

A Framework for the Description of Spatiotemporal Relationships*

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Abstract

Spatiotemporal data model, which is the basis of spatiotemporal information management, deals with the representation and manipulation of spatiotemporal data. So far many spatiotemporal data models have been proposed, but most of them concentrated on the representation of spatiotemporal objects and few of them make systematic studies on spatiotemporal relationships. Based on the semantics of spatiotemporal changes, this paper first proposes a systematic classification on spatiotemporal relationships. And then a framework for the representation of different types of spatiotemporal relationships is presented. We classify spatiotemporal relationships into two categories, which are static spatiotemporal relationships and dynamic spatiotemporal relationships. The latter is further divided into two types: time-varying topology and history topology. The definition and representation of these spatiotemporal relationships are discussed in detail. Through the research on spatiotemporal relationships, we can further develop a more functional spatiotemporal data model that support both spatiotemporal objects and spatiotemporal relationships.

Keywords: Spatiotemporal Database; Spatiotemporal Relationship; Topology .

1. Introduction

Spatiotemporal data management has become a critical technology for important applications such as Geographic Information Systems (GIS), environmental information systems, and multimedia. Spatiotemporal data model, which is the basis of spatiotemporal data management, deals with the representation and manipulation of spatiotemporal data. So far many spatiotemporal data models have been proposed [1-9], but most of them concentrated on

the representation of spatiotemporal objects and few of them make systematic study on spatiotemporal relationships. To define a data model, not only the representation of objects but also the relationships of objects should be concerned [10]. So the representation of spatiotemporal relationships is really a key issue in spatiotemporal modeling. Traditional spatial relationships usually refer to static topological relationships among spatial objects at current time point [11-14]. But spatiotemporal relationships are far beyond this.

Based on the semantics of spatiotemporal changes in the real world, a systematic classification on spatiotemporal relationships is proposed in this paper, as well as a framework to represent different types of spatiotemporal relationships. We classify spatiotemporal relationships into two categories, which are static spatiotemporal relationships and dynamic spatiotemporal relationships. The latter is further divided into two types: time-varying topology and history topology.

2. Spatiotemporal Changes

One limitation that researchers of spatiotemporal databases and temporal GIS seem to impose on their models is that objects can only be created, changed and eventually removed. However this is a too simplistic view in a spatial context. Spatial objects may also split into two or more objects, and two or more objects may also be merged into a single one. There are different kinds of changes existed in the real world, and current spatiotemporal data models are usually short in supporting different types of changes completely. This is mainly because of the insufficient cognition to the real world.

According to the object-oriented view, the objects in the real world are identified by identifiers, and the state of an object is represented by its internal attributes, which consist of spatial attributes and non-spatial attributes. The former describe the position and

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region occupied by an object, and the latter are those attributes that are related to the applications an object is involved in, which are called *thematic attributes*. So according to the structure of an object, the spatiotemporal changes can be divided into two categories, which are: (1) *life* (the appearance and disappearance, and merging and splitting of objects) and (2) *processes* (changes of internal attributes). And *processes* can be further classified into *spatial processes* and *thematic processes*, according to what part of a spatiotemporal object changes.

When we consider the spatial relationships among geo-objects, we find that the spatial topological relationships among objects also change with time. This is mainly because the *spatial processes* of objects. E.g. as an object moves, the spatial topological relationship with other specific objects will change. Thus we define this type of change as *topological change*.

Thus, the spatiotemporal change of an object now could be any one among the following types:

(1) **TYPE 1** (*spatial processes*): the spatial attributes of an object change with time, such as spread of fire, flowing of flood and change of land boundary.

(2) **TYPE 2** (*thematic processes*): the thematic attributes of an object change with time, such as changes of soil type and change of the ownership of a land.

(3) **TYPE 3** (*life*): changes that result in the appearance, disappearance, merging or splitting of objects

(4) **TYPE 4** (*topological changes*): changes of an object's spatial topological relationships with other certain object. For example, the spatial topological relationship between a moving car and a road will change with time.

3. Classification on Spatiotemporal Relationships

Based on the study on spatiotemporal changes, we classify spatiotemporal relationships into *static spatiotemporal relationships* and *dynamic spatiotemporal relationships*, as shown in Fig.1.

The *static spatiotemporal relationship* between two spatiotemporal objects, which is at a certain time instant, refers to the spatial topological relationship between these two objects, E.g. in Fig.2 the spatial topological relationship between *A* and *B* at t_0 .

Dynamic spatiotemporal relationships refer to the relationships of spatiotemporal objects along the time line. This is mainly because a spatiotemporal object has *life* and *topological changes*. We classify dynamic spatiotemporal relationships into two types: *history*

topology and *time-varying topology*. *History topology* is the spatiotemporal relationship between a spatiotemporal object and its "parents and children", which means where and how a spatiotemporal object comes from, and what it changes into. *Time-varying topology* is the changing history of spatial topological relationship between two spatiotemporal objects. In Fig.2 the relationship between *A* and *C* along the time line is history topology, while the relationship between *B* and *D* from t_1 to t_2 is time-varying topology.

