Management of Spatio-temporal Data and Realization of Change Process in A Land Information System

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Abstract:

Many existing GIS or LIS application databases support efficiently spatial management for objects, but fail to support the time-varying information. They just represent the current state of entities in the real world. Whenever a new entity is inserted into a database, the old one would be deleted and never seen again in the database. In fact, the original or previous states of entities may be equally important to the practical management and decision-making. The focus of this paper is to provide spatio-temporal support for the existing GIS or LIS application database. The goal is to extend the existing functions of the application database so that the existing data resource can be taken good advantages. A land information system case will be taken as an example to implement the spatio-temporal support and realize the change process of landuse parcel.

1. Introduction:

With the development of GIS technology and application, many governmental administrative agencies and commercial agencies have developed GIS application systems and built various databases to assist the management. Most of them just represent the current state of entities in the real world with little considerations on data needs for temporal information. Whenever a new entity is inserted into a database, the old one should be deleted. Associating temporal information with spatial entities is useful to trace or compare the changes with time. And the support for the development of information systems involving time-varying, geo-reference information, termed spatio-temporal information, has been a long-term user's requirement in a variety of areas, such as cadastral systems that capture the histories of landparcels, routing systems to compute possible routes of vehicles, and forecast prediction system ([1]), environmental monitoring and impact assessment, resource management, decision support and etc.

Spatio-temporal information and spatio-temporal database have been studied for a long time from Snapshot Model (Armstrong, 1988), Space-Time Composite Model (Langran and Chrisman, 1988), event-based (Peuquet and Duan, 1995) to object-oriented data models (Worboys, 1992, Raper and Livingstone, 1995) and other advanced spatiotemporal data models. These models have the potential to support the requirements and operations about temporal information management, to a certain extent, but for the existing GIS or LIS databases which have been used in practical application or production and have stored plenty of spatial and non-spatial data, how to attach temporal supports is still a problem.

If some appropriate measures are adopted to mend the existing GIS or LIS application databases and their operations, the existing database resources will be taken better advantages in more areas. This is the aim of this paper, which focuses on enhancing the existing GIS application databases by the support for the temporal information.

The rest of the paper is organized as follows. In Section 2, the type of spatiotemporal data and applications are listed for the base of the sequent content. Section 3 introduces some of the concepts of GIS or LIS databases expressed in relational databases and object-oriented data models. In Section 4, we provide a method to extend the existing GIS or LIS application databases to support temporal information and present an example of usage about the method. In section 5, conclusions are drawn.

2. Spatio-temporal data type and applications

Different applications require different types of spatio-temporal data and different spatio-temporal operations. Nectaria and Christian (1999) categorized the spatio-temporal applications into the three sorts according to the types of spatio-temporal data. The first application involves objects with continuous motions but without changes of the shape such as a moving car. The second one deals with discrete changes of objects such as landparcels. The third one manages objects integrating continuous motions as well as changes of the shape such as a storm or a fire.

The three kinds of applications have different changing rules. Each application requires specific functions or operations. To date there is little spatio-temporal database that is able to each kind of the applications. The paper mainly discusses the second application ---- discrete changes of objects especially landparcels.

3. Data model and structure of existing GIS and LIS databases

With the department of database technology and data modeling, there are three generations of the database technology. The first generation is hierarchy and network database. The second generation is the relational database. Relational database combining object-oriented data modeling is the third generation. With the rise of object-oriented technology, the key problem to overcome the hampers of GIS is to develop an object-oriented spatial database management at first. But now the new object-oriented spatial database management system is not strong enough to support the requirements of commercial applications. So the relational database management system (RDBMS) is still dominant in the field of database application. So far some famous large commercial relational databases have been trying to add components to deal with the spatial data. For example, Oracle 8 added a component named Oracle Spatial Data Options (SDO) to make Oracle handle the non-spatial data and spatial data. That is a new data model ---- the object-relationship data model.

Many of the existing GIS databases are based on the third generation of database ---- relational database combining object-oriented data modeling. And there are two methods to realize this kind of database. One method is the spatial data handled by the file system like Geostar NT 3.0, while another one is done with the relational table like Arc/info. The common point of the two methods is that both spatial data structures are based on the object-oriented data model. The method provided in this paper mainly solves the spatio-temporal problem of this kind of database.

Based on the object-oriented data model, entities are represented as a set of the geometry-based spatial objects. Thematic characteristics are represented as attributes of spatial objects. The key to support the temporal information in the above database is to build a connection between the spatial object and the temporal object.

