MECHANISM AND METHODS OF FUZZY GEOGRAPHICAL OBJECT MODELING*

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ABSTRACT:

Fuzziness is an important aspect of the uncertainties of spatial data. In this paper, the mechanism and methods of spatial modeling for fuzzy geographical objects are focused and the following two issues are resolved: (1) Modeling fuzzy geographical objects; (2) Modeling the relation between two fuzzy geographical objects. In the first issue, fuzzy geographical objects are defined by the novel object-oriented modeling method. In the second issue, fuzzy object classes and fuzzy geographical object classes are defined by Unified Modeling Language (UML), and the method of modeling fuzzy spatial relationship is put forward. Then an integrated UML graph is established to express the conceptual model of fuzzy geographical objects as well as the fuzzy topological relations between objects. Finally, the UML Graph can be input to the general relation database to finish the database design.

1. INTRODUCTION

Spatial data models are the abstract representation of the real world (Chen, 1995; Zeiler, 1999). Generally, the phenomena in the real world are distributed in discrete or continuous form. Accordingly, the object model and the field model are used to describe them respectively in GIS (Molenaar, 1999). In the object models, spatial distributions are represented by discrete points, lines and polygons (or areas), such as the vector data structure. While in the field models, single-valued functions defined in the continuous space are used, such as the raster data structure.

In traditional GIS, the fuzzy information is usually dealt with as certain one for simplicity. In one hand, this simplify has impelled the development of GIS, and at the other hand, it results in the inaccurate conclusions. So the new methods need to be found to solve the fuzziness in the data as to improve the data quality and the credibility. Fuzzy set theory is such a novel method that can be used in spatial data modeling and processing to reduce the inaccuracy of spatial data.

2. FUZZY GEOGRAPHICAL OBJECTS MODELING

2.1 Fuzzy Sets

When we classify and extract geographical information, the three fundamental principles of logic derived from by ancient Greek philosopher Aristotle are adopted subconsciously(Li, 1984), that is: (1) the law of identity—something is always identical with itself; (2) the law of contradiction—something cannot exist and not exist at the same time; (3) the law of excluded middle—something either exists or it does not, no middle condition is possible. These principles are also the rules that most mathematics and computer science should obey. But in the geosciences, a distinct characteristic is that the distributions of most geographical phenomena are not abrupt changes but gradual changes. As a result, it is hard to partition the real world into an exclusive, unoverlapping set. To understand and reconstruct the real world, the complicated reality must be abstracted. In substance, the well-defined geographical objects are man-made. So it can be considered that geographical information is usually composed of the objects with uncertain boundaries (Burrough and Frank, 1998), and many geographical relations and objects can be considered fuzzy.

Fuzzy set theory, or fuzzy sets for simplicity, is put forward by Zadeh (1965). It provides a quantitative method to process the fuzziness in the complex systems. In classical set theory, one element can be only included or excluded by one set, that is, the result is only can be 'true' or 'false'. While in fuzzy set theory, one element can have partial membership to a set, or have many memberships to many different sets (Zadeh, 1965). As to a universe X and a fuzzy set A, the relation of a element x ($x \in X$) and A can be represented by the formula below:

$$A = \{x, \mu_A(x)\}, \quad \mu_A(x) \in [0,1], \quad x \in X \qquad (1)$$

Where, μ_A is the membership function of A, and $\mu_A(x)$ is called the membership of the element x to the set A.

2.2 Fuzzy Geographical Objects

The definition of fuzzy geographical objects is extended from exact geographical objects. Vagueness or fuzziness means that the concrete classifications or descriptions lack for crisp or exact boundaries (Cross and Firat, 2000). The boundaries of fuzzy geographical objects refer to not only the boundaries of the geometry, but also of the definitions, that is, the definitions themself are ambiguous.

