

## DEVELOPMENT OF A GIS DATA MODEL WITH SPATIAL, TEMPORAL AND ATTRIBUTE COMPONENTS BASED ON OBJECT-ORIENTED APPROACH

SHI Wenzhong  
ZHANG Minwen

**KEY WORDS** object-orientation; GIS data modeling; spatial, temporal and attribute model

**ABSTRACT** This paper presents a conceptual data model, the STA-model, for handling spatial, temporal and attribute aspects of objects in GIS. The model is developed on the basis of object-oriented modeling approach. This model includes two major parts: (a) modeling the signal objects by STA-object elements, and (b) modeling relationships between STA-objects. As an example, the STA-model is applied for modeling land cover change data with spatial, temporal and attribute components.

### 1 Introduction

A geographical object normally possesses three components: spatial, temporal and attribute aspects. The first component describes the spatial extent of an object, such as the boundary of a land parcel. The second describes time-related information, for instance, the beginning and end time of a land parcel. The third describes the attribute characteristics of objects, for example, the type of land cover. These three components constitute a complete image of an object.

In most of the current GIS, the relational data model is utilized to manage the attribute data while the spatial data are managed by the file management system of a specific GIS. A deficiency of the relational data model is that it does 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 con-

cepts. The object-oriented data models, on the other hand, can overcome this deficiency to express and manipulate the complicated knowledge structures.

The development of object-oriented modeling for geographical information can be divided into three stages. First stage: modeling objects with purely spatial component, Egenhofer and Frank (1989) and Worboys, *et al.* (1990) obtained some representative results. Second stage: modeling objects with spatial and temporal components. Worboys (1992a) developed a model for handling data with spatial and temporal components by use of the conceptual ST-atoms. Third stage: modeling objects with spatial, temporal and attribute components. This paper presents a model in the third development stage of the models, which handles spatial, temporal and attribute aspects of an object. To develop this conceptual model, the STA-model, an object-oriented data modeling approach is used.

### 2 Object-oriented data modeling

Object-orientation includes object-oriented modeling, object-oriented database management (OODBMS) and object-oriented programming lan-

---

SHI Wenzhong, Associate Professor, Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong  
E-mail: lswzshi@polyu.edu.hk

guages (OOPLAS). The object-orientation approach is referred to the conceptual GIS data modelling.

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. Object collecting operations may constitute its protocol. Many objects with similar protocols may be grouped into an object class. 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 superclass and add in their own behavior. In modeling GIS data using an object-oriented approach, two major aspects need to be considered: objects and relationships between objects.

### 3 The STA-object model

The most essential part of the object-oriented approach is the concept of an object. A real entity of whatever complexity can be modeled as an object in an object-oriented model. In order to describe geographical entities, an STA-object is defined here as an object with spatial, temporal and attribute components. Such an STA-object may change either in its spatial extent over time or in its attributes. For instance, a parcel of land may change by reducing its size or varying its shape over time-spatial extent change. On the other hand, the attribute of the land parcel may also change over time, e. g., the land cover type changes from forest to urban. Therefore, an object is completely described only if a model can handle both spatial and attribute changes over time.

An STA-object comprises spatio-temporal (ST-) and attribute-temporal (AT-) components. The objects corresponding to these two components are defined as ST-objects and AT-objects. This is

shown in Fig. 1. Worboys (1992b) presented a model to handle ST-objects. In this study, the Worboys' model is extended to include the AT-component. The Worboys' model was developed according to the following assumptions. Firstly, the underlying spatial framework is assumed to be embedded in a Euclidean plane, i. e., there is a pair of axes labelled  $x$  and  $y$  defining two dimensional planar space. Secondly, time is represented as one dimensional, linearly ordered and uni-directional. This time dimension is orthogonal to the two spatial dimensions. These assumptions are also valid for the STA-model. The general STA-object model is described analytically as follows.

$\langle \text{Object} \{ \text{O-ID}, S(x_k, y_k, t), A(t), t \in [t_b, t_e] \} \rangle$

Where, O-ID is the identifier of the object, unique for each object;  $S(x_k, y_k, t)$  is the function of spatial extent which is determined by a set of coordinates  $(x_k, y_k)$  and time  $(t)$ ;  $A(t)$  indicates the attribute change over time;  $[t_b, t_e]$  is the life span of the object defined by its begin time  $(t_b)$  and end time  $(t_e)$ . In the STA-model,  $A(t)$  is developed in this work, because in many cases an object attribute may change in addition to its spatial extent changing over time. For example, the land cover type may change over time.

