Fuzzy Data Modeling Based on XML Schema

Li Yan
Northeastern University
Shenyang 110004, China
86-24-83681823
yanlily@yahoo.com

Z. M. Ma
Northeastern University
Shenyang 110004, China
86-24-83681582
zongmin_ma@yahoo.com

Jian Liu
Northeastern University
Shenyang 110004, China
86-24-83681823
liujian@163.com

ABSTRACT
Interest in XML has been growing over the last few years and XML has been the de-facto standard of information representation and exchange over the web. However, the real world is filled with imprecision and uncertainty. Classical databases have been extended to deal with imprecise and uncertain data. In this paper, we investigate how to incorporate fuzzy data into XML. We identify multiple granularity of data fuzziness in XML. Based on possibility distribution theory, we have possibilities associated with elements as well as attribute values of elements in XML. A fuzzy XML data model that addresses all of the fuzziness is developed based on XML Schema.

Categories and Subject Descriptors
H.2.7 [**Database Management**]: Systems – *distributed databases*; I.5.1 [**Pattern Recognition**]: Model – *fuzzy set.*

General Terms
Languages

Keywords
XML, fuzzy data modeling, Schema

1. INTRODUCTION
With the wide utilization of the web and the availability of huge amount of electronic data, information representation and exchange over the web become important and XML has been the de-facto standard [3, 4]. XML and related standards are technologies that allow the easy development of applications that exchange data over the web such as e-commerce (EC) and supply chain management (SCM).

In real-world applications, however, information is often vague or ambiguous. Classical databases are hereby extended to deal with imprecise and uncertain data. Fuzzy relational databases have extensively been investigated in last two decades [2, 6, 9, 11]. More recently, fuzzy object-oriented databases and fuzzy conceptual data models are receiving increasing attentions [7, 16].

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If we want to export the data in fuzzy databases into an XML format, it is clear that we do need methods to represent and process fuzzy data in XML. In fact, the fuzziness in EC and SCM has received considerable attentions and fuzzy set theory has been used to implement web-based business intelligence [10, 12, 13]. Unfortunately, being current standard for data representation and exchange on the web, XML is not able to represent imprecise and uncertain data although databases with imprecise and uncertain information have extensively been discussed.

Currently, little research has been done in managing imperfect XML data. XML with incomplete information [1] and probabilistic data [5, 8] in XML have been proposed. Without presenting XML representation model, the data fuzziness in XML document was discussed directly according to the fuzzy relational databases in [19], and the simple mappings from the fuzzy relational databases to fuzzy XML document were provided also. More recently, a fuzzy XML data model was proposed in [20], which is based XML DTD. In this paper, we identify multiple granularity of data fuzziness in XML. We particularly develop a fuzzy XML data model based on XML Schema, which addresses all of the fuzziness. A central contribution of the paper is the definition of a framework for fuzzy XML data modeling, which is believed to be one of the foundations of implementing web-based intelligent information management.

The remainder of the paper is organized as follows. Section 2 gives the basic knowledge on imperfect information and fuzzy set theory. The data fuzziness in XML is identified in Section 3. On the basis, Section 4 presents a fuzzy representation model for fuzzy data in XML. Section 5 concludes this paper.

2. IMPERFECT INFORMATION AND FUZZY SET THEORY

2.1 Imprecise and Uncertain Information
Inconsistency, *imprecision*, *vagueness*, *uncertainty*, and *ambiguity* are five basic kinds of imperfect information in database systems.

Inconsistency is a kind of semantic conflict, meaning the same aspect of the real world is irreconcilably represented more than once in a database or several different databases. For example, the *age* of *George* is stored as 34 and 37 simultaneously. Information inconsistency usually comes from information integration.

Intuitively, the imprecision and vagueness are relevant to the content of an attribute value, and it means that a choice must be made from a given range (interval or set) of values but we do not know exactly which one to choose at present. In general, vague information is represented by linguistic values. For example, the *age* of *Michael* is a set {18, 19, 20, 21}, a piece of imprecise information, and the *age* of *John* is a linguistic "*old*", a piece of vague information.

The uncertainty is related to the degree of truth of its attribute value, and it means that we can apportion some, but not all, of our belief to a given value or a group of values. For example, the possibility that the *age* of *Chris* is 35 right now should be 98%. The random uncertainty, described using probability theory, is not considered in the paper.

