AN OBJECT-ORIENTED SPATIO-TEMPORAL DATA MODEL

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ABSTRACT:

The paper proposes an object-oriented spatio-temporal data model based on space-time composite by taking advantage of high topological representation ability of the space-time composite data model and investigating the key concepts and technologies of object-oriented method. Then, the paper describes how to structure and manipulate spatio-temporal data. The spatio-temporal data model introduced in this literature can explicitly represent topology change of spatial entities over time dimension and quickly restore the topological information at specific time point. It's proved that the spatio-temporal data model can save storage, reduce data redundancy, accelerate responding speed and expand the functions of spatio-temporal queries and analyses.

1. INTRODUCTION

Nowadays, it is very imperative to research and develop GIS with time dimension. Three fundamental characteristics of geographical entities include space, attribute and time. The ideal GIS should implement unified storage and management of these three types of data, retrieve these data according to variant requirement, accomplish spatial, temporal and spatiotemporal analysis (Ott, 2001). However, due to the limitation of the software and hardware aspects of computer and some other technology factors, conventional GIS represents the real world in a spatially referenced data model and neglects the time dimension. The salient technology obstacle hinders the further application of GIS in many domains which need information relevant to spatio-temporal aspects. Consequently, the emerging of Temporal Geographical Information Systems (TGIS) is very urgent to meet such requirement.

Spatio-temporal data model serves as the basis of TGIS (CAO, 2001). With the fast development of science and technology, spatio-temporal data can be obtained through many ways such as earth observation satellite, GPS, LIDAR, etc. Huge volumes of these data have been collected over the past few decades and are being recorded at an ever-increasing rate. They enrich the contents of databases while increasing the complexity of management. It becomes unwieldy if we still use the existing 2D spatial data models to structure these data. Accordingly, spatio-temporal data model appears to be the key issue because it influences the flexibility and efficiency of TGIS and restricts its development of other aspects.

Many researchers have pay attention to the design of spatio-temporal data model and have made some efforts. But the normalized spatio-temporal data model still lies in the exploring stage. The paper makes some research on spatio-temporal data model based on the following considering: exactly describing the time dimension of spatial data, correctly representing the geographical world with the least data volume and conveniently acquiring the information what we need, especially the time-varying topological information.

In section 2, problems encountered are listed and an object-oriented spatio-temporal data model is proposed. In section 3, we describe the spatio-temporal data model in detail including model designing and how to store and handle of spatio-temporal data. In section 4, we conclude the paper and point to the benefits of the model we bring forward in the literature.

2. PROBLEMS AND PROPOSITION

The research on spatio-temporal data model in GIS has only experienced several decades, so there are many things to study in the field. In 1992, the publication of "Time in Geography Information System", a doctor paper authored by Gail Langran, indicated the formal beginning of spatio-temporal data model in GIS. Although there are some spatio-temporal data models that have been brought forward up to now, but none is the optimal model in TGIS. Originally, researchers attempted to extend the existing spatial data models directly and proposed some kind of spatio-temporal data models such as sequent snapshots, base state with amendments, space-time composite, space-time cube, etc. (PEUQUET, 2002). Yet, these models are inherently problematic because they handle time as an attribute. Later, event-based spatio-temporal data model, triad, tupu data model, non-first-normal form data model, object-oriented spatio-temporal data model and so on were put forward. Though these models are improved than above, they cannot be applied to all conditions.

Each existing spatio-temporal data model has both its own benefits and limitations. For example, we adopt time slices to record geographic data at different time intervals. So the change can be known by comparing two temporally neighbouring time slice maps. Yet sequent snapshots result in much data redundancy because it also stores the unchanging feature. Especially when the number of time slices increases, system efficiency will be reduced sharply. Although base state with amendments data model has made up for the deficiencies of sequent snapshots and is easily to be implemented in current GIS software, it is difficult to analyse the time dimension and takes long time to retrieve the history data. To space-time composite, it has the high topological representation ability, but is difficult to carry out in the current GIS software.

Topological information is very important for spatial entities. When we take time dimension into consideration, topology relationships between spatial entities become very complex. So it is urgent to propose a spatio-temporal data model which has the ability to represent time-varying topology. But none of the existing spatio-temporal data model can be well applied. In order to fulfil this aim, we combine the object-oriented technology and space-time composite data model, and address an object-oriented spatio-temporal data model based on space-time composite.

Object-oriented technology can model the real world in a more natural way, break through the limitation of relational form and directly support nested objects and length-changeable records. It is the most effective means to support complex spatio-temporal objects to model. Space-time composite has the high ability to represent the topological information. So based on the two technologies, the spatio-temporal data model we propose in the paper enriches the semantic representation and has the higher ability of spatio-temporal analysis.

