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

Commission II, WG II/1

KEY WORDS: GIS, Temporal, Spatio-temporal data modeling, Spatio-temporal database, Object-relational database

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 data modeling 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).

---

* Supported by the Chinese National Fundamental Surveying and Mapping Project Foundation of China under Grant No.1460130524207; the National High-Tech Research and Development Plan of China under Grant Nos.2006AA12Z214; the National Grand Fundamental Research 973 Program of China under Grant No. 2006CB701304; the Open Foundation of Key Laboratory of Geo-information of SBSM of China under Grant No.B2618.
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 evolution 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 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.

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.

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).
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.

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.

---

**Table 1. Change event table**

<table>
<thead>
<tr>
<th>EID</th>
<th>NAME</th>
<th>EVENT_TIME</th>
<th>CREATE_DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Change1</td>
<td>2004/01/01</td>
<td>2005/01/01</td>
</tr>
<tr>
<td>2</td>
<td>Change2</td>
<td>2006/01/01</td>
<td>2007/01/01</td>
</tr>
</tbody>
</table>

**Table 2. Correlation link table**

<table>
<thead>
<tr>
<th>EID</th>
<th>TYPE</th>
<th>OLD_OID</th>
<th>NEW_OID</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ALTER(1:n)</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>1</td>
<td>ALTER(1:n)</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>ALTER(n:1)</td>
<td>11</td>
<td>101</td>
</tr>
<tr>
<td>2</td>
<td>ALTER(n:1)</td>
<td>11</td>
<td>102</td>
</tr>
</tbody>
</table>

**Table 3. Current entity table**

<table>
<thead>
<tr>
<th>OID</th>
<th>VTB</th>
<th>VTE</th>
<th>TTB</th>
<th>TTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>2006/01/01</td>
<td>NOW</td>
<td>2007/01/01</td>
<td>UC</td>
</tr>
<tr>
<td>102</td>
<td>2006/01/01</td>
<td>NOW</td>
<td>2007/01/01</td>
<td>UC</td>
</tr>
</tbody>
</table>

**Table 4. History entity table**

<table>
<thead>
<tr>
<th>OID</th>
<th>VTB</th>
<th>VTE</th>
<th>TTB</th>
<th>TTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2000/01/01</td>
<td>2004/01/01</td>
<td>2001/01/01</td>
<td>2005/01/01</td>
</tr>
<tr>
<td>2</td>
<td>2000/01/01</td>
<td>2004/01/01</td>
<td>2001/01/01</td>
<td>2005/01/01</td>
</tr>
<tr>
<td>11</td>
<td>2004/01/01</td>
<td>2006/01/01</td>
<td>2005/01/01</td>
<td>2007/01/01</td>
</tr>
</tbody>
</table>
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.

ACKNOWLEDGEMENTS

This work was supported by Chinese National Fundamental Surveying and Mapping Project (No.1460130524207) and Open-fund of Key Laboratory of Geo-information of SBSM (State Bureau of Surveying and Mapping). The authors are also grateful to anonymous referees for their constructive suggestions.

References from Journals:

References from websites: