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Fuzzy Spatio-temporal Data Modeling Based on XML Schema

Xu Chen[a], Li Yan[b], Weijun Li[a], Fu Zhang[c]

[a]*Internet Network Information Center, North Minzu University, Yinchuan 750021, China*
[b]*College of Computer Science and Technology, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China*
[c]*School of Computer Science and Engineering, Northeastern University, Shenyang 110819, China*

Abstract. With the rapid development of Internet and Big data applications, massive time and space data need to be processed. In order to manage space and time data, the key point is to build a correct data model. There are a lot of fuzzy temporal and spatial information in the real world, and XML has been a useful technology for dealing with various information in the context of Web. In this paper, we first study the fuzzy spatio-temporal data tree by extending the XML Schema and then propose a fuzzy spatio-temporal data model based on XML. Finally, we use the meteorological data to illustrate the validity and usability of the model.

1. Introduction

The real world is always changing in space over time. Hence, a lot of time and space data are produced. With the rapid development of the Internet, Big data [1], and Artificial Intelligence [2], the requirements of spatio-temporal data management can reflect not only the objective fact but also internal relations of valuable results produced by data mining. The key to spatio-temporal data management is to build a suitable spatio-temporal data model. Currently, there are some studies on traditional spatio-temporal data model, such as ER model [3-5], EER model [6, 7], and UML model [8-11], with the purpose of which is to represent spatio-temporal data.

In real-world applications, information often is ambiguity or vagueness. Due to the measurement error and the discretization of data, the spatio-temporal information of the entity and the various relationships usually contain fuzziness. That is, the fuzziness is considered to be an inherent feature of the spatio-temporal application [12]. To make the traditional database represent and deal with the fuzzy information, a lot of research work has been done on the fuzzy database model, and some fruitful theoretical results have been obtained [13], including fuzzy concept data model (e.g., ER[14], EER[15], UML[16]), fuzzy logic database model(e.g., RDB[17], OODB[18, 19]), emerging fuzzy data model (e.g., XML[20]). However, these fuzzy data models can only represent the fuzzy values of the general attributes of the entities, and can not represent the fuzziness of the spatio-temporal attributes.

XML has been widely used as a standard language to represent and exchange various data on the Web due to the electronic description structure of XML and its text and non-proprietary formats. There have

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Email addresses: Fuzzychx@gmail.com (Xu Chen), yanli@nuaa.edu.cn (Li Yan), liweijun628@gmail.com (Weijun Li), zhangfu216@126.com (Fu Zhang)

been several efforts aimed at combining spatial and temporal properties into XML documents, including spatial and temporal data. First, the current research focuses on how to represent and manage spatial data in crisp XML documents. Document [21] uses multidimensional XML to represent spatial data and establishes links with attributes. Document [22] discusses the representation of spatial data in XML, mainly by combining spatial data with XML documents through " wrapped" and analyse it by graphics. Secondly, a small amount of work has begun to focus on the ambiguity of spatio-temporal data. Fuzzy spatio-temporal XML data model is establishing in [23], after discussing the spatio-temporal data, a simple XML data model is given, and then the XML query is presented.

However, the existing research work does not take into account the completeness of the semantics of spatio-temporal data in XML. That is, it does not take full account of the relationship between time and space, and does not reflect the semantic relations between spatio-temporal entities and classes. Thus, the model can not be applied to more application scenarios.

In Section 2, we discuss the semantics of fuzzy spatio-temporal data, including fuzzy time data, fuzzy spatial data. Section 3 discusses the fuzzy spatio-temporal data tree and gives the relationship with the fuzzy spatio-temporal data model. Section 4 extends XML Schema to establish an association with the XML data tree. In the Section 5, the paper expatiates on the feasibility of fuzzy spatio-temporal XML data model using XML document.

2. Fuzzy spatio-temporal data

2.1. Fuzzy time data

Due to various factors, time data usually show a lot of uncertainty. In order to express these uncertainties, we give the relevant definitions for fuzzy time objects and time relations.

2.1.1. Fuzzy time object

Definition 1.1 (Fuzzy time point). A fuzzy time point is a series of time points with the probability that an event occurs. Let the $\dot{t}_p$ be an indefinite time point in the time domain, and the fuzzy time point is denoted by $\dot{t}_p = (t, \delta)$, $\delta \in [0, 1]$, t is the determined time point, where δ is the membership degree of the time point t, the greater the δ, the higher the likelihood.

Definition 1.2 (Fuzzy time interval). The fuzzy time interval is a period of time consisting of two end time points, the start time and the end time, at least one of which is a fuzzy time point. Let $\dot{t}_i$ denotes a fuzzy time interval, t_s denotes the starting time point, δ_s denotes the membership degree of t_s, t_e denotes the time point of end, δ_e denotes the membership degree of t_e, so the fuzzy time interval can be expressed as $\dot{t}_i = (t_s, \delta_s, t_e, \delta_e)$, where $\delta_s \in [0, 1]$ and $\delta_e \in [0, 1]$.

2.1.2. Fuzzy time relations

The fuzzy time relation is the definition of the relationship between the time point and the time interval. The current research is more about the time topological relation, and the research on the relationship between the time direction and the time metric is less.

Definition 1.3 (Fuzzy temporal direction relation). The fuzzy time direction relation is the sequence relation between fuzzy time objects, which indicates the direction relation between two fuzzy time objcets. The fuzzy time direction relationship can be expressed by a quaternion of $\dot{R}_{t-direction} = (\dot{t}_1, \dot{t}_2, \tau_d, \delta_d)$, $\tau_d \in \{\rightarrow, \leftarrow\}$,$\delta_d \in$[0, 1], where $\dot{t}_1$ and $\dot{t}_2$ represent two different fuzzy time objects, τ_d values are $\rightarrow$ and $\leftarrow$, and their relative directions are forward ($\dot{t}_1 < \dot{t}_2$) or backward ($\dot{t}_1 > \dot{t}_2$), δ_d indicates the membership degree of this direction relationship.

Definition 1.4 (Fuzzy temporal metric relation). The fuzzy time metric relation represents the length / distance between two fuzzy time objects. The fuzzy time metric can be represented by any time granularity, for example, e.g., seconds, minutes, or hours. The fuzzy time metric can be expressed by a quaternion of $\dot{R}_{t-metric} = (\dot{t}_1, \dot{t}_2, \tau_m, \delta_m)$, $\tau_m \in$ [0, N], $\delta_m \in$[0, 1], where $\dot{t}_1$ and $\dot{t}_2$ represent two different fuzzy time objects. The value of τ_m is any natural number, which represents two fuzzy time objects, δ_m indicates the membership degree of the metric relationship.

Definition 1.5 (Fuzzy temporal topological relation). Fuzzy time topological relation refers to two fuzzy time objects in the case of continuous deformation of things, the occurrence of the same time the event remains unchanged. Fuzzy time topological relations can be expressed by a quaternion $\dot{R}_{t-topological}$ = ($\dot{t}_1$, $\dot{t}_2$, τ_t, δ_t), τ_t ∈ [Disjoint, Contain, Overlap, Meet, Equal], δ_t ∈[0, 1], where $\dot{t}_1$ and $\dot{t}_2$ represent two different fuzzy time objects. τ_t values are Disjoint, Contain, Overlap, Meet, Equal, which represent different topologies relationship, δ_t indicates the membership degree of these topological relations.

2.2. Fuzzy spatial data

2.2.1. Fuzzy spatial object

Fuzzy spatial data refers to data that describe the location, shape, size, and distribution of spatial entities, which containing fuzziness, based on the spatial position of the Earth's surface.