4. A method to support temporal information in existing GIS or LIS application database

Geostar NT 3.0 and Arc/info represent the entities as geometry-based spatial objects, such as point, line, polygon and composite objects composed of point, line, polygon objects. Thematic characteristics are stored in RDBMS. Each spatial object has its own geometry identity code (Geometry ID) which is generated by the software and is a bridge to connect the spatial object with its thematic characteristics. The Geometry ID also can be used as a bridge to connect spatial objects and the temporal information (Figure 1). Besides the Geometry ID, users can define a user-ID for one spatial object or entity according to his/her requirement. The user-ID is arranged and controlled by the user while the Geometry ID is controlled by the software.

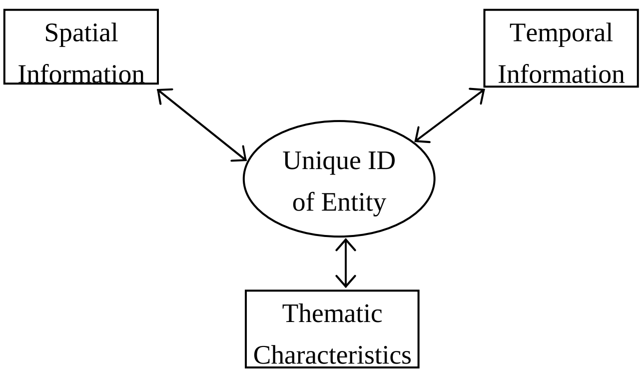


Figure 1. The relationship of spatial information, thematic characteristics and temporal information

4.1 The method based on file system

If an existing GIS or LIS database handles spatial information with a file system, the temporal information can be represented with a kind of file format as follows. (Suppose it would handle two types of time: transaction time and valid time.)

[File header]

1. "TEMPORAL_DATA"	Char	15
2. Valid length of the file	DWORD	4
3. Offset	DWORD	4

[File Body]

1. Geometry ID of spatial object	long	4
2. Version Number	long	4
3. Transaction time	date	4
4. Valid beginning time	date	4
5. Valid ending time	date	4

A composite entity records not only its own temporal information as a whole, but also each object in its recorded temporal information. So it can support requirements on different levels. For example, a university is a composite entity composed of buildings, roads, lakes and so on. When a road is widened, the time of the change occurring will be recorded on the road object but not on the university because as a whole the university has no change. This change is not of the same use to the management of the city in which the university lies.

Moreover, if spatial objects are managed on a feature-based structure, the feature information such as feature ID can also be recorded in the above temporal information file, which will speed up the query process.

For an existing database such as a land information database, the first step is to get the Geometry ID of each landparcel. The second is to decide the valid beginning time of the existing landparcels while the last is to put them into the file designed in advance. In application, when the geometric shape or thematic characteristics of a piece of landparcel is changed, the time of the change occurring will be recorded as the valid ending time of the landparcel. The landparcel becomes a historical and inactive object. At the same time a new record will be written into the file whose valid beginning time is as same as the above ending time. The inactive landparcel will be invisible in the display interface. The valid beginning time and the valid ending time limit the life span of a piece landparcel.

For shape change and thematic characteristics change, the new landparcel has different meanings. In land information system, there are various possibilities to cause the shape change such as splitting a piece of landparcel into several pieces, merging several pieces into one big piece and etc. For a geometry-base spatial object, the change of the geometric shape will lead to the generation of a new geometry object with a new Geometry ID. The spatial information of the new geometry object will be written into the above file and its thematic characteristics are also recorded.

If a piece of landparcel just changes its ownership, landuse type, net area or other thematic characteristics, this change belongs to the thematic characteristics change without any shape change. In this circumstance, the new landparcel has the same Geometry ID as the old one. How to distinguish between these two landparcels? Stating as the above, thematic characteristics are handled in RDBMS. One way to solve the problem is to add two fields into thematic table----“Beginning Time” and “Ending Time” ---- to record the valid beginning time and ending time. When thematic characteristics of a spatial object has something changed, the “Ending Time” field of the old record will be set as the time of the change occurring and a new record with new thematic information will be appended whose “Beginning Time” is of the same time.

4.2 The method based on relational table

The above part provides a method on the file system. It is also suitable for the database in which spatial information is handled with relational tables such as Arc/Info. The difference is to build a relational table to store the temporal information instead of a file (Table 1).

Field Description	**Data Type**	**Field Length**
Geometry ID of Spatial Object	Long	4
Transaction Time	Date	4
Valid Beginning Time	Date	4
Valid Ending Time	Date	4

Table 1. Temporal information repressed as relational table (“Temporal Table”)

Each spatial object has its temporal record in this table. Its beginning time and ending time has the same meaning and operation as that in file system. For thematic characteristics, the same measure is adapted to add temporal information into the thematic table ---- “Thematic Table”.

4.3 Temporal query and tracking based on this method

4.3.1 Temporal Query

Based on the above “Temporal Table” and “Themaic Table”, specific examples of queries relating to geographical changes occurring through time and geographical states at a concrete time or time interval would include: (Taking a land information system as an example.)

(1) Which landparcels had some changes in 1999 and how about the states of the

landparcels before and after the change?

The first step is to build a SQL sentence according to the conditions.

"***SELECT*** * ***FROM*** *ThematicTable* ***WHERE*** *EndingTime=1999* ***OR*** *(BeginningTime=1999* ***AND*** *(EndingTime>1999* ***OR ISNULL****(EndingTime)))* "

The second step is to execute the SQL sentence to get a result record set. The result record set includes the thematic information as well as the Geometry ID of the spatial objects in accordance with the conditions. Then relative spatial operations will make the inactive object visible and highlight all of the objects. From the result, we can view the different states before and after the change.

(2) What is the state of all the landparcels in 2000?

*"**SELECT** Geometry_ID **FROM** TemporalTable **WHERE** BeginningTime<=2000 **AND** (EndingTime>2000 **OR ISNULL**(EndingTime))".*

The result record set includes the Geometry IDs of all the spatial objects which were active in 2000. To highlight these objects and browse the historical state of landparcels. The further operation is to query the thematic information of these spatial objects according to Geometry IDs.

4.3.2 Tracking the change process

Besides the change of geometric shape and thematic characteristics of a piece of landparcel, the change of rivers or roads lying on the landparcel also can cause the change of the landparcels. The changes of rivers or roads change the valid or net areas of the landparcel. For example, A new road building on a parcel will account for the area of the parcel so that the valid area or net area of the parcel will be reduced. In order to track these change processes, the relationship between both states before and after change of the landparcel should be recorded, which includes the Geometry ID of spatial objects before and after the change, the reason of change and the time of change occurring. A relational table can do so very well (Table 2).

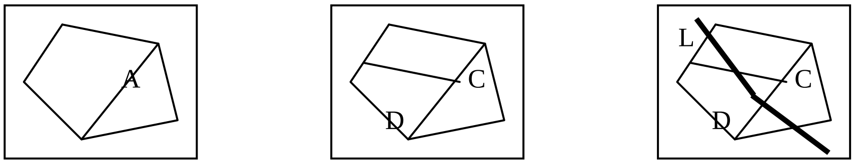
Field Description	**Data Type**	**Field Length**
Geometry ID of Old Spatial Object	Long	4
Geometry ID of New Spatial Object	Long	4
Reason of Change	String	8
Time of Change Happening	Date	4

Table 2. Relationship between the states before change and after change

The reasons of change had better be encoded so that some mistakes can be avoided. From this table, we not only keep tracking of the change process of a landparcel, but also analyze the trend of the landuse change. It is very important for land management and decision-making.

4.4. Example of usage

The following example presents the usage of the above method in the land information system of Guangdong Province. The basic platform of this land information system is Geostar NT 3.0. We have developed some special operations for the land management application with Visual Basic Language. The aim of this application system is to manage land registration, grant the land attestation, implement the land change operation, keep tracking the historical states and make report tables and etc. We have adopted the above method to attach temporal information to the system and the results basically consist with the requirement of users. The following example will represent the main results of the system about temporal management and operation. (See Figure 2)



1998 **1999** **2000**

Fig. 2 The states of landparcels at 1998, 1999, 2000 time

Geometry_ID	User_ID	Transaction Time	Beginning Time	Ending Time
1	A	10/20/1998	1998	
2	B	10/20/1998	1998	

Table 3. Temporal information table at 1998 time

Geometry_ID	User_ID	Transaction Time	Beginning Time	Ending Time
1	A	10/20/1998	1998	1999
2	B	10/20/1998	1998	
3	C	10/20/1999	1999	
4	D	10/20/1999	1999	

Table 4. Temporal information table at 1999 time

Geometry_ID	User_ID	Transaction Time	Beginning Time	Ending Time
1	A	10/20/1998	1998	1999
2	B	10/20/1998	1998	2000
3	C	10/20/1999	1999	2000
4	D	10/20/1999	1999	2000
2	B	10/20/2000	2000	
3	C	10/20/2000	2000	
4	D	10/20/2000	2000	
5	L	10/20/2000	2000	