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Modeling fuzzy geographical objects is extraordinary meaningful. The real world is always complex and full of various uncertainties. But, in general geographical object modeling, only the crisp objects are considered, which can not reflect the complication and the uncertainty of the real world so as to GIS has a low level in decision making. Fuzzy geographical object modeling has some commonness with the crisp object modeling, but also has the difference for its spatial characteristic and fuzziness. All the objects should be defined distinctly before modeling. Geographical objects which are the embodiment of 'objects' in computer science have both attributes and positions properties. So the object-oriented modeling method with some extension can be used to model geographical objects as well.

2.3 Modeling Fuzzy Geographical Objects

Much work on fuzzy geographical object modeling has been done recently. Burrough and McDonnell (1998) discussed 'Fuzzy Sets and Fuzzy Geographical Objects' in a single Chapter in their monograph, and considered fuzzy set an important part of the basic theories in GIS. Molenaar (1998) discussed 'Fuzzy Spatial Objects' in his monograph. In July 2000, the journal *Fuzzy sets and Systems* published a special issue 'Uncertainty in Geographic Information Systems' to discuss the process of uncertainty in GIS, fuzzy set theory is an important method to do with the uncertainty in GIS (Goodchild, 2000). In July 2001, the journal *International Journal of Intelligent Systems* published a special issue 'Extending Fuzzy Theory to Object-Oriented Modeling' to discuss the applications of fuzzy set theory in object-oriented modeling (Lee, 2001). In January 2003, some mature applications could be found in the special issue 'Incorporating Fuzzy Sets in Geographic Information Systems' of the journal *Transactions in GIS* (Robinson et al., 2003). In 2005, a book focused on the fuzzy modeling of spatial information is published (Petry et al., 2005). Most of the researches above focused on raster-based fuzzy geographical object modeling, fuzzy topological relations, and fuzzy spatial queries and so on, and most of them associated with certain applications, such as soil classification and location selections (Cheng et al., 1997). Vector-based fuzzy geographical object modeling is relatively few.

In this paper, the conceptual model of fuzzy geographical objects is based on points, lines and polygons (or areas) in vector data model of GIS. Our goal is to model the spatial positions, attributes and spatial relations of geographical objects. Unified modeling language (UML) is used to display the classes, objects and relations. But UML does not contain fuzzy semantic, and we will try to extend it to model fuzzy geographical objects.

3. THE CONCEPTUAL MODEL OF FUZZY GEOGRAPHICAL OBJECTS

3.1 Fuzzy Classes

Quantitative or qualitative languages are often used to describe data, and different data types correspond with different kinds of operations. Similarly, special data types are needed to note the description of geographical phenomena by the data models. The data types and the relative operations usually used in GIS are described in Table 1.

Data Type	Allowed values	Allowed operations
Boolean	0 or 1	Logical and indicator operations: Truth versus Falsehood
Nominal	Any names	Logical operations, classification and identification
Ordinal	$0 \sim \infty$	Logical and ranking operation, comparisons of magnitude
Integer	Integer	Logical operations, integer arithmetic
Real	Real number	All logical and numerical operations
Topological	Integer	Indicate links between entities

Table 1. Data types in GIS (Burrough and McDonnell, 1998)

In many GIS models, the geometries often defined by points, lines and polygons. Otherwise, the objects of points, lines and polygons with special attributes can be customized. But all of those objects have crisp boundaries. A new kind of data type is needed to define fuzzy geographical objects so as to get a better description of them.

Fuzzy classes are more complex than fuzzy objects, which refers to a object type that contains fuzzy information in the description of the attributes or the relations of object types. The fuzzy data type put forward here is based on the vector data model in the conceptual modeling of spatial databases. It must

Fuzzy Class	Description
FuzzyGeometry	Mainly used to define the shapes, relative attributes and operations of fuzzy geographical objects.
FuzzyPosition	Mainly used to define the position of fuzzy geographical object, which is the geographic position, relative operations and etc. in certain coordinate system.
FuzzyAttribute	Mainly used to define the value, BaseDataType, membership of attribute value, or used to determinate the membership function of fuzzy attribute value.
FuzzyRelation	Mainly used to define the various fuzzy relations between the fuzzy geographical objects(various clear relations are contained of course), such as distance, orientation, topology and operation etc.
BaseDataType	Mainly used to define the base data type relate to defuzzification, as well as the domain, default values and allowed operations etc.
FuzzyValueType	Mainly used to define the value, default value, domain, membership, fuzzy membership function etc..