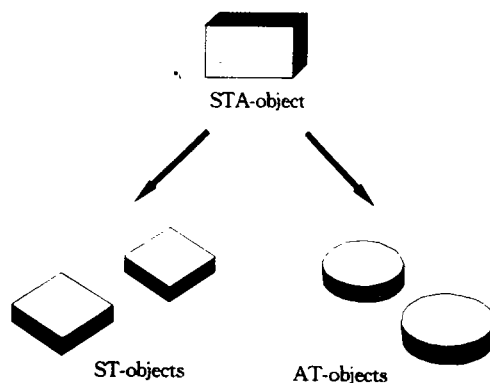


Fig. 1 Description of an STA-object by ST-object and AT-object

To represent the general STA-object model in a computer, the STA-object model is further subdivided into finite smaller elements, the STA-elements. Thus, the STA-object can be represented by a collection of STA-elements. There is need to make the following assumptions for STA-element representation: (a) changes in the object in the spa-

tial extent only take place at finite time points; and (b) change in an attribute of an STA-object can be approximately represented by the top and bottom attributes of an STA-element. Analytically, an STA-element is described as:

$$\langle \text{Element} \{ \text{E-ID}, [x_k, y_k]_{\text{E-ID}}, [t_i, t_j], [A_{\text{top}}, A_{\text{bottom}}] \} \rangle$$

Where, E-ID is the identifier of an STA-element, unique for each STA-element;  $[x_k, y_k]_{\text{E-ID}}$  are coordinates of the spatial extent of the element, fixed within time interval  $[t_i, t_j]$ ;  $[t_i, t_j]$  is the time interval which is determined by the times of the top and bottom faces;  $t_i$  and  $t_j$  are the times when the spatial extent or attribute of an STA-object changes;  $A_{\text{top}}, A_{\text{bottom}}$  are the attributes on the top and bottom faces of the STA-element, the attribute of the STA-element may continually change within  $[t_i, t_j]$  but can be approximately represented by  $A_{\text{top}}$  and  $A_{\text{bottom}}$ . Fig. 2 shows an example of the STA-element.

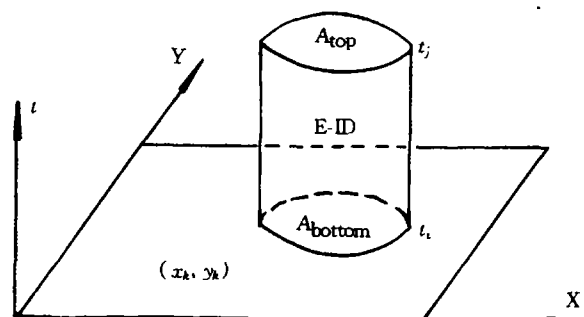


Fig. 2 An example of the SAT-element

Thus far, we have described the STA-object model as a collection of STA-elements. Beside the objects themselves, another aspect of object-oriented modeling is the relationships and operations between the STA-objects.

## 4 Relationships and operations between STA-objects

In this study, relationships between STA-objects are described by the relationships that exist between the composed STA-elements. The strategy of describing relationships between STA-elements is to project STA-elements to spatial, temporal and attribute domains, and then to describe the relationships among the projected elements in the three do-

main respectively. By projections, an STA-element can be described by an S-element in spatial domain ( $D_S$ ), an A-element in attribute domain ( $D_A$ ), and a T-element in temporal domain ( $D_T$ ), as shown in Fig. 3.

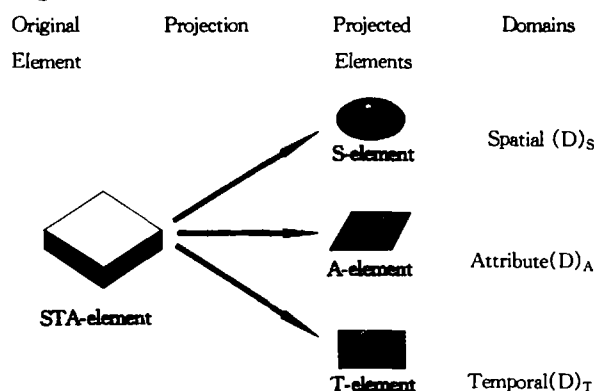


Fig. 3 Projection of an STA-element into three domains

According to the assumptions of the STA-object model, the time axis is orthogonal to the  $x, y$  axes of the spatial domain. Thus, it is possible to project an STA-element into the spatial and temporal domains using geometrical projection techniques. The projected result in the temporal domain (T-element) is a time interval which is defined by the top and the bottom time of an STA-element. The projection in the attribute domain is defined as the transformation of the attributes of the top and bottom faces of an STA-element to a relational table. Having projected the STA-elements to the three domains, the relationships between STA-objects can be described in these domains respectively in terms of relationships between the projected elements.