Definition 1.6 (Fuzzy spatial point). A fuzzy spatial point is a point where its exact location is not determined within a possible area. The fuzzy space point is represented by the quaternion $\dot{s}_p = (x, y, z, \delta_p)$,where (x, y, z) are the coordinates of the fuzzy point in the three-dimensional coordinate system, $\delta_p \in [0, 1]$ is the fuzzy membership degree of the point in the coordinates (x, y, z).

Definition 1.7 (Fuzzy spatial line). A fuzzy spatial line is a collection of two points with fuzziness, and the position of the line is within a known area, and the coordinates of its two endpoints may be fuzzy. The fuzzy spatial line is formally represented by the tuple $\dot{s}_l$=(x_1, y_1, z_1, δ_{l1}, x_2, y_2 , z_2, δ_{l2}), where (x_1, y_1, z_1) is the coordinates of one end of the fuzzy spatial line, (x_2, y_2, z_2) is the coordinates of the other end of the fuzzy spatial line, $\delta_{l1} \in [0, 1]$ and $\delta_{l2} \in [0, 1]$ represent the fuzzy membership degrees of the two coordinates respectively.

Definition 1.8 (Fuzzy spatial region). The fuzzy spatial region is a known area where the boundary is uncertain, and can be represented by MBR (Minimum Bounding Rectangle) [24]. The fuzzy spatial region is formally represented by the tuple $\dot{s}_r$=(x_{min}, y_{min}, δ_{min}, x_{max}, y_{max}, δ_{max}), where (x_{min}, y_{min}) is the two coordinates of the minimum vertex of the fuzzy spatial region, (x_{max}, y_{max}) is the two coordinates of the maximum vertex of the fuzzy spatial region, $\delta_{min} \in [0, 1]$ is the membership degree of the minimum vertex, and $\delta_{max} \in [0, 1]$ is the membership degree of the maximum vertex.

2.2.2. Fuzzy spatial relations

Fuzzy spatial relation refers to the spatial relationship between fuzzy spatial objects, including fuzzy spatial direction, metric and topological relations.

Definition 1.9 (Fuzzy spatial direction relation). The spatial direction relation is fuzziness due to the uncertainty of spatial entity location, the ambiguity of spatial entity attributes and the vague of spatial entity boundary. The spatial orientation of fuzzy space can be expressed by a quaternion $\dot{R}_{s-direction}$ = ($\dot{s}_1$, $\dot{s}_2$, ψ_d, δ_d), ψ_d ∈{→, ↓, ←, ↑, ↘, ↙, ↖, ↗},δ_d ∈[0, 1], where $\dot{s}_1$ and $\dot{s}_2$ represent two different fuzzy spatial objects. The values of ψ_d is →, ↓, ←, ↑, ↘, ↙, ↖ and ↗, and the relative direction of two fuzzy spatial objects is east, south, west, north, southeast, northeast, southwest and northwest, ψ_d indicates the membership degree of fuzzy spatial direction relationship, from 0 to 1.

Definition 1.10 (Fuzzy spatial metric relation). The fuzzy spatial metric relation describes the relative position and distribution of fuzzy space entities, and can objectively reflect the degree of proximity between fuzzy entities. Fuzzy spatial metric relationship can be expressed by a quaternion $\dot{R}_{s-metric}$ = ($\dot{s}_1$, $\dot{s}_2$, ψ_m, δ_m), ψ_m ∈ [0, N], δ_m ∈[0, 1], where $\dot{s}_1$ and $\dot{s}_2$ represent two different fuzzy spatial objects. The value of ψ_m is an arbitrary natural number, which represents the exact distance between two fuzzy spatial objects, δ_m denote membership degree of the fuzzy spatial metric relationship.

Definition 1.11 (Fuzzy spatial topological relation). Fuzzy spatial topological relations refer to the content that remains unchanged under the topology change, such as rotation, proportional transformation and so on. Due to the fuzziness of spatial data, such as fuzziness of position, fuzziness of attribute and fuzziness of subjective, the relationship is also fuzziness. Fuzzy spatial topological relationship can be expressed by a quaternion $\dot{R}_{s-topological}$ = ($\dot{s}_1$, $\dot{s}_2$, ψ_s, δ_s), ψ_s ∈ [Equal, Meet, Overlap, Contain, Disjoint, Intersect], δ_s ∈[0, 1], where $\dot{s}_1$ and $\dot{s}_2$ represent two different fuzzy spatial objects. ψ_s can be Equal, Meet, Overlap, Contain, Disjoint and Intersect, it represents the topological relation between fuzzy spatial objects, and δ_s denote membership degree of the fuzzy spatial topological relationship.

3. Fuzzy spatio-temporal XML data tree

3.1. Structure of fuzzy spatio-temporal data tree

For XML documents, a basic structure is the data tree, which makes the XML document have a clear, hierarchical structure. Such structure also makes XML documents easy to expand, transplant, and easy to facilitate the operation of such data query. This paper introduces the fuzzy spatio-temporal concept to enhance the expression of the spatial and temporal semantics of XML data tree. We give a formal definition of fuzzy spatio-temporal XML data tree containing event information as follows.

Definition 2.1 (Fuzzy spatio-temporal XML data tree). A fuzzy spatio-temporal XML data tree is a ten-tuple $F_{tree} = (V, \zeta, \gamma, \lambda, \varphi, \psi, \eta, \iota, \tau, \kappa)$,where:

(1) $V = (V_1,...,V_i)$ is a set of finite node sets;

(2) ζ is a label set that can mark directions and relationships, which are used to mark the direction, time relationship, and spatial relationship associated with each node in the tree;

(3) $\gamma \in \{(V_m, V_n) | V_m, V_n \in V\}$ denotes a directed fuzzy spatio-temporal data tree;

(4) λ defines the partial order relation (reflexivity, antisymmetry, and transitivity) of fuzzy spatio-temporal data tree V, which is used to represent the order relation between documents;

(5) φ is used to represent the time data of node v_i in fuzzy temporal data, $\varphi \in \{(V_m, V_n) | V_m, V_n \in V\}$;

(6) ψ is used to represent the spatial data of node v_i in fuzzy spatio-temporal data,$\psi \in \{(V_m, V_n) | V_m, V_n \in V\}$;

(7) η is used to describe fuzzy spatio-temporal events;

(8) ι represents the depth of the node $v \in V$ in the fuzzy spatio-temporal data tree, the default depth of the root is 1, and the depth of the next layer is incremented by 1.

(9) $\tau \in [0, 1]$ is the membership of tree node $v \in V$, which indicates the possibility of the existence of the tree nodes;

(10) κ is a possible function that shows the probability that the child node belongs to the parent node.

3.2. Fuzzy spatio-temporal data model and structure of XML data tree

Definition 2.2. An abstract fuzzy spatio-temporal data model can be expressed as a six-tuple $\dot{M}$ =(*Fclass*, *Frelationship*, *Fattribute*, *Fevent*, *Ftime*, *Fspace*), where:

(a) *Fclass* =($\check{c}_1, \check{c}_2,..., \check{c}_k$) is a fuzzy spatio-temporal class. If $\check{O} = (\check{o}_1, \check{o}_2,..., \check{o}_m)$ denotes a fuzzy spatio-temporal entity, then *Fclass* = ($\check{o}_1, \check{o}_2,..., \check{o}_m$).

(b) *Frelationship* = ($\check{r}_1, \check{r}_2,..., \check{r}_w$) denotes a fuzzy spatio-temporal relationship;

(c) *Fevent* = ($\check{e}_1, \check{e}_2,..., \check{e}_q$) denotes a fuzzy spatio-temporal event;

(d) *Fattribute* = ($\check{a}_1, \check{a}_2,..., \check{a}_n$) denotes fuzzy spatio-temporal characteristics;

(e) *Ftime* denotes fuzzy time data;

(f) *Fspace* denotes fuzzy space data.

