Implementation of Object-oriented GIS Data Model with Topological Relations between Spatial Objects

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Abstract—Traditional GIS (Geographical Information System) data models are focused on the description of the data organizational structure and constraints from single aspect, which are the absence or little relevance of the hierarchy and connotation of data objects. These data models do not match the natural concept of humans about geographical spatial data and also failed to fully consider the spatial relationships and arithmetic operations with the relationship between geographic objects. Object-oriented technology mimics the human way of thinking as much as possible, it appears to overcome the shortcomings of traditional software design methods and improve the stability and reusability of the software systems. Based on the existing GIS data model, this paper introduces the basic idea of object-oriented GIS data model combined the object-oriented methods and the vectorial expression of spatial entities, and describes the definition and implementation of the object-oriented GIS data model. Furthermore, the topological operations between spatial objects have been defined in the paper for the importance of topological relationships among spatial relationships. The topological operations are directly defined in geometry classes by means of methods, and they include Touch, Disjoint, Cross, Contains, Overlaps, and Intersects and so on.

1. Introduction

GIS (Geographical Information System) as an important part of spatial information science, is usually defined as spatial information systems using systems engineering and information science theory and methods to access, store, manage, analyze and describe all or part of the earth's surface and geo-spatial distribution supported by the computer software and hardware [1]. GIS can integrate global or regional information, be widely used in government and business organizations, and achieved remarkable results in spatial data management, office automation, decision-making assistance, etc. Geospatial information is the expression targeted of geographical information system, so it is needed for the definition and expression of the location of geospatial information, spatial relations and property to describe geospatial information [2]. Geographic information system data objects have multidimensional and complex character, including a variety of data models, such as not only relational model, but also topology model and grid model. However, these models are focused on the description of the data organizational structure and constraints from single aspect, which are the absence or little relevance of the hierarchy and the rich connotation of data objects. The traditional data models inherit the advantages of cartography method, and it is beneficial to use computer technology for spatial data processing and storage [3]. But as the development of network, computer and database, etc. related technologies, besides, the great demands for spatial information and the rapid expansion of spatial data, the traditional data models describing the spatial entities could not satisfy the sharing requirements of spatial information. In addition, a deficiency of the traditional GIS spatial data models is that they do not match the natural concept of humans about geographical spatial data. People must artificially transfer their mental models into a restrictive set of non-spatial concepts. And they are also failed to fully consider the spatial relationships and arithmetic operations with the relationship between geographic objects, therefore it is difficult to make spatial relations and algorithms as a part of GIS data model.

In the early 90s of the 20th century, people used the object oriented technology develop GIS software, and accordingly put forward object-oriented GIS data model. The object-oriented GIS data models can overcome the deficiency to express and manipulate the complicated knowledge structures. It has proved to be a good solution for the design of non-conventional application where the complexity of data and the underlying relationships are critical issues [4].

OOT (Object-Oriented Technology) is used widely as software development and programming technique and it is from the real world objective existence of things (that is objects) to construct software systems. Object-oriented technology mimics the human way of thinking as much as
possible in constructing software systems to make software development methods and process of human understanding of the world as close as possible to solve problems and process [5]. It appears to overcome the shortcomings of traditional software design methods and improve the stability and reusability of the software systems. Object-oriented technology made tremendous impact and effectiveness for the software industry [6].

Object-oriented GIS data model is a new generation one which is combined with object-oriented technology and GIS technology, and it is the direction of development of GIS data model. It broke the constraints of the relational model paradigm, and directly support for nested objects and variable length records. It can effectively integrate with spatial data and attribute data, which has great advantages in disposing complex geographical objects, and has applied initially in three-dimensional spatial data model, temporal data model, etc. [7]. Some scholars have researched and achieved certain results in spatial data model, for instance, Egenhofer and Frank (1989) obtained some representative results [8].

In this paper, object-oriented methodologies are the main line. Based on analyzing and summarizing the strengths and weaknesses of existing GIS data model, we analyzes and discusses the object-oriented geographic data model’s description, expression, and the topological relations between spatial objects from the objective world of human cognition. In addition, defines simple objects, complex objects and the various spatial classes, and builds some topological operations of object-oriented geographic objectives.

The paper is organized as follows: in section 2 we summarize and define the spatial data model, for which the concrete implementation will be put forward. Section 3 introduces the topological 9-intersection and discusses the topological operations, for these topological operations we will give the detailed definition and implement them. And the conclusions in section 4 describe an implementation and discuss future research activities based on these results.

2. GIS Data Model

Data model is the development of conceptual model in the computer field. As the name suggests, the data model is abstraction of the real world by the means of data. Geospatial data model is a special case of data model in GIS study field, and an important foundation for GIS development [1]. Data models are generally unfamiliar to computer systems users, but they excel in providing a clear view of how the various things about which we want to store and retrieve information are related to each other. Those "things" are referred to in data modeling as entities.

A. Object-oriented GIS Data Model

Objects meet human cognition features. Object-oriented data model has become the most popular data model for the current period with features of abstraction, encapsulation, and inheritance, etc. It shows the great capability to express and store geographic data [5, 8].

