EXTENDING OBJECT-RELATIONAL DATABASE TO SUPPORT SPATIO-TEMPORAL DATA*

Wang Huibing

Key Laboratory of Geo-Informatics of State Bureau of Surveying and Mapping, Chinese Academy of Surveying and Mapping, Beijing 100039, China - wanghb@casm.ac.cn

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ABSTRACT:

Object-Relational Database (ORDB) techniques are developed rapidly in recent years and widely used for spatial data storage and manipulation. The ORDB has strong basis both on theories and applications, and if well extended, it can also be used to handle spatio-temporal data. Although ample research on spatio-temporal data modeling has been performed, very little work exists on how to implement a spatio-temporal information inside an ORDB. This paper aims at building spatio-temporal database system from design to implementation via extending object-relational database, including design spatio-temporal object model and a general spatio-temporal data model, then implement a spatio-temporal information system based on these model proposed, last a case study on practical spatio-temporal data handle examined.

1. INTRODUCTION

Despite pressing need, current RDBMS support for spatio-temporal data is limited and inadequate, and most existing spatio-temporal access methods cannot be readily integrated into an RDBMS (D. Mallett, M. A. Nascimento, V. Botea, and J. Sander, 2005). Database systems have been continually adapting to support new data-types, for instance, support for spatial data management is now standard in most Relational Database Management Systems (RDBMSs). The ORDB has strong basis both on theories and applications, and if well extended, it can also be used to handle spatio-temporal data. Although ample research on Spatio-Temporal Access Methods (STAMs) has been performed, very little work exists on how to provide a STAM inside a RDBMS, being a notable exception (D. Mallett, M. A. Nascimento, V. Botea, and J. Sander, 2005). This work fills this crucial need by proposing a spatio-temporal access method which can be fully integrated within any ORDB. We present STDB (Spatio-temporal Database) schema, a technique that extends an object relational database management system with additional capabilities for spatio-temporal data support.

2. SPATIO-TEMPORAL DATA MODEL

Spatio-temporal databases have been the focus of considerable research activity over a significant period (Paton, N.W., 2000). The spatio-temporal data model is the key to handling spatial and temporal data simultaneously. Spatio-temporal datasets consist lots of spatio-temporal objects (ST-Objects), first, we analyze and model spatio-temporal object.

2.1 Spatio-temporal object model (STOM)

Space and time are most important and basic information in the real world. Spatial and temporal attributes should be connected together. There are mainly two different notions of time which are relevant for temporal databases. One is called valid time (begin time and end time), the other is transaction time. The former denotes the time period during which an object is true with respect to the real world. The later is the time period during which an object is stored in the database. Note that these two time periods do not have to the same for a single object.
Any spatial object has theme/spatial/time attributes which represents the what/where/when structure, STOM model encapsulates spatio-temporal object as a whole of theme, space and time by object-oriented approach. STOM model references OpenGIS simple features specification as the basis of spatial domain, and adopts bitemporal model, which includes both valid time and transaction time, as the basis of time domain.

2.2 Event and State

Event and state is one pair of the most important basic conception in temporal database. One object may have different states during its life-span; event is the process from one state to another. In general, we record event by time instance and state by time span in database. State is an existent form of geographical entity in a given time range, and it is a comparatively stable process. The state of a spatio-temporal object can be divided into attribute state and spatial state, and then spatial state can be divided into spatial topological state and spatial geometry state (Figure 1).

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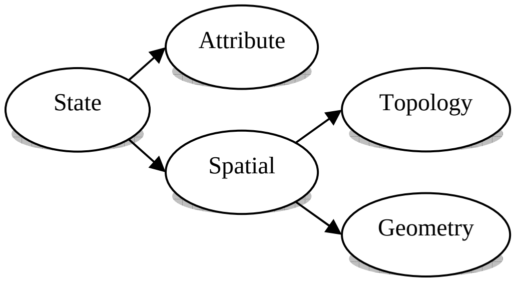


Figure 1. A spatio-temporal Object State

2.3 Correlation link

The disappearance of one object is usually coincident with the involvement of new object's appearance, and vice versa. We record such information in database as *correlation link*.
Parent object's death and child object's birth was triggered by the same event, in other words, parent(s) object and child object(s) have inheritable relationship in their life span. The relationship of object's variation inheritance is very important in the process of state evolvement and temporal data updates, and it is useful to track an object's various states over time, so we need build spatio-temporal dynamic correlation.
Figure 2 shows the state/event concept by an example. For object A, it splits into two objects B and C at time t_1 (an event occurred), and its state began at t_0 and ended at t_1. As for object B, its parent object is A, children objects are D and E, we recorded these information in database as correlation link. Other object in the figure follows the same rule.