### 4.1 Relationships in the spatial domain

In order to describe relationships between S-elements in the spatial domain, three aspects need to be considered: (a) spatial object classes which construct spatial objects; (b) relationships between spatial object classes; and (c) spatial operations based on which new relationships and classes are generated.

Spatial object classes are considered within a two dimensional Euclidean plane. The spatial objects can be divided into three classes; point, line and area. The spatial class has a disjoint subclass 0-ext which is a point, and non-zero-ext. Class point is based on coordinates  $x$  and  $y$ . Class non-zero-ext has a disjoint subclass 1-ext and 2-ext of one and

two dimensional extent respectively.

Spatial operations are defined on the basis of the spatial object classes which may be taken as a base set. There are several types of operations of spatial objects, such as metric, topological, set-theoretic, and order. The metric is defined as the distance between two points of that space. The topological operations is defined by introducing the concept of neighborhood and it leads to topological spaces (Egenhofer and Franzosa, 1991). Set-theory is based on logic, it is the perspective of membership functions. Order involves containment of sets and leads to posets and lattices (Kainz *et al.*, 1993). Each of these operations defines several operators for it. These can be used to deal with the relationships between the spatial objects. For example, the topological operators are closure, boundaries, components, extremes, clockwise, etc. The relationships of topology are: interior, adjacency, orientation, etc. Order operators include inclusion, containment and others. In spatial data retrieval, the most used relationships are the topological ones. The topological relationships of the three spatial object classes are summarized in Table 1.

Table 1 Topological relations between spatial object classes

	point	line	area
point	"adjacency"	"point on line" "point to the right of line", "point to the left of line"	"interior" "point on boundary", "adjacency"
line		"overlap" "adjacency"	"adjacency", "separation"
area			"interior", "adjacency", "connectivity", "overlap"

All or some of these six groups of relationships may be used for different applications. For example, relationships between areas can be used for describing relationships between different land cover units.

#### 4.2 Relationships in the attribute domain

##### (a) Attribute object classes

In many cases, objects are grouped into several distinct classes according to their attribute features. Each class includes a number of attributes, and each

object of a class has a list containing values for each attribute. When two or more classes have common attributes, the common attributes can define a superclass. The class at the lower level will inherit all attributes of the superclass.

##### (b) Operations and relationships of attribute object classes

The attribute component plays a dominant role in the object definition for many cases. The relationships for attribute objects may include classification, generalization, aggregation, association, etc. Those objects with the same data type, the same operations and the same attributes in the real world can be grouped into a class, this is called as a classification. Thus, the classification will often result in "member-of" relationship. In a common object-oriented model, this is referred to as "is-member-of". However, in temporal GIS, we deal with change over time. Therefore, we define "was-member-of", "is-member-of" or "will-be-member-of" relationships between STA-objects for different times. Other relationships, such as generalization, aggregation and association, are also extended to include time features within them. The relationships are summarized in Table 2.

#### 4.3 Relationships in temporal domain

##### (a) Temporal object classes

In the temporal domain, two temporal object classes are defined as: an instant of time (0-ext temporal object) and a time interval (1-ext temporal object). The one dimensional extent of time is different from 1-ext of spatial arc. In the temporal domain, time is defined only as a one-directional variable.

##### (b) Relationships in temporal object classes

Three groups of relationships between 0-ext and 1-ext temporal object classes can be defined as follows: the relationships within two 1-ext temporal objects, the relationships within two 0-ext temporal objects, and relationships between a 0-ext and a 1-ext temporal object. Within each of these groups, the relationships are further defined, such as the relationships "overlap", "meet", "during", "equal", and "late" of two 1-ext temporal objects. These three groups of relationships are summarized in

Table 2 The attribute relationships between objects

classification	generalization	aggregation	association
"was-member-of"	"was-a"	"was-part-of"	"was-included"
"is-member-of"	"is-a"	"is-part-of"	"is-included"
"will-be-member-of"	"will-be-a"	"will-be-part-of"	"will-be-included"

Table 3 The temporal relationships

	0-ext	1-ext
0-ext	"difference", "equal" "early", "late"	"during", "meet", "disjoint"
1-ext		"overlap", "meet", "during" "disjoint", "equal", "early", "late"

Table 3. These definitions are visualized in Fig. 4 and further explained in the following section.