Table 2. The Definitions of Main Fuzzy Classes

be noted that only simple points which are single points in Euclidean Space, simple lines defined by two points and the points between them, simple polygons defined by a boundary and all the points in it are studied here.

Concretely, an abstract class Fuzzy is defined firstly, which is the superclass of all the fuzzy data types. And then the class FuzzyRelation and the class GeographicalObjects are inherited from it. All the fuzzy geographical objects are inherited from GeographicalObjects, from which the class FuzzyGeometry and the class FuzzyAttribute are defined. A class FuzzyValueType is defined to represent the fuzzy value. Accordingly, a class BaseDataType is defined to compute the attributes repressed by fuzzy languages which described by the class FuzzyValueType. Main fuzzy classes are described in Table 2.

In the paper, UML is extended to be used in the definitions of the fuzzy classes. The capital 'F' is added on the left of the class name indicating that the class is fuzzy. The prefix 'fy' is added before the fuzzy attributes. And ○F is added on the line representing the fuzzy relations (see Figure 7). An example of the fuzzy classes named Village is described in Figure 1.

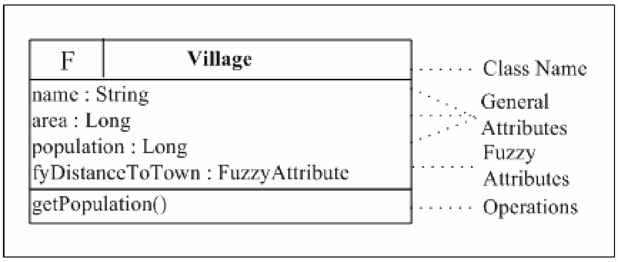

Figure 1. Fuzzy class Village

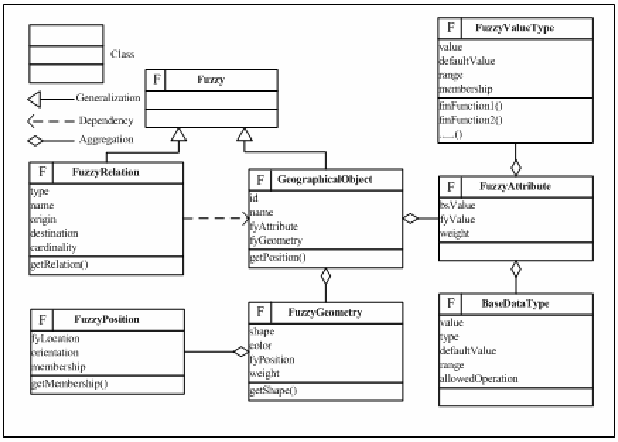

Figure 2. The Fuzzy Classes and the Relations between Them

The main fuzzy classes described in Table 2 and the relations between them are detailed in Figure 2. In Figure 2, some fuzzy attributes are defined for lack of information or fuzziness in the objects: in the class GeographicalObject, 'fyAttribute' (FuzzyAttribute) represents the fuzzy attribute information of geographical objects, and 'fyGeometry' (FuzzyGeometry) represents the fuzzy geometry; in the class FuzzyAttribute, 'fyValue'(FuzzyValueType) represents the fuzzy attribute value; in the class FuzzyGeometry, 'fyPosition'(FuzzyPosition) represents the fuzzy geographical position.

