A Feature-Based Temporal Representation and Its Implementation with Object-Relational Schema for Base Geographic Data in Object-Based Form

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Abstract: This paper introduces a feature-based temporal representation for base geographic data in object-based form and studies its implementation with the object-relational (OR) schema. In this temporal representation, a feature is a temporal feature, which may occupy multiple temporal spaces and have multiple temporal themes during its lifespan; time is represented using different states of temporal features. There exist m-n temporal relationships between temporal features, and 1-1 temporal relationships between temporal spaces and between temporal themes. Next, we compare the implementation of the temporal data model in relational (R), object-relational (OR), and object-oriented (OO) database, and argue the OR schema fits the model best. Finally, we discuss two possible ways to visualize the spatio-temporal data stored in the OR schema, which is not currently supported by most GIS. One approach is to create a flat view based on an OR table, and then work with the view instead of the original OR table in GIS. Another way is to develop a new GIS, which can work with the OR schema directly. The second approach has advantages over the first one. This paper aims to provide temporal information for base geographic data in object-based form.

1 Introduction

The geographic environment is changing either gradually or abruptly. Geographic representation, which models the real world in the computer information systems, should also represent the changing reality. After over thirty years' development, geographic information science (GI Science) and technology are now good at representing spatial information. Nevertheless, temporal information is not well represented as spatial information is. Usually, when the environment changes, the most current information is collected, and the geographic database is updated with the new data. Old data are simply deleted and can no longer be retrieved. This approach is cost efficient to most database owners, especially when computers were expensive, slow, and had only small storage space in the past. However, temporal information is useful for better understanding the dynamic geographic reality and human-environment interaction. For example, spatio-temporal information is required for geographic analysis such as urban growth and disease spreading over time and space. Because of the importance of time, spatio-temporal representation is recognized as a long-term research challenge by UCGIS (2004), and USGS (2001) proposed to provide a temporal dimension in *The National Map—Topographic Mapping for the 21st Century*. The research objective of this paper is to propose a spatio-temporal framework for base geographic data in object-based form and study its implementation in OR database.

In this paper, "base geographic data" refers to geographic data, such as elevation, land cover, and transportation, which are used commonly in many geographic information system (GIS) applications. Since base geography data are used so frequently in geographic analyses, they are often collected by certain organizations such as U.S. Geological Survey and Census Bureau in the United States, and shared as a national spatial data infrastructure (NSDI 2004). Currently, there are two major spatial forms of base geographic data, object-based and field-based. In this paper, we confine our study on time to base geographic data in object-based form.

1.1 Characteristics of Time and Spatio-Temporal Changes in Base Geographic Data

In base geographic data, the main characteristic of time is absolute and linear, although there also exists cyclical time. For example, the shorelines change from season to season. Both discrete and continuous time exist in base geographic data. Elevation and land use/cover may evolve continuously or discretely, while census boundaries change discretely. An event or change takes place at point time, and a world status is valid during an interval time. For example, we say land use of a parcel was changed from agriculture to residential at one point time, or the land use was agriculture during the particular time interval.

World time, the time that a fact is true in reality, is more important than database time, the time that the data are recorded in computer system; but world time is not always available. For example, it is easy to get exact temporal information about the changes of a census boundary, but relatively difficult to monitor the changes occurring to other base geographic data. Usually, the temporal information obtained lags behind the world time, and the time when a change is detected is often used to substitute world time.

The temporal granularity of base geographic data is relatively coarser than that of a weather forecast or flight schedule. It may be one month, one year, or even ten years. For census boundaries, it can be ten years; while for land use/land cover, the temporal granularity can be one year or one month, or even several days when rapid changes take place.

The spatio-temporal changes in base geographic data may be continuous, discrete, or stepwise. For example, changes in census boundaries are discrete, while those in roads are stepwise since the construction of roads lasts for a period of time. Changes in elevation might be continuous, or discrete if an earthquake takes place. For simplicity of representation, all changes to base geographic data are treated as discrete in this paper. In this way, an event or change happens at one point time, and a world status is kept during a time interval. In this paper, we study linear world time and discrete spatio-temporal change; temporal granularity for base geographic data is not fixed, but relatively coarse.

