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Transforming Fuzzy Spatiotemporal Data From Relational Databases to XML

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ABSTRACT On account of the poor shareability of fuzzy spatiotemporal data in Web while XML could contribute to information performance and information interaction flexibly, we study the methodology of modeling the fuzzy spatiotemporal data based on relational database and transforming fuzzy spatiotemporal data from relational database to XML. In this paper, we propose a kind of fuzzy spatiotemporal relational model and devise a temporal edge approach to transform fuzzy spatiotemporal relational data into XML documents, which is devoted to capturing the semantics of fuzzy spatiotemporal features, such as temporal feature, spatial feature, and fuzzy feature. The unique of this approach is that no schema information is required for transformation of fuzzy spatiotemporal data. Finally, the study would solve the challenge of both information share and information transfer between relational database and XML of fuzzy spatiotemporal data. Such approach of transformation would make a contribution to the interoperability of fuzzy spatiotemporal data between relational database and XML.

INDEX TERMS Fuzzy spatiotemporal, XML, relational database, transformation.

I. INTRODUCTION

With the development of Web application, spatiotemporal information plays an important role in many applications such as the environmental changes monitoring [23], the moving vehicle detection [21], [41], visual object tracking [16], traffic sensor data processing [37], even biometric recognition [2], clinical and experimental electrophysiology [5] during these years. Recently, the fuzzy spatiotemporal concept has been raised [34], [40]. Different from generic data, it is known for the fuzzy feature. Due to the unique attributes of fuzzy spatiotemporal data, it needs an appropriate method to express the spatio-temporality, fuzziness, and topological relationship. In the current computer science field, large amounts of data are stored in traditional relational databases in virtue of the reliability, maturity and independence of it. Because relational databases have advantages of storing and managing data, that is inevitable to store spatiotemporal data in relational databases. The formers have investigated the approach of modeling it based on UML [18], [26], OWL DL ontology [45], object-oriented database [11] and knowledge-base [38] in addition to relational database [1], [25]. However, these works are isolated. The various types of data models [19] and the new technology of database also spring up endlessly and extensively make the high degree of heterogeneity, the case of which caused the small islands of information. It is of utmost urgency to solve the current problem both in data transmission and data sharing.

Fortunately, XML [14] develops rapidly and has been the de facto standard for representing and exchanging data on the Web, which has become the major medium for integrating and exchanging data of different organizations on account of its simplicity, readability and portability. There are also a series of works arising on modeling spatiotemporal data based on XML [13], [27], [29]. For better sharing data, it is important to make the transformation between relational databases and XML documents. Therefore, a range of studies on it has been published in recent years [3], [15], [19], [22]. But these works are directed at general data and ignore the temporal, spatial features and the fuzzy ones. As for fuzzy spatiotemporal data, several studies have been raised [8], [26] and the transformation of which are unidirectional. There is little progress in the transformation of fuzzy spatiotemporal data among heterogeneous databases, especially the one from relational databases to XML. The task of converting fuzzy spatiotemporal data between relational database and XML still demands further attention. However, although our work cannot be extended on previous achievements directly, the previous efforts provide basic methods of modeling fuzzy spatiotemporal data based on relational database and XML document for references.

In this paper, we design a fuzzy spatiotemporal data model in relational database to capture the semantics of fuzzy spatiotemporal features. To enhance the fuzzy information sharing in Web, we study a temporal edge approach to convert fuzzy spatiotemporal relational data to XML document. Apart from that, we also devise a fuzzy spatiotemporal data tree based on ER model to finish the task of transformation.

The remainder of the paper is organized as follows. In Section II, we review previous efforts in modeling fuzzy spatiotemporal data on relational database, XML and the transformation between them. After establishing a fuzzy spatiotemporal data model based on relational database in Section III, we put forward the method of transforming fuzzy spatiotemporal data from relational database to XML in Section IV and Section V concludes the paper.

II. RELATED WORK

Structured models could be benefit to data transmission and data sharing. It is such a significant project to structure the fuzzy spatiotemporal data. But Transforming flat, unordered relational structure into hierarchical, ordered XML data is not a straightforward task. In this part, we review previous efforts in spatiotemporal data modeling and transforming, also introduce the transformation of generic data.

A. FUZZY SPATIOTEMPORAL DATA MODELING BASED ON RELATIONAL DATABASE

Fuzzy values have been employed to model and handling fuzzy information in relational databases has been proposed since Zadeh [43] introduced the theory of fuzzy sets and possibility [44]. Tatarinov *et al.* [38] used a meteorological database application in an intelligent database architecture, which combined an object-oriented database with a knowledgebase for modeling and querying spatiotemporal objects. Antova *et al.* [1] devised a powerful query language which was built on the basis of PostgreSQL. It used the concept of U-relations in order to maximize space-efficiency. After that, Ma [25] introduced fuzzy extended entity-relationship (FEER) model, fuzzy nested relational databases and then developed the approaches to mapping the fuzzy EER model to the fuzzy nested relational schema, Zhao *et al.* [46] put forward the fuzzy ER data model with description logic based on DLR. To extract knowledge from fuzzy relational databases automatically, Ma *et al.* [31] and [28] propose an approach by means of fuzzy DL and studied the conjunctive querying techniques from tractable to more expressive fuzzy DLKBs (Description Logic knowledge bases). There are also various fuzzy conceptual data models were reviewed in [32].

B. FUZZY SPATIOTEMPORAL DATA MODELING BASED ON XML

There is also some achievement on fuzzy XML, proposed a fuzzy XML data model based on XML DTD [26] and new one based on XML Schema [27], [42] to solve the problem that XML DTD lacks enough expressive power to properly describe highly structured data, presented strategies of transforming two general fuzzy spatiotemporal data trees into one binary fuzzy spatiotemporal data tree which adopted XML twig pattern technique to determine topological relationship continuously and could reduce unnecessary execution time of querying the desired nodes [9] and provided a generic overview of the approaches to modeling fuzzy XML data and identifying possible research opportunities from the point of fuzzy XML data management [10], [29], for example. Ma and Chen also devised the fuzzy spatiotemporal UML data model and provided the rules for converting the fuzzy spatiotemporal UML data model to the fuzzy spatiotemporal XML model [18], [26], respectively. Recently, Bai and Ma *et al.* [12] and [30] focused on consistency conditions for fuzzy spatiotemporal data in XML documents and proposed algorithms for fixing these inconsistencies. In the meantime, Bai *et al.* [13] devoted to the uncertain spatiotemporal data model based on XML and presented a series of algebraic operations based on the model they proposed to capture uncertain spatiotemporal information, then presented some queries on fuzzy spatiotemporal XML data [6], [7]. That is already mature enough to model fuzzy spatiotemporal data on XML.

