Spatio-temporal GIS Data Model Based on Event Semantics

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1 Introduction

More requests were presented on history data disposal in many aspects such as cadastral management, land use management, urban planning management and population management etc. At present, there is need to realize the trace-back and recurrence and to complete query, statistics and analysis. With the development of remote sensing (RS) and global position system (GPS), more real-time information can be provided for GIS. How to receive and utilize the real-time data, keep object changes and recover these changes are urgent problems in GIS, while conventional GIS data models emphasize static representations of reality.

There are mainly four kinds of models to record and deal with historical information. The first is time-stamping layers and time-stamping attributes. The time-stamping layers are also called the snapshot model, which leads lots of redundant data. The time-stamping attribute is also called the space-time composite model, which needs to reconstruct the thematic and temporal attribute information when any change happens. The second is the event-driven spatio-temporal model. The third is the spatio-temporal object model. These two models can not keep the continuity of object because the identities of object changes when any change happens. The last is the three-domain model, which can keep the continuity of the object, but not record actions which lead to changes and not solve the problems of trace-back when only attribute change happens.
2 Description of event semantics

Usually events are described by recording when the events happened, where the events happened, what has happened and who has been involved in the events. Here time can be divided into instant (at a time point) and interval (based on a time interval). When recording events, instant is usually chosen as time unit, that is to say, different granularity instant is chosen to describe when the events happened. Usually instant, position, object, action and related attributes are recorded when events happened. According to wave-particle duality theory, time is continuous in macrocosm while time is discrete in microcosm, that is to say, continuous time is composed of discrete time. Accordingly, object identities, instant, spatial position, events, object attributes and the relationships between them can be used to describe the spatial object. And all of them can be connected by object identities as shown in Fig. 1.

![Fig. 1 Spatio-temporal information description of event semantic model](image)

In this model, according to the way of describing an events, all the information are divided into five domains, namely, attribute domain, time domain, space domain, events domain and relation domain. Attributive information can be described in the attribute domain which records object attributes and thematic information. Temporal information can be described in the time domain which records the happening instant. Spatial information can be described in the space domain which records the spatial information such as spatial location, spatial relationship (planar topology, temporal topology and changing paternity) and spatial attributes (length or area) etc. Event information can be described in the event domain which records the actions causing the change. These four domains can be connected by object identities in the relationship domain, then a main table, which contains all aspects of an object and is suitable for query, statistics and analysis, is formed. This model can be realized either by extended-relational database or by object-oriented database.

3 Spatio-temporal GIS data model

In the model, supposing \( T \) is time, \( T_i \) is used to denote the state when time is equal to \( i \), for example, \( T_1 \) is used to denote the initial state, while \( T_2 \), \( T_3 \), \( T_4 \), \( T_5 \) and \( T_6 \) are used to denote different changing states, respectively. Object identity is OBJID, which indicates the parcel number of the changing parcels. Attribute identity is ATTRID, which indicates the attributive changes of the parcel. Temporal identity is TIMEID, which indicates the instant information when the change happens. Spatial identity is SPACEID, which indicates the spatial changes of the parcel. Event identity is ACTID, which indicates the reason why the change happens. The change procedure of land parcel are shown in Fig. 2 (the characters indicate the object identities, and the numbers indicates the spatial identities).

According to Fig. 2, we can obtain the attribute table (Table 1), the time table (Table 2) and the event table (Table 3).

| ATTRID | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | ... |
|--------|---|---|---|---|---|---|---|---|---|----|----|----|-----|
| OWNER  | Zhu| Li| Wan| Xu| Shi| He| Wu| Li| Ni| Luo| Lu|   |     |
|        | San| Si| Wu| Hua| Zha| Jun| Li| Si| Jun| Shu| Yan| Di|     |
| ...    |   |   |   |   |   |   |   |   |   |    |   |   |     |
Fig. 2 Procedure of land parcel change

| Table 2 | Time table |
|---------|------------|
| TIMEID  | ST   | TIME       |
| 1       | T1   | 1999-10-10 |
| 2       | T2   | 1999-10-20 |
| 3       | T3   | 1999-10-31 |
| 4       | T4   | 2000-05-04 |
| 5       | T5   | 2000-06-01 |
| 6       | T6   | 2000-07-01 |

| Table 3 | Event table |
|---------|-------------|
| ACTID   | ACTNAME     |
| 1       | Division    |
| 2       | Combination |
| 3       | Boundary adjustment |
| 4       | Add new     |
| 5       | Attribute change |

Each table is relatively simple and records one aspect of the object, respectively. The operation includes adding related attributes to parcels and establishing links with relationship table. The space table is rather complex, which records not only planar topology but also temporal topology and changing paternity.

According to Fig. 2, the changing paternity can be presented by tree, as shown in Fig. 3, recorded by recording father node and the spatial topology can be realized by recording planar topology and the father-children changing relationship. According to Fig. 3, we can obtain Table 4.

Fig. 3 Tree of land parcel changes
Table 4 Space table

| SPACEID | LOCATION | AREA | TOPOLOGY | FATHERID |
|---------|----------|------|----------|----------|
| 1       | L1       | S1   | TOPO1    | -1       |
| 2       | L2       | S2   | TOPO2    | -1       |
| 3       | L3       | S3   | TOPO3    | -1       |
| 4       | L4       | S4   | TOPO4    | -1       |
| 5       | L5       | S5   | TOPO5    | -1       |
| 6       | L6       | S6   | TOPO6    | 3        |
| 7       | L7       | S7   | TOPO7    | 3        |
| 8       | L8       | S8   | TOPO8    | 4        |
| 9       | L9       | S9   | TOPO9    | 4        |
| 10      | L10      | S10  | TOPO10   | 7,9      |
| 11      | L11      | S11  | TOPO11   | 8        |
| 12      | L12      | S12  | TOPO12   | 8        |
| 13      | L13      | S13  | TOPO13   | 5,11     |
| 14      | L14      | S14  | TOPO14   | 6        |
| 15      | L15      | S15  | TOPO15   | 13       |
| 16      | L16      | S16  | TOPO16   | -1       |

Note: "-1" denotes that there is no father node.