## 5 STA-model for land cover change data

As an example, the STA-model is applied for modeling land cover change data. These include modeling land cover parcels as STA-objects by a collection of STA-elements, and the relationships among the objects. In a practical application, land cover change is very complex. The first step is to abstract the nature of these changes (Zhang, 1993). Land cover may change either spatially or in attribute. The spatial change includes aspects of geometry (e. g. , position, shape and size), topology (e. g. , adjacency, orientation, connectivity) and aggregation structure (decomposition, combination or mixture of them). Attribute may change either qualitatively or quantitatively.

### 5.1 STA-object model for land cover parcels

A set of simulated land cover parcels, which change over time, are shown in Fig. 5. A static land cover parcel is represented by object  $O_m(A_n)$ , where the " $O_m$ " represents the spatial extent of the land cover parcel, and " $A_n$ " represents the attribute values of the parcel. In the following description we assume the attribute only indicates the type of the land cover parcel.

At time  $t_1$ , there are two land cover parcels  $O_0(A_0)$  and  $O_1(A_1)$ . At time  $t_2$ , the attribute of

parcel  $O_0(A_2)$  changes from  $A_0$  to  $A_2$  and a new parcel  $O_3(A_3)$  was generated within parcel  $O_1(A_1)$ . At time  $t_3$ , the spatial extent of  $O_0(A_2)$  was reduced as  $O_6(A_2)$  to accommodate the parcel  $O_5(A_1)$ , and the parcel  $O_3(A_3)$  disappeared due to changing back to parcel  $O_1(A_1)$ . At time  $t_4$ , the attribute of parcel  $O_6(A_4)$  changes from  $A_2$  to  $A_4$ . Now, STA-elements are built up to describe the land cover changes over a period, where E-ID represents the identifier of a land cover parcel;  $[x_k, y_k]_{E-ID}$  represents the spatial extent of the STA-element;  $[t_i, t_j]$  represents the time interval of the change from  $t_i$  to  $t_j$ ;  $A_{top}$  and  $A_{bottom}$  represent the end land cover type and the start one respectively. Based on the STA-element description, the land cover change data are thus described by a collection of STA-elements as shown in Fig. 6.

