuple $O_F = (c_a, C_F, R, F, S, Q, O, L, U)$, where:

(1) c_a, C_F, R, F, S, U have same interpretations as defined in definition 6.

(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, e.g. "very cheap".

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

(4) $L \subseteq (Q \times C_F) \cup (C_F \times Q)$ is a binary relation from Q to C_F or C_F to Q. $< q, c_F > or < c_F, q > \in L$ mean 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.

Definition 8 (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 6, 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 on U . In the other words, C_F is a fuzzy partition of U .

(3) C_F has an ordered relation $\leq$, and $< C_F, \leq >$ is a complete ordered set, i.e. all concepts in C_F constitute a chain $c_1 \leq c_2 \leq \cdots \leq c_n$.

An example of basic fuzzy ontology is O_F = （ c_a = price of product, C_F = {cheap, appropriate, expensive}, $U = [0,100]$ ）, where “cheap” ≤ “appropriate” ≤ “expensive” , and the membership functions are shown in Fig 1.

The Semantic Web, introduced by Tim Bemers-Lee, uses Resource Description Framework (RDF) to add structure and meaning to Web applications. RDF data model “resource-property-value” is the current standards for establishing semantic interoperability on the Web [16]. Fig. 2 describes “basic fuzzy ontology” as a resource in RDF. The RDF statements are as following:

```
<rdf: Description  ID= “Basic fuzzy ontology”>
    <t: values>   <rdf: Seq>
       <rdf: li  resource= “# Fuzzy concept 1”/>
       <rdf: li  resource= “# Fuzzy concept 2”/>
       <rdf: li  resource= “# Fuzzy concept 3”/>
    </rdf: Seq>   </t: values>
</rdf: Description>
<rdf: Description  ID= “Price of product”>
    <t: values>   <rdf: Seq>
       <rdf: li  resource= “# cheap”/>
       <rdf: li  resource= “# appropriate”/>
       <rdf: li  resource= “# expensive”/>
    </rdf: Seq>  </t: values>
</rdf: Description>
<rdf: Description  ID= “cheap”>
    <rdf: type resource= “# Fuzzy concept”/>
    <t:   membership_function   resource=   “#
membership function 1”>
</rdf: Description>
<rdf: Description  ID= “appropriate ”>
    <rdf: type resource= “# Fuzzy concept”/>
    <t:   membership_function   resource=   “#
membership function 2”>
</rdf: Description>
<rdf: Description  ID= “expensive ”>
    <rdf: type resource= “# Fuzzy concept”/>
    <t:   membership_function   resource=   “#
membership function 3”>
</rdf: Description>
```

Each fuzzy concept is associated with a membership function. There are many types of membership functions. Some of the common ones are:

(1) Triangular. A triangular shaped curve can be described by three points, namely: (x1, 0), (x2, 1), and (x3, 0). The RDF statements are as following:

```
<rdf: Description  ID= “membership function 1”>
    <rdf: type resource= “# triangular”/>
        <t: points>
            <rdf: Seq>
              <rdf: li  resource= “# point1 ”/>
              <rdf: li  resource= “# point1”/>
              <rdf: li  resource= “# point2”/>
            </rdf: Seq>
        </t: points>
</rdf: Description>
```