If we want to represent the fuzzy spatio-temporal data model accurately, we need to establish the correspondence between the fuzzy spatio-temporal data model and the fuzzy spatio-temporal data tree. Therefore, a formal definition of the relation is given:

Definition 2.3. The relationship between Fuzzy spatio-temporal data tree $F_{tree} = (V, \zeta, \gamma, \lambda, \varphi, \psi, \eta, \iota, \tau, \kappa)$ and fuzzy spatio-temporal data model $\dot{M}$ =(*Fclass*, *Frelationship*, *Fattribute*, *Fevent*, *Ftime*, *Fspace*) is as follows.

- *Fclass* $\sim V, \zeta, \gamma, \lambda, \varphi, \psi, \eta, \iota, \kappa$
- *Frelationship* $\sim V, \zeta, \lambda, \eta$
- *Fattribute* $\sim V, \lambda, \iota, \tau$
- *Fevent* $\sim V, \zeta, \gamma, \lambda, \eta, \iota, \tau, \kappa$
- *Ftime* $\sim V, \zeta, \lambda, \varphi, \iota, \tau$
- *Fspace* $\sim V, \zeta, \lambda, \psi, \iota, \tau$

Where ∼ represents the correspondence between the data tree and the model.

For example, *Fclass* is a fuzzy spatio-temporal entity/class, where V is an element node on a fuzzy spatio-temporal tree, and an entity/class is a critical element node; ζ is a label with a direction and semantic relation, which is associated with a fuzzy spatio-temporal entity/class, and a corresponding association; γ corresponds to fuzzy spatio-temporal data tree; λ corresponds to the order relationship between nodes; φ, ψ corresponds to spatio-temporal data related to classes and entities; η corresponds to events that are related to entity/class; ι corresponds to the depth of the entity/class; κ corresponds to the possibility that the node element belongs to the parent node.

By correlating the fuzzy spatio-temporal data model elements and fuzzy spatio-temporal XML data tree, we get the mapping between fuzzy spatio-temporal data model in the data tree, which is defined as follows:

Definition 2.4. Fuzzy spatio-temporal data model $\dot{M}$ =(*Fclass*, *Frelationship*, *Fattribute*, *Fevent*, *Ftime*, *Fspace*) is expressed in XML data tree F_{tree} = (V, ζ, γ, λ, φ, ψ, η, ι, τ, κ) as:

- V = {*FST Data, Fclass, Ftime, Fevent, Fspace, Fattribute, Frelationship, FTObject, FTRelation, FSObject, FSRelation, FRgener, FRaggre, FRassoc, FTpoint, FTinterval, FTRdirection, FTRmetric, FTRtopology, FSpoint, FSline, FSregion, FSRdirection, FSRmetric, FSRtopology*,(t, δ), (t_s, δ_s, t_e, δ_e), (→, ←), *TVal*, (Equal, Meet, Overlap, Contain, Disjoint), (x, y, z, δ_p), (x_1, y_1 , z_1, δ_{l1}, x_2, y_2, z_2, δ_{l2}), (x_{min}, y_{min}, δ_{min}, x_{max}, y_{max}, δ_{max}), (→, ↓, ←, ↑, ↘, ↙, ↖, ↗), *SVal*, (Equal, Meet, Overlap, Contain, Disjoint, Intersect)}
- ζ = {*Frelationship, FRgener, FRaggre, FRassoc, FTRdirection, FTRmetric, FTRtopology, FSRdirection, FSRmetric, FSRtopology,* (→, ←), *TVal*, (Equal, Meet, Overlap, Contain, Disjoint), (→, ↓, ←, ↑, ↘, ↙, ↖, ↗), *SVal*, (Equal, Meet, Overlap, Contain, Disjoint, Intersect)}
- φ = {Ftime, FTObject, FTRelation, FTpoint, FTinterval, FTRdirection, FTRmetric, FTRtopology, $((t, \delta))$, (t_s, δ_s, t_e, δ_e), (→, ←), *TVal*, (Equal, Meet, Overlap, Contain, Disjoint)}
- ψ = {*Fspace, FSObject, FSRelation, FSpoint, FSline, FSregion, FSRdirection, FSRmetric, FSRtopology*, (x, y, z, δ_p), (x_1, y_1 , z_1, δ_{l1}, x_2, y_2, z_2, δ_{l2}), (x_{min}, y_{min}, δ_{min}, x_{max}, y_{max}, δ_{max}), (→, ↓, ←, ↑, ↘, ↙, ↖, ↗), *SVal*, (Equal, Meet, Overlap, Contain, Disjoint, Intersect)}
- η = *Fclass, Frelationship*
- ι (*FST Data*) = 1; ι (*Fclass, Ftime, Fevent, Fspace, Fattribute, Frelationship*) = 2; ι (*FTObject, FTRelation , FSObject, FSRelation, FRgener, FRaggre , FRassoc*) = 3; ι (*FTpoint, FTinterval, FTRdirection, FTRmetric, FTRtopology, FSpoint, FSline, FSregion, FSRdirection, FSRmetric, FSRtopology*) = 4, ι ((t, δ), (t_s, δ_s, t_e, δ_e), (→, ←), *TVal*, (Equal, Meet, Overlap, Contain, Disjoint), (x, y, z, δ_p), (x_1, y_1, z_1, δ_{l1}, x_2, y_2, z_2, δ_{l2}), (x_{min}, y_{min}, δ_{min}, x_{max}, y_{max}, δ_{max}), (→, ↓, ←, ↑, ↘, ↙, ↖, ↗), *SVal*, (Equal, Meet, Overlap, Contain, Disjoint, Intersect)) = 5

Through the above definition, we sort out the correspondence between the model elements and the data tree elements, so we get the representation of the spatio-temporal elements in the data tree, as shown in Figure 1:

According to definition 2.4, all the node elements first correspond to V, and then the relation labels of each layer correspond to ζ. All the time elements correspond to φ, and all the spatial elements correspond to ψ. All the event elements correspond to η, and finally, the corresponding elements are placed at different depths according to the analysis results of ι.

4. Representation of fuzzy data in XML data tree and schema

To represent and use fuzzy temporal and spatial information in XML modeling, we need to introduce some new fuzzy constructors and spatio-temporal representations in XML data tree to realize the extension of XML. Adding a new fuzzy spatio-temporal data constructor requires the XML data tree to be defined. The earliest use of the document mode of XML is DTD, but DTD does not follow the XML syntax. Some

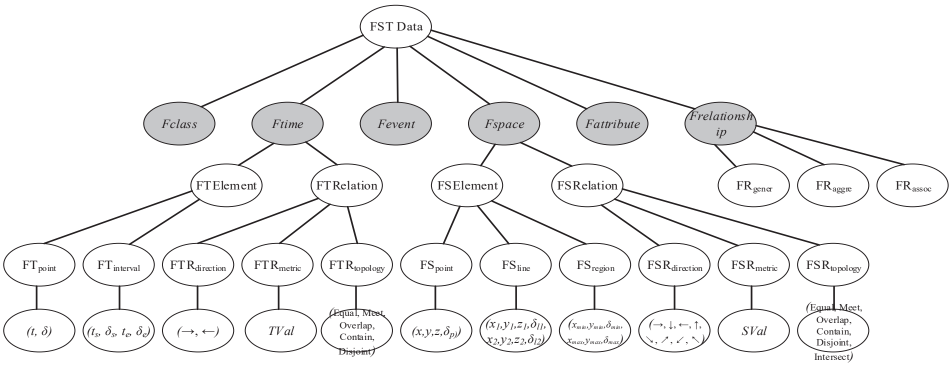

Figure 1: Fuzzy XML data tree structure

data types are also limited, which leads to naming conflicts. However, Schema can expand a large number of data types and support element inheritance and attribute groups. Therefore, the W3C is the official recommendation of the Schema. To accommodate more fuzzy information and spatio-temporal information in XML, XML Schema needs to be extended. The following shows the representation of fuzzy spatio-temporal data in the XML data tree and XML Schema.