1.2 Literature Reviews

Thrift (1977) proposed time as an additional dimension to the space. Thereafter, little was done until 1990s (Hazelton 1991, Kelmelis 1991, Langran 1992, Al-Taha 1992, Wachowicz 1999, Yuan 1997). Langran's (1992) *Time in Geographic Information System* is regarded as a landmark in temporal GIS (Al-Taha 1992, Hornsby and Egenhofer 2000, Peuquet 2002). Among the variant spatio-temporal approaches proposed heretofore, most of them work with either object-data (Worboys 1994, Chen and Le 1996, Hornsby and Egenhofer 2000) or field-data (Peuquet and Duan 1995). Although there exist spatio-temporal frameworks for both object- and field–data, such as the Triad by Peuquet (1994) and the sequential snapshots (Langran 1992), different models are often required to optimally represent object- or field- data because of the complexity of spatio-temporal data (Sengupta and Yan 2004, Yuan *et al.* 2004). This is analogous to the distinction between field- and object-view in spatial representation (Galton 2003).

Besides the distinction of object- and field-form in spatial domain, there is another distinction, continuous vs. discrete change in temporal domain (Galton 2003, Grennon and Smith 2004, Hornsby and Egenhofer 2000, Yuan *et al.* 2004). Although modeling dynamic processes or continuous change is identified as a research objective (Yuan 2004), the large body of literatures in GIS community studies discrete spatio-temporal changes, which is relatively easy (Hornsby and Egenhofer 2000). In the community of computer science, especially database, continuous spatio-temporal change is theoretically modeled as functions of time (Erwig *et al.* 1999, Frank 2003), but little has described how to implement such temporal function in GIS.

A feature is an entity in the real world, and an object in the computer system. It has three basic characteristics: space, theme, and time (Berry 1964). Usery (1996) proposed a conceptual framework of feature-based GIS (FBGIS) from region theory for both object- and field-based data. In FBGIS, space, theme, and time are three separate dimensions and each dimension has attributes and relationships. FBGIS is at highly abstract level and does not give details in implementing the three dimensional conceptual model in computer system, especially for both spatial representations. This paper follows the direction of FBGIS by conceptualizing the spatio-temporal information based on feature, but time is modeled differently from that in FBGIS and implementation in computer system is provided.

The remainder of this paper is organized as follows. Section 2 introduces feature-based temporal representation for base geographic data in object-based form. Section 3 describes the implementation of the temporal representation in OR schema, which is compared with OO and relational database. Section 4 discusses visualization of spatio-temporal data managed in OR database. Discussion and conclusions are presented in section 5.

2 Feature-Based Temporal Representation

In the feature-based temporal representation, a feature has three components, space, time, and theme, but these three components are not considered as three separate dimensions as in a space-time cube. Instead, the time dimension is incorporated into the feature and its other two components (figure 1). Therefore, a feature is a temporal feature, and it may have multiple temporal spaces and multiple temporal themes during its lifespan. In other words, a feature and its space and theme are all functions of time (equations 1, 2 and 3).

$$\text{Temporal feature} = f(\mathrm{t}) \qquad (\textit{Equation } 1)$$

$$\text{Temporal space} = g(\mathrm{t}) \qquad (\textit{Equation } 2)$$

$$\text{Temporal theme}_{\mathrm{i}} = h_i(\mathrm{t}) \qquad (\textit{Equation } 3)$$

In equation 3, $\text{theme}_{\mathrm{i}}$ is the one of the themes belonging to the feature. In this study, time and spatio-temporal changes are simplified as discrete. Therefore, function f(t) can be simplified as below (equation 4).

$$f(t) = \begin{cases} f_0 \ldots \ldots \ t \in [t_0, t_1) \\ f_1 \ldots \ldots \ t \in [t_1, t_2) \\ \ldots \\ f_n \ldots \ldots \ t \in [t_n, NOW \ ] \end{cases} \qquad (\textit{Equation } 4)$$