Table 5 is a relation table, which connects objects, time, space, events and attributes through unchanged object identities. Both the space change and the attribute change can be recorded by using this relationship, that is to say, no matter which kinds of change happens, such operation as record, query, statistics, trace and analysis can be done for the historical information. It overcomes the shortcoming of neglecting attribute change in the model based on the spatial change, at the same time, it is rather easy for people to perform historical query. The relationship between each aspect of the object can be described as Table 5 shows.

Table 5 Relation table

| OBID | TIMEID | SPACEID | ACTID | ATTRID |
|------|--------|---------|-------|--------|
| A    | 1      | 1       | 0     | 1      |
| B    | 1      | 2       | 0     | 2      |
| C    | 1      | 3       | 0     | 3      |
| D    | 1      | 4       | 0     | 4      |
| E    | 1      | 5       | 0     | 5      |
| F    | 2      | 7       | 1     | 6      |
| G    | 2      | 8       | 1     | 4      |
| H    | 3      | 10      | 2     | 8      |
| D    | 3      | 8       | 5     | 9      |
| D    | 4      | 12      | 1     | 9      |
| H    | 4      | 11      | 1     | 10     |
| E    | 5      | 13      | 2     | 5      |
| C    | 6      | 14      | 3     | 11     |
| E    | 6      | 15      | 3     | 5      |
| I    | 6      | 16      | 4     | 12     |

Note: "0" denotes the initial state.

4 Spatio-temporal query

Time can be conceptually divided into instant and interval. Accordingly, query can be divided into two categories: query based on instant and query based on interval.

4.1 Query based on instant

This kind of query includes "Who", "When", "Where", "How (or How happened)" and "What".

1. "Who" means the object query based on certain time point.
   Q1: Who changed on May 5th, 2000?
   Select TIMEID from Table 2 where TIME = 2000-05-04, the result is: 4;
   Select OBJID from Table 5 where TIMEID = 4, the result is: D, H.

2. "When" means time query based on certain time point.
   Q2: When did Lu Di become the owner of the land parcel?
   Select ATTRID from Table 1 where OWNER = Lu Di, the result is: 12;
   Select TIMEID from Table 5 where ATTRID = 12, the result is: 6;
   Select TIME from Table 2 where TIMEID = 6, the result is: 2000-07-01.

3. "Where" means the spatial query based on certain time point and certain object.
   Q3: Where was Xu Hua's land parcel on December 10th 1999?
   Select TIMEID from Table 2 where TIME = 1999-10-10, the result is: 1;
   Select ATTRID from Table 1 where OWNER = Xu Hua, the result is: 4
   Select SPACEID from Table 5 where TIMEID = 1 and ATTRID = 4, the result is: 4;
   Select LOCATION from Table 4 where SPACEID = 4, the result is: L4.

4. "How" means the event query based on certain time point.

5. "What" means attributes and thematic query based on certain time point.
4.2 Query based on interval

Same to the query based on instant, the query based on interval also includes the aspects, “Who”, “When”, “Where”, “How (or How happened)” and “What”. The difference is that this query is based on a time interval. The following is an example.

Q5: What changes have happened to parcel C from September 10th, 1999 to July 8th, 2000?

Select TIMEID from Table 2 where TIME > 1999-09-10 and TIME is closest to 1999-09-10, the result is 1;

Select TIMEID from Table 2 where TIME < 2000-07-08 and TIME is closest to 2000-07-08, the result is 6;

Select ACTID from Table 5 where OBJID = C and TIMEID = 1 and TIMEID = 6, the result is, 1, 3;

Select ACTNAME from Table 3 where ACTID = 1 or ACTID = 3, the result is division, boundary adjustment.

5 History trace-back and recurrence

5.1 Single land parcel history trace-back and recurrence

Because the object identities are fixed during the object change, according to Table 5, the single land parcel history can be got and the history trace-back and recurrence can be accomplished. The following is an example.

Q6: The recurrence of the single land parcel C.

Select TIMEID, SPACEID, ACTID, ATTRID from Table 5 where OBJID = C, the results are:

2, 6, 1, 3,
6, 14, 3, 11.

From Table 4, their spatial location can be obtained, and at the same time their attribute change and the events which lead to change can be displayed.

5.2 District history trace-back and recurrence

Q7: The trace-back of the district in Fig. 2.

Firstly, get the whole state of the district at the final state as shown at T6 in Fig. 2. It can be seen from Table 5 that three parcels C, E and I have changed at T6, and their SPACEID and ACTID are 14, 15, 16 and 3, 3, 4, respectively. If ACTID = 5, then the spatial location is unchanged. Otherwise, find their AFTHERID in Table 4 and gain their spatial state at T6, as shown at T5 in Fig. 2. The following parcels may be deduced by analogy, thus the initial state at T1 can be obtained and the trace-back of the whole district can be accomplished.

6 Conclusions

From the perspective of the history data utilization, the spatio-temporal GIS data model based on event semantics is discussed. Time, space, reason and attributes (thematic) are connected by using their exclusive object identities, thus it is very convenient for common history query, combined query, history trace-back and recurrence. Here, only the model itself is discussed, therefore, further researches must be done on the construction of the temporal topology, the selection of instant, the analysis and application of temporal information.

References

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