3. THE SPATIAL-TEMPORAL DATA MODEL

3.1 Model Designing

At present, most GIS softwares structure the spatial data quite differently, but the thought to model the real world by the scattered distributed point, line, area and their combination, is identical. In the internal GIS data exchanging format, point, line and area are also looked on as three basic types of data. In order to be easily applied in current GIS software, here we also model the spatial data by point object, line object and area object, and organize these data by the concept of layer. We assume that the objects in the same layer exist in the same plane. If they intersect or self-intersect, one or more cross points must exist, and spatial objects will be segmented into smaller non-intersection or self-intersection ones. We believe that area objects in the same layer are mutually exclusive and compose of a complete coverage.

We merge several snapshots of geographic world at different time intervals into one composite layer. Based on the assumption described in the above paragraph, composite layer consist of three spatio-temporal elements, i.e. node, arc and polygon. We only record the relationships between spatial objects and spatio-temporal elements in composite layer, and we can get the time-varying topological information of every spatial object at each specific time point from the composite layer.

In order to conveniently extend temporality in current GIS software, we utilize the thought of oriented object and abstract the real world objects to the models consisting of space object, attribute object and time object. The general structure of spatio-temporal object is: <OBJ: {Spatio-temporal object ID, spatial feature, attribute feature, time feature, relationships}>. Every spatio-temporal object has a unique ID which will keep unchanging from its generation to disappearance no matter how many varieties it experiences. Spatio-temporal objects are classified into spatio-temporal point object, spatio-temporal line object, spatio-temporal area object and their combination. In the same way, each spatio-temporal element is encapsulated to an independent object with characteristics of space, attribute and time. Likewise, every spatio-temporal element has a unique ID.

In composite layer, each kind of spatio-temporal object is composed of one or more types of spatio-temporal elements. We may take fig.1 as an example. Fig.1 (a) denotes the original state at T_1 time point. When it experiences topology changing at T_2, T_3 time point, the corresponding state represents are (b) and (c) in fig.1. The composite layer is fig.1 (d). Through the topological information of spatio-temporal elements explicitly recorded in the relational tables, we can retrieve the topology relationships of every spatio-temporal object at any specific time point.

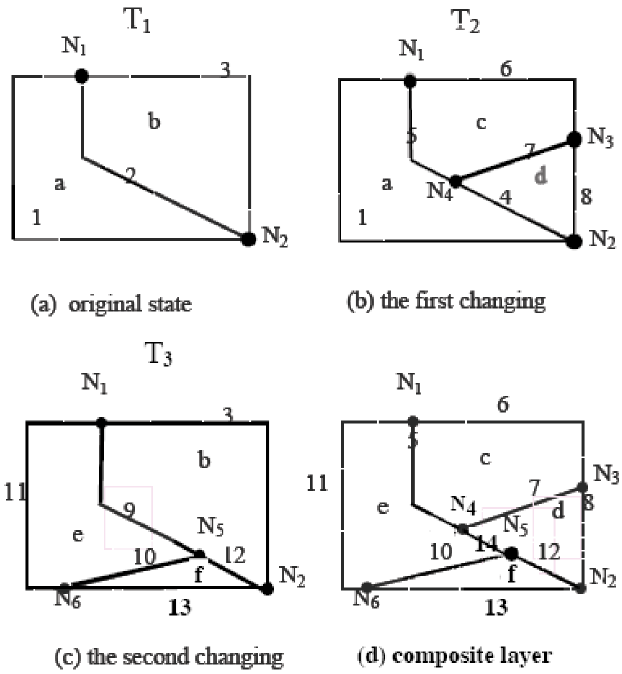

Figure 1. Spatio-temporal entities variation from T_1 to T_3

The following part will explain how to organize these data and handling method.

3.2 Organizing Data and Handling Method

Topological relationships between static spatial objects are maintained by inherent topological structure. While we introduce the time dimension into spatial data, topological relationships become very complex. Versioning, the common solution to solve the description questions such as spatial location and shape variation in time dimension, can not well describe the topological relationships in time dimension. In order to properly express the complex, dynamic and correlated spatio-temporal objects, topology changes of spatial entities over time dimension are explicitly represented. This formal representation of topology changes forms a fundamental and complete representative ability for time-varying topology. Table 1 to 5 are relational tables of current and history spatio-temporal elements.