The attributes and operations of the main fuzzy classes are described as follows:

(1) GeographicalObject: id—the identity of an object, which exists in the whole lifecycle of the object; name—the name of the object; fyAttribute—the fuzzy attributes of the object; fyGeometry—the fuzzy geometry of the object, and it can be generalized in fuzzy points, fuzzy lines or fuzzy areas; getPosition()—the method to get the geographical position of the object。

(2) FuzzyRelation: type—the type of the fuzzy relation; name—the name of the fuzzy relation; origin and destination—the source object and the sink object respectively, and the type of them are all GeographicalObject; Cardinality—the cardinality of the relation (1:1; 1:n; m:n); getRelation()—the method to get the fuzzy relation such as fuzzy overlay and fuzzy orientation relation.

(3) FuzzyAttribute: bsValue—the attribute value expressed with base data type; fyValue—the fuzzy attribute value; weight—the weight of the attribute and the value of it is in the interval [0,1].

(4) FuzzyValueType: value—the attribute value expressed in fuzzy languages, such as 'about 20' and 'young'; defaultValue—the default attribute value expressed in fuzzy languages; range—the range of the attribute value expressed in fuzzy languages; membership—the membership of the attribute; fmFunction1() and fmFunction2()—the membership functions.

(5) BaseDataType: value—the attribute value expressed with basic data types; type—the name of the basic data type; defaultValue—the default value expressed with basic data types; range—the range of the attribute value expressed with basic data types; allowedOperation—the operations allowed on the attribute value.

(6) FuzzyGeometry: shape—the geometric shape of the object; color—the color of the object; fyPosition—the fuzzy position of the object; weight—the weight of the geometric (spatial) property, and the value of it is in the interval [0,1]; getShape()—the method to get the shape of the object.

(7) FuzzyPosition: fyLocation—the fuzzy location of the object. In conventional GIS, the location is expressed as a spatial location under certain geographical references. For example, a point is represented by a pair of coordinates (x, y), and a line is represented by two points which are named begin point and end point respectively, and an area is represented by several lines linked to a close boundary. But in fuzzy geographical objects, the fuzzy spatial locations can not simply be represented by exact coordinates, and in Section 3.2, the expression of fuzzy locations will be discussed in detail; orientation—the orientation of the object; membership—the possibility or the membership that the spatial location represented by fyPosition is the true location of the object; getMembership()—the membership function.

3.2 Fuzzy Geographical Object Classes

The fuzzy geographical object classes should be first built when modeling geographical objects. The objects that have similar attributes can be aggregated into an object class, and in turn a lineage tree can be constructed. In terms of the inheritance mechanism in object-oriented modeling, the subclasses can be defined through inheriting the superclasses.

Based on the fuzzy classes defined above, the subclasses of GeographicalObject, which include FuzzyPoint, FuzzyLine, and FuzzyArea, can be defined which are described by Figure 3.

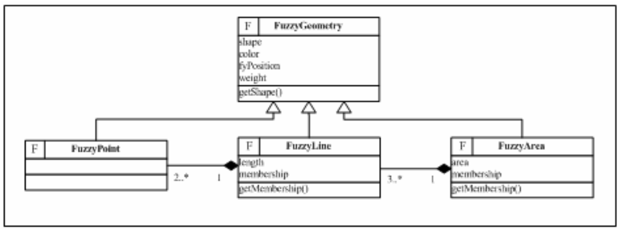

Figure 3. Class FuzzyGeometry and its subclasses

The attribute fyLocation should be extended for the locations of fuzzy points, fuzzy lines and fuzzy areas are different, and that is, the meanings of the attribute fyLocation of the class FuzzyPosition are different. As for the definition of the fuzzy location, the referential objects with crisp boundaries are defined which are represented by the attributes refCoordinate, the function baseline, the function crispBoundary for fuzzy points, fuzzy lines and fuzzy areas respectively. The location of fuzzy objects can be defined in terms of the location relation relative to the referential objects. For example, the nearer the distance between the fuzzy point and the reference point the membership that the fuzzy point is relative to the reference point is larger. The extended definition of fuzzy location is described by Figure 4.