C. TRANSFORMATION OF GENERIC DATA FROM RELATIONAL DATABASE TO XML

It is known to have linear time complexity in XML databases that based on RDBMS, which is generally based on Document Object Model (DOM) or Simple API for XML (SAX) [4]. Concerning the transformation between XML and relational database, there are three basic methods. In the first two approaches, the tags, attributes of XML schema and the content of the XML document are stored as database values in relational databases [3]. One of which is storing XML documents as a whole within a single database attribute, such as Oracle [33], whose drawback is no more possible to lock only parts of this document for update purposes in the area of transaction management. Another one is shredding, such as decomposing XML documents into a graph structure before storing them into database tables [17] and translating the conceptual schema of a relational database into XML schema based on EER [19]. A disadvantage of it is that has got to construct the schema before querying data we need, which enhances the task size of query, makes query formulation cumbersome and decreases the query efficiency. The structure of XML documents is mapped to a corresponding relational schema to allow the transformation to already existing relational schemata, which are stored in XML documents referencing to the mapping [15], [35], [36], [39]. And the last one solved the disadvantages above mentioned.

D. TRANSFORMATION OF SPATIOTEMPORAL DATA BETWEEN RELATIONAL DATABASE AND XML

Although the work of the transformation between relational database and XML has developed for several decades, the study of transforming fuzzy spatiotemporal data from relational databases to XML documents has only recently started and still merits further attention. To improve the interoperability of fuzzy spatiotemporal data between XML and relational database, Ma has investigated the formal conversions from the fuzzy UML model to the fuzzy XML model and the formal mapping from the fuzzy XML model to the fuzzy relational databases based on decomposition [26]. But this approach of transformation depends on the existence of a schema. There is an edge-based approach arose to solve it [24]. Bai *et al.*[8] optimized it and proposed a temporal edge approach to transform fuzzy spatiotemporal XML data into relational databases, which need no schema information for the transformation of fuzzy spatiotemporal data. Unfortunately, the reverse operations of these approaches are not taken into consideration.

III. FUZZY SPATIOTEMPORAL RELATIONAL DATA MODEL

In this part, we introduce some basic concepts comprising the definition and operation of modeling fuzzy spatiotemporal data in relational database. Distinct from general spatiotemporal data, fuzzy spatiotemporal data have a set of unique characteristics accounting for that. So we introduce the theory of fuzzy sets to describe fuzzy feature of fuzzy spatiotemporal data in this thesis. Fuzzy sets are sets whose elements have degrees of membership. Fuzzy set theory defines the membership of elements as possibility distribution, which accesses the membership of elements in the sets progressively. There is the membership function valued in the real unit interval [0, 1] be used to signify it in possibility distribution theory. When the degree of membership valued 1 or 0, that means the membership is certain one where the element absolutely belongs to the set or exactly the opposite. In the following sections, we call it as possibility collectively. Then we introduce the *MBR* to represent the position of fuzzy information, which indicates the conjunctive changes in the time period p of a rectangular. Given $t \in p$, the position of the *MBR* in t could be expressed by *x-axis* and *y-axis*: $x_{min} \leq x(t) \leq x_{max} \cap y_{min} \leq y(t) \leq y_{max}$, which could be represented as (x_{min}, y_{min}), (x_{max}, y_{max}).

The distinction of base tables between fuzzy spatiotemporal databases and general ones lies in the requirement of expressing temporal, spatial and fuzzy information of the former. Due to the conjunctive changes of that above-mentioned information, it is difficult to store just in one table. Therefore we propose 5 types of tables that link to each other by *ordinal* to represent fuzzy spatiotemporal information, which called *summary*, *OID*, *ATTR*, *position* and *motion*, respectively. *Summary* is the total information of the data; *OID* which called historical topological structure is the changing history of the spatiotemporal data and changes of which depict spatiotemporal objects changing into other spatiotemporal objects, such as creation, split, mergence, elimination and so on; *ATTR* is the static attribute of fuzzy spatiotemporal data while *position* and *motion* are dynamic ones which devote to describe the fuzzy position, velocity and the movement trend.

Definition 1 (Summary Type): The 4-tuple S (o, F_s, t, p) depicts the summary information of fuzzy spatiotemporal data, where o records the ordinal, F_s records fuzzy spatiotemporal data, t records the time, p records the possibility.

Definition 2 (Representation of Time): Use a pair (t_s, t_e) to describe the valid time period of fuzzy spatiotemporal data, where t_s is the begin time of the change of information, t_e is the end time of it. It is noted that t_s and t_e are both fuzzy time. As to the creation of fuzzy spatiotemporal data, there is no t_e. For simplicity, we regard the value of t_e as ∞. However, it doesn't mean the data would last forever.

Definition 3 (Representation of Ordinal): Given o as the ordinal of fuzzy spatiotemporal data, denoted by $0.1, 0.2 \ldots 0.k$ $(k \in N^+)$ when the table is summary type. Otherwise denoted by 0.k-m.n (m $=$ 1, 2, 3, 4, $n \in N^+$) when there is no sublists, where $0.k$ is the ordinal in summary table, n is the place in the table, m is the type of the table which means *OID*, *ATTR*, *position* and *motion*, respectively; If present, denoted by $0.k\text{-}m.n.p.q \ldots$ $(m = 1, 2, 3, 4;\ k, n, p, q \in N^+)$, where both p and q are the position in each sublist.

TABLE 1. Fuzzy spatiotemporal data clouds.

ordinal	fuzzy spatiotemporal data	time
0.1	cloud1	(t_1, t_2)
0.2	cloud2	(t_{14}, t_{15})
0.3	cloud3	(t_{16}, t_{17})

Example 1: As is shown in Table 1, it gives three fuzzy spatiotemporal data called *cloud1*, *cloud2* and *cloud3* of *Clouds*, whose ordinal are "0.1," "0.2" and "0.3" that means the first, the second and the third place in *summary* table, the valid time period are "(t_1, t_2)," "(t_{14}, t_{15})"and "(t_{16}, t_{17})," respectively.

Definition 4 (OID Type): The 4-tuple O (o, O_n, O_t, t) depicts the historical topological structure of spatiotemporal data, where o records the ordinal that references to Definition 3, O_n records the change's name *Oname*, O_t records the change's type *Otype*, t records the time where there is described in detail in Definition 2.

TABLE 2. *OID* of *Clouds*.

ordinal	Oname	Otype	time
0.1-1.1	WizKhalifa	create	(t_3)
0.2-1.2	Krovanh	create	(t_{18})
0.3-1.3	Nepartak	create	(t_{19})

Example 2: As is shown in Table 2, it gives the *OID* of three data in table 1. Take *cloud1* as example, its ordinal is "0.1-1.1" which means the ordinal is "0.1" in summary table and "1.1" in *OID* table, its name is "WizKhalifa" and the type is "create," the time of which is "(t_3)."