The ambiguity means that some elements of the model lack complete semantics leading to several possible interpretations.

Generally, several different kinds of imperfection can co-exist with respect to the same piece of information. For example, the *age* of *Michael* is a set {18, 19, 20, 21} and their possibilities are 70%, 95%, 98%, and 85%, respectively. Imprecision, uncertainty, and vagueness are three major types of imperfect information.

Imprecision and inconsistency are essentially properties of the information itself whereas uncertainty is a property of the relation between the information and our knowledge about the world. To model imprecision and uncertainty, the various approaches are presented in [18]. These models are grouped into two large categories, namely, *the symbolic* and *the quantitative* models. Fuzzy sets introduced by Zadeh [14] have been widely used for the quantification of imprecision.

2.2 Fuzzy Set and Possibility Distribution

Based on the classification of imperfect information, different types and sources of imperfect information have been investigated [17]. Many of the existing approaches dealing with imprecision and uncertainty are based on the theory of fuzzy sets [14] and possibility distribution theory [15]. A fuzzy set, say {0.7/18, 0.95/19, 0.98/20, 0.85/21} for the age of Michael, is more informative because it contains information imprecision (the age may be 18, 19, 20, or 21 and we do not know which one is true) and uncertainty (the degrees of truth of all possible age values are 0.7, 0.95, 0.98, and 0.85) simultaneously.

Let U be a universe of discourse. A fuzzy value on U is characterized by a fuzzy set F in U. A membership function

$$\mu_F: U \rightarrow [0, 1]$$

is defined for the fuzzy set F, where $\mu_F(u)$, for each $u \in U$, denotes the degree of membership of u in the fuzzy set F. Thus the fuzzy set F is described as follows:

$$F = \{\mu_F(u_1)/u_1, \mu_F(u_2)/u_2, ..., \mu_F(u_n)/u_n\}$$

When the membership function $\mu_F(u)$ above is explained to be a measure of the possibility that a variable X has the value u, where X takes values in U, a fuzzy value is described by a possibility distribution π_X [15].

$$\pi_X = \{\pi_X(u_1)/u_1, \pi_X(u_2)/u_2, ..., \pi_X(u_n)/u_n\}$$

Here, $\pi_X(u_i)$, $u_i \in U$ denotes the possibility that u_i is true. Let π_X and F be the possibility distribution representation and the fuzzy set representation for a fuzzy value, respectively.

3. FUZZINESS IN XML DOCUMENT

As we have known, two kinds of fuzziness can be found in relational model: one is to associate membership degrees with individual tuples and another is to represent attribute values with possibility distributions. A membership degree associated with a tuple is interpreted to mean the possibility of the tuple being a member of the corresponding relation. A possibility distribution represented an attribute value means we do not know a crisp value of the attribute but only know the range of values that the attribute may take and the possibility of each value being true.

XML data is structured and XML can represent imprecise and uncertain information naturally. In the case of XML, membership degrees may be associated with elements. It is also possible to associate possibility distributions with attribute values of elements. XML restricts attributes to have a unique single value. We modify the schema in XML to make any attribute into a sub-element.

Now let us interpret what a membership degree associated with an element means, given that the element can nest under other elements and more than one of these elements may have an associated membership degree. The existential membership degree associated with an element should be the possibility that the state of the world includes this element and the sub-tree rooted at it. For an element with the sub-tree rooted at it, each node in the sub-tree is not treated as independent but dependent upon its root to node chain. Each possibility in the source XML document is assigned conditioned on the fact that the parent element exists certainly. In other words, this possibility is a relative one upon the assumption that the possibility the parent element exists is exactly 1.0. In order to calculate the absolute possibility, we must consider the relative possibility in the parent element. In general, the absolute possibility of an element ε can be obtained by multiplying the relative possibilities found in the source XML, along the path from ε to the root. Of course, each of these relative possibilities will be available in the source XML document. By default, relative possibilities are regarded as 1.0.

Consider a chain $A \rightarrow B \rightarrow C$ from the root node A. Assume that the source XML document contains the relative possibilities *Poss* $(C|B)$, *Poss* $(B|A)$, and *Poss* (A), associated with the nodes C, B, and A, respectively. Then we have

$$Poss(B) = Poss(B|A) \times Poss(A) \text{ and}$$
$$Poss(C) = Poss(C|B) \times Poss(B|A) \times Poss(A).$$

Here, *Poss* $(C|B)$, *Poss* $(B|A)$, and *Poss* (A) can be obtained from the source XML document.