For the traditional data model, data structure is separated with it. However, for the object-oriented data model, its data model and data structure is consistent with the data model and data structure is the concrete realization of the data model.

Many objects with similar features may be grouped into an object class. Spatial objects in GIS can be divided into two classes: simple objects and complex objects. Simple objects are not decomposable, and from its geometric nature, they can be further divided into point objects, line objects, region objects and complex objects composed by them if they are considered within a two dimensional Euclidean plane. Therefore these four types can be used as the type of super-class of various objects in GIS. The following are the four kinds of objects.

1. Point objects: such as stations, hydrological stations, tower and so on.
2. Line objects: rivers, roads and so on.
3. Region objects: such as lakes, vegetation, land and so on.
4. Complex objects: such as schools (schools which can include a pavilion, roads, lakes, etc.).

A geographical entity can be composed with one of these three simple objects, complex geographical entities can be constituted by a variety of simple objects, or even the other complex objects. Abstracting certain types of attributes and operations with public characteristics can form a more general super-class. Such as paddy fields and dry land is agricultural land, deciduous forest and evergreen forest is the forest, rivers, lakes and ponds are summarized water systems.

Object-oriented data model is the product of the combination with object-oriented programming language and the semantic data model. They involve four abstract concepts: classification, generalization, aggregation and association, and two semantic tools: inheritance and dissemination other than the encapsulation of data and operations [9]. We have used object-oriented methodologies design object-oriented GIS data model, shown in Figure 1. There are some classes of objects which are not decomposable. Classes of composite objects may be formed from primitive classes using aggregation and form a set of objects of the same class using generalization. The set of classes under a naturally partial order based upon their level of generality forms an inheritance hierarchy. The subclasses inherit all the behavior from the super-class and add in their own behavior. The base Geometry class has subclasses for Point, Curve, Surface and GeometryCollection. Two-dimensional collection classes named MultiPoint, MultiPolyline and MultiPolygon for modelling geometries are corresponding to collections of Points, Polyline and Polygons respectively. MultiSurface and MultiCurve are introduced as abstract super-classes generalized the collection interfaces.
The attributes, methods and assertions for each geometry class are described in followed section.

B. The Concrete Implementation of Object-oriented GIS Data Model

GIS can achieve the extensive application in geographical data, in fact, GIS is an information system that process, store, retrieve and display geographical data. In object-oriented data modeling, all computational entities are modeled as objects which have an identity describing the current status of each object. An object will support requests for a set of operations, the action of which may depend upon the current status of the object and which may alter its future behavior [10].

Point objects have these data items: identification number, code, location coordinates, etc, and some operations such as displaying, adding, deletion and modifying and so on. A Point is a 0-dimensional geometry and represents a single location in coordinate space. It has an x-coordinate value and a y-coordinate value. The class of point object is as follows:

```java
public class Point: Geometry
private double x;
private double y;
private int fid;
private string code;
//Add some methods here
```

The line objects are composed of one or more curves that involved nodes at both ends. With the data items such as identification number, coding, curves, the line objects have the operations of displaying, adding, deletion, modifying, and calculation length. The class of line object is as follows:

```java
public class Polyline: Curve
private Point[] Vertices;
private int fid;
private string code;
private double length;
//Add some methods here
```

Region objects are composed of one or more lines with identification number, code, arc strings and other data items. In addition, region objects have often interior point coordinates (see Figure 2), area [11], and even the minimum bounding rectangle coordinates. Furthermore the related operations include displaying, adding, deletion, modifying, and calculation area, etc. The class of polygon object is as follows:

```java
public class Polygon: Surface
private LinearRing ExteriorRing;
private LinearRing[] InteriorRings;
private int fid;
private string code;
private double area;
//Add some methods here
```

Point, line and region, three simple objects, are related to the isolated points, nodes, and arcs and so on, and have the close connection with label objects.

Any kind of model can not reflect all aspects of the real world, so as the complexity of the things and phenomena especially. It was impossible to design a common data structure and data model to adapt to all the aspects, it often shows the advantages when describing a kind of problem, but it is inefficient in describing another problem.

3. Topological relationships between spatial objects

Thus far, we have described the objects in object-oriented GIS data model. Beside the objects themselves, another aspect of object-oriented modeling is the relationships and operations between the spatial objects.

There are several types of operations of spatial objects, such as topological, metric, set-theoretic, and order. Most categorizations of spatial relations distinguish between topological relations, such as inclusion or overlap, and metrical relations, such as distance and directions [12]. In spatial data retrieval, the most used relationships are the topological ones. The topological operations are defined by introducing the concept of neighborhood and it leads to topological spaces (Egenhofer and Franzosa, 1991) [13]. It is agreed upon that topological relations are of great importance regarding to GIS data sets consistency. Most of GIS do not deal with topological relations, or consider only few relations such as adjacency and inclusion [14].