Table 5. Temporal information table at 2000 time

Old Geometry_ID	New Geometry_ID	Time of Change	Reason of Change
1	3	1999	Split
1	4	1999	Split
2	2	2000	Add Line
3	3	2000	Add Line
4	4	2000	Add Line
NULL	5	2000	Add Line

Table 6. Relationship between the states before change and after change

- During 1998, landparcel A and B is in an active state and they have common border. Landparcel A has landuse type “Farmland” while B has landuse type “Construction”. Table3 records their temporal information.
- In 1999, landparcel A is split into C and D. Landparcel C has landuse type “Farmland” and D has landuse type “Construction”. Landparcel A is inactive and invisible whose “Ending Time “ is “1999”(See Table 4)
- In 2000, a new road L crosses landparcel B, C and D. The width of road L is 30m. It shares the valid area with these landparcels. So landparcel B, C and D all are in new states (See table 5).
- Table 6 records the relationship among these spatial objects before and after change. The “Old Geometry_ID” represents the old object before change while the “New Geometry_ID” represents the new object after change.

“Reason of Change” in the Table 6 shows the operations causing these changes. Its domain is various such as splitting a landparcel, merging several landparcels, adding new line objects, deleting old line objects, etc. The results of these changes are complex and different. For example, landparcel A with “Old Geometry_ID” 1 is split into landparcel C and D separately with “New Geometry_ID” 3 and 4. If there are rivers or roads in landparcel A and the splitting line cross these rivers or road, they will also be split into two or more parts. Each part has its “New Geometry_ID”. The old ones are all inactive and invisible in 1999 like landparcel A. In 2000, road L was built through landparcel B, C and D. These landparcels’ valid areas are reduced, but their shapes have no changes, so they have the same Geometry_ID in 2000 as that in 1999.

If we add three fields “Old Landuse”, “New Landuse” and “Change Area” in Table 6, the table will be more useful (See table 7). “Old Landuse” means the landuse type of the old object while “New Landuse” means that of the new object. “Change Area” records how many areas are changed from the old landuse type to the new landuse type.

Old Geometry_ID	**New Geometry_ID**	**Old Landuse**	**New Landuse**	**Change Area(m2)**	**Change Date**	**Change Reason**
1	3	Farmland	Farmland	2000	1999	Split
1	4	Farmland	Construction	3500	1999	Split
2	5	Construction	Road	200	2000	Add Line
3	5	Farmland	Road	250	2000	Add Line
4	5	Construction	Road	300	2000	Add Line

Table 7. Relationship between the states before change and after change

The relationship between “Old Geometry_ID” and “New Geometry_ID” of Table 7 has a different meaning from that of Table 6. Take the fourth record as an example to explain the meaning of the record. Due to adding new line object----road L with “New Geometry_ID” 5, landparcel C with “Old Geometry_ID” 3 lost part of its area ---- 250 square meters, to be used as road in 2000. The relationships between “Old Geometry_ID” and “New Geometry_ID”, “Old Landuse” and “New Landuse”, represent the direction of the land changes. From this table, we not only keep tracking of the change process of spatial object, but also know clearly about the direction of

land change and monitor the land change. For example, we can query how many square meter farmlands were used as the construction land in 1999. The SQL sentence is:
"SELECT oldGeometry_ID, newGeometry_ID, SUM(changeArea) FROM Table7 WHERE oldLanduse="Farmland" AND newLanduse="Construction" AND changeDate = 1999".
The query result not only represents the total change area from farmland to construction land but also tell us which farmland was used as the construction land by highlighting the spatial objects corresponding with *oldGeomery_ID* and *newGeometry_ID.*

5. Conclusion:

We view the spatio-temporal data modeling and applications. Focusing on the discrete change of and among objects, we provide a method to extend the existing GIS and LIS application databases to support temporal information and operations. Then an example of the method is described in detail the process of the method.

The method mainly focuses on the extension of relationship or object-oriented GIS or LIS databases and is mainly available for the discrete change of and among objects. Because the storage and operations of temporal information are based on relational tables, this method is also suitable for object-relationship GIS or LIS databases. The key is to build the object-time relationship with any format such as data table or data file. This relationship allows changes from time to spatial entities or their components to be easily tracked and compared.

The complexity of the underlying domain and the great variety of data that characterizes GIS applications make the design process of a all-purpose spatiotemporal database management system very difficult and complicated. So we have to adopt suitable measures according to different GIS application.

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