Definition 5 (ATTR Type): The 4-tuple A (o, A_n, A_t, t) depicts the static attribute of fuzzy spatiotemporal data, where o denotes the ordinal that connects to Definition 3, A_n denotes the attribute name which called *Aname*, A_t denotes the attribute type which called *Atype*, t denotes the time which could retrospect to Definition 2.

TABLE 3. ***ATTR* of *cloud1*.**

ordinal	Aname	Atype	time
0.1-2.1	covered cities	conjunctive	(t_4, t_5)
0.1-2.2	cloud density	disjunctive	(t_6, t_7)

Example 3: As is shown in Table 3, for attributes of *cloud1* which called covered cities and cloud density, whose ordinal are "0.1-2.1" and "0.1-2.2," type are conjunctive and disjunctive, time are "(t_4, t_5)" and "(t_6, t_7)," respectively.

Definition 6 (Position Type): The 5-tuple P (o, M_i, M_a, t, p) depicts the positional information of fuzzy spatiotemporal data, where o is the ordinal which traces to Definition 3, M_i is the minimum of position that can be described by *min* (x_{min}, y_{min}), M_a is the maximum of position that can be described by *max* (x_{max}, y_{max}), t is the time and the representing method as indicated in Definition 2, p is the possibility of the position.

TABLE 4. ***Position* of *cloud1*.**

ordinal	min	max	time	possibility
0.1-3.1	(3, 5)	(6, 8)	(t_8, t_9)	0.8
0.1-3.2	(4, 5)	(7, 6)	(t_8', t_9')	0.85

Example 4: As is shown in Table 4, it takes *cloud1* as example, given the positional information of it in "(t_8, t_9)," the ordinal is "0.1-3.1"and the possibility is "0.8," the *MBR* are "(3, 5)" and "(6, 8)," respectively.

Definition 7 (Motion Type): The 5-tuple M (o, x, y,t, p) depicts the motional information of fuzzy spatiotemporal data, where o records the ordinal that references to Definition 3, x and y record the direction and the velocity that called *x-axis* and *y-axis*. It is noted that the direction could be "↑," "↓," "←" and "→." Time is represented as t which could retrospect to Definition 2 and p is used to record the possibility of the motion.

TABLE 5. ***Motion* of *cloud1*.**

ordinal	x-axis	y-axis	time	possibility
0.1-4.1	→	↑	(t_{10}, t_{11})	0.7
0.1-4.2	4	6	(t_{12}, t_{13})	0.8

Example 5: As is shown in Table 5, there is the motional information of *cloud1* has been displayed. "→" and "↑" in (t_{10}, t_{11}) mean the directions on *x-axis* and *y-axis* are north and east, respectively. Possibility of the direction is 0.7. "4" and "6" in (t_{12}, t_{13}) represent the velocities on *x-axis* and *y-axis* are "4" and "6," respectively. Possibility of the velocity is "0.8."

The possibilities all above mentioned are relative ones. Since a relational database is composed of multiple tables that are linked together in some meaningful way, it can be used to describe fuzzy spatiotemporal data. As to the case that elements or attributes of spatiotemporal data is fuzzy, which can be denoted by fuzzy framework to indicate the possibility of elements change into those elements or attributes in relational databases. The possibility is relative and based on the assumption that the possibility is exactly 1.0 before the change. Such the possibility should be called relative possibility.

As for sublist, we'll give an example to specify in detail.

TABLE 6. ***Covered cities* of *cloud1*.**

ordinal	covered city	time	possibility
0.1-2.1.1	shenyang	(t_4, t_5)	0.8
0.1-2.1.2	dalian	(t_4, t_5)	0.7

TABLE 7. ***Cloud density* of *cloud1*.**

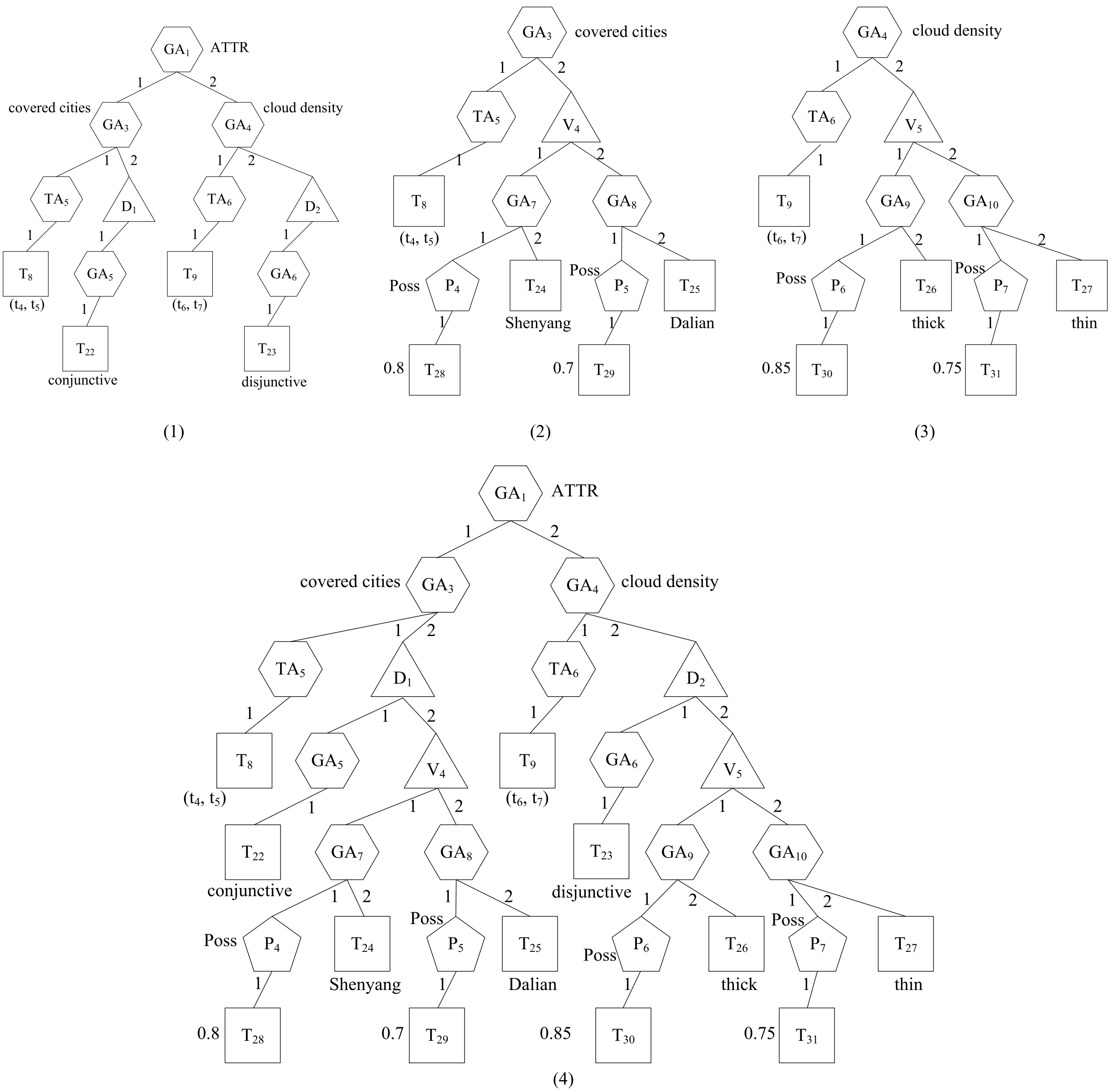
ordinal	cloud density	time	Possibility
0.1-2.2.1	thick	(t_6, t_7)	0.85
0.1-2.2.2	thin	(t_6, t_7)	0.75