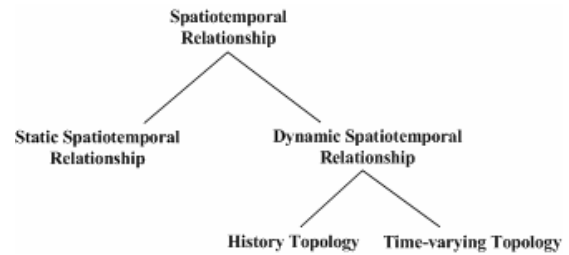


Fig. 1. Classification on spatiotemporal relationships

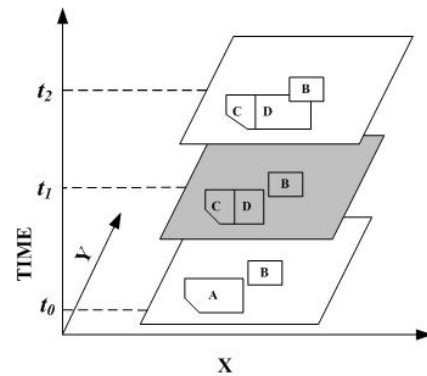


Fig. 2. Static spatiotemporal relationships and dynamic spatiotemporal relationships

4. Representation of Spatiotemporal Relationships

4.1. Static Spatiotemporal Relationship

Static spatiotemporal relationships refer to the spatial topological relationships between two spatiotemporal objects at one specific time instant. In this paper we use an implicit way to represent static spatiotemporal relationships. In spatiotemporal applications, there must be some spatial topological relationship between two different spatiotemporal objects at a given time instant, since each spatiotemporal object occupies some location in space. And more importantly this relationship may change with time. If we explicitly store the static spatiotemporal relationships in database, then we need to add new records whenever the related objects

change. For those interested objects we can use time-varying topology to explicitly record this type of changes, but we need not and also are not able to record the static spatiotemporal relationships between any objects. In this paper, we use a set of *predicates* defined on spatiotemporal objects to computer static spatiotemporal relationships.

Spatial topological relationship is one of the important issues in the researches on GIS and spatial databases. So far many people studied this issue and got some valuable results [11-13], among which the 9-Intersection model [11] has been widely accepted. The 9-Intersection model can completely represent spatial topological relationships. In this paper we just use the previous model to represent static spatiotemporal relationships [14].

First we define the following symbols:

Suppose that a spatial object A is a point set. The boundary of A is marked as ∂A , and the interior of A is marked as A° . So we can get the equation $A = \partial A \cup A^\circ$. And the dimension of A is defined by $dim(A)$ [14].

Then the set of predicates is defined as follows:

- *Disjoint*: $disjoint(A, B) \Leftrightarrow A \cap B = \Phi$;
- *Meet*: $meet(A, B) \Leftrightarrow A^\circ \cap B^\circ = \Phi \wedge A \cap B \neq \Phi$;
- *Overlap*: $Overlap(A, B) \Leftrightarrow A^\circ \cap B^\circ \neq \Phi \wedge (dim(A^\circ \cap B^\circ) = dim(A^\circ) = dim(B^\circ)) \wedge A \cap B \neq A \wedge A \cap B \neq B$;
- *Intersect*: $intersect(A, B) \Leftrightarrow A^\circ \cap B^\circ \neq \Phi \wedge (dim(A^\circ \cap B^\circ) < max(dim(A^\circ), dim(B^\circ))) \wedge A \cap B \neq A \wedge A \cap B \neq B$;
- *Contain*: $contain(A, B) \Leftrightarrow A^\circ \cap B^\circ \neq \Phi \wedge A \cap B = B$;
- *Equal*: $equal(A, B) \Leftrightarrow A = B$.

Fig.3 shows an example.

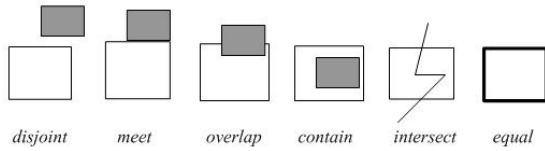


Fig. 3. The set of spatial topological relationships

4.2. Representation of History Topology

In this paper we use an explicit way to represent history topology, which is to store each change of spatiotemporal relationships in database.

In order to define the structure of history topology, we first give the definition of *history topology state*.

Definition 1. *history topology state*: If an object O appears, disappears, merges or splits at instant t , then the state of O at t is called a *history topology state*, denoted as $E_h(O_p, O_n, CT, t)$, where O_p is the set of

object of O 's ancestors and O_n is the set of object of O 's offspring, CT is the type of change, it could be *appearance*, *disappearance*, *merging* or *split*.

The ancestors of O denote those objects that produce O , while the offspring of O indicate those objects that are produced from O .