4.1. Representation of fuzzy spatio-temporal entity/class

■ Representation in the XML data tree

As shown in Figure 3, by analyzing the fuzzy spatio-temporal data model, it is necessary to consider the three kinds of fuzziness [25]of the fuzzy spatio-temporal entity/class in the XML data tree. In the data tree, the gray line ellipse is used to represent the crisp attributes and the dotted gray ellipses are used to show the ambiguity of the first level which means that the possibility of the class belonging to the data model. We use the ellipse "Poss" with solid lines to represent the ambiguity of the second level of the class which means the possibility that the entity belongs to the class.

5. Representation of fuzzy data in XML data tree and schema

5.1. Fuzzy spatio-temporal data model and structure of XML data tree

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■ Representation in the XML Schema

XML includes two types of fuzziness[26]. The first fuzziness is related to the element, which can be expressed by relative membership degree. The second one is related to the element attribute values, and they are all represented by fuzzy sets. The fuzzy entity/class element in spatio-temporal data has the same characteristic attribute as crisp fuzzy entity/class. Based on the method of literature [27], fuzzy entity/class that cannot contain the spatio-temporal information elements can be represented as shown in figure 2(a). The "*Val*" in line 11 indicates the possibility of an element in the XML document, and "*Dist*" on line 18 is a fuzzy constructor, which represents the probability distribution.

(a) Fuzzy spatio-temporal entity/class

```
<xs:element name="FuzzyObject/Class" type="FuzzyObject/Classtype"/>
 <xs:complexType name="FuzzyObject/Classtype">
  <xs:sequence>
     <xs:element ref="Crispelement"/>
     <xs:element ref="Fuzzyelement"/>
    </xs:sequence>
 </xs:complexType>
<xs:element name="Crispelement" type="xs:string" minOccurs="0" maxOccurs="1"/>
<xs:element name="Fuzzyelement" type="Fuzzyelementtype" minOccurs="0" maxOccurs="1"/>
 <xs:complexType name="Fuzzyelementtype">
  <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>
  <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="conjunctive"/>
    </xs:complexType>
 </xs:complexType>
```

(b) Fuzzy temporal objects

```
    <xs:element name="FuzzyTime" type="FuzzyTimetype"/>
    <xs:complexType name="FuzzyTimetype">
           <xs:choice minOccurs="0" maxOccurs="2">
           <xs:element ref="FuzzyTimePoint" type="FuzzyTimePointtype"/>
           <xs:element ref="FuzzyTimeInterval" type="FuzzyTimeIntervaltype"/>
           </xs:choice>
    </xs:complexType>
  <xs:simpleType name="FuzzyTimePointtype">
           <xs:union memberTypes="TimePoint Val"/>
    </xs:simpleType>
    <xs:element name="TimePoint" type="xs:dataTime"/>
  <xs:simpleType name="FuzzyTimeIntervaltype">
     <xs:union memberTypes="FuzzyStartingTime FuzzyEndingTime"/>
    </xs:simpleType>
    <xs:simpleType name="FuzzyStartingTime">
     <xs:union memberTypes="StartingTime Val"/>
    </xs:simpleType>
    <xs:simpleType name="FuzzyEndingTime">
     <xs:union memberTypes="EndingTime Val"/>
    </xs:simpleType>
    <xs:element name="StartingTime" type="xs:dateTime"/>
    <xs:element name="EndingTime" type="xs:dateTime"/>
```

(c) Fuzzy temporal relationships

```
<xs:element name="FuzzyTimeRelations" type="FuzzyTimeRelationstype"/>
 <xs:complexType name="FuzzyTimeRelationstype">
  <xs:sequence>
   <xs:element name="Aclass" type="Fuzzyelementtype"/>
   <xs:element name="Bclass" type="Fuzzyelementtype"/>
  </xs:sequence>
  <xs:choice minOccurs="0" maxOccurs="3">
   <xs:element name="FuzzyTimeDirection" type="FuzzyTimeDirectiontype"/>
    <xs:element name="FuzzyTimeMetric" type="FuzzyTimeMetrictype"/>
    <xs:element name="FuzzyTimeTopological" type="FuzzyTimeTopologicaltype"/>
  </xs:choice>
</xs:complexType>
 <xs:simpleType name="FuzzyTimeDirectiontype">
  <xs:restriction base="xs:string">
  <xs:pattern value="←|→"/>
  </xs:restriction>
 </xs:simpleType>
 <xs:simpleType name="FuzzyTimeMetrictype">
  <xs:union memberTypes="TimeMetric Val"/>
 </xs:simpleType>
<xs:element name="TimeMetric" type="xs:time"/>
<xs:simpleType name="FuzzyTimeTopologicaltype">
 <xs:restriction base="xs:string">
 <xs:pattern value="Equal|Meet|Overlap|Contain|Disjoint"/>
 </xs:restriction>
</xs:simpleType>
```

(d) Fuzzy spatial data

```
<xs:element name="FuzzySpatial" type="FuzzySpatialtype"/>
<xs:complexType name="FuzzySpatialtype">
<xs:choice minOccurs="0" maxOccurs="3">
   <xs:element name="FuzzySpatialPoint" type="FuzzySpatialPointtype"/>
   <xs:element name="FuzzySpatialLine" type="FuzzySpatialLinetype"/>
   <xs:element name="FuzzySpatialRegion" type="FuzzySpatialRegiontype"/>
</xs:choice>
</xs:complexType>
<xs:simpleType name="FuzzySpatialPointtype">
 <xs:union memberTypes="SpatialPoint Val"/>
</xs:simpleType>
<xs:complexType name="SpatialPoint">
 <xs:sequence>
   <xs:element name="Xaxis" type="xs:float"/>
   <xs:element name="Yaxis" type="xs:float"/>
 </xs:sequence>
</xs:complexType>
<xs:simpleType name="FuzzySpatialLinetype">
 <xs:union memberTypes="FuzzyEndpoint FuzzyEndpoint"/>
</xs:simpleType>
<xs:simpleType name="FuzzyEndpoint">
 <xs:union memberTypes="Endpoint Val"/>
</xs:simpleType>
<xs:complexType name="Endpoint">
 <xs:sequence>
   <xs:element name="Xaxis" type="xs:float"/>
   <xs:element name="Yaxis" type="xs:float"/>
   <xs:element name="Zaxis" type="xs:float"/>
 </xs:sequence>
</xs:complexType>
<xs:simpleType name="FuzzySpatialRegiontype">
 <xs:union memberTypes="FuzzyRegionpoint FuzzyRegionpoint"/>
</xs:simpleType>
<xs:simpleType name="FuzzyRegionpoint">
 <xs:union memberTypes="Regionpoint Val"/>
</xs:simpleType>
<xs:complexType name="Regionpoint">
 <xs:sequence>
   <xs:element name="Xaxis" type="xs:float"/>
   <xs:element name="Yaxis" type="xs:float"/>
 </xs:sequence>
</xs:complexType>
```