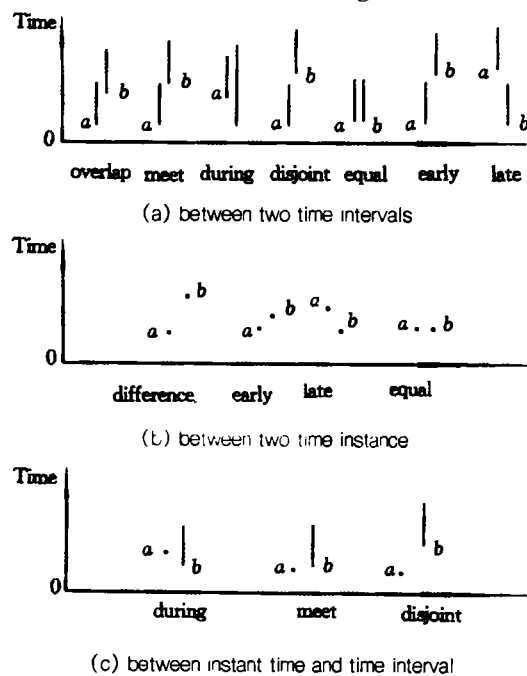


Fig. 4 Relationship between temporal object classes

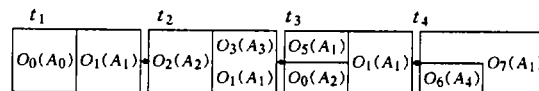


Fig. 5 Land cover regions change over time

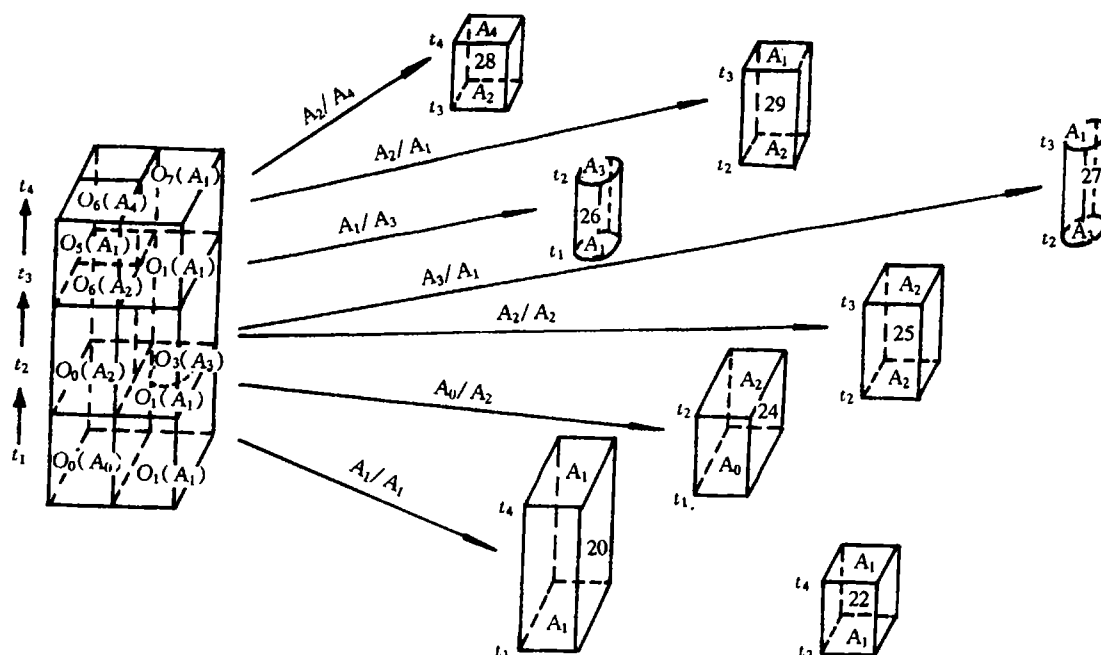


Fig. 6 Representing STA-objects of land cover regions by STA-elements

## 5.2 Modeling relationships between land cover parcels

Relationships between land cover parcels are described by relationships between the composed STA-elements. The STA-elements of land parcels are firstly projected to the three domains: spatial, temporal and attribute. The relationships between elements are then described by the relationships within the three domains respectively.

Relationships in the spatial domain are illustrated in Fig. 7. Each element is projected to a spatial domain and an S-element, spatial extent of the element, are generated. The relationships among the spatial extent of elements include: "equal" and "subset" of set theoretic relationships; "adjacency" of topological relationship; and "contain" of order relationship. Relationships in the temporal domain are shown in Fig. 8. Each element is projected to the attribute domain and A-elements are generated which represent land cover types of top and bottom faces of an STA-element.

The relationships among A-elements include: "is-a", "part of", and "include" in this example. Relationships in the temporal domain are demonstrated in Fig. 9. Each entity is a projection of an STA-element in the temporal domain, T-element. It represents the time intervals determined by the top time and bottom time of an STA-element of the land parcel changing over time. Relationships among T-

objects include: "during", "meet", "equal". Thus, the relationships of land parcels are described in terms of relationships of the composed elements within the three domains.

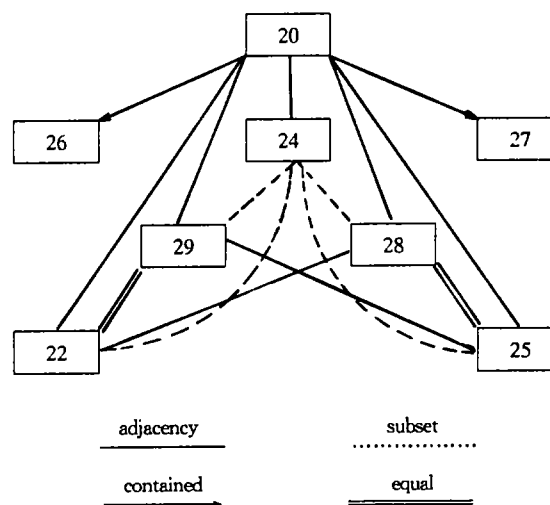


Fig. 7 Relationships of land cover change in the spatial domain

## 6 Conclusions

In the field of GIS conceptual modeling using the object-oriented approach, this study further developed attribute component additional to spatial and temporal components of geographic data. The STA-model was developed on the basis of an object-oriented approach for handling geographic data with spatial, temporal, and attribute components. The