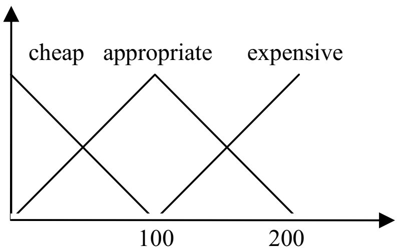

Figure 1. Membership functions in ontology

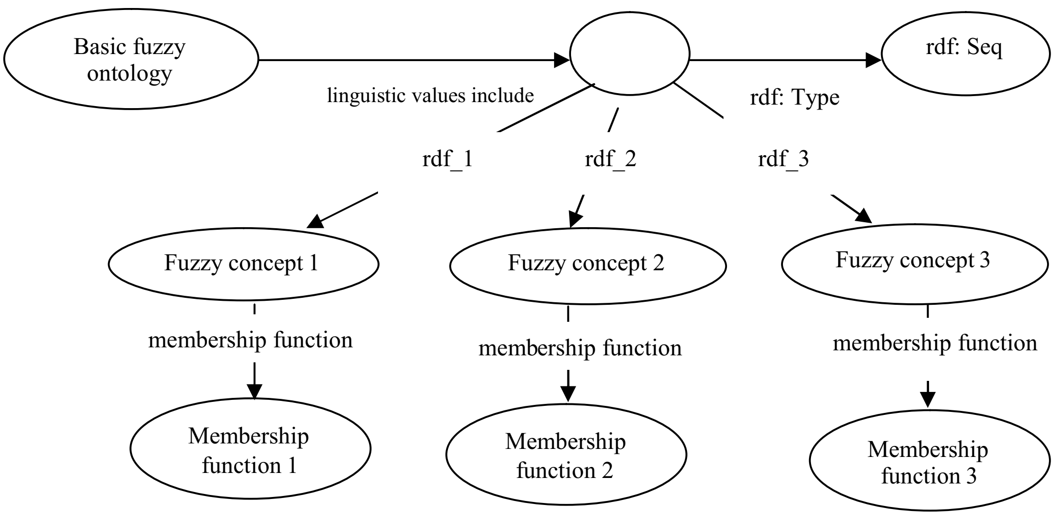

Figure 2. Linguistic variable ontology representation in RDF

(2) Trapezoidal. A trapezoidal shaped curve can be described by four points, namely: (x1, 0), (x2, 1), (x3,1), and (x4, 0). The RDF statements are as following:

```
<rdf: Description ID= "membership function 2">
   <rdf: type resource= "# trapezoidal"/>
   <t: points>   <rdf: Seq>
        <rdf: li resource= "# point1"/>
        <rdf: li resource= "# point2"/>
        <rdf: li resource= "# point2"/>
        <rdf: li resource= "# point3"/>
   </rdf: Seq>  </t: points>
</rdf: Description>
<rdf: Description ID= "point1">
   <rdf: value rdf: datatype= "&xsd; decimal">
  0 </rdf: value>
</rdf: Description>
<rdf: Description ID= "point2">
   <rdf: value rdf: datatype= "&xsd; decimal">
  100 </rdf: value>
</rdf: Description>
<rdf: Description ID= "point3">
   <rdf: value rdf: datatype= "&xsd; decimal">
  200 </rdf: value>
</rdf: Description>
```

V. FUZZY ONTOLOGY FRAMEWORK

Combining fuzzy domain ontology with fuzzy linguistic variable ontology, we obtain the three-layered fuzzy ontology framework shown in Fig. 3.

The framework comprises the set of concepts and relations, set of properties and set of fuzzy linguistic variable ontologies. The relation between concept and property is "property of", and the relation between property and fuzzy linguistic variable ontology is "value of", in which property's value can be either standard data type or linguistic values of fuzzy concepts. The framework is the extension of RDF data model "resource-property-value". Since considering the essential semantic relationships between fuzzy concepts, the framework facilitates the information retrieval at semantic level.

VI. INFORMATION RETRIEVAL FOR E-COMMERCE

In the open and distributed environments of WWW, in order to integrate and reuse information and knowledge in E-commerce, ontology becomes the means to model knowledge for customer [17]-[18] and product [19]-[21]. But the standard ontology is not able to handle fuzzy phenomenon and uncertainty of information and knowledge. In fact, it is sufficient for managers and customers to obtain some message in linguistic values rather than in accurate numeric values, such as customer information, product information and supplier information etc. For instance, the linguistic values for customer income include "low", "middle", "high" etc, and linguistic values for product price include "cheap", "appropriate", "expensive" etc. These linguistic values have uncertainty and are fuzzy concepts.

Using the three-layered fuzzy ontology framework, we construct the ontology structure for customer, product and supplier knowledge shown in Fig. 4, in which the linguistic values are represented formally through fuzzy linguistic variable ontologies. The main fuzzy linguistic variable ontologies are as following:

O1= (age, {old, middle-aged, midlife, youth, youngster, adult , …});

O2= (income, {little, low, middle, high, …});

O3= (customer type, {new customer, loyalty customer, gold customer, big customer, lost customer, switched customer …});

O4= (price,{very cheap, cheap, appropriate, expensive, very expensive});

O5= (zone of influence, {regional, national, international, …});

O6= (quality, {poor, middle, good, very good});

O7= (delivery time, {very deferred, deferred, on time});

O8= (evaluate grade, { very weak, weak, neutral, strong, excellent}).