For attribute values of elements, XML restricts attributes to have a unique single value. It is not difficult to find that this restriction does not always hold true. It is often the case that some data item is known to have multiple values – these values may be unknown completely and can be specified with a possibility distribution. For example, the e-mail address of a person may be multiple character strings because she or he has several e-mail addresses available simultaneously. In the case that we do not have complete knowledge of the e-mail address for Tom Smith, we may say that the e-mail address may be "*TSmith@yahoo.com*" with possibility 0.60, "*Tom_Smith@yahoo.com*" with possibility 0.85, "*Tom_Smith@hotmail.com*" with possibility 0.85, "*TSmith@hotmail.com*" with possibility 0.55, and "*TSmith@msn.com*" with possibility 0.45.

In contrast, some data item is known to have single unique value. For instance, the age of a person in year is a unique non-negative integer. If such value is unknown so far, we can use the following possibility distribution: {0.4/23, 0.6/25, 0.8/27, 1.0/29, 1.0/30, 1.0/31, 0.8/33, 0.6/35, 0.4/37}. Based on the discussion above, it is clear to find that we have two kinds of interpretation of a fuzzy data represented by a possibility distribution: fuzzy disjunctive data and fuzzy conjunctive one.

In summary, we have two kinds of fuzziness in XML: the fuzziness in elements (we use membership degrees associated with such elements); the fuzziness in attribute values of elements (we use possibility distribution to represent such values). Note that, for the latter, there exist two types of possibility distribution (i.e., disjunctive and conjunctive possibility distributions) and they may occur in child elements with or without further child elements in the ancestor-descendant chain.

Figure 1 gives a fragment of an XML document with fuzzy

```
1. <courses>
2. <course CName = "Artificial Intelligence">
3. <Val Poss = 0.8>
4. <department DName = "Computer Science and Technology">
5. <teacher TID = "2114812007">
6. <Dist type = "disjunctive">
7. <Val Poss = 0.8>
8. <tname>Vincent Lyot</tname>
9. <title>Associate Professor</title>
10. <salary>3000</salary>
11. <tel>024-83680001</tel>
12. </Val >
13. <Val Poss = 0.6>
14. <tname>Vincent Lyot</tname>
15. <title>Professor</title>
16. <salary>5000</salary>
17. <tel>024-83660001</tel>
18. </Val >
19. </Dist>
20. </teacher>
21. <student SID = "20023056">
22. <sname>Tom Smith</sname>
23. <age>
24. <Dist type = "disjunctive">
25. <Val Poss = 0.4>23</Val>
26. <Val Poss = 0.6>25</Val>
27. <Val Poss = 0.8>27</Val>
28. <Val Poss = 1.0>29</Val>
29. <Val Poss = 1.0>30</Val>
30. <Val Poss = 1.0>31</Val>
31. <Val Poss = 0.8>33</Val>
32. <Val Poss = 0.6>35</Val>
33. <Val Poss = 0.4>37</Val>
34. </Dist>
35. </age>
36. <grade>95</grade>
37. <email>
38. <Dist type = "conjunctive">
39. <Val Poss = 0.60>TSmith@yahoo.com</Val>
40. <Val Poss = 0.85>Tom_Smith@yahoo.com</Val>
41. <Val Poss = 0.85>Tom_Smith@hotmail.com</Val>
42. <Val Poss = 0.55>TSmith@hotmail.com</Val>
43. <Val Poss = 0.45>TSmith@msn.com</Val>
44. </Dist>
45. </email>
46. </student>
47. </department >
48. </Val>
49. </course>
50. <course CName = "Information Science">
51. </course>
52. </courses>
```

Figure 1. A Fragment of Fuzzy XML Document

4. FUZZY REPRESENTATION MODEL

4.1 Representation of Fuzzy Data in XML Document

It is not difficult to see from the example given above that a possibility attribute, denoted Poss, should be introduced first, which takes a value between 0 and 1. This possibility attribute is applied together with a fuzzy construct called Val to specify the possibility of a given element existing in the XML document.

Consider line 3 of Figure 1. <Val Poss = 0.8> states that the possibility of the given element department being *Computer Science and Technology* is equal to 0.8. For an element with possibility 1.0, pair <Val Poss = 1.0> and </Val> is omitted from the XML document.