In equation 4, f_0, f_1, and f_{n} are all constants, representing the status of the feature during corresponding interval time $[t_0, t_1)$, $[t_1, t_2)$, and $[t_n, NOW]$ respectively. The word "NOW" means the feature is still valid as status f_n at this time. Similar to $f(t)$, functions $g(t)$ and $h(t)$ can be simplified as equation 5 and 6.

$$g(t) = \begin{cases} g_0 \dots \dots t \in [t_0, t_1) \\ g_1 \dots \dots t \in [t_1, t_2) \\ \dots \\ g_m \dots \dots t \in [t_m, NOW] \end{cases} \qquad (Equation\ 5)$$

$$h_i(t) = \begin{cases} h_{i0} \dots \dots t \in [t_0, t_1) \\ h_{i1} \dots \dots t \in [t_1, t_2) \\ \dots \\ h_{ik} \dots \dots t \in [t_k, NOW] \end{cases} \qquad (Equation\ 6)$$

In equation 4, 5, and 6, the interval time $[t_0, t_1)$ in equation 4 is not necessarily the same as that in equation 5 or 6.

In the UML conceptual framework of the feature-based temporal model (figure 2), a temporal feature may have one or many temporal spaces and one or many temporal themes; there exist temporal relationships, "Was/Became", between temporal features, between temporal spaces, and between temporal themes. The difference is temporal relationships between temporal features are m-n, while those between temporal spaces and between temporal themes are 1-1. Temporal themes related with temporal space, such as area and length, are treated as attributes of temporal space, while others are modeled as temporal themes belonging to temporal features.

Besides the temporal relationships, there also exist two other kinds of non-temporal relationships. First, there are spatial topological relationships between the temporal spaces, which coexist at certain time-period. Second, there are other non-temporal relationships such as 'Connects To' and 'Flows To'. For example, one highway has 'Connects To' relationship with another highway, or a river has "Flows To" relationship with a lake or another river. These non-temporal relationships are not further discussed in this paper.

This approach is reasonable for object-based data, because a feature is the basic element in the object-view. It represents time in temporal feature using its status rather than the change. In order to get the spatio-temporal changes, temporal spaces have to be compared for differences.

3 Implementation of the Temporal Representation in Object-Relational Schema

3.1 Comparing OR with OO and Relational database

To efficiently manage the huge spatio-temporal base geographic data, we must think about database management system (DBMS). Simple file is not good at data editing and retrieving, especially when the file is large. The feature-based temporal representation may be implemented in relational database management system (RDBMS), object-relational database management system (ORDBMS), or object-oriented database management system (OODBMS).

Among these three types of DBMS, ORDBMS fit the spatio-temporal data model best. RDBMS is insufficient at modeling complex spatio-temporal features represented in the feature-based temporal framework. A UML model like figure 2 has to be broken down into several relational tables, and JOIN and RELATE, the least efficient operations, are unavoidable in data manipulation. OODBMS takes the advantages of OO programming into database management. However, OODBMS is not successful in commercial database marketplace for certain reasons and almost died of (Garcia-Molina *et al.* 2002). One of the shortcomings of OODBMS is not good at backwards compatibility to RDBMS, which is used by almost all of the databases on the world. ORDBMS implement the OO features in relational database, so ORDBMS has good backwards compatibility to RDBMS and supports OO features as OODBMS does. It provides OO features including abstract data type and inheritance, and is more mature than OODBMS. The feature-based temporal representation can take advantage of these features, especially nested table, collection, and reference. The 1-m “has” relationships between a temporal feature and its temporal spaces or temporal themes can be well represented using nested table, and the m-n temporal relationships between temporal features can be modeled using collection data type. Therefore, the object-relational schema is efficient in storing and querying spatio-temporal data modeled in the feature-based temporal representation.

3.2 An Example of OR Schema

Table 1 shows an example of base geographic feature in an OR table. This feature has no temporal relationship with other features. It has two temporal spaces and three temporal theme values for its theme—“Population”. This temporal feature is valid since 1990. In the year 2000, both space and population changed. Three years later, its population changed from 1500 to 1800. The entire row models the spatio-temporal information of this feature.

The OR schema of table 1 is listed in the Appendix.