There is a lot of semantic relation between fuzzy concepts. For instance:

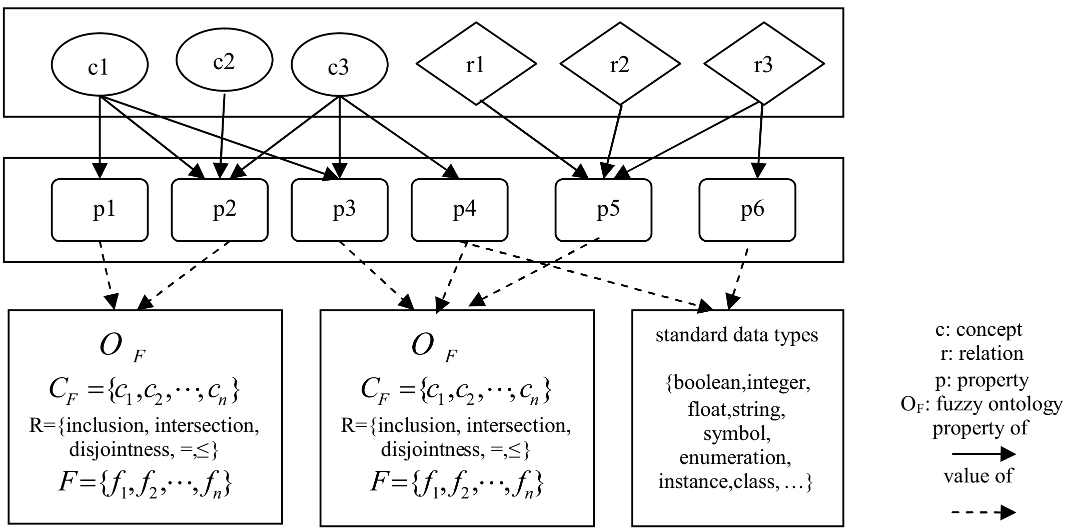

Figure 3. Three-layered fuzzy ontology framework

- "middle-aged" = "midlife", "old" ⊆ "adult", "middle-aged" ⊆ "adult", "youth" ⊆ "adult";
- "gold customer"= "big customer", "switched customer" ⊆ "lost customer";
- "very cheap" ≤ "cheap" ≤ "appropriate" ≤ "expensive" ≤ "very expensive";
- "very weak" ≤ "weak" ≤"neutral" ≤ "strong" ≤ "excellent";
- ┐"on time"= {"very deferred" , "deferred"};
- reversion ("poor")= "good", reversion ("cheap")= "expensive", etc.

Fig. 5 shows the RDF graph for linguistic variable ontology O1 which includes a set of fuzzy concepts and their semantic relation. The part of RDF statements to represent these ontologies is as following:

```
<rdf: Description ID= "age">
    <t: values>
      <rdf: Seq>
        <rdf: li resource= "#youngster"/>
        <rdf: li resource= "#youth"/>
        <rdf: li resource= "#midlife"/>
        <rdf: li resource= "#old"/>
      </rdf: Seq>
      <rdf: li resource= "#middle-aged"/>
      <rdf: li resource= "#old"/>
    </t: values>
</rdf: Description>
```