Example 6: As is shown in Table 6 and Table 7, there two tables are sublists of Table 3, for the sake of supplementing the attribute of Table 3. In (t_4, t_5), the possibility of covering *Shenyang* and *Dalian* are "0.8" and "0.7," respectively. The ordinal of covering *Shenyang* and *Dalian* are "0.1-2.1.1" and "0.1-2.1.2," respectively. In (t_6, t_7), the possibility of the *cloud density* is "thick" or "thin" is "0.85"or "0.75." The ordinal of that are "0.1-2.2.1" and "0.1-2.2.2," respectively.

Among the 5 types of table defined, *summary* is the table to record the total information of data, *OID* is the table to depict the historical topological properties of data, *ATTR* is a kind of static table and *position* and *motion* are dynamic ones. Overall, the four types of table contribute to describe certain types of attribute of data that are *OID*, *ATTR*, *position* and *motion*, which could be regarded as sublists of summary table. Meanwhile they also have their own sublists. And as such, the fuzzy spatiotemporal relational databases can store a large amount of fuzzy spatiotemporal information, which meets the demand of the storage of data in various fuzzy spatiotemporal applications.

IV. TRANSFORMATION OF FUZZY SPATIOTEMPORAL DATA FROM RELATIONAL DATABASE TO XML

In this section, we exhibit a generic approach to transform fuzzy spatiotemporal data from relational model to XML model. Relational databases can be converted to ordered tree structure. Define a fuzzy spatiotemporal data tree has 8 types of nodes: root, element, general attribute, spatial



(1) (2) (3)

(4)

FIGURE 1. Fuzzy spatiotemporal data tree that concludes sublists.

attribute, temporal attribute, text, fuzzy structure and possibility attribute, where general attribute, spatial attribute and temporal attribute are all attribute nodes. Each attribute node owns the certain name and value. Define the general attribute as static attribute, spatial attribute and temporal attribute as dynamic one to describe the change of position and time, respectively. We regard per tuple in tables of *summary* type and *OID* type as element, *ATTR* type as general attribute, *position* type, *motion* type and their sublists as spatial nodes where we put forward representing the fuzzy attribute by using fuzzy structure. We consider time and possibility columns in one table as temporal attribute node and possibility attribute node, respectively. The exact value would be indicated as text node. It is noted that possibility, temporal and text nodes can be used as descendant nodes of element, general attribute and spatial attribute nodes.

Definition 8 (General Nodes): Given a table X (A, B, C, D), regard X as root node, each of tuples $S_1, S_2, S_3, \ldots, S_k$ $(k = N^+)$ as child nodes of X, the attribute columns as the child nodes of S_k which expressed as A_k, B_k, C_k, D_k $(k = N^+)$. If there is a sublist table A_k (E_k, F_k, G_k), then regard the attributes called E_k, F_k, G_k as child nodes of A_k, descendant nodes of S_k and X. It is noted that S_k $(k = 1)$ could be omitted and the attribute columns A_k, B_k, C_k, D_k should be the child nodes of X immediately when there is only one tuple in the table.

Regarding the relationship among tuples in all tables, if there are two tuples in the same length of the ordinal which only different from the last place, it means they share the same parent node and which are sibling node to each other; if in different length and the short one is the same with the left part of the long one entirely, they are parent-child relationship when whose lengths are different from one bite, otherwise they are ancestor-descendant relationship.

Definition 9 (Fuzzy Structure): Given a fuzzy spatiotemporal data table X (A, B, C, D), build the fuzzy structure nodes $V_1, V_2, V_3, \ldots, V_k$ ($k \in N^+$) as the child nodes of S_k, S_k ($k = 1$) could be omitted and the fuzzy attribute columns V_k should be the child nodes of X directly when there is only one tuple in the table. The attribute columns A, B, C, D will be the child nodes of V_k. And the part of sublists conferences to Definition 8.

Example 7: As is shown in Fig. 1 which takes Table 3, Table 6 and Table 7 as example, it regards *ATTR* as parent node and sets covered cities and cloud density as whose child nodes. Since covered cities and cloud density are fuzzy, we build the fuzzy structure nodes D_1 and D_2 as their child nodes. For Table 3, there are sublists called Table 6 and Table 7 linked with it, which are both fuzzy data. So we build the fuzzy structure nodes V_4 and V_5 as their child nodes, build GA_7, GA_8 and GA_9, GA_{10} as the child nodes of V_4 and V_5, respectively. At last, we take the attribute columns of sublists as the descendant nodes of root node *ATTR*.

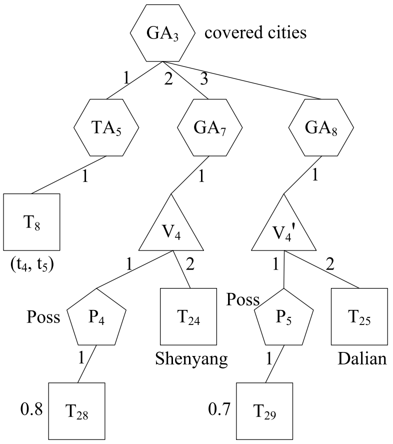


FIGURE 2. The original fuzzy spatiotemporal data tree of Table 6.

About the fuzzy spatiotemporal data tree of Table 6 in Fig. 1, it should be constructed as Fig. 2. On account of the same fuzzy structure of GA_7 and GA_8, we combine V_4 and V_4' as the parent nodes of GA_7 and GA_8 for simplicity. Similarly, we can get the fuzzy spatiotemporal data tree of Table 7, too.

In the case of the relationship among the nodes, we put forward an approach that uses the edges of fuzzy spatiotemporal data tree to denote it.