Based on pair <Val Poss> and </Val>, possibility distribution for an element can be expressed. Also possibility distribution can be used to express fuzzy element values. For this purpose, we introduce another fuzzy construct called Dist to specify a possibility distribution. Typically a Dist element has multiple Val elements as children, each with an associated possibility. Since we have two types of possibility distribution, the Dist construct should indicate the type of a possibility distribution, being disjunctive or conjunctive.

Again consider Figure 1. Lines 24-34 are the disjunctive Dist construct for the age of student Tom Smith. Lines 38-44 are the conjunctive Dist construct for the email of student Tom Smith. It should be pointed out that, however, the possibility distributions in line 24-34 and line38-44 are all for leaf nodes in the ancestor-descendant chain. In fact, we can also have possibility distributions and values over non-leaf nodes. Observe the disjunctive Dist construct in lines 6-19, which express the two possible statuses for the employee with ID 2114812007. In these two *employee* values, lines 7-12 are with possibility 0.8 and lines 13-18 are with possibility 0.6.

4.2 The Schema Definitions

It has been shown above that the XML document may contain fuzzy information. As a result, several fuzzy constructs have been introduced. In order to accommodate these fuzzy constructs, it is clear that the Schema of the source XML document should be correspondingly modified. In this section, we focus on the definitions of the Schema for fuzzy XML data modeling.

First we define ***Val*** element as follows:

```
<xs:element name="Val" type="valtype"/>
<xs:complexType name="valtype">
<xs:sequence>
<xs:element name="original-definition" minOccurs="0"
maxOccurs="unbounded"/>
```

```
<xs:attribute name=”Poss” type=”xs:fuzzy” minOccurs=”0”
maxOccurs=”unbounded” default=”1.0”/>
</xs:sequence>
</xs:complexType>
```

Then we define ***Dist*** element as follows:

```
<xs:element name=”Dist” type=”disttype”/>
<xs:complexType name=”disttype”>
<xs:element name=”Val” type=”valtype” minOccurs=”1”
maxOccurs=”unbounded”/>
<xs:attribute values=”disjunctive conjunctive”
default=”disjunctive”/>
</xs:complexType>
```

Now we modify the element definition in the classical Schema so that all of the elements can use possibility distributions (Dist). For a sub-element that only contains leaf elements, its definition in the Schema is as follows.

```
<xs:element name=”leafElement” type=”leafelementtype”/>
<xs:complexType name=”leafelementtype”>
<xs:sequence>
<xs:element name=”original-definition” type=”xs:type”
minOccurs=”0” maxOccurs=”unbounded”/>
<xs:element name=”Dist” type=”disttype” minOccurs=”0”
maxOccurs=”unbounded”/>
</xs:sequence>
</xs:complexType>
```

For an element that contains leaf elements without any fuzziness, say the “sname” in the student in Figure 1, its definition in the Schema is as follows.

```
<xs:element name=”original-definition” type=”xs:type”
minOccurs=”0” maxOccurs=”unbounded”/>
```

For an element that contains leaf elements with fuzziness, say “age” in the student in Figure 1, its definition in the Schema is as follows.

```
<xs:element name=”leafElement” type=”leafelementtype”/>
<xs:complexType name=”leafelementtype”>
<xs:element name=”Dist” type=”disttype” minOccurs=”0”
maxOccurs=”unbounded”/>
</xs:complexType>
```

For a sub-element that does not contain any leaf elements, its definition in the Schema is as follows.

```
<xs:element name=”nonleafElement” type=”nonleafelementtype”/>
<xs:complexType name=”nonleafelementtype”>
<xs:sequence>
<xs:element name=”original-definition” type=”xs:type”
minOccurs=”0” maxOccurs=”unbounded”/>
<xs:element name=”Dist” type=”disttype” minOccurs=”0”
maxOccurs=”unbounded”/>
<xs:element name=”Val” type=”valtype” minOccurs=”0”
maxOccurs=”unbounded”/>
</xs:sequence>
</xs:complexType>
```

For an element that does not contain leaf elements without any fuzziness, its definition in the Schema is as follows.

```
<xs:element name=”nonleafElement” type=”nonleafelementtype”/>
<xs:complexType name=”nonleafelementtype”>
<xs:element name=”original-definition” type=”xs:type”
minOccurs=”0” maxOccurs=”unbounded”/>
</xs:complexType>
```