4 Visualization of Spatio-Temporal Data Organized in the Object-Relational Schema

Although the OR schema fits the feature-based temporal representation very well, it encounters difficulties in visualizing the spatio-temporal data within an existing GIS environment. Almost all commercial GIS today support data stored in RDBMS, but not ORDBMS. There are two possible ways to get around this problem. One approach is to create a flat view based on an OR table, and then work with the view instead of the original OR table in GIS. Another way is to develop a new GIS, which can work with the OR schema directly. The second approach has advantages over the first one.

In the first approach, a view should be created based on an OR table because the flat view is similar to a relational table and is readable in GIS. Further query can be carried out against the view rather than against the original object-relational table. However, current GIS must be extended in order to edit the spatio-temporal data or visualize the history of a temporal feature or a geographical area in animation mode, which may be very difficult, and the advantages of OR schema is lost in data manipulation in this approach.

In the second approach, a new GIS supporting OR schema is designed. In this study, we develop a prototype temporal GIS using Java programming language, which is object-oriented. The new system is simple compared with existing commercial GIS, but it can work with spatio-temporal data in OR schema. The second approach, developing a new GIS, is better than the first approach, because it gives more flexibility in working with the complex spatio-temporal data. The disadvantage with the second approach is the heavy workload in developing a new GIS from scratch.

For example, figure 3 shows original status of the temporal feature in table 1. Its table window has two parts. The upper part tells the attributes for original snapshot, and the lower part gives all temporal information of the feature selected in the upper part. If there are many features in table 1, there will be as many records in the upper part of the table window, but the lower part of the table can only show one feature history at a time. Figure 4 portrays the feature in the year 2002, and figure 5 shows current status of the feature. Figure 3 is valid from 1990 till (not include) 2000, figure 4 is valid from 2000 till (not include) 2003, and figure 5 is valid since 2003. From figure 3 to 4, the feature becomes smaller and the theme value changes. From figure 4 to 5, spatial information is the same, only the theme value changed from 1500 to 1800.

5 Discussion and Conclusions

This paper studies temporal representation for base geographic data in object-based form. It simplifies time and spatio-temporal changes in base geographic data as discrete, then propose to represent time based on temporal feature. A temporal feature has temporal spaces and temporal themes. All of them are functions of time. When time and change are treated as discrete, these temporal functions can be simplified as constants during corresponding interval times. This makes it possible to model a feature history with several interval times and valid statuses during the intervals.

The temporal representation proposed in this paper can be best implemented in OR schema, which supports ADT and fits the feature-based temporal data model very well. In order to visualize spatio-temporal data organized in OR tables, we suggest to develop a new temporal GIS rather than extending an existing one, because the existing GIS environment overall limits the advantages of OR schema. However, there is lots of work to develop a new system.

In this research, we figure out another advantage of developing a new temporal GIS. Most existing GIS are layer based, and each layer has fixed spatial type--point, line, or polygon. While in ORDBMS, spatial type of a feature is not specified at table level, but at record level. Therefore, one type of feature can be represented as multiple spatial types, and this can benefit the spatial representation of base geographic data. For example, in base geographic data, building should be represented as point or polygon according to its size. In existing GIS, we can not define such a building feature class. However, it is possible in our temporal GIS. An original small house changed to a big building can be represented from a point to a polygon in OR schema and visualized as such in our temporal GIS.

In this study, the temporal GIS developed is very crude. Our next step is to add data editing, feature defining, and more visualization programs to the temporal GIS. Further, real world feature data, such as census boundary and transportation should be put into the feature tables for better experiments.