Definition 10 (Ordinal and Type of Edge): Given the parent node A and its child node B, combine them and get an edge A-B, assign the created edges with ordinal 1, 2, 3, 4, …, n ($n \in N^+$) in order from left to right if there are sibling nodes that share the same parent nodes. We divide the edges into seven types: *DD*, *DF*, *FD*, *FF*, *DT*, *TD*, *FT*, where the *DD* edge depicts the parent and the child node of the edge are deterministic nodes, the *DF* edge represents the parent and the child node of the edge are deterministic node and fuzzy node, the *FD* edge indicates the parent and the child node of the edge are fuzzy node and deterministic node, the *FF* edge denotes the parent and the child node of the edge are both fuzzy ones, the *DT* edge expresses the parent node is deterministic and the child node is temporal, the *TD* edge means the parent and the child node of the edge are temporal node and deterministic node, the *FT* edge describes the parent and the child node of the edge are fuzzy node and temporal node.

With regard to the *DF* edge, the *FD* edge, the *FF* edge and the *FT* edge that possess fuzzy node in virtue of the fuzzy structure, which is introduced to signify the fuzzy information. There is no TF edge in that the child nodes of the temporal attribute nodes must be text nodes.

Example 8: As is shown in Fig. 3 which takes the Table 4 as example, there are two different positions in two time periods, so we create two nodes that named *position1* and *position2* and introduce the fuzzy structure nodes V_1 and V_1' to describe the fuzzy positions clearly. Then combine the parent nodes with their child nodes in order from the root node. We use V_1 and V_1' to depict the fuzzy features of *position1* and *position2*. After that we assign the ordinal of created edges in order as Definition 10 shows. About the types proposed in Definition 10, SA_1-SA_3 and SA_1-SA_4 are both *DD* edges; SA_3-TA_2 and SA_4-TA_2' are both *DT* edges; SA_3-V_1 and SA_3-V_1' are both *DF* edges; TA_2-T_5 and TA_2'-T_5' are both *TD* edges; V_1-P_1, V_1-E_4, V_1-E_5, V_1-E_6, V_1-E_7, V_1'-P_1', V_1'-E_4', V_1'-E_5', V_1'-E_6' and $V1'$-E_7' are *FD* edges.

Definition 11 (Nodes With Multiple Time Periods): Given the temporal attribute columns of X: n_i, n_j, n_p, n_q (i, j, p, $q = 1, 2 \ldots$), n_j is the subset of n_i, n_q is the subset of n_p and n_p is the descendant set of n_i. Then we have $n_q \subset n_j$ and $\cup n_k = n_j$ ($k \in q$). We can draw a conclusion that n_j is the child node of n_i, n_q is the the child node of n_p and n_p is the descendant node of n_i in the data tree.

Example 9: Table 5 is a case study of the node with multiple time periods in relational database. If known time period (t_{12}, t_{13}) is contained by (t_{10}, t_{11}), we create the temporal attribute nodes TA_3, TA_7 and text nodes T_6, T_{18} as their child nodes to record (t_{10}, t_{11}) and (t_{12}, t_{13}), respectively. Then regard TA_3 as ancestor node of TA_7 and the temporal attributes nodes of the Table 5 are represented as TA_3 and TA_7 in Fig. 6.

In the actual approach of transformation, given the *summary* table, *OID* table, *ATTR* table, *position* table, *motion* table and some other sublists of fuzzy spatiotemporal data M, and the generic operation of converting fuzzy spatiotemporal data can be expressed by the following processes:

Step 1: Create the root nodes of each tables and the child nodes of it as E_i, GA_i or SA_i depends on the type of the table, where the operation is described in detail in Definition 8.

Step 2: Judge whether there is fuzzy information or not, create the fuzzy structure nodes V_i if there is and the operation is described in detail in Definition 9.

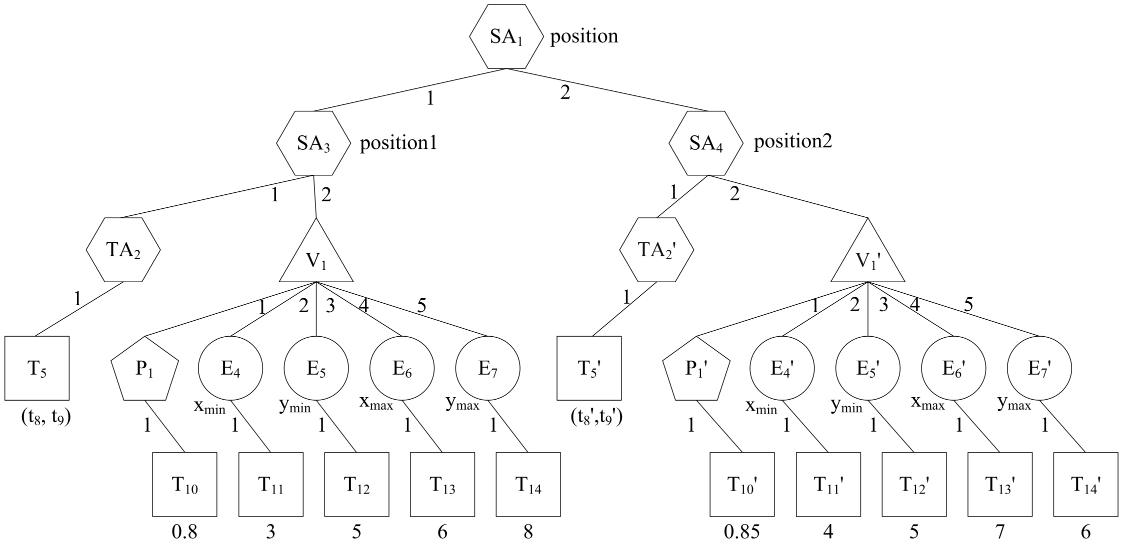


FIGURE 3. **Fuzzy spatiotemporal data tree of Table 4.**

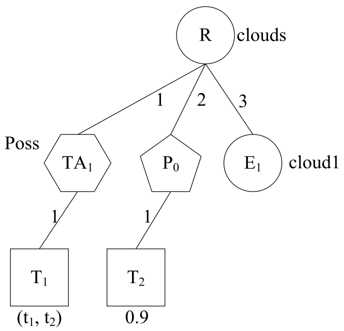


FIGURE 4. **Fuzzy spatiotemporal data tree of Table 1.**

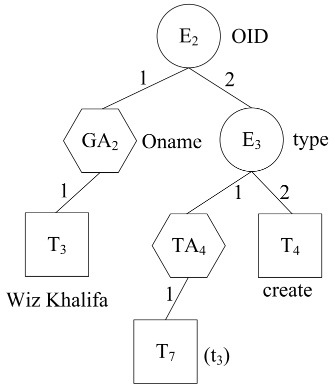


FIGURE 5. **Fuzzy spatiotemporal data tree of Table 2.**

Step 3: Create the possibility attribute nodes P_i. For the value of possibility columns are 1.0, we believe that there is no possibility attribute nodes.