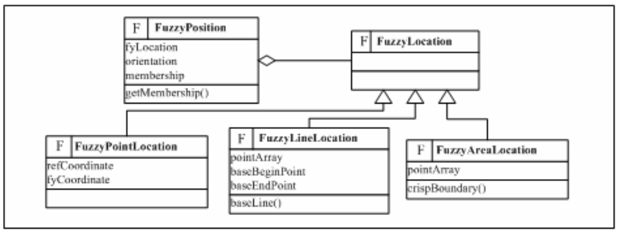

Figure 4. UML extension of fuzzy position's definition

When the attribute shape of the class FuzzyGeometry is point, line, or polygons (or areas), the attribute fyLocation of the class FuzzyPosition will be of the type FuzzyPointLocation, FuzzyLineLocation or FuzzyAreaLocation respectively.

(1) FuzzyPointLocation: the degree of proximity of the fuzzy point to a reference point can be used to represent the location of it, which is expressed with the attribute membership of the class FuzzyPoint. The membership is attained by the function getMembership() of the class FuzzyPoint. In the class FuzzyPointLocation, the attribute refCoordinate represents the coordinate of the reference point, and the attribute fyCoordinate is the coordinate of the fuzzy point.

(2) FuzzyLineLocation: pointArray represents the array storing the coordinates of the fuzzy point. baseBeginPoint and baseEndPoint represent the begin point and the end point of the base line whose mathematical expression defined by the function baseLine(). The membership is attained by the function getMembership() of the class FuzzyLine. It is advert that the attribute membership is single-valued in the class FuzzyPoint, while in the class FuzzyLine, it is multi-valued for a line is constituted of many points. Figure 5 is the demonstration of fuzzy lines.

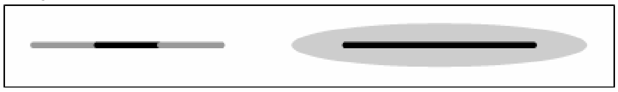

Figure 5. Fuzzy Lines

(3) FuzzyAreaLocation: Similarly, pointArray represents the points that constitute the fuzzy area, and the function crispBoundary() represents the mathematical expression of the crisp boundary. Figure 6 is Some Smooth Continuous Fuzzy Polygons.

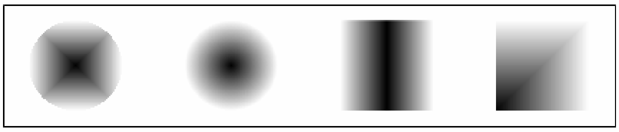

Figure 6. Some Smooth Continuous Fuzzy Polygons

As to fuzzy points, fuzzy lines and fuzzy areas, the referential objects are defined respectively, whose definition is difficult and should be resolved in terms of the data at hand and the working experience.

4. FUZZY SPATIAL RELATIONS

Fuzzy relations were first put forward by Zadeh (1965), which have been extended by Klir and Folger (1988) later. Fuzzy relations are fuzzy subsets derive from the Cartesian product of several ordinary sets, and the strengths of fuzzy relations are represented by their membership functions (Altman, 1994). Spatial relations changed when crisp geographical objects turn to be fuzzy ones and be represented with fuzzy data types, so the general spatial relations should be extended to be fuzzy spatial relations.

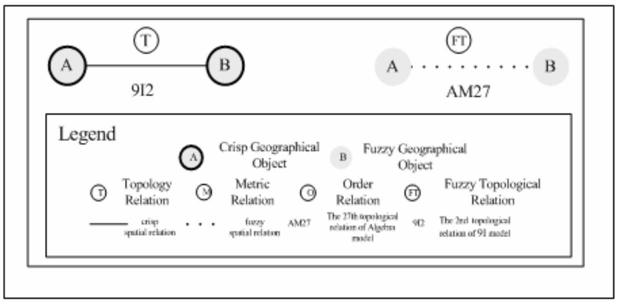

Figure 7. The expression of fuzzy spatial relation

As mentioned above, in the class FuzzyRelation, the attribute 'type' represents the types of fuzzy relations, which can occur between two spatial objects, or between two nonspatial objects, or between one spatial object and one nonspatial object. Fuzzy spatial relations can be fuzzy topological, fuzzy metric or fuzzy order relations, and the UML model can be described in Figure 7. Nonspatial relations have nothing to do with the types. The UML model of fuzzy topological relations is described in Figure 8.