PolygonID	ArcID	TimeVaryingPolygonType
c	－5,6,7	T_1 T_2 PP/ T_2 T_3 PE/ T_3 NOW PP//
d	－7,8,-14,12	T_1 T_2 PP/ T_2 T_3 PE/ T_3 NOW PP//
e	5,14,10,11	T_1 T_3 PP/ T_3 NOW PP//
f	-10,-12,13	T_1 T_3 PP/ T_3 NOW PP//

Table 1. Ploygon spatial-temporal element table

ArcID	StrartNode	EndNode	LeftPolygon	RightPolygon	LineID	Vertex	TimeVaryingArcType
5	N_1	N_4	c	e			T_1 T_2 AP/ T_2 T_3 AE/ T_3 NOW AP//
6	N_1	N_3	NULL	c			T_1 T_2 AP/ T_2 T_3 AE/ T_3 NOW AP//
7	N_3	N_4	d	c			T_1 T_2 AI/ T_2 T_3 AE/ T_3 NOW AI//
8	N_3	N_2	Null	d			T_1 T_2 AP/ T_2 T_3 AE/ T_3 NOW AP//
10	N_5	N_6	f	e			T_1 T_2 AI/ T_2 T_3 AI/ T_3 NOW AP//
11	N_6	N_1	NULL	e			T_1 T_2 AP/ T_2 T_3 AP/ T_3 NOW AE//
12	N_2	N_5	f	d			T_1 T_2 AP/ T_2 T_3 AP/ T_3 NOW AE//
13	N_2	N_6	NULL	f			T_1 T_2 AP/ T_2 T_3 AP/ T_3 NOW AE//
14	N_4	N_5	d	e			T_1 T_2 AP/ T_2 T_3 AP/ T_3 NOW AP//

Table 2. Arc spatial-temporal element table

NodeID	X	Y	ArcID	TimeVaryingNodeType
N_1			5,6,11	T_1 T_2 NE/ T_2 T_3 NE/ T_3 NOW NE //
N_2			8,12,13	T_1 T_2 NE/ T_2 T_3 NE/ T_3 NOW NE //
N_3			6,7,8	T_1 T_2 NP/ T_2 T_3 NE/ T_3 NOW NP //
N_4			7,5,14	T_1 T_2 NP/ T_2 T_3 NE/ T_3 NOW NP //
N_5			10,12,14	T_1 T_2 NP/ T_2 T_3 NP/ T_3 NOW NE //
N_6			10,11,13	T_1 T_2 NP/ T_2 T_3 NP/ T_3 NOW NE //

Table 3. Node spatial-temporal element table

PolygonID	SubObject	ExistTime
a	e,f	T_1 T_3 //
b	c,d	T_1 T_2 / T_3 NOW //

Table 4. Polygon entities history table

ArcID	SubObject	ExistTime
1	13,11	T_1 T_3 //
2	5,14,-12	T_1 T_2 //
3	6,8	T_1 T_2 / T_3 NOW //
4	14,-12	T_2 T_3 //
9	5,14	T_3 NOW //

Table 5. Arc entities history table

Before we organize above data structure, we make some agreements: topological relationships between node and arc are arrayed by angle anticlockwise, the boundary direction of polygon spatio-temporal element conforms to right hand rule, arc direction is positive when it is same with the boundary direction of polygon spatio-temporal element, otherwise negative. In table 5, arc spatio-temporal elements are arrayed from the start node to the end node of arc entity, and their directions are positive when they are same with the direction of arc entity, otherwise negative. Time period is left closed and right open interval. For instance, interval T_1 to T_3 means any time point t which meets the following inequation: $T_1 \leq t \leq T_3$.

In table 1, TimeVaryingPolygonType field indicates the topology of polygon spatio-temporal element in sequential time interval, and there are PP and PE two types. PP means polygon spatio-temporal element is a part of a polygon entity while PE shows it is a polygon entity. In table 2, TimeVaryingArcType field describes the topology of arc spatio-temporal element which has three types, i.e. AI, AP and AE. AI means that arc spatio-temporal element is located in the inside of a polygon entity while AP and AE respectively mean the part boundary and real boundary of polygon entity. In table 3, TimeVaryingNodeType field displays the topology of node spatio-temporal element which has three types, i.e. NI, NP and NE. NI means that node spatio-temporal element is located in the inside of polygon entity. NP means it is in a boundary of polygon entity but not the start or end node of the boundary. NE means it is the truly node of a polygon entity.

When we restore the topology at a given time point, we must use the topology described in the last paragraph. It has been proved that the static spatial topology representation capability of composite layer topology is as strong as that of static layer topology. For example, we can get the topology at time point T_1, T_2 or T_3 from the relational tables of spatial-temporal elements.

4. CONCLUSIONS

The paper presents a new spatio-temporal data model which can well answer some question related to topology. As time dimension is considered as an independent resources paralleling to spatial dimension, topological relationships between entities become very complex. Through the explicitly recording topology change of spatio-temporal elements in composite layer, we can easily get the topological information at given time point. At the same time, we adopt the object-oriented technology to organize and manage data, so it is easy to be implemented in current GIS software. The spatio-temporal data model also reduces data redundancy and expands the functions of spatio-temporal queries and analysis.

The model we proposed also has its limitation. When the number of time points increases, the composite layer will become very complex. To solve this problem, we advise to set key time points. Between neighbouring time points, we build a composite layer and record the information. Each composite layer overlaps the neighbouring layer. By this way, we can easily get time-varying topological information.

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