Step 4: Create the temporal attribute nodes TA_i. We can create the temporal attribute nodes one by one and then delete the redundant ones towards the temporal columns in the same value. We state that if the time period of a node is the same with its descendant nodes, delete the ones of its descendant nodes. It is noted that the temporal attribute node of a node n is optional since the temporal attribute of n can be inherited from its ancestor node.

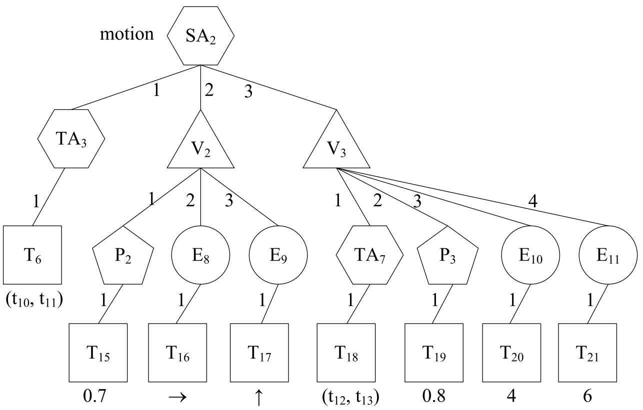


FIGURE 6. **Fuzzy spatiotemporal data tree of Table 5.**

Step 5: Create the text nodes to record the specific value for nodes created before.

Step 6: Combine the parent node m with its child nodes n_i, form the edge m-n_i $(i = 1, 2, 3 \ldots k)$, $k \in N^+$.

Step 7: Combine the created trees of every tables, look up and compare the root nodes with the terminal nodes, replace A_x with B if the root nodes of B is the same with the terminal nodes A_x of A, or look up the ordinal that shorter than the root nodes in one bite and is the same with left section of the root nodes which named X_0 when there is no similar nodes in the tree X, regard the found node X_0 as the parent node of X and combine them.

Step 8: Assign the ordinal of each edges where the operation is described in detail in Definition 10.

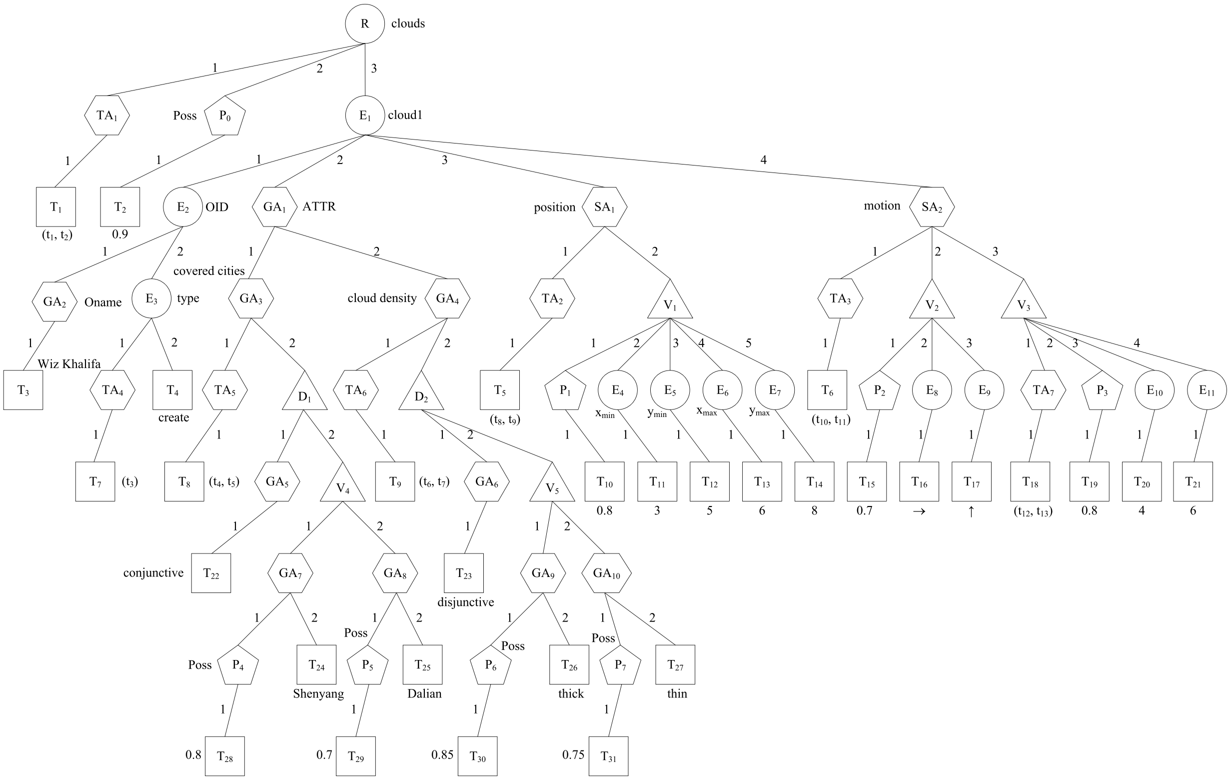


FIGURE 7. Fuzzy spatiotemporal data tree of *cloud1*.

```
1. <clouds Ts = “t1” Te = “t2”>
  2. <Val Poss = 0.9>
  3. <cloud1>
    4. <OID>
      5. <OID Oname = “Wiz Khalifa”>
    6. </OID>
    7. <type Ts = “t3”>“create”</type>
    8. <ATTR>
      9. <covered cities Ts = “t4” Te = “t5”>
        10. <Dist type = “conjunctive”>
          11. <Val Poss = 0.8>Shenyang</Val>
          12. <Val Poss = 0.7>Dalian</Val>
        13. </Dist>
      14. </covered cities>
      15. <covered cities Ts = “t4’” Te = “t5’”>
        16. <Dist type = “conjunctive”>
          17. <Val Poss = 0.9>Shenyang</Val>
          18. <Val Poss = 0.8>Dalian</Val>
        19. </Dist>
      20. </covered cities>
      21. <cloud density Ts = “t6” Te = “t7”>
        22. <Dist type = “disjunctive”>
          23. <Val Poss = 0.85>thick</Val>
          24. <Val Poss = 0.75>thin</Val>
        25. <Dist>
      26. </cloud density>
    27. </ATTR>
    28. <position Ts = “t8” Te = “t9”>
      29. <Val Poss = 0.8>
        30. <xmin>3</xmin>
        31. <ymin>5</ymin>
        32. <xmax>6</xmax>
        33. <ymax>8</ymax>
      34. </Val>
    35. </position>
    36. <position Ts = “t8’” Te = “t9’”>
      37. <Val Poss = 0.85>
        38. <xmin>4</xmin>
        39. <ymin>5</ymin>
        40. <xmax>7</xmax>
        41. <ymax>6</ymax>
      42. </Val>
    43. </position>
    44. <motion Ts = “t10” Te = “t11”>
      45. <Val Poss = 0.7>
        46. <xaxis>“ ”</xaxis>
        47. <yaxis>“ ”</yaxis>
      48. </Val>
      49. <Val Ts = “t12” Te = “t13”>
        50. <Val Poss = 0.8>
        51. <xval>4</xval>
        52. <yval>6</yval>
      53. </Val>
    54. </motion>
  55. </cloud1>
 56. </Val>
57. </clouds>
```

FIGURE 8. Fuzzy spatiotemporal XML documents of *cloud1*.