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Appendix

The following code in SQL language shows the definition of the OR table and related abstract data types in the Oracle database. The detailed member function for object type, "Interval_objtyp", is not given.

```
CREATE TYPE Interval_objtyp AS OBJECT (
        StartTime       DATE,
        EndTime         DATE,
        MEMBER FUNCTION     Before   RETURN BOOLEAN,
        MEMBER FUNCTION     Equal    RETURN BOOLEAN,
        MEMBER FUNCTION     Meet     RETURN BOOLEAN,
        MEMBER FUNCTION     Overlap      RETURN BOOLEAN,
        MEMBER FUNCTION     During   RETURN BOOLEAN,
        MEMBER FUNCTION     BeginWith    RETURN BOOLEAN,
        MEMBER FUNCTION     EndWith      RETURN BOOLEAN,
        MEMBER FUNCTION     Within   RETURN BOOLEAN);
CREATE TYPE Space_objtyp AS OBJECT(
        SpaceID         NUMBER,
        Shape           MDSYS.SDO_GEOMETRY,
        SpaceTime       Interval_objtyp,
        Area            NUMBER,
        Length          NUMBER);
```

```
CREATE TYPE Theme_objtyp AS OBJECT (
    ThemeID         NUMBER,
    ThemeTime       Interval_objtyp,
    Value           NUMBER);
CREATE TYPE Space_ntabtyp AS TABLE OF Space_objtyp;
CREATE TYPE Theme_ntabtyp AS TABLE OF Theme_objtyp;
CREATE TYPE Feature_objtyp;
CREATE TYPE TmpRel_vartyp AS VARRAY(1000) OF REF Feature_objtyp;
CREATE TYPE TmpRel_objtyp AS OBJECT (
    TmpRelID        NUMBER,
    TmpRel          REF     Feature_objtyp,
    ChangeDate      DATE);
CREATE TYPE TmpRel_ntabtyp AS TABLE OF TmpRel_objtyp;
CREATE OR REPLACE TYPE Feature_objtyp AS OBJECT (
    FeatureID       NUMBER,
    FeatureTime     Interval_objtyp,
    Was             TmpRel_ntabtyp,
    Became          TmpRel_ntabtyp,
    Spaces          Space_ntabtyp
) NOT FINAL;
CREATE TYPE Census_objtyp UNDER Feature_objtyp (Population    Theme_ntabtyp);
```

```
CREATE TABLE Census_objtab OF Census_objtyp (
    PRIMARY KEY (FeatureID) )
    OBJECT IDENTIFIER IS PRIMARY KEY
    NESTED TABLE Was STRORE AS Was_ntab (
            (PRIMARY KEY (Nested_table_id, TmpRelID))
            ORGANIZATION INDEX COMPRESS)
            RETURN AS LOCATOR
    NESTED TABLE Became STRORE AS Became_ntab (
            (PRIMARY KEY (NESTED_TABLE_ID, TmpRelID))
            ORGANIZATION INDEX COMPRESS)
            RETURN AS LOCATOR
    NESTED TABLE Spaces STRORE AS Shape_ntab (
            (PRIMARY KEY (NESTED_TABLE_ID, SpaceID))
            ORGANIZATION INDEX COMPRESS)
            RETURN AS LOCATOR
    NESTED TABLE Pop STRORE AS Pop_ntab (
            (PRIMARY KEY (NESTED_TABLE_ID, ThemeID))
            ORGANIZATION INDEX COMPRESS)
            RETURN AS LOCATOR;
```

Figure 1 Feature and its space, time, and theme (ORIGINAL)

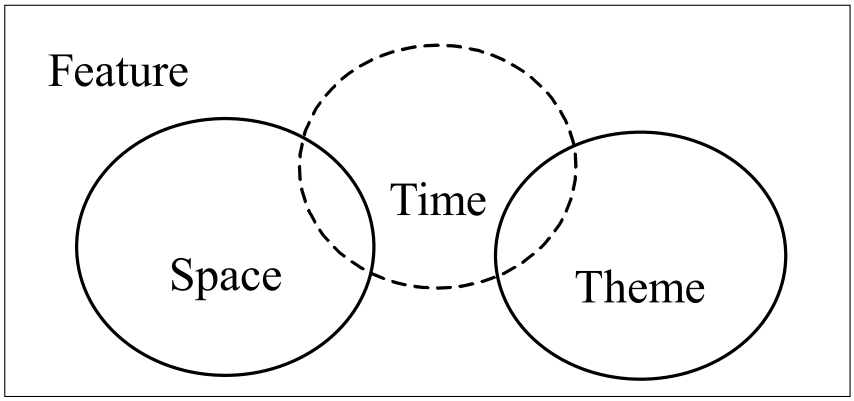


Figure 2 UML conceptual framework of feature-based temporal model (ORIGINAL)