STA-model is constructed by two aspects: a) the STA-object model, and b) relationships between STA-objects. An STA-object was built up by a collection of STA-elements. The relationships between the STA-objects were described by relationships of projected STA-elements in spatial, temporal and attribute domains respectively. Several types of relationships in the spatial domain were described, such

as metric, topological, set-theoretic and order. In the temporal domain, temporal object classes and relationships were extended. In the attribute domain, the commonly used relationships in an object-oriented data model like "is-a" were further extended to include relationships such as "was-a" and "will-be-a". An important feature of the STA-model is that the model can handle geographic data with

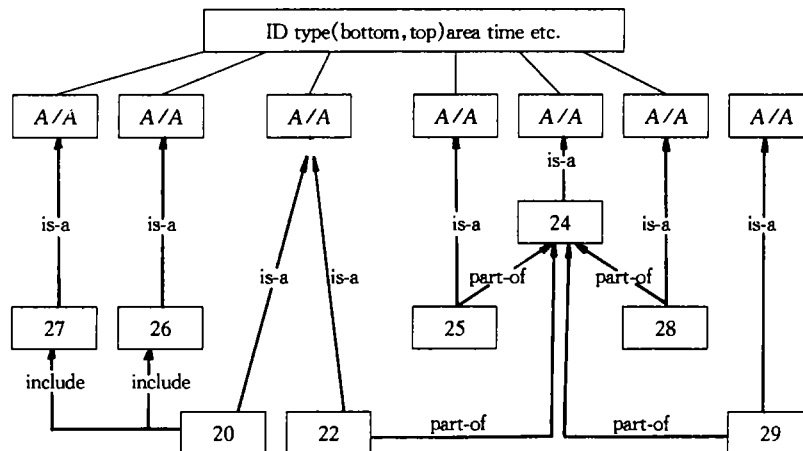


Fig. 8 Relationships of land cover change in the attribute domain

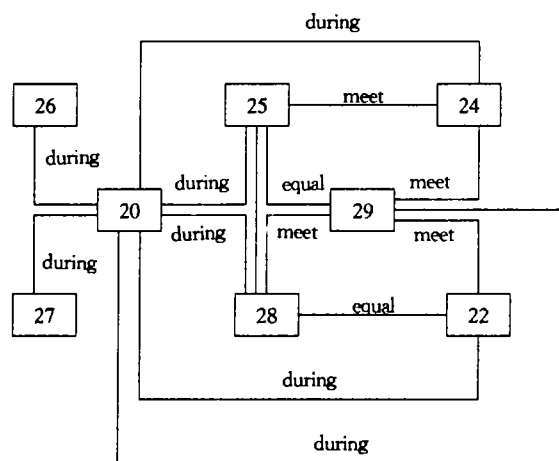


Fig. 9 Relationships of land cover change in the temporal domain

spatial, temporal and attribute components. This is demonstrated by applying the model for handling simulated land cover change data.

## References

- 1 Egenhofer M J, Franzosa R D. Point-set topological spatial relations. *International Journal of Geographical Information System*, 1991, 5(2): 161~174
- 2 Egenhofer M J, Frank A. Object-oriented modelling in GIS: inheritance and propagation. In: *Proceedings of Auto-Carto 9*. USA: Baltimore, 1989. 588~598
- 3 Kainz W, Egenhofer M J, Greasley I. Modelling spatial relations and operations with partially order sets and lattices. *International Journal of Geographical Information System*, 1993, 7(3): 215~229
- 4 Worboys M F. A Model for spatio-temporal information. In: *Proceedings of 5th International Symposium on Spatial Data Handling*. USA: Charleston, 1992a. 602~611
- 5 Worboys M F. Object-oriented models of spatio-temporal information. In: *Proceedings of GIS/LIS'92*, 1992b. 825~834
- 6 Worboys M F, Hearnshaw H M, Maguire D J. Object-oriented data modelling for spatial databases. *International Journal of Geographical Information System*, 1990, 4(4) 369~383
- 7 Zhang M W. Temporal geographical information system techniques for monitoring landcover change: [M S Dissertation]. ITC, The Netherlands, 1993.
- 8 Zhang M W, Shi W Z. Modelling spatial, temporal and attribute aspects of object in GIS. In: *Proceedings of International Symposium on Remote Sensing. GIS and GPS in Sustainable Development and Environment Monitoring*. Hong Kong, 1995. 583~591
- 9 Zhang M W, Shi W Z. Implementation of a Conceptual Model for Handling Geographical Information. In: *Proceedings of the 4th International Symposium of LIES-MARS*. China, Wuhan, 1995. 161~169