According to the procedure above mentioned, we can create the fuzzy spatiotemporal data tree of fuzzy data M.

Example 10: Assume the time period (t_{12}, t_{13}) is contained by (t_{10}, t_{11}), create the tree of Table 1-7 based on Step.1-6 as Fig.4, Fig.5, Fig.1, Fig.2 and Fig.6, respectively. According to Step.7, combine the five created trees references to Step. 9. It is obvious that *OID*, *ATTR*, *position* and *motion* are child nodes of *cloud1*, combine E_1 with E_2, GA_1, SA_1 and SA_2, form the edges E_1-E_2, E_1-GA_1, E_1-SA_1 and E_1-SA_2. At last, assign the created edges in order as Step. 8 shows, then we create the fuzzy spatiotemporal data tree of *cloud1* which is shown as Fig. 7. Due to the limited space, we omit the *position2* in Fig. 2 and the part of *position* in actual transformation is the same with Fig. 3.

In a sense, the XML document consists of a structure of data tree, which makes it easy to transform between XML documents and trees. Generally, an XML document is composed of root node, element nodes, attribute nodes and text content nodes. All elements can have $n(n \geq 0)$ other nodes like elements, attribute and text content as its subelements. From a formal modeling point of view, we consider the attribute nodes as elements of a special kind in this paper because there is no difference between an attribute and an element node and both of which perform as nodes in data tree. Thanks to the flexible format and the character of self-definition of XML, we can divide the nodes of XML data tree into element nodes and attribute nodes as required.

As is shown in Fig. 8, which is the result of transformation depend on the tree of Fig. 7. We define the temporal attribute nodes and possibility attribute nodes as the attribute nodes of XML document and the text nodes are regarded as text content nodes, the root node Clouds in the tree is considered as root node of XML document, and other nodes are defined as element nodes.

V. CONCLUSION

In this study, we investigated the methodology of modeling the fuzzy spatiotemporal data. Furthermore, an approach of transforming fuzzy spatiotemporal data from relational databases to XML documents has been proposed. We concluded a fuzzy spatiotemporal data tree based on ER, which contributed to the transformation above mentioned.

Future work will focus on evaluating the results of the proposed approach and extending the studies on the application of the transformation of fuzzy spatiotemporal data. We plan to further investigate a more convenient process to convert fuzzy spatiotemporal data. What's more, we will also devote to developing an automatic transformation of spatiotemporal data from relational database to XML without human intervention.

REFERENCES

[1] L. Antova, T. Jansen, C. Koch, and D. Olteanu, "Fast and simple relational processing of uncertain data," in *Proc. ICDE*, Cancun, Mexico, 2008, pp. 983–992.

[2] M. Ataş, "Hand tremor based biometric recognition using leap motion device," *IEEE Access*, vol. 5, pp. 23320–23326, 2017.

[3] M. Arenas, P. Barcelo, L. Libkin, and F. Murlak, "Relational and XML data exchange," *Synthesis Lectures Data Manage.*, vol. 2, no. 1, pp. 1–112, 2010.

[4] M. Atay, A. Chebotko, D. Liu, S. Lu, and F. Fotouhi, "Efficient schema-based XML-to-relational data mapping," *Inf. Syst.*, vol. 32, no. 3, pp. 458–476, 2007.

[5] F. A. Beltrán-Molina, J. Requena-Carrión, F. Alonso-Atienza, and N. Zemzemi, "An analytical model for the effects of the spatial resolution of electrode systems on the spectrum of cardiac signals," *IEEE Access*, vol. 5, pp. 18488–18497, 2017.

[6] L. Bai, Y. Li, and J. Liu, "FSPTwigFast: Holistic twig query on fuzzy spatiotemporal XML data," *Appl. Intell.*, vol. 47, no. 4, pp. 1224–1239, 2017.

[7] L. Bai, Y. Li, and J. Liu, "Fast leaf-to-root holistic twig query on XML spatiotemporal data," *J. Comput.*, vol. 12, no. 6, pp. 534–543, 2017.

[8] L. Bai, L. Yan, Z. M. Ma, and C. Xu, "Incorporating fuzziness in spatiotemporal XML and transforming fuzzy spatiotemporal data from XML to relational databases," *Appl. Intell.*, vol. 43, no. 4, pp. 707–721, 2015.

[9] L. Bai, L. Yan, and Z. M. Ma, "Determining topological relationship of fuzzy spatiotemporal data integrated with XML twig pattern," *Appl. Intell.*, vol. 39, no. 1, pp. 75–100, 2013.

[10] L. Bai, L. Yan, and Z. M. Ma, "Fuzzy spatiotemporal data modeling and operations in XML," *Appl. Artif. Intell.*, vol. 29, no. 3, pp. 259–282, 2015.

[11] L. Bai, Z. Jia, and J. Liu, "Formal transformation of spatiotemporal data from object-oriented database to XML," *J. Digit. Inf. Manage.*, vol. 15, no. 1, p. 1, 2017.

[12] L. Bai, Z. Shao, Z. Lin, and S. Cheng, "Fixing inconsistencies of fuzzy spatiotemporal XML data," *Appl. Intell.*, vol. 47, no. 1, pp. 257–275, 2017.

[13] L. Bai, X. Cao, and W. Jia, "Uncertain spatiotemporal data modeling and algebraic operations based on XML," *Earth Sci. Informat.*, pp. 1–19, 2017. [Online]. Available: https://doi.org/10.1007/s12145-017-0322-6

[14] T. Bray, J. Paoli, C. M. Sperberg-McQueen, E. Maler, F. Yergeau, and J. Cowan, "Extensible markup language (XML)," *World Wide Web J.*, vol. 2, no. 4, pp. 27–66, 1997.

[15] R. Bourret, C. Bornhovd, and A. Buchmann, "A generic load/extract utility for data transfer between XML documents and relational databases," in *Proc. 2nd Int. Workshop Adv. Issues E-Commerce Web-Based Inf. Syst.*, Milpitas, CA, USA, Jun. 2000, pp. 134–143.

[16] M. Cen and C. Jung, "Complex form of local orientation plane for visual object tracking," *IEEE Access*, vol. 5, pp. 21597–21604, 2017.