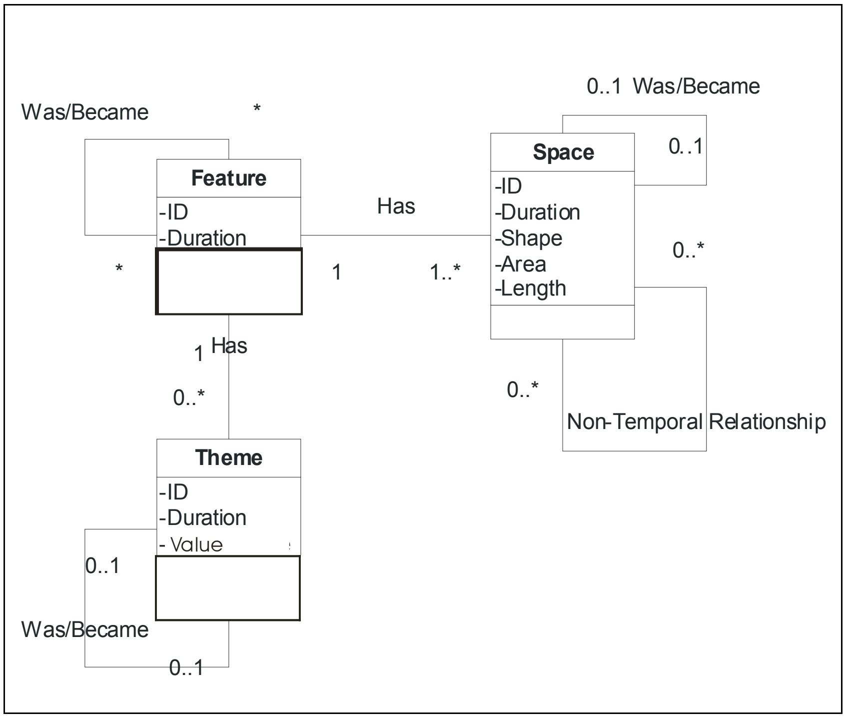
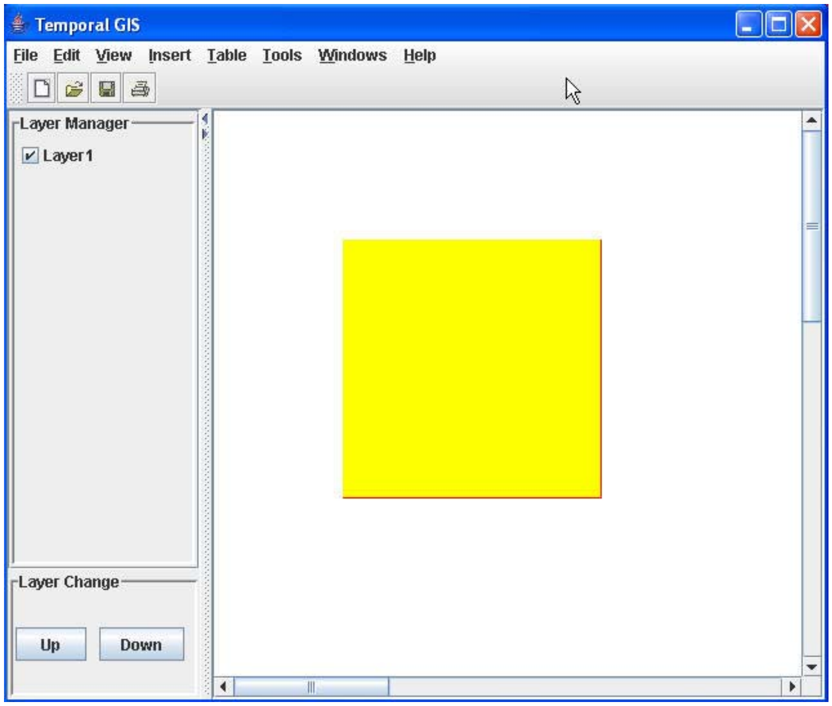