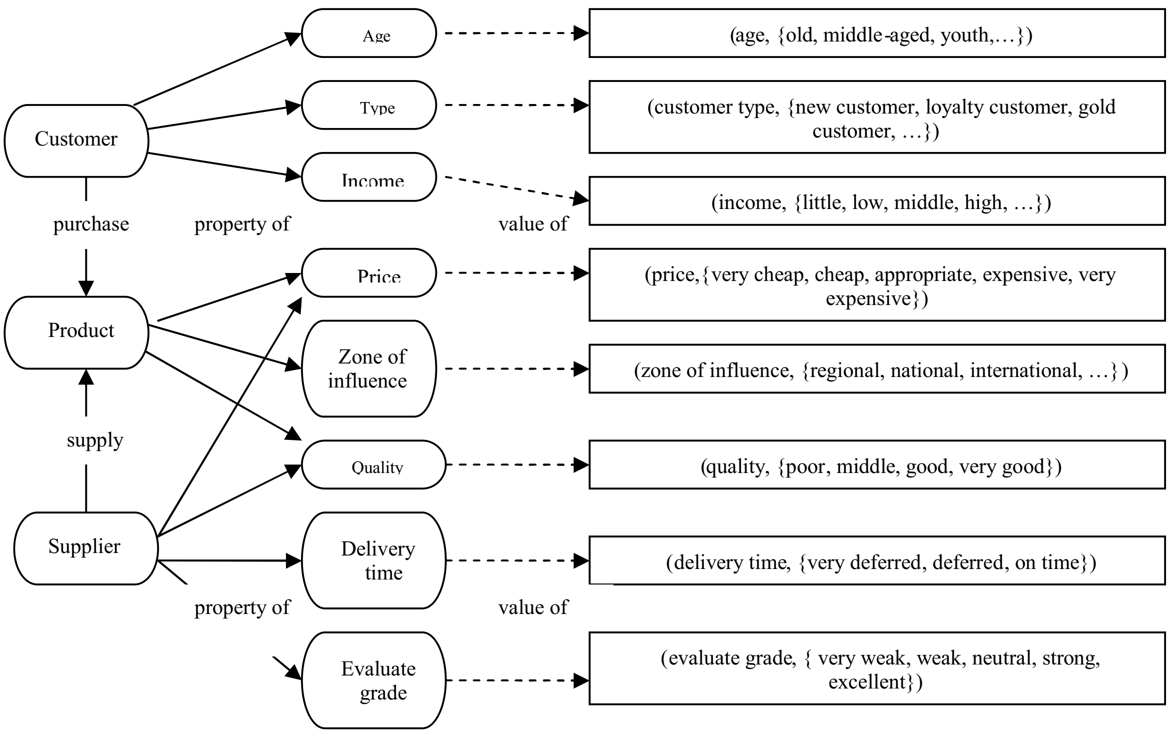

Figure 4. Ontology structure for customer, product and supplier knowledge (portion)

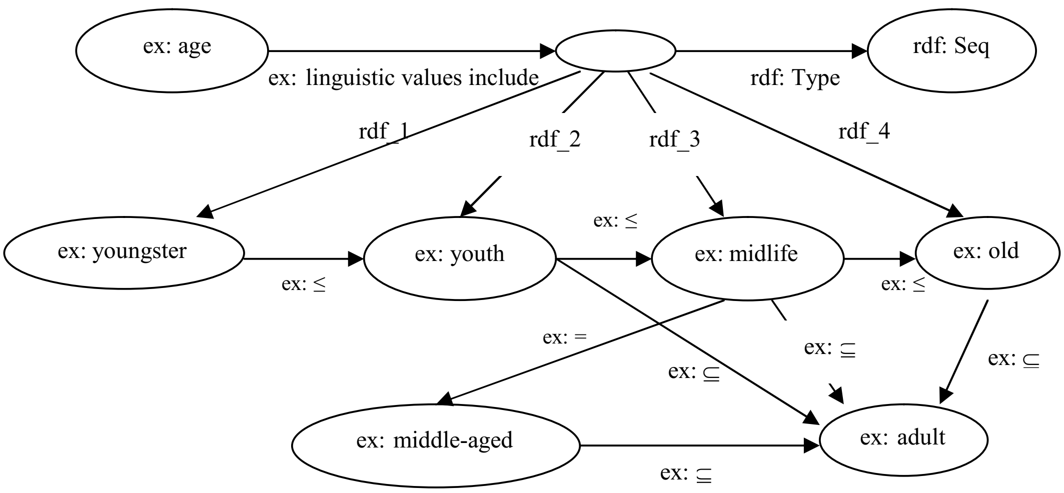

Figure 5. An example of RDF graph for linguistic variable ontology

```
<rdf: Description  ID= "quality">
    <t: values>    <rdf: Seq>
        <rdf: li  resource= "# poor"/>
        <rdf: li  resource= "# middle"/>
        <rdf: li  resource= "# good"/>
        <rdf: li  resource= "# very good"/>
    </rdf: Seq>    </t: values>
</rdf: Description>
```

Furthermore, we build the information retrieval system shown in Fig.6. Since the process for information retrieval is based on the knowledge ontology, the semantic and concept research can be achieved. Especially, using linguistic value of fuzzy concept, we can construct the research pattern such as: ***SELECT*** *instance of concept* ***FROM*** *Data source* ***WHERE*** *(property of concept)* <***comparison operator***> *"Linguistic value of fuzzy concept"*, in which the comparison operators includes: equal comparison (=), unequal (≠), less than or equal (≤) and greater than or equal (≥) etc.

For instance, we can retrieve "product" information through "price" of property, using the search statement such as: *SELECT Product (name, brand, price, ...) FROM Data source WHERE Product.price ≤ " expensive"*. The standard ontology and other fuzzy ontology are not able to handle the search condition at semantic level, which includes fuzzy concept and semantic relation between them.