For a sub-element that does not contain leaf elements but a fuzzy value, its definition in the Schema is as follows.

```
<xs:element name=”nonleafElement” type=”nonleafelementtype”/>
<xs:complexType name=”nonleafelementtype”>
<xs:element name=”Val” type=”valtype” minOccurs=”0”
maxOccurs=”unbounded”/>
</xs:complexType>
```

For a sub-element that does not contain leaf elements but a set of fuzzy values, its definition in the Schema is as follows.

```
<xs:element name=”nonleafElement” type=”nonleafelementtype”/>
<xs:complexType name=”nonleafelementtype”>
<xs:element name=”Dist” type=”disttype” minOccurs=”0”
maxOccurs=”unbounded”/>
</xs:complexType>
```

The Schema the fuzzy XML document in Figure 1 is shown as follows.

```
<? xml version=”1.0”? >
<xs:schema xmlns:xs=”http://www.w3.org/2001/XMLSchema”>
<xs:element name=”courses”>
<xs:complexType>
<xs:element name=”course” type=”coursetype” minOccurs=”0”
maxOccurs=” unbounded”/>
</xs:complexType>
</xs:element>
<xs:complexType name=”coursetype”>
<xs:element name=”Val” type=”valtype” minOccurs=”1”
maxOccurs=” unbounded”/>
<xs:attribute name=”CName” type=”xs:IDREF”
use=”REQUIRED”/>
</xs:complexType>
<xs:complexType name=”valtype”>
<xs:sequence>
<xs:element name=”department” type=”worktype” minOccurs=”0”
maxOccurs=” unbounded”/>
<xs:element name=”tname” type=”xs:string” minOccurs=”0”
maxOccurs=” 1”/>
<xs:element name=”title” type=”xs:string” minOccurs=”0”
maxOccurs=” 1”/>
<xs:element name=”salary” type=”xs:string” minOccurs=”0”
maxOccurs=” 1”/>
<xs:element name=”tel” type=”xs:string” minOccurs=”0”
maxOccurs=” 1”/>
</xs:sequence>
<xs:attribute name=”Poss” type=”xs:fuzzy” minOccurs=”0”
maxOccurs=”unbounded” default=”1.0”/>
</xs:complexType>
<xs:complexType name=”worktype”>
<xs:sequence>
<xs:element name=”teacher” type=”teachertype” minOccurs=”0”
maxOccurs=” unbounded”/>
<xs:element name=”student” type=”studenttype” minOccurs=”0”
maxOccurs=” unbounded”/>
</xs:sequence>
<xs:attribute name=”DName” type=”xs:IDREF”
use=”REQUIRED”/>
</xs:complexType>
<xs:complexType name=”teachertype”>
<xs:element name=”Dist” type=”disttype” />
```

```
<xs:attribute name=”TID” type=”xs:IDREF” use=”REQUIRED”/>
</xs:complexType>
<xs:complexType name=”disttype”>
<xs:element name=”Val” type=”valtype” minOccurs=”1”
maxOccurs=” unbounded”/>
<xs:attribute values=”disjunctive conjunctive”
default=”disjunctive”/>
</xs:complexType>
<xs:complexType name=”studenttype”>
<xs:sequence>
<xs:element name=”sname” type=”xs:string” minOccurs=”0”
maxOccurs=” 1”/>
<xs:element name=”age” type=”agetype” minOccurs=”0”
maxOccurs=” 1”/>
<xs:element name=”grade” type=”xs:string” minOccurs=”0”
maxOccurs=” 1”/>
<xs:element name=”email” type=”emailtype” minOccurs=”0”
maxOccurs=” 1”/>
</xs:sequence>
<xs:attribute name=”SID” type=”xs:IDREF” use=”REQUIRED”/>
</xs:complexType>
<xs:complexType name=”agetype”>
<xs:element name=”Dist” type=”disttype”/>
</xs:complexType>
<xs:complexType name=”emailtype”>
<xs:element name=”Dist” type=”disttype”/>
<xs:attribute values=”conjunctive”/>
</xs:complexType>
</xs:schema>
```

5. CONCLUSION

By using possibility distribution theory, this paper has identified multiple granularity of data fuzziness in XML, which are possibilities associated with elements and possibility distributions representing attribute values of elements. A fuzzy XML data model that addresses all of the fuzziness has hereby developed.

6. ACKNOWLEDGMENTS

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