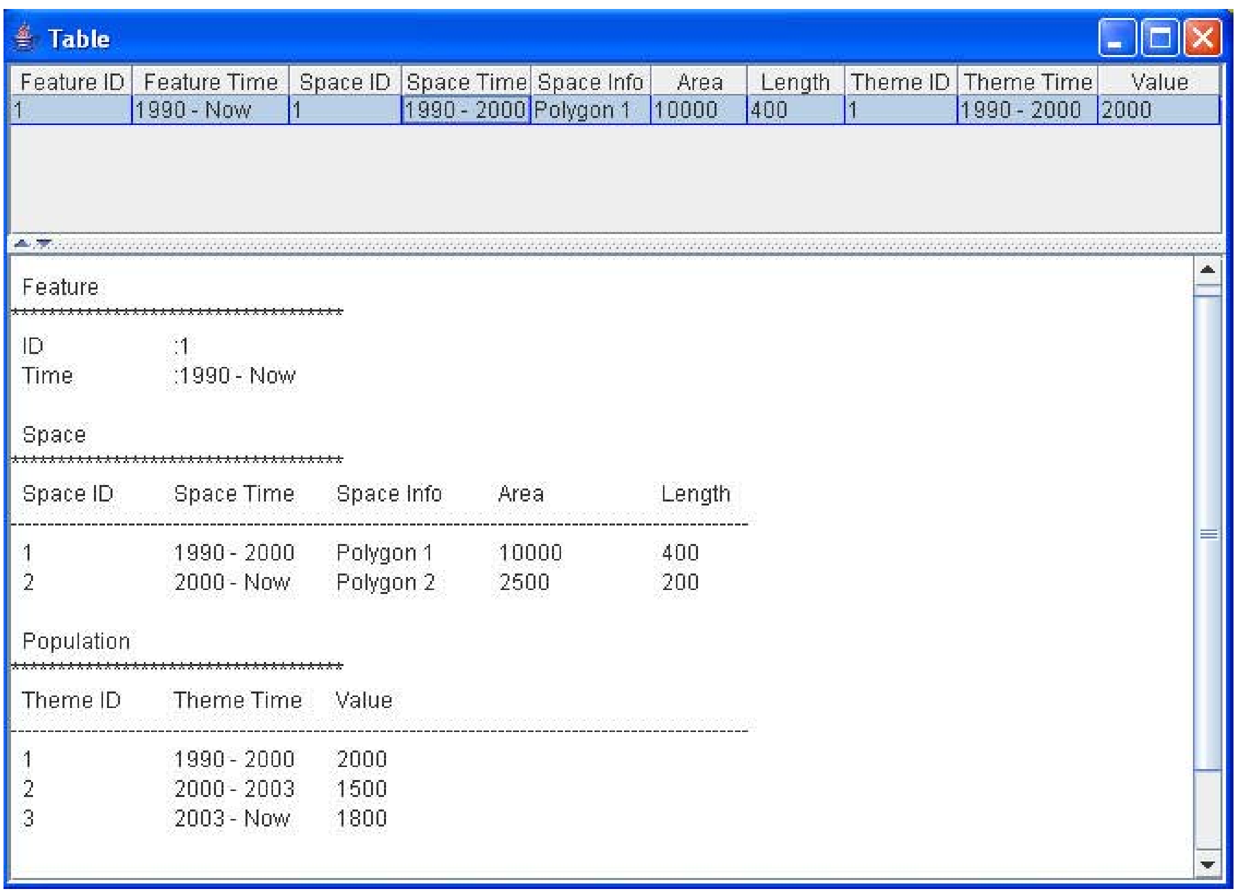