Using the "order relation" defined in fuzzy linguistic variable ontology : "very cheap" ≤ "cheap" ≤ "appropriate" ≤ "expensive" ≤ "very expensive" , we can transform the search statement to: *SELECT Product (name, brand, price, ...) FROM Data source WHERE Product.price = "very cheap" or Product.price = "cheap" or Product.price = "appropriate" or Product.price = "expensive"*, in which every sub-condition is ordinary and can be completed easily in SQL engine of DBMS.

When retrieving the information about gold customer by the statement: *SELECT Customer (name, age, income,...) FROM Data source WHERE Customer.type="gold customer",* we can obtain the information about big customer using equivalence relation: "gold customer"= "big customer".

When retrieving the information about lost customer by the statement: *SELECT Customer (name, age, income,...) FROM Data source WHERE Customer.type="lost customer",* we can obtain the information about switched customer using inclusion relation: "switched customer" ⊆ "lost customer". In the same way, using inclusion relation: "old" ⊆ "adult", "middle-aged" ⊆ "adult" and "youth" ⊆ "adult" and equivalence relation: "middle-aged" = "midlife", we can transform the search statement: *SELECT Customer (name, age, income,...) FROM Data source WHERE Customer.age="adult"* to: *SELECT Customer (name, age, income,...) FROM Data source WHERE Customer.age="adult" or Customer.age = "old" or Customer.age = "middle-aged" or Customer.age = "midlife" or Customer.age = "youth".*

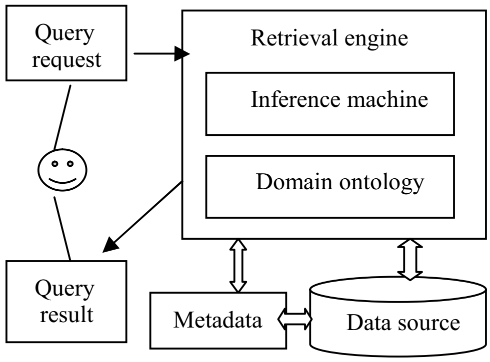

Figure 6. Information retrieval system

Using the "complement relation" defined in fuzzy linguistic variable ontology: ┐"on time"= {"very deferred", "deferred"}, when retrieving the information about supplier by the statement: *SELECT Supplier (name, address, phone,...) FROM Data source WHERE Supplier.delivery time≠"on time",* we can transform the search statement to: *SELECT Supplier (name, address, phone, ...) FROM Data source WHERE Supplier.delivery time = "very deferred" or Supplier.delivery = "deferred".*

Using the "reversion relation" defined in fuzzy linguistic variable ontology: reversion ("cheap") = "expensive", when retrieving the information about product by the statement: *SELECT Product (name, brand, price, ...) FROM Data source WHERE Product.price = REVERSION ("cheap"),* we can transform the search statement to: *SELECT Product (name, brand, price, ...) FROM Data source WHERE Product.price = "expensive".*

VII. Conclusion

People can obtain information from data resources by semantic querying based on ontology. To achieve fuzzy semantic retrieval in E-Commerce, this paper has presented information retrieval system based on fuzzy ontology framework. The framework includes three parts: concepts, properties of concepts and values of properties, in which property's value can be either standard data type or linguistic values of fuzzy concepts. The framework is the extension of RDF data model "resource-property-value", which is the current standard for establishing semantic interoperability on the Semantic Web. The semantic query expansions have been constructed by order relation, equivalence relation, inclusion relation, complement relation between fuzzy concepts defined in fuzzy linguistic variable ontologies, which facilitates the information retrieval at semantic level.

Our further researches lay on the semantic query expansion using complex fuzzy semantic relations in RDF query language such as RDQL, RQL, SeRQL.

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REFERENCES

[1] D. Fensel, F. van Harmelen, I. Horrocks, D.L.McGuinness, and P.F. Patel-Schneider, “OIL: an ontology infrastructure for the semantic web,” *IEEE Intelligent Systems*, vol.16, no.2, 2001, pp. 38-45.

[2] T. Berners-Lee, “Semantic web road map, W3C design issues”, http://www.w3.org/DesignIssues/Semantic.html, 1998.

[3] P. Castells, M. Fernandez, D. Vallet, “An adaptation of the vector-space model for ontology-based information retrieval,” *IEEE Transactions on Knowledge and Data Engineering*, vol.19, no. 2, 2007, pp. 261-272.