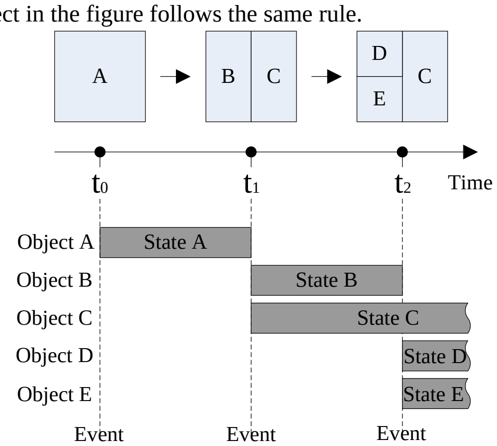


Figure 2. An example of state changes over time

For one ST-Object, it has x (x = 0,1,2,…,n) predecessors and y (y = 0,1,2, …,n) successors. Figure 3 express ST-Object class to represent ST-Object in real world (The ST-Object class may have other member variables and functions, such as temporal and geometry). In Figure 3, we use ST-Object correlation link to record and manipulate ST-Object's predecessors and successors, the correlation link is consisted of predecessors (m_PreID_Array), successors (m_NextID_Array) variables and some manipulate member functions.

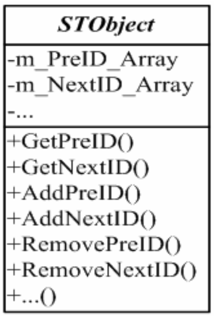


Figure 3. STObject class for programming

Obviously, ST-Object's predecessor or successor may have its predecessors and successors, the same rule to others. So, when we track one ST-Object over time through correlation link, the historic sequence of change looks like a tree (Correlation Tree, Figure 4).
The information of correlation link and correlation tree are very useful for ST-Object's tracking via various timestamps.

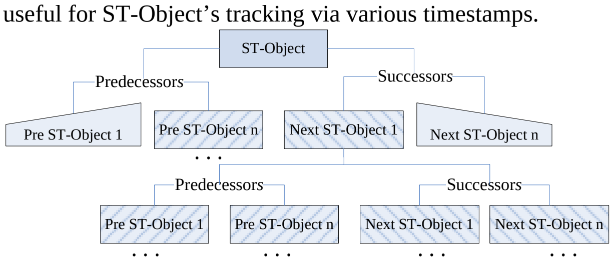


Figure 4. ST-Object correlation tree

2.4 "Version-difference" spatio-temporal data model

Building an appropriate spatio-temporal data model concerning about both spatial and temporal aspects, which can be used to organize and manipulate spatio-temporal entities more effectively and enrich spatio-temporal feature's semantics (theme, spatial and time), is critical to spatio-temporal information system. Many spatio-temporal data models have been proposed, dealing with data storage and management (Wang, H.B., 2005). The main models documented are as follows:

- Snapshot Model: Complete area under investigation must be brought into GIS every time point.
- Amendment Vector Model: The initial state and changes at later time points are mapped. With the algebraic topology the state at every time point can be reconstructed.
- Spatio Bitemporal Model: Enhancement of the amendment vector model using valid and transaction time.
- Object-Oriented Model: Object-oriented concepts are used to model the spatio-temporal system. Standards like the spatial and the temporal schema from ISO were defined, but regrettably no standard depicts the spatiotemporal characteristics of geographic information. So a conceptual object-oriented spatio-temporal model was defined integrating existing standards and existing models integrating space and time.