[17] A. Chebotko, M. Atay, S. Lu, and F. Fotouhi, "XML subtree reconstruction from relational storage of XML documents," *Data Knowl. Eng.*, vol. 62, no. 2, pp. 199–218, 2007.

[18] X. Chen, L. Yan, W. Li, and Z. M. Ma, "Reengineering fuzzy spatiotemporal UML data model into fuzzy spatiotemporal XML model," *IEEE Access*, vol. 5, pp. 17975–17987, 2017.

[19] E. F. Codd, "Data models in database management," *ACM SIGMOD Rec.*, vol. 11, no. 2, pp. 112–114, 1981.

[20] J. Fong, F. Pang, and C. Bloor, "Converting relational database into XML document," in *Proc. DEXA*, Munich, Germany, 2001, pp. 61–65.

[21] Z. Han, G. Shen, S. Yu, N. Ding, J. Tian, and Y. Tang, "Active trace: A sparse spatiotemporal representation for videos," *IEEE Access*, vol. 5, pp. 22433–22442, 2017.

[22] D. Lee, M. Mani, F. Chiu, and W. W. Chu, "NeT & CoT: Translating relational schemas to XML schemas using semantic constraints," in *Proc. CIKM*, McLean, VA, USA, 2002, pp. 282–291.

[23] Z. Li *et al.*, "A spatiotemporal indexing approach for efficient processing of big array-based climate data with MapReduce," *Int. J. Geograph. Inf. Sci.*, vol. 31, no. 1, pp. 17–35, 2017.

[24] J. Liu, Z. M. Ma, and X. Feng, "Storing and querying fuzzy XML data in relational databases," *Appl. Intell.*, vol. 39, no. 2, pp. 386–396, 2013.

[25] Z. M. Ma, "Modeling fuzzy information in the EER and nested relational database models," in *Flexible Databases Supporting Imprecision and Uncertainty* (Studies in Fuzziness and Soft Computing), vol. 203, Berlin, Germany: Springer, 2006, pp. 123–146.

[26] Z. M. Ma and L. Yan, "Fuzzy XML data modeling with the UML and relational data models," *Data Knowl. Eng.*, vol. 63, no. 3, pp. 972–996, 2007.

[27] Z. M. Ma, J. Liu, and L. Yan, "Fuzzy data modeling and algebraic operations in XML," *Int. J. Int. Syst.*, vol. 25, no. 9, pp. 925–947, 2010.

[28] Z. M. Ma, F. Zhang, L. Yan, and J. Cheng, "Querying fuzzy description logics and ontology knowledge bases," in *Fuzzy Knowledge Management for the Semantic Web* (Studies in Fuzziness and Soft Computing), vol. 306, Berlin, Germany: Springer, 2014, ch. 7, pp. 181–231.

[29] Z. M. Ma and L. Yan, "Modeling fuzzy data with XML: A survey," *Fuzzy Sets Syst.*, vol. 301, pp. 146–159, Oct. 2016.

[30] Z. M. Ma, L. Bai, Y. Ishikawa, and L. Yan, "Consistencies of fuzzy spatiotemporal data in XML documents," *Fuzzy Sets Syst.*, Mar. 2017. [Online]. Available: https://doi.org/10.1016/j.fss.2017.03.009

[31] Z. M. Ma, F. Zhang, L. Yan, and J. Cheng, "Extracting knowledge from fuzzy relational databases with description logic," *Integr. Comput.-Aided Eng.*, vol. 18, no. 2, pp. 181–200, 2011.

[32] Z. M. Ma and L. Yan, "A literature overview of fuzzy conceptual data modeling," *J. Inf. Sci. Eng.*, vol. 26, no. 2, pp. 427–441, 2010.

[33] R. Murthy and S. Banerjee, "Xml schemas in Oracle XML DB," in *Proc. VLDB*, Berlin, Germany, 2003, pp. 1009–1018.

[34] N. Salamat and E. Zahzah, "Fuzzy spatio-temporal relations analysis," in *Proc. 7th Int. Conf. Inf. Technol. New Generat.*, Las Vegas, NV, USA, Apr. 2010, pp. 301–306.

[35] J. Shanmugasundaram, K. Tufte, C. Zhang, G. He, D. J. Dewitt, and J. F. Naughton, "Relational databases for querying XML documents: Limitations and opportunities," in *Proc. VLDB*, San Francisco, CA, USA, 1999, pp. 302–314.

[36] J. Shanmugasundaram, J. Kiernan, E. J. Shekita, C. Fan, and J. Funderburk, "Querying XML views of relational data," in *Proc. VLDB*, vol. 1. 2001, pp. 261–270.

[37] A. Sözer, A. Yazıcı, H. Oğuztüzün, and O. Taş, "Modeling and querying fuzzy spatiotemporal databases," *Inf. Sci.*, vol. 178, no. 19, pp. 3665–3682, 2008.

[38] I. Tatarinov, S. D. Viglas, K. Beyer, J. Shanmugasundaram, E. Shekita, C. Zhang, "Storing and querying ordered XML using a relational database system," in *Proc. SIGMOD*, New York, NY, USA, 2002, pp. 204–215.

[39] E. Tossebro and M. Nygård, "Uncertainty in spatiotemporal databases," in *Proc. Int. Conf. Adv. Inf. Syst.*, Izmir, Turkey, 2002, pp. 43–53.

[40] Y. Wang, "Real-time moving vehicle detection with cast shadow removal in video based on conditional random field," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 19, no. 3, pp. 437–441, Mar. 2009.

[41] L. Yan, Z. M. Ma, and J. Liu, "Fuzzy data modeling based on XML schema," in *Proc. ACM Symp. Appl. Comput.*, New York, NY, USA, 2009, pp. 1563–1567.

[42] L. A. Zadeh, "Fuzzy sets," *Inf. Control*, vol. 8, no. 3, pp. 338–353, Jun. 1965.

[43] L. A. Zadeh, "Fuzzy sets as a basis for a theory of possibility," *Fuzzy Sets Syst.*, vol. 1, no. 1, pp. 3–28, 1978.

[44] F. Zhang, Z. M. Ma, Y. Lv, and X. Wang, "Formal semantics-preserving translation from fuzzy ER model to fuzzy OWL DL ontology," in *Proc. WI*, Washington, DC, USA, 2008, pp. 503–509.

[45] F. Zhang, Z. M. Ma, and L. Yan, "Representation and reasoning of fuzzy ER model with description logic," in *Proc. IEEE Int. Conf. IEEE World Congr. Comput. Intell.*, Hong Kong, Jun. 2008, pp. 1358–1365.

[46] Z. Zhao, W. Ding, J. Wang, and Y. Han, "A hybrid processing system for large-scale traffic sensor data," *IEEE Access*, vol. 3, pp. 2341–2351, Nov. 2015.

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