Topological spatial relationships between two geometric objects have been a topic of extensive study. In
recent years, results of study on the topological relationship between spatial objects are the 4-intersection model, 9-intersection model and the dimensionally extended 9-intersection model [15]. The 9-intersection describes binary topological relations in terms of the intersections of the interiors, boundaries, and exteriors of the two spatial objects. This topological model has been designed by Max J. Egenhofer in [16] and in [17]. In the model, binary topological relations between two objects A and B are defined in terms of the 9-intersections of A’s boundary (OA), A’s interior (A°) and A’s exterior (A-) with the boundary (OB), interior (B°) and exterior (B-) of B.

The concepts of interior, boundary and exterior are well defined in general topology. For a review of these concepts the user is referred to Egenhofer, et al [16], these concepts can be applied in defining spatial relationships between two-dimensional objects in two-dimensional space. Some spatial relationship predicates have been defined in [17] for better understanding the topological relationships, the definition of these predicates (such as Touch, Disjoint, Cross, Within, Overlap, Contain, and Intersect) is given below, each object a and b can be a point, a line or a polygon [18]. In these definitions the term P is used to refer to 0 dimensional geometries (Points and MultiPoints), L is used to refer to one-dimensional geometries (Polylines and MultiPolylines) and R (Region) is used to refer to two-dimensional geometries (Polygons and MultiPolygons).

A. Touch

The Touch relation between two geometries a and b applies to the R/R, L/L, L/R, P/R and P/L groups of relationships but not to the P/P group. It is defined as:

\[ \text{Touch}(a, b) \Leftrightarrow (I(a) \cap I(b) = \emptyset) \land (a \cap b) \neq \emptyset \]  

(1)

The method defined in the spatial object classes:

\[ \text{Boolean Touch(Geometry a, Geometry b)} \{...\} \]

B. Disjoint

Given two topologically closed geometries a and b, a disjoint b is defined as:

\[ \text{Disjoint}(a, b) \Leftrightarrow a \cap b = \emptyset \]  

(2)

The method defined in the spatial object classes:

\[ \text{Boolean Disjoint(Geometry a, Geometry b)} \{...\} \]

C. Cross

The Cross relation between two geometries a and b applies to P/L, P/R, L/L and L/R situations. It is defined as:

\[ \text{Cross}(a, b) \Leftrightarrow (\dim I(a) \cap I(b) < \max(\dim I(a), \dim I(b))) \land (a \cap b \neq a) \land (a \cap b \neq b) \]  

(3)

The method defined in the spatial object classes:

\[ \text{Boolean Cross(Geometry a, Geometry b)} \{...\} \]

D. Within

The Within relation is defined as:

\[ \text{Within}(a, b) \Leftrightarrow (a \cap b = a) \land (I(a) \cap E(b) \neq \emptyset) \]  

(4)

The method defined in the spatial object classes:

\[ \text{Boolean Within(Geometry a, Geometry b)} \{...\} \]

E. Overlaps

The Overlaps relation between two geometries a and b applies to R/R, L/L and P/P situations. It is defined as:

\[ \text{Overlaps}(a, b) \Leftrightarrow (\dim I(a) = \dim I(b) = \dim (I(a) \cap I(b))) \land (a \cap b \neq a) \land (a \cap b \neq b) \]  

(5)

The method defined in the spatial object classes:

\[ \text{Boolean Overlaps(Geometry a, Geometry b)} \{...\} \]

F. Contains

The Contains relation is defined as:

\[ \text{Contains}(a, b) \Leftrightarrow \text{Within}(b, a) \]  

(6)

The method defined in the spatial object classes:

\[ \text{Boolean Contains(Geometry a, Geometry b)} \{...\} \]

G. Intersects

The Intersects relation is defined as:

\[ \text{Intersects}(a, b) \Leftrightarrow \text{Disjoint}(a, b) \]  

(7)

The method defined in the spatial object classes:

\[ \text{Boolean Intersects(Geometry a, Geometry b)} \{...\} \]

Spatial operations are defined on the basis of the spatial object classes which may be taken as a base set. They are Boolean methods that are used to test for the existence of a specified topological spatial relationship between two geometries.

Due to limited space, this paper only gives the definition of topological operations, and did not give the specific realization.

4. Conclusions

Object-Oriented Technology is used widely a software development and programming technique and it is from the real world objective existence of things to construct software systems.

Based on the existing GIS data model, this paper introduces the basic idea of object-oriented GIS data model combined the object-oriented methods and the vectorial expression of spatial entities, and then focus on the methods and processes of vectorial description for the basic spatial
entities element of points, lines and regions. The geographical spatial information includes not only the geometric information of spatial entities, but also the spatial relationships between spatial objects. While the most used relationships are the topological ones in GIS, in our model, we use class methods to reflect the basic operations and topological operations. Among them, basic operations include access to the basic coordinate system of spatial objects, spatial objects boundary and computing spatial objects length and area, etc, and topological ones include touching, disjointing, crossing, containing, overlapping, and intersection and so on.

Object-oriented GIS data model can effectively integrate with spatial data and attribute data, which has great advantages in disposing complex geographical objects. The model has been developed in our own object-oriented GIS platform named YUMap, which has been realized by programming with C# .NET. However object-oriented GIS data model is still in the theoretical study and preliminary implementation phases, its implementation ways required further exploration to more effectively organize, store and manage massive data, and support the massive spatial data sharing, analysis and decision-making operation.

References