The methods presented in this paper are based upon a spatio-temporal data model named "Version-difference" model proposed by Wang, H.B. (2005). In the version-difference model (based on Amendment Vector Model), the terms *version* and *difference* are used to represent spatio-temporal data at an instance and changes over time. We need not store all information of every state in the interested area, but only the data at base state (version) and changes (difference) between the state considered and the base state to minimize storage. Unchanged features are not duplicated (Wang, H.B., 2005).

Base version focusing on data present situation and always representing the current state is introduced, and data at any time can be reconstructed by version and difference model, dataset may look different at different states. This model has been applied in real project and achieved good results.

This difference-based model provides a better understanding of the set of possible alterations to a ST-Object as it evolves over space and time, enables the extension of spatial data models and the development of GIS query languages that incorporate such semantics of change.

3. SPATIO-TEMPORAL DATA ORGANIZATION

Adopt "version-difference" model to support object-oriented design, reduce data redundancy and save space for storage. According to the version-difference model, we store spatio-temporal data into four logical databases to hold different information.

3.1 Current database

It stores the whole spatio-temporal dataset of current state. Because current dataset will be accessed frequently, we take it as base state in order to improve database performance.

3.2 Process database

Transitions are processes representing evolution and therefore subject to constraints, which are preconditions to limit, avoid or force a change. In other words, some change may be uncorrectable and cannot be happened in reality, we name it “fake change”. When the “fake change” occurred, the database should discard the alteration and rollback. Obviously, the process database stores the information of dynamic correlation so as to query and trace history.

3.3 Difference database

The latest state of an object will be updated to the **Current Database** once it was changed at a valid event, the old state of the object will be moved to this database, and also the process of transition will be stored in **Process Database**. The event should be arranged by time order, and the difference between the current state and old state will be stored when all the condition or constraint are all reasonable. Given a specific time, it is easy to obtain a previous state and rollback the current spatio-temporal relations and implement corresponding calculations.

3.4 Version database

Version is a snapshot of dataset at a given point of time. Users can browse the spatio-temporal data of any time instance and make a version into the version database. After this, the version dataset can be browsed and manipulated quickly, and it can be regarded as a base state of other version dataset whose time stamp is earlier to this one.

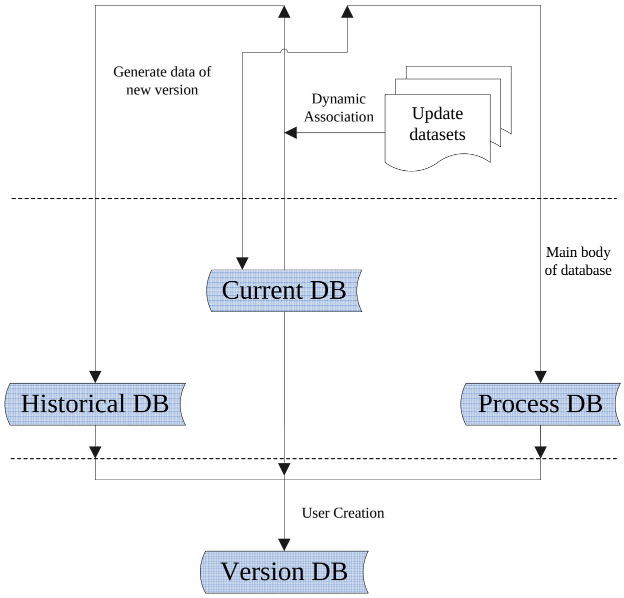


Figure 5. Relationship between the four logical databases

4. IMPLEMENTATION

In our implementation, we use Oracle 9i as our Object Relational Database Management System. In addition to our table design according with spatio-temporal data organization specifics, some details should be taken into account when implementing the database schemas for the system. We use several dataset manage tables to manage dataset stored hierarchically, and a set of log tables to record the system log information. We develop a spatio-temporal database engine which is the underlying component that the Object Relational Database Management System uses to create, retrieve, update and delete data from database.

Each ST-Object is associated with two times: valid time and transaction time. The valid time captures the time at which a record is true in the real world. It is typically represented as an interval [VTB, VTE], which means that the record is valid from time VTB to time VTE in the real world. Transaction time refers to the time at which a new value is posted to the database by a transaction, and constitutes the interval [TTB, TTE] during which the value reported by a particular transaction is current in the database (i.e. the interval bounded by the time when another update arrives). Valid and transaction time are orthogonal in that each could be independently recorded, and each has specific properties associated with it. Current time is denoted by variables for the time attributes VTE and TTE, the variable UC (denoting ‘until changed’) is used for TTE, and the variable NOW is used for VTE.