(e) Fuzzy spatial relationship

```
<xs:element name="FuzzySpatialRelations" type="FuzzySpatialRelationstype"/>
 <xs:complexType name="FuzzySpatialRelationstype">
  <xs:sequence>
   <xs:element name="Aclass" type="Fuzzyelementtype"/>
   <xs:element name="Bclass" type="Fuzzyelementtype"/>
  </xs:sequence>
  <xs:choice minOccurs="0" maxOccurs="3">
   <xs:element name="FuzzySpatialDirection" type="FuzzySpatialDirectiontype"/>
    <xs:element name="FuzzySpatialMetric" type="FuzzySpatialMetrictype"/>
    <xs:element name="FuzzySpatialTopological" type="FuzzySpatialTopologicaltype"/>
  </xs:choice>
 </xs:complexType>
<xs:simpleType name="FuzzySpatialDirectiontype">
 <xs:restriction base="xs:string">
 <xs:pattern value="→| ↓| ←| ↑| ↘| ↗| ↙| ↖"/>
 </xs:restriction>
</xs:simpleType>
<xs:simpleType name="FuzzySpatialMetrictype">
 <xs:union memberTypes="SpatialMetric Val"/>
</xs:simpleType>
<xs:element name="SpatialMetric" type="xs:string"/>
<xs:simpleType name="FuzzySpatialTopologicaltype">
 <xs:restriction base="xs:string">
 <xs:pattern value="Equal|Meet|Overlap|Contain|Disjoint|Intersect"/>
 </xs:restriction>
</xs:simpleType>
```

(f) Fuzzy spatio-temporal events

```
01 <xs:element name="FuzzySTEvent" type="FuzzySTEventtype"/>
02   <xs:simpleType name="FuzzySTEventtype">
03     <xs:union memberTypes="STEvent Val"/>
04   </xs:simpleType>
05 <xs:element name="STEvent" type="STEventtype"
06   <xs:complexType name="STEventtype" >
07     <xs:choice minOccurs="1" maxOccurs="1">
08       <xs:element name="One-Way" type="One-Waytype"/>
09       <xs:element name="Two-Way" type="Two-Waytype"/>
10     </xs:choice>
11   </xs:complexType>
12 <xs:complexType name="One-Waytype">
13   <xs:sequence>
14     <xs:element ref="Aclass"/>
15     <xs:element ref="Eventclass"/>
16     <xs:element ref="Bclass"/>
17   </xs:sequence>
18 </xs:complexType>
19 <xs:complexType name="Two-Waytype">
20   <xs:sequence>
21     <xs:element ref="Aclass"/>
22     <xs:element ref="Eventclass"/>
23   </xs:sequence>
24   <xs:sequence>
25     <xs:element ref="Bclass"/>
26     <xs:element ref="Eventclass"/>
27   </xs:sequence>
28 </xs:complexType>
29 <xs:element name="Eventclass" type="Eventclasstype"/>
30   <xs:complexType name="Eventclasstype">
31     <xs:attribute name="ID" use="required" id="ID"/>
32   </xs:complexType>
33 <xs:element name="Aclass" type="Eventelementtype"/>
34 <xs:element name="Bclass" type="Eventelementtype"/>
35   <xs:complexType name="Eventelementtype">
36     <xs:attribute name="IDREF" use="required" id="IDREF"/>
37     <xs:attribute type="Fuzzyelementtype"/>
38   </xs:complexType>
```

(g) Fuzzy spatio-temporal generalization

```
01 <xs:element name="Fuzzygeneralization" type="Fuzzygeneralizationtype"/>
02   <xs:complexType name="Fuzzygeneralizationtype">
03     <xs:sequence>
04       <xs:element name="Superclass" type="Superclasstype"/>
05      <xs:element name="Subclass" type="Subclasstype"/>
06     </xs:sequence>
07   </xs:complexType>
08   <xs:complexType name="Superclasstype">
09     <xs:attribute name="ID" use="required" id="ID"/>
10     <xs:attribute type="Fuzzyelementtype"/>
11   </xs:complexType>
12   <xs:complexType name="Subclasstype">
13     <xs:attribute name="IDREF" use="required" id="IDREF"/>
14     <xs:attribute type="Fuzzyelementtype"/>
15   </xs:complexType>
```

(h) Fuzzy spatio-temporal aggregate

```
01 <xs:element name="Fuzzyaggregation" type="Fuzzyaggregationtype"/>
02   <xs:complexType name="Fuzzyaggregationtype">
03     <xs:sequence>
04       <xs:element name="Aggregates" type="Aggregatestype"/>
05       <xs:element name="Composition" type="Compositiontype"/>
06     </xs:sequence>
07   </xs:complexType>
08   <xs:complexType name="Aggregatestype">
09     <xs:attribute name="ID" id="ID" use="required"/>
10     <xs:attribute type="Fuzzyelementtype"/>
11   </xs:complexType>
12   <xs:complexType name="Compositiontype">
13     <xs:attribute name="IDREF" id="IDREF" use="required"/>
14     <xs:attribute type="Fuzzyelementtype"/>
15   </xs:complexType>
```

(i) Fuzzy spatio-temporal association

```
01 <xs:element name="Fuzzyassociation" type="Fuzzyassociationtype"/>
02   <xs:complexType name="Fuzzyassociationtype">
03     <xs:sequence>
04       <xs:element name="Assclass" type="Assclasstype"/>
05       <xs:element name="Beassclass" type="Beassclasstype"/>
06     </xs:sequence>
07   </xs:complexType>
08   <xs:complexType name="Assclasstype">
09     <xs:attribute name="ID" id="ID" use="required"/>
10     <xs:attribute type="Fuzzyelementtype"/>
11   </xs:complexType>
12   <xs:complexType name="Beassclasstype">
13     <xs:attribute name="IDREF" id="IDREF" use="required"/>
14     <xs:attribute type="Fuzzyelementtype"/>
15   </xs:complexType>
```

Figure 2: Fuzzy XML data tree structure.

To distinguish between crisp object and fuzzy entity/class, namely *Crispelement* and *Fuzzyelement*, are introduced into XML Schema. The *Crispelement* in line 8 represents a crisp entity/class that does not contain spatio-temporal information. *Fuzzyelement* on line 9 represents an entity/class with fuzzy, which is a child of FuzzyClass/Object. *FuzzyClass/Object* indicates that the fuzzy spatio-temporal entity/class consists of the crisp element *Crispelement* and the fuzzy element *Fuzzyelement*.

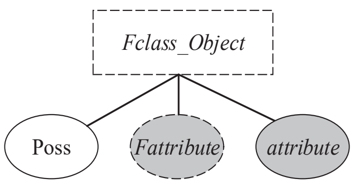

Figure 3: Representation of fuzzy spatio-temporal entity/class in XML data trees

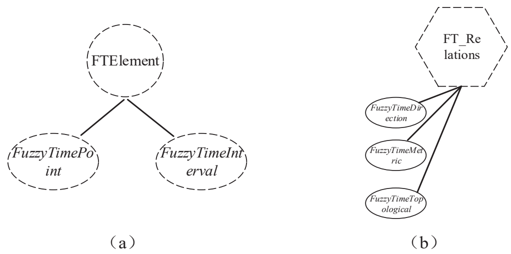

Figure 4: Representation of fuzzy temporal data in XML data trees

5.2. *Representation of fuzzy time data*

5.2.1. *Representation of fuzzy time objects*

■ Representation in the XML data tree

As shown in Figure 4 (a), in the XML data tree, using dashed rectangles indicates that the time data is fuzzy. The following dashed ellipse can represent a fuzzy time objects.

■ Representation in the XML Schema

In XML Schema, the fuzzy time object is represented by "*FuzzyTime*" as shown in Figure 2(b). The fuzzy time object "*FuzzyTime*" includes the fuzzy time point "*FuzzyTimePoint*" and the fuzzy time interval "*FuzzyTimeInterval*."