Definition 2. *history topology*: The history topology $HT(O)$ of an object O in $[t_0, t_n]$ is a series of history topology states $\langle E_0, E_1, E_2, \dots, E_m \rangle$, where for each $0 \leq i \leq m$, E_i is a history topology state. The history topology instant of E_i is denoted as t_h^i and satisfies: $t_0 \leq t_h^i < t_h^{i+1} \leq t_n, 1 \leq i \leq m - 1$.

Fig. 4 is an example that shows the changing history of a land. This is very typical in land management system. In Fig. 3, a land O_1 was created at t_1 and saved in database, at t_2 O_1 splitted into O_2 and O_3 , and at t_3 the land O_3 further splitted into O_4 and O_5 , and at t_4 O_2 and O_4 were merged and became a new field O_6 , and at t_5 O_5 was eliminated from the database. The spatiotemporal relationships among these objects during the time period are represented using history topology as following:

$$\begin{aligned}
 HT(O_1) &= \langle (\Phi, \Phi, appearance, t_1), (\Phi, \{O_2, O_3\}, split, t_2) \rangle \\
 HT(O_2) &= \langle (\{O_1\}, \Phi, split, t_2), (\Phi, \{O_6\}, merging, t_4) \rangle \\
 HT(O_3) &= \langle (\{O_1\}, \Phi, split, t_2), (\Phi, \{O_4, O_5\}, split, t_3) \rangle \\
 HT(O_4) &= \langle (\{O_3\}, \Phi, split, t_3), (\Phi, \{O_6\}, merging, t_4) \rangle \\
 HT(O_5) &= \langle (\{O_3\}, \Phi, split, t_3), (\Phi, \Phi, disappearance, t_5) \rangle \\
 HT(O_6) &= \langle (\{O_4, O_5\}, \Phi, merging, t_4) \rangle
 \end{aligned}$$

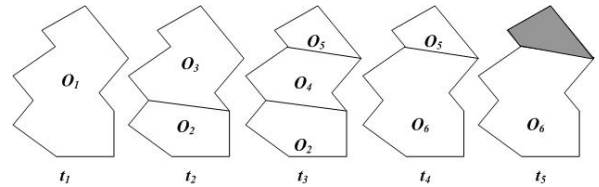


Fig. 4. History topology among lands

4.3. Representation of Time-varying Topology

The representation of time-varying topology is like that of history topology. We also use the explicit way. That is mainly because in most applications users are only interested in changes of spatial topological relationships between specific objects. So we must indicate of which objects we want to model the changes of spatial topological relationships.

The definition of *time-varying topology* is based on the spatial topological state.

Definition 3. spatial topological state: If the spatial topological relationship between an object O and another object O_n remains static in $[t_s, t_e]$, we say the object O has a spatial topological state in $[t_s, t_e]$ with object O_n . We define it as $E_s(O_n, TT, [t_s, t_e])$, where O_n is the object that O is related with. TT is the type of spatial topological relationship, it could be *disjoint*, *meet*, *overlap*, *contain*, *intersect* or *equal*. The instant t_s is called the start instant of E_s , while t_e is the end instant of E_s .

Definition 4. time-varying topology: The *time-varying topology* $TF(O)$ of an object O in $[t_0, t_n]$ is a series of spatial topological states $\langle E_0, E_1, E_2, \dots, E_m \rangle$, where for each $0 \leq i \leq m$, E_i is a spatial topological state. The start instant of E_i is denoted as t_s^i and the end instant of E_i is t_e^i . And $TF(O)$ satisfies: $t_s^0 = t_0$ and $t_e^m = t_n$ and $t_s^{i+1} = t_e^i + l$.

Fig. 5 is an example about time-varying topology. Suppose that in the application users want to model the changes of the spatial topological relationship between object O and O_1 , and then we can create a *time-varying topology* for the object O , which will record such spatiotemporal relationships. In Fig.4 the spatiotemporal relationships between object O and O_1 during the time period $[t_0, t_3]$ are represented by the *time-varying topology* $TF(O)$ as follows:

$TF(O) = \langle (O_1, disjoint, [t_0, t_1]), (O_1, overlap, [t_1, t_2]), (O_1, contain, [t_2, t_3]), (O_1, meet, [t_3, NOW]) \rangle$

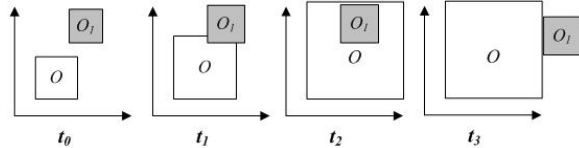


Fig. 5. Topological changes occur in $[t_0, t_3]$

5. Conclusions and Future Work

Spatiotemporal data model deals with representation and manipulation of spatiotemporal objects, as well as spatiotemporal relationships. Unfortunately, so far there is no systematic research on spatiotemporal relationships. In this paper, we have deeply studied the spatiotemporal relationships and presented a framework for the modeling of spatiotemporal relationships. The research on spatiotemporal relationships can be used to build a relatively functional spatiotemporal data model, which can represent not only spatiotemporal objects but also spatiotemporal relationships. Future work will focus on the development of a unified spatiotemporal data model that supports both spatiotemporal objects and spatiotemporal relationships.

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