In this paper, ST-Object’s whole information with correlation link is recorded in four tables: the table of correlation link, change event record, entity’s current state and entity’s history state. Current entity table and history entity table stores ST-Object’s current and history entity data, change event table records the event information about ST-Object’ change, correlation link table records ST-Object’s correlation link. The four tables’ structure and relation are expressed in Figure 6. This structure stores unchanged objects only once.

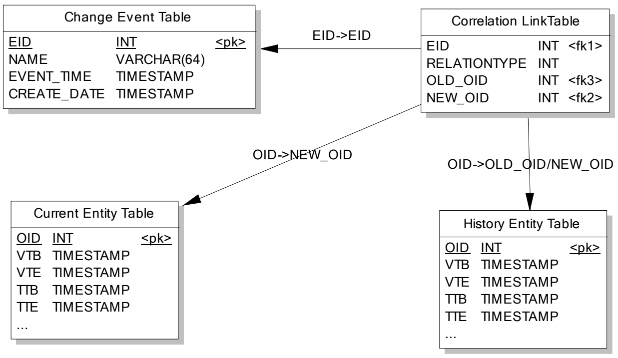


Figure 6. Database structure of ST-Objects and correlation link

Figure 7 shows an example of land parcel changes, the time granularity is day, and the current time (CT) is 2007/05/01. Parcel 1 and 2 merged to be one parcel 11 at time 2004/01/01, then spitted into parcel 101 and 102 at time 2006/01/01, parcel's entities and corresponding correlation information are exemplified in table 1,2,3 and 4.

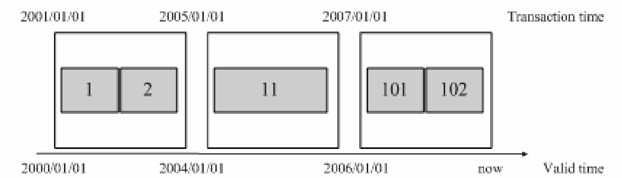


Figure 7. An example of land parcel changes

EID	NAME	EVENT_TIME	CREATE_DATE	…
1	Change1	2004/01/01	2005/01/01	
2	Change2	2006/01/01	2007/01/01	

Table 1. Change event table

EID	TYPE	OLD_OID	NEW_OID	…
1	ALTER(1:n)	1	11	
1	ALTER(1:n)	2	11	
2	ALTER(n:1)	11	101	
2	ALTER(n:1)	11	102	

Table 2. Correlation link table

OID	VTB	VTE	TTB	TTE	…
101	2006/01/01	NOW	2007/01/01	UC	
102	2006/01/01	NOW	2007/01/01	UC	

Table 3. Current entity table

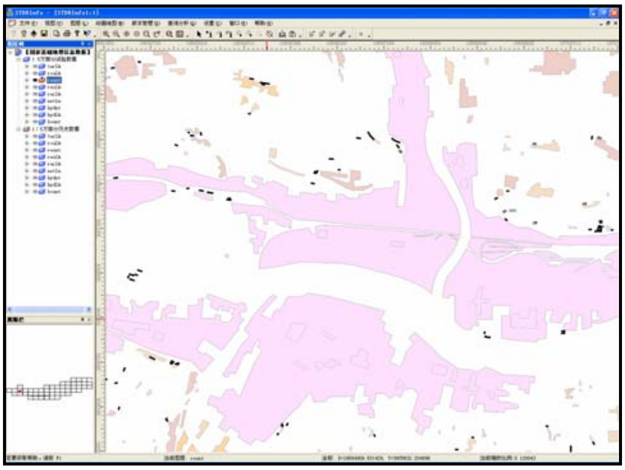
OID	VTB	VTE	TTB	TTE	…
1	2000/01/01	2004/01/01	2001/01/01	2005/01/01	
2	2000/01/01	2004/01/01	2001/01/01	2005/01/01	
11	2004/01/01	2006/01/01	2005/01/01	2007/01/01	