5.2.2. *Representation of Fuzzy time relation*

■ Representation in the XML data tree

As shown in Figure 4 (b), the left half of the dashed hexagon is used to denote the fuzzy time relation. The name of the fuzzy time relation and its value are placed in the three ellipses on the right which are fuzzy time direction relationship, fuzzy time metric relationship, and fuzzy time topological relations.

■ Representation in the XML Schema

In Figure 2(c), "*FuzzyTimeDirection*", "*FuzzyTimeMetric*" and "*FuzzyTimeTopological*" represent the fuzzy time direction relationship, the fuzzy time metric relationship, and the fuzzy time topological relation. These three elements are the sub-elements of "*FuzzyTimeRelations*". In addition, "*FuzzyTimeRelations*" indicates a fuzzy time relationship.

5.3. *Representation of fuzzy spatial data*

5.3.1. *Representation of fuzzy spatial objects*

■ Representation in the XML data tree

As shown in Figure 5(a), in the XML data tree, the dotted square is used to indicate that the spatial data is fuzzy. The following dashed ellipse may represent a fuzzy space point, a fuzzy space line, or a fuzzy spatial region.

■ Representation in the XML Schema

In XML Schema, the fuzzy spatial object is represented by "*Fuzzyspatial*" as shown in Figure 2(d), the fuzzy spatial object "*FuzzyObject*" includes the fuzzy spatial point "*FuzzyspatialPoint*" the fuzzy spatial line "*FuzzyspatialLine*", and the fuzzy spatial region "*FuzzyspatialRegion*."

5.3.2. *Representation of Fuzzy spatial relation*

■ Representation in the XML data tree

As shown in Figure 5(b), the left half of the dashed hexagon is used to denote the fuzzy spatial relation. The name of the fuzzy spatial relation and its value are placed in the three ellipses which are fuzzy spatial direction relationship, fuzzy spatial metric relationship, and fuzzy spatial topological relations.

■ Representation in the XML Schema

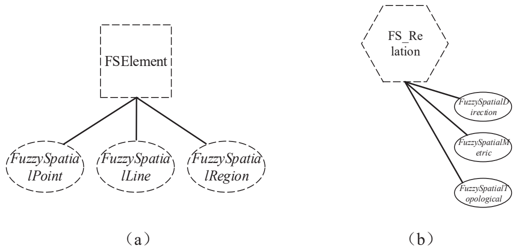

Figure 5: Representation of fuzzy spatial data in XML data trees

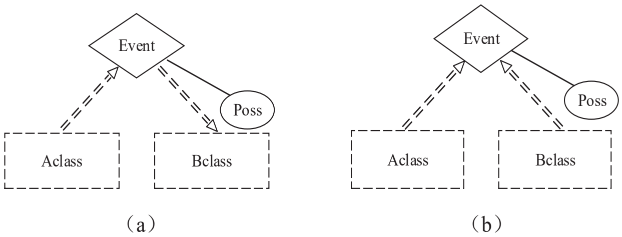

Figure 6: Representation of fuzzy spatio-temporal events in XML data trees

In Figure 2(e), "*FuzzySpatialDirection*", "*FuzzySpatialMetric*" and "*FuzzySpatialTopological*" represent the fuzzy spatial relationship. These three elements are the sub-elements of "*FuzzySpatialRelations*". In addition, "*FuzzySpatialRelations*" indicates a fuzzy spatial relationship.

5.4. Representation of fuzzy spatio-temporal event

Fuzzy spatio-temporal events are the reasons for the development and change of things in the fuzzy spatio-temporal phenomenon.

■ Representation in the XML data tree

In the fuzzy spatio-temporal XML data tree, we use the diamond to represent the name of the event, use the double dashed line and the hollow triangle to indicate the direction of the event, and use the elliptical "Poss" to indicate the likelihood of the event. Figure 6(a) shows the unidirectional fuzzy spatio-temporal event, and Figure 6(b) shows the events that interact with each other.

■ Representation in the XML Schema

In XML Schema, the occurrence of events is ambiguous and the occurrence of events is directional. As shown in Figure 2(f), "*FuzzySTEvent*" represents a fuzzy spatio-temporal event, which consists of the spatio-temporal event "*STEvent*" and the possibility of occurrence "*Val*." "*EventDirection*" is the direction in which the event occurred, including the one-way event "*One-Way*" and the two-way event "*Two-Way*."

5.5. Representation of fuzzy spatio-temporal semantic relations

In the real world, there are a lot of relationships between various entity/class, which make the whole world to be a holistic and organic system. Thus, it is necessary to consider the different semantic relations between entity and class at the time of modeling so that the model can represent rich content. In this paper, the semantic relations between fuzzy spatio-temporal entity/class mainly include fuzzy spatio-temporal generalization, fuzzy spatio-temporal aggregation, and fuzzy spatio-temporal association. Next, we will discuss how to represent these semantic relationships in the XML data tree and the XML Schema document.

■ Representation in the XML data tree

Figure 7(a) shows the fuzzy spatio-temporal generalization relationship, which uses solid lines and hollow triangles to represent subclasses and superclass. Figure 7(b) shows the fuzzy spatio-temporal

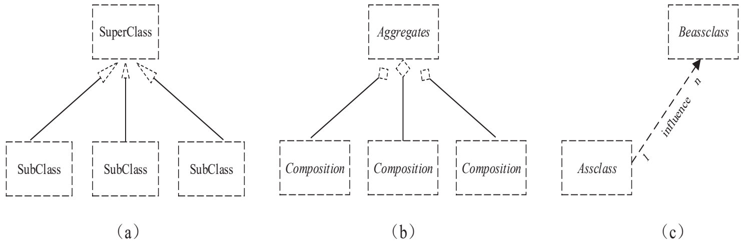

Figure 7: Representation of fuzzy spatio-temporal semantic relations XML data trees

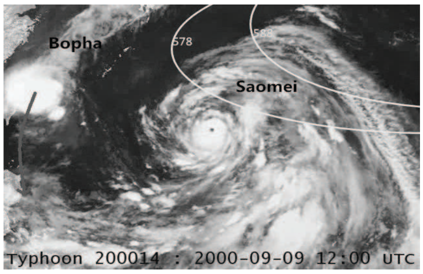

Figure 8: Meteorological examples of fuzzy spatio-temporal

aggregation relationship, which uses the solid line plus hollow diamond to represent the composition and aggregate. Figure 7(c) shows the fuzzy spatio-temporal association, which uses the dotted line and the solid triangle to represent the associative class (*Assclass*) and the associated class (*Beassclass*).

■ Representation in the XML Schema

As shown in figures 2(g), 2(h), and 2(i), the fuzzy spatio-temporal generalization, fuzzy spatio-temporal aggregation, and fuzzy spatio-temporal association are defined in XML Schema.

6. Application of fuzzy spatio-temporal XML data model

6.1. Analyzing the instance and create a fuzzy XML data tree

In order to verify the validity and feasibility of the proposed fuzzy spatio-temporal data model, we analyze the movement of the tropical cyclones *Saomei* and *Bopha* under the influence of subtropical high. As shown in Figure 8, 578 and 588 represent subtropical highs. Under the influence of subtropical high, two tropical cyclones are moving constantly.