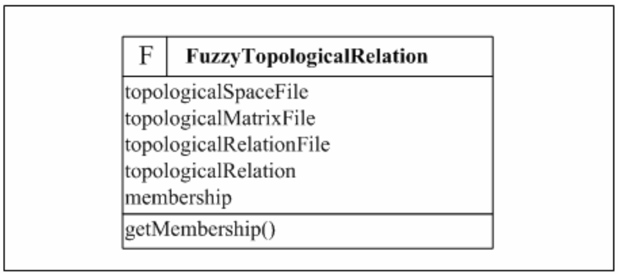

Figure 8. UML description of fuzzy topological relation

In Figure 8, TopologicalSpaceFile and TopologicalMatrixFile both represent the store path of the files, in which the fuzzy topological space and the fuzzy topological relation matrix are defined with mathematic methods respectively. TopologicalRelationFile also represents the store path of a file in which all kinds of fuzzy topological relations are defined and numbered in certain order. TopologicalRelation refers to a kind of fuzzy topological relation such as AM27(Clementini and Felice,1996), and membership which is attained by the membership function getMembership() refers to the degree that the relation is as the same as one of the relations defined in the file TopologicalRelationFile.

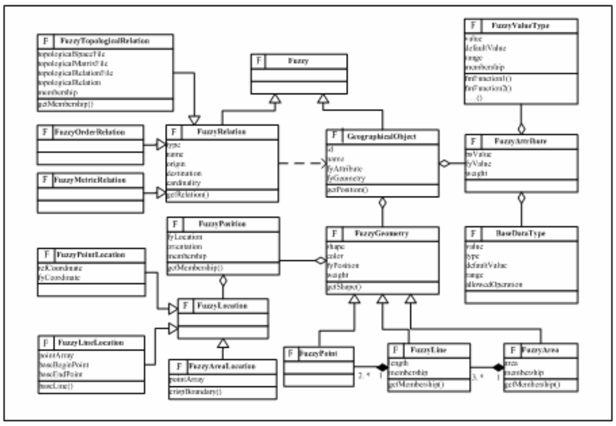

Figure 9. The Complete Description of Fuzzy Objects with UML

Thus we can integrate all the UML models above into a complete conceptual model of fuzzy geographical objects, which is described in Figure 9. And the model can be imported into object-relation database such as Oracle 9i after certain adaptation to finish the logical design of the database.

5. CONCLUSIONS AND DISCUSSIONS

Some primary work on the modeling of the fuzzy geographical objects is done in the paper. With the higher requirement of the intelligent process of spatial data, the more applications of fuzzy set theory and other soft computing methods into spatial operations, knowledge expression and reasoning will be realized, which can accelerate the development of geographical technologies, especially intelligent GIS and spatial decision support systems(SDSS).

Nowadays, uncertainty, including fuzziness, is always neglected in GIS because the data model is based on the Boolean logic. And obviously, fuzzy set theory provides a promising logic base for intelligent GIS. Based on the spatial database, the locations and the attributes of fuzzy geographical objects, as well as the fuzzy topological relations are studied through modeling points, lines and areas on the two-dimensional space. Considering the uncertain nature and the universality of fuzzy geographical objects, the class fuzzy geometry and the class fuzzy attribute should be embedded in spatial database with the development of information technologies.

In order to apply fuzzy geographical object modeling better, many problems still need to be resolved such as: (a) modeling three-dimensional(3D) and complex objects; (b) modeling the fuzziness in time, data integrity and logical consistency; (c) the selection of the proper membership functions; (d) the research on the propagation and the accumulation of fuzziness; (e)the design of fuzzy query languages and friendly user interfaces; (f) the visualization of fuzzy geographical objects and the results of the fuzzy queries; and (g) the logical and the physical modeling of fuzzy geographical objects.

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