Table 4. History entity table

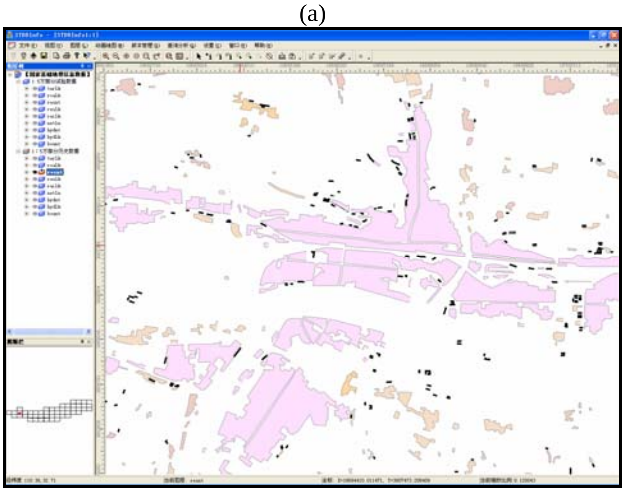
5. CASE STUDY

We take the spatio-temporal information system as multi-temporal national fundamental geographic information data management system, test results show that the system suitable to manage spatio-temporal data.

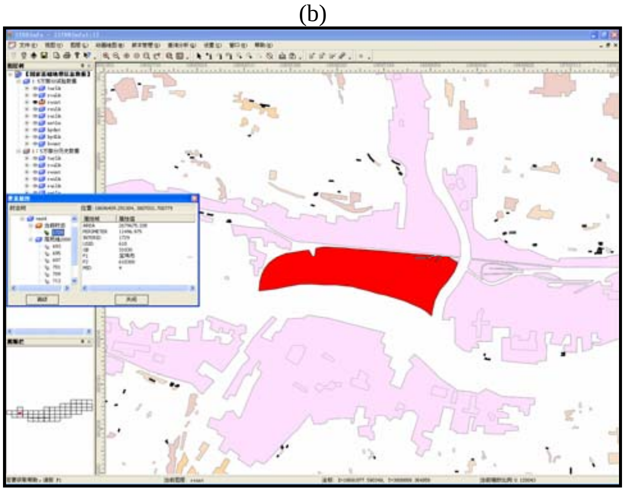
Figure 8 shows an example of tracking result of ST-Objects. (a) and (b) are different time data of a same city area, (a) is newer then (b); (c) and (d) are tracking results of ST-Object after change detection.



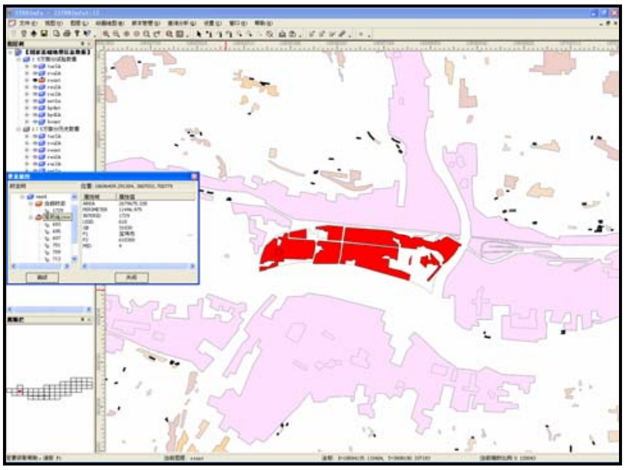
(a)



(b)



(c)



(d)

Fig. 8. An example of tracking result of ST-Objects

6. CONCLUSION AND FUTURE WORK

Spatio-temporal data storage and manipulation are two important aspects of spatio-temporal database. This study aims at extending object relational database management system to support spatio-temporal data. In this study, STOM model encapsulate ST-Object's main attributes as a whole, "Version-difference" spatio-temporal data model and storage structure form the spatio-temporal database structure, simultaneously, correlation link and correlation tree structure were introduced to record ST-Object's states changed by time. This schema is effectively to handle multi-version spatial data into object relational database, implementation and case result were verified. Further studies will focus on temporal query language and spatial-temporal topology.

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