First of all, according to the actual situation of the application, the data corresponding to the fuzzy spatio-temporal data tree F_{tree} is analyzed and listed, $F_{tree} = (V, \zeta, \gamma, \lambda, \varphi, \psi, \eta, \iota, \tau, \kappa)$, where:

V = {*Event(Move), Subtropical High, Saomei(a), FTRelation/FSRelation, Bohpa(a), Poss, west-extending point, The North Pacific subtropical high, The West Pacific subtropical high, FSObject, FTObject, FRgener, FTRdirection, FTRmetric, FTRtopology, FSRdirection, FSRmetric, FSRtopology, Pressure, location variation of ridge line, Intensity for grade 4 With 0.6 degree, speed,* (x, y, z, δ_p), $(t_s,\ \delta_s,\ t_e,\ \delta_e)$, →, 0.5*hours*, ↖, 1400*km*, Disjoint, (t, δ), $(x_1,\ y_1,\ z_1,\ \delta_{l1},\ x_2,\ y_2,\ z_2,\ \delta_{l2})$}; ζ = {*FRgener, FTRdirection, FTRmetric, FTRtopology, FSRdirection, FSRmetric, FSRtopology*, →, 0.5*hours*, ↖, 1400*km*, Disjoint }; φ = {*FTObject, FTRdirection, FTRmetric, FTRtopology*, $(t_s,\ \delta_s,\ t_e,\ \delta_e)$, →, 0.5*hours*, (t, δ)}; ψ = {*FSObject, FSRdirection, FSRmetric, FSRtopology*, (x, y, z, δ_p)), ↖, 1400*km*, Disjoint}; η = {*Saomei(a), Bohpa(a), Event(Move)*}; ι (*Event(Move)*) = 1; ι (*Saomei(a)Subtropical High, Bohpa(a), Poss, FTRelation/FSRelation*) = 2; ι (*The North Pacific subtropical high, The West Pacific subtropical high, FSObject, FTObject*) = 3; ι (*west-extending point, Pressure, location variation of ridge line, Intensity for grade 4 With 0.6 degree, speed,* (x, y, z, δ_p), $(t_s, \delta_s, t_e, \delta_e)$, →, 0.5*hours*, ↖, 1400*km*, Disjoint, $(t,\ delta)$, $(x_1,\ y_1\ ,\ z_1,\ \delta_{l1},\ x_2,\ y_2,\ z_2,\ \delta_{l2})$ = 4.

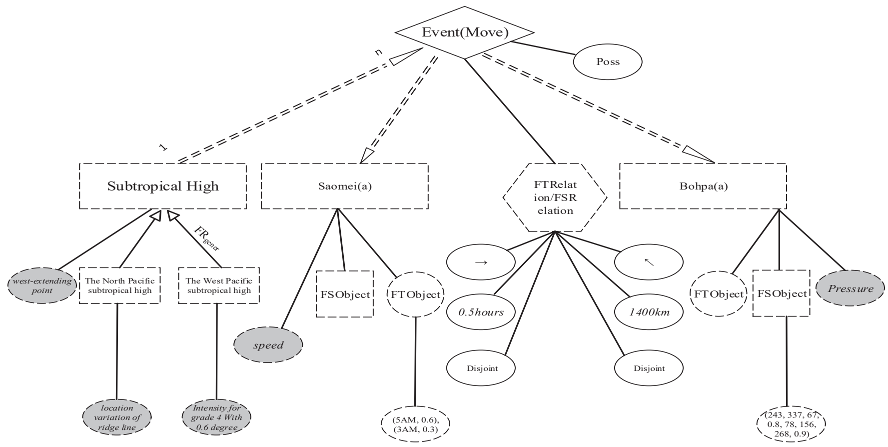

Figure 9: Fuzzy spatio-temporal XML data trees with event move

Then, by analyzing the fuzzy temporal and spatial XML elements, we get the fuzzy spatio-temporal XML data tree shown in figure 9.

Figure 9 shows a XML-based fuzzy spatio-temporal data tree. The root of the tree is an event Event (move). In the diamond, we add the event name to indicate the specific content of the event.

The second layer is *Subtropical High*, *Saomei (a)*, *Bopha (a)*, fuzzy time relation and fuzzy spatial relation, where the dashed rectangle represents the fuzzy spatio-temporal entity/class, *Subtropical High* to *Event*, *Event* to *Saomei (a)* and *Bopha (a)*. We use double dashed lines and hollow triangles to indicate the direction of the event, and the letters 1 and n represent a one-to-many relationship, that is, the subtropical high pressure has an effect on the movement of multiple tropical cyclones. The fuzzy time relation and fuzzy space relation of tropical cyclone *Saomei (a)* and *Bopha (a)* are represented by a dashed hexagon.

In the third layer of "*west-extending point*" and "*speed*", we use the gray dotted ellipse to indicate the fuzzy characteristic attribute. *The North Pacific subtropical high* and *the West Pacific subtropical high* use hollow arrows with solid lines pointing to *Subtropical High*, indicating that they are fuzzy spatio-temporal generalization, *the North Pacific subtropical high* and *the West Pacific subtropical high* are subclasses. *Subtropical High* is a superclass, *FSObject* uses dashed squares to represent fuzzy space entity / class, and *FTObject* uses dashed circles to represent fuzzy time entity/class. The three elements on the left side of the dashed hexagon are connected from top to bottom, which represents the fuzzy time direction relation, the fuzzy time metric relation, and the fuzzy time topological relation. In addition, the three elements on the right side represent the fuzzy spatial direction relationship, the fuzzy spatial metric relation, and the fuzzy space topological relation. The fourth layer of (x, y, z, δ_p), $(t_s, \delta_s, t_e, \delta_e)$, (t, δ) and $(x_1, y_1, z_1, \delta_{l1}, x_2, y_2, z_2, \delta_{l2})$ represent fuzzy spatial points, fuzzy time interval, fuzzy time point, and fuzzy spatial line.

6.2. Creating a spatio-temporal XML data model

The tree structure of XML not only makes the XML document easy to parse, but also provides clear self-description syntax, which is helpful for modeling the spatio-temporal data. According to the discussion of the third and fourth sections, we present a fuzzy spatio-temporal XML Schema model of the event.

As shown in Figure 10, it is a document of the fuzzy spatio-temporal XML Schema for the event. Lines 1-13 represent a one-way event called Subtropical High affecting the movement of Saomei (a) and Bohpa (a). Lines 14-21 show the generalized relationship between Subtropical High and The North Pacific subtropical high and The West Pacific subtropical high. Lines 22-33 represent the fuzzy temporal relationships between Saomei (a) and Bohpa (a). Lines 34-45 represent the fuzzy spatial relationships of Saomei (a) and Bohpa (a).

```
<xs:element name="Event(Move)" type="FuzzySTEventtype"/>
<xs:simpleType name="FuzzySTEventtype">
<xs:union memberTypes="STEvent Val"/>
</xs:simpleType>
<xs:element name="One-Way" type="STEventtype"
<xs:complexType name="One-Waytype">
        <xs:sequence>
        <xs:element ref="Subtropical High"/>
            <xs:element ref="Eventclass"/>
            <xs:element ref="Saomei(a)"/>
            <xs:element ref="Bohpa(a)"/>
        </xs:sequence>
        </xs:complexType>
 <xs:element  name="Fgen_SNW" type="Fuzzygeneralizationtype"/>
 <xs:complexType name="Fuzzygeneralizationtype">
        <xs:sequence>
            <xs:element name="Superclass" type="Superclasstype"/>
            <xs:element name="The North Pacific subtropical high"
              type="Subclasstype"/>
     <xs:element name="The West Pacific subtropical high"
              type="Subclasstype"/>
        </xs:sequence>
         </xs:complexType>
          <xs:element name="FTR_SH(a)"
                type="FuzzyTimeRelationstype"/>
        <xs:complexType name="FuzzyTimeRelationstype">
             <xs:sequence>
<xs:element name="Saomei(a)" type="Fuzzyelementtype"/>
<xs:element name="Bopha(a)" type="Fuzzyelementtype"/>
     </xs:sequence>
     <xs:choice minOccurs="0" maxOccurs="3">
     <xs:element name="→" type="FuzzyTimeDirectiontype"/>
     <xs:element name="0.5hours"  type="FuzzyTimeMetrictype"/>
      <xs:element name="Disjoint"
              type="FuzzyTimeTopologicaltype"/>
      </xs:choice>
 </xs:complexType>
 <xs:element name="FSR_SH(a)"
        type="FuzzySpatialRelationstype"/>
 <xs:complexType name="FuzzySpatialRelationstype">
   <xs:sequence>
     <xs:element name="Saomei(a)" type="Fuzzyelementtype"/>
     <xs:element name="Bopha(a)" type="Fuzzyelementtype"/>
   </xs:sequence>
 <xs:choice minOccurs="0" maxOccurs="3">
 <xs:element name="↖" type="FuzzySpatialDirectiontype"/>
 <xs:element name="1400Km" type="FuzzySpatialMetrictype"/>
 <xs:element name="Disjoint"
        type="FuzzySpatialTopologicaltype"/>
  </xs:choice>
 </xs:complexType>
```