[4] J. Li, J. Y. Song, H. Zhong, “Ontology-based query division and reformulation for heterogeneous information integration,” *Journal of Software*, vol.18, no.10, 2007, pp. 2495−2506. (in Chinese)

[5] L. A. Zadeh, J. Kacprzyk, *Fuzzy logic for the management of uncertainty*, John Wiley & Sons, Inc, 1992.

[6] D. H. Widyantoro, J. Yen, “A fuzzy ontology-based abstract search engine and its user studies,” in: *Proceedings of the 10th IEEE International Conference on Fuzzy Systems*, Melbourne, Australia, 2001, pp. 1291-1294.

[7] D. Parry, “A fuzzy ontology for medical document retrieval,” in: *Proceedings of the Second Workshop on Australasian Information Security, Data Mining and Web Intelligence, and Software Internationalization*, Dunedin, New Zealand, 2004, pp. 121- 126.

[8] Raymond Y.K. Lau, “Fuzzy domain ontology discovery for business knowledge management,” *IEEE Intelligent Informatics Bulletin*, vol.8, no.1, 2007, pp. 29-41.

[9] C. S. Lee, Z. W. Jian, and L. K. Huang, “A fuzzy ontology and its application to news summarization,” *IEEE Transactions on Systems, Man and Cybernetics (Part B)*, vol.35, no.5, 2005, pp. 859- 880.

[10] Q. T. Tho, S. C. Hui, A. C. M. Fong, and T. H. Cao, “Automatic fuzzy ontology generation for semantic web,” *IEEE Transactions on Knowledge and Data Engineering*, vol.18, no.6, 2006, pp. 842- 856.

[11] Muhammad Abulaish, Lipika Dey, “A fuzzy ontology generation framework for handling uncertainties and nonuniformity in domain knowledge description,” in: *Proceedings of 2007 International Conference on Computing: Theory and Applications*, Kolkata, 2007, pp. 287-293.

[12] Muhammad Abulaish, Lipika Dey, “Interoperability among distributed overlapping ontologies – a fuzzy ontology framework,” in: *Proceedings of the 2006 IEEE/WIC/ACM International Conference on Web Intelligence*, Hong Kong, 2006, pp.397-403.

[13] Calegari Silvia, Ciucci Davide, “Fuzzy ontology and fuzzy-OWL in the KAON project,” in: *Proceedings of 2007 IEEE International Conference on Fuzzy Systems Conference*, London, UK, 2007, pp.1-6.

[14] K. Atanassov, “Operators Over Interval-valued Intuitionistic Fuzzy Sets,” *Fuzzy Sets and Systems*, vol.64, no.2, 1994, pp.159-174.

[15] T. R. Gruber, “A Translation Approach to Portable Ontology Specification,” *Knowledge Acquisition*, vol.5, no.2, pp. 199-220.

[16] John W.T. Lee, Alex K.S. Wong, “Information retrieval based on semantic query on RDF annotated resources,” in: *Proceedings of the 2004 IEEE International Conference on Systems, Man and Cybernetics*, 2004, pp. 3220-3225.

[17] X. W. Lu, F. Jiang, L. W. Hou, “Customer features extraction based on customer ontology,” *Computer Engineering,* vol.31, no.5, 2005, pp. 31-33. (in Chinese)

[18] Ma Huinan, Wu Jiangning, Dang Yanzhong, “Ontology-driven information retrieval system for customers' complaints of mobile communication services,” in: *Proceedings of 2006 International Conference on Management Science and Engineering*, Lille, 2006, pp. 30-35.

[19] Hu Yujie, Li Shanping, Guo Ming, “Ontology Based Product Knowledge Representation,” *Journal of Computer Aided Design & Computer Graphics*, vol. 15, no.12, 2003, pp. 1531-1537. (in Chinese)

[20] Fu Xiangjun, Li Shanpin, Guo Ming, “Ontology Knowledge Representation for Product Data Model,” *Journal of Computer Aided Design & Computer Graphics*, vol.17, no.3, 2005, pp. 570-577. (in Chinese)

[21] Fu Xiangjun, Li Shanping, Guo Ming, “Rules for Ontology Level Expression in Product Data,” *Journal of Computer Aided Design & Computer Graphics*, vol.17, no.6, 2005, pp. 1159-1166. (in Chinese)

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