Figure 10: Fuzzy spatio-temporal XML data model with event move.

6.3. *Modeling validation using the XML document*

Figure 11 is a data document about the fuzzy spatio-temporal event (Move), which verifies the model as follows:

Lines 2 to 10 show that this is a fuzzy spatio-temporal event about the movement phenomenon, and "< *ValPoss* = "0.9"/ >" means that the probability of occurrence of an event is 0.9. "*One-Way*" means that the event is unidirectional from "*Subtropical High*" to "*Saomei(a)*". "*Bopha(a)*" is a one-to-many relationship.

Lines 11-15 show fuzzy spatio-temporal generalizations; the superclass is "*Subtropical High*" subclasses are "*The North Pacific subtropical high*" and "*The West Pacific subtropical high*."

Lines 16-29 show fuzzy time relationships and fuzzy spatial relationships from "*Saomei (a)*" to "*Bopha (a)*". These relationships include the fuzzy time direction relationship "*FuzzyTimeDirection*"(its value is "→"), Fuzzy time metric relationship "*FuzzyTimeMetric*"(its value is "0.5*hours*"), Fuzzy time topology "*FuzzyTimeTopological*" (its value of "Disjoint"), Fuzzy spatial direction relationship "*FuzzySpatialDirection*" (its value is "↖"), Fuzzy spatial metric relationship "*FuzzySpatialMetric*" (its value is "1400*Km*"), and Fuzzy spatial topology "*FuzzySpatialTopological*" (its value is "Disjoint").

Lines 30-37 represent the particular attribute "*location variation of ridge line*" of the subtropical high, where the probability distribution functions "*Dist*" and "*disjunctive*" are used which means that the probability of "*quick*" is 0.6 and the "*slow*" probability is 0.3.

Lines 38-48 indicate that "*Morning*" is a fuzzy time object of the tropical cyclone "*Saomei (a)*" which is a fuzzy time point with a membership degree of 0.5. The probability of "5 *AM*" is 0.6 and the probability of "3 *AM*" is 0.3.

Lines 50-66 indicate that "*Track*" is a fuzzy spatial object of the tropical cyclone "*Bopha (a)*", which is a fuzzy spatial line "*FuzzySpatialLine*" with a membership degree of 0.3. The coordinates of the two endpoints of the line and their membership are (243, 337, 67, 0.8) and (78,156, 268, 0.9).

It can be seen that the data of the instance corresponds to the model element of XML Schema, which verifies that the model can express the contents of the spatio-temporal event well and show the data in depth. Therefore, we confirm the validity and usability of the model.

```xml
<Meteorological_phenomena>
  <Event_Move>
    <Val Poss="0.9"/>
    <STEvent STEvent="One-Way">
      <Eventelement name="Subtropical High"/>
      <Eventclass name="Event(move)"/>
      <Eventelement name="Saomei(a)"/>
      <Eventelement name="Bopha(a)"/>
    </STEvent>
  </Event_Move>
<Fuzzygeneralization>
  <Superclass name="Subtropical High"/>
  <Subclass name="The North Pacific subtropical high"/>
  <Subclass name="The West Pacific subtropical high"/>
</Fuzzygeneralization>
<FuzzyTimeRelations>
  <FuzzyClass_Object name="Saomei(a)"/>
  <FuzzyClass_Object name="Bopha(a)"/>
  <FuzzyTimeDirection Value="→"/>
  <FuzzyTimeMetric Value="0.5hours"/>
  <FuzzyTimeTopological Value="Disjoint"/>
</FuzzyTimeRelations>
<FuzzySpatialRelations>
  <FuzzyClass_Object name="Saomei(a)"/>
  <FuzzyClass_Object name="Bopha(a)"/>
  <FuzzySpatialDirection Value="↖"/>
  <FuzzySpatialMetric Value="1400Km"/>
  <FuzzySpatialTopological Value="Disjoint"/>
</FuzzySpatialRelations>
<Fuzzyelement name="Subtropical High">
  <Fuzzyattribute name="location variation of ridge line">
    <Dist type ="disjunctive">
      <Val Poss="0.6">quick</Val>
      <Val Poss="0.3">slow</Val>
    </Dist>
  </Fuzzyattribute>
</Fuzzyelement>
<Fuzzyelement name="Saomei(a)">
  <FuzzyTime name="Morning">
    <FuzzyTimePoint>
    <Val Poss="0.5"/>
    <Dist type ="conjunctive">
      <Val Poss="0.6">5AM</Val>
      <Val Poss="0.3">3AM</Val>
    </Dist>
    </FuzzyTimePoint>
  </FuzzyTime>
</Fuzzyelement>
<Fuzzyelement name="Bopha(a)">
  <FuzzySpatial name="Track">
    <Val Poss="0.3"/>
    <FuzzySpatialLine>
      <FuzzyEndpoint>
        <Xaxis>243</Xaxis>
        <Yaxis>337</Yaxis>
        <Zaxis>67</Zaxis>
        <Val Poss="0.8"/>
      </FuzzyEndpoint>
      <FuzzyEndpoint>
        <Xaxis>78</Xaxis>
        <Yaxis>156</Yaxis>
        <Zaxis>268</Zaxis>
        <Val Poss="0.9"/>
      </FuzzyEndpoint>
    </FuzzySpatialLine>
  </FuzzySpatial>
</Fuzzyelement>
</Meteorological_phenomena>
```

Figure 11: Validating the model using the XML document.

7. Summaries and Discussions

Data tree is the most basic structure of XML documents, which is the most important basis for fuzzy XML data documents. The feature of data tree supports the ease of operation and scalability of XML. In this study, we first discuss the important role of fuzzy XML data tree and the relationship between fuzzy spatio-temporal data model. Then, the representation of fuzzy spatio-temporal data on Schema is discussed, including the representation of fuzzy spatio-temporal entity/class, fuzzy time data, fuzzy spatial data, fuzzy events, and fuzzy spatio-temporal semantic relations. Furthermore, the fuzzy XML data tree is established according to the characteristics of meteorological phenomena and the fuzzy spatial, and temporal data model based on XML is determined. At the same time, according to the characteristics of meteorological phenomena, the fuzzy XML data tree is designed, and the fuzzy spatio-temporal data model based on XML is created. Finally, the validity and availability of the model are evaluated using the meteorological data.

In the future, we will add a lot of experimental data based on the existing model and consider the XML in the storage and query research. Furthermore, we will validate fuzzy XML based on approximate XML document/grammar tree validation [28, 29].

References

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