Figure 3 Original status of the temporal feature in table1 (ORIGINAL)





Feature ID	Feature Time	Space ID	Space Time	Space Info	Area	Length	Theme ID	Theme Time	Value
1	1990 - Now	1	1990 - 2000	Polygon 1	10000	400	1	1990 - 2000	2000

Feature
****

ID :1
Time :1990 - Now

Space
****

Space ID	Space Time	Space Info	Area	Length
1	1990 - 2000	Polygon 1	10000	400
2	2000 - Now	Polygon 2	2500	200

Population
****

Theme ID	Theme Time	Value
1	1990 - 2000	2000
2	2000 - 2003	1500
3	2003 - Now	1800

Figure 4 Temporal feature in table1, 2002 (ORIGINAL)

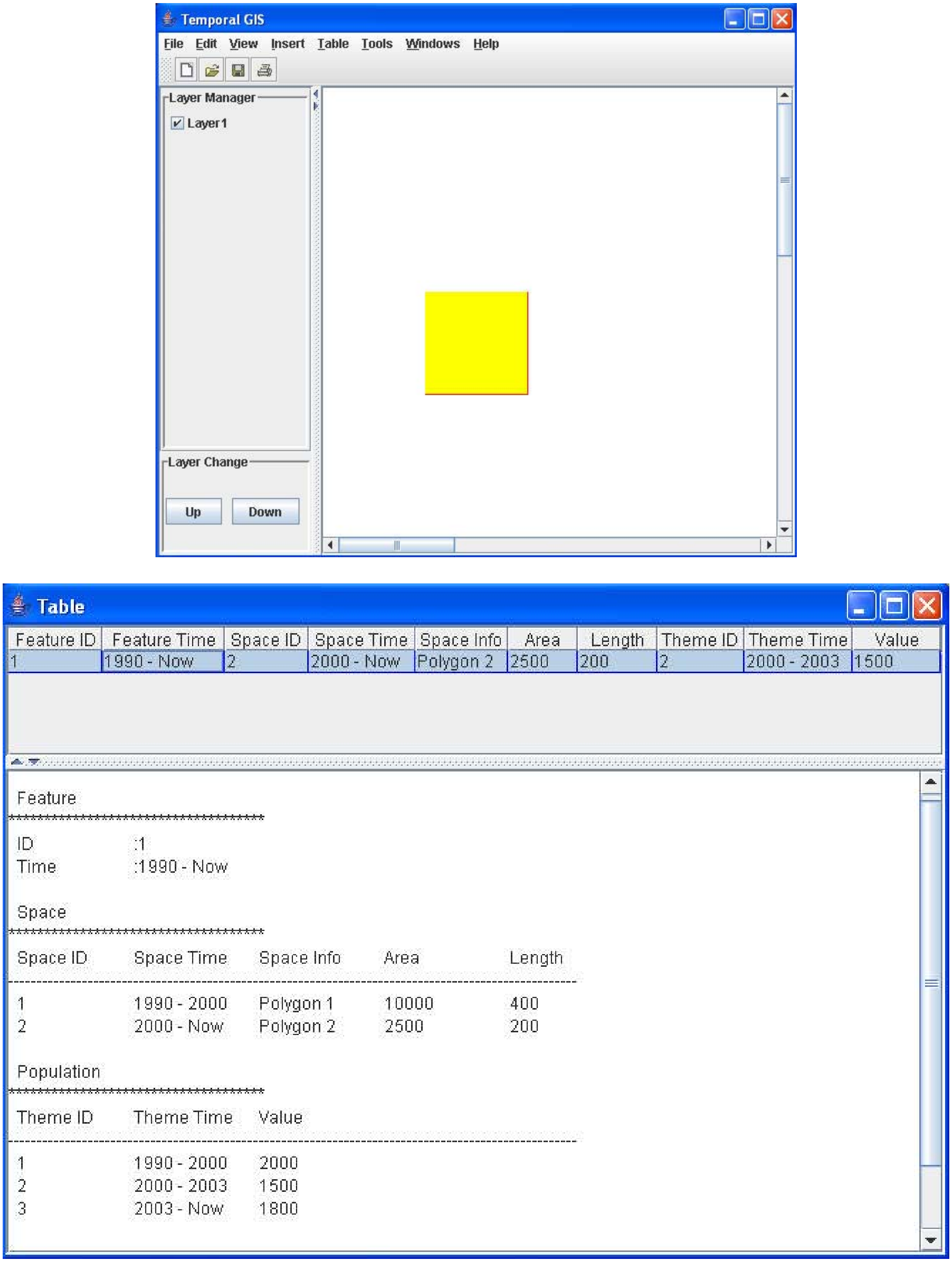


Figure 5 Current status of the temporal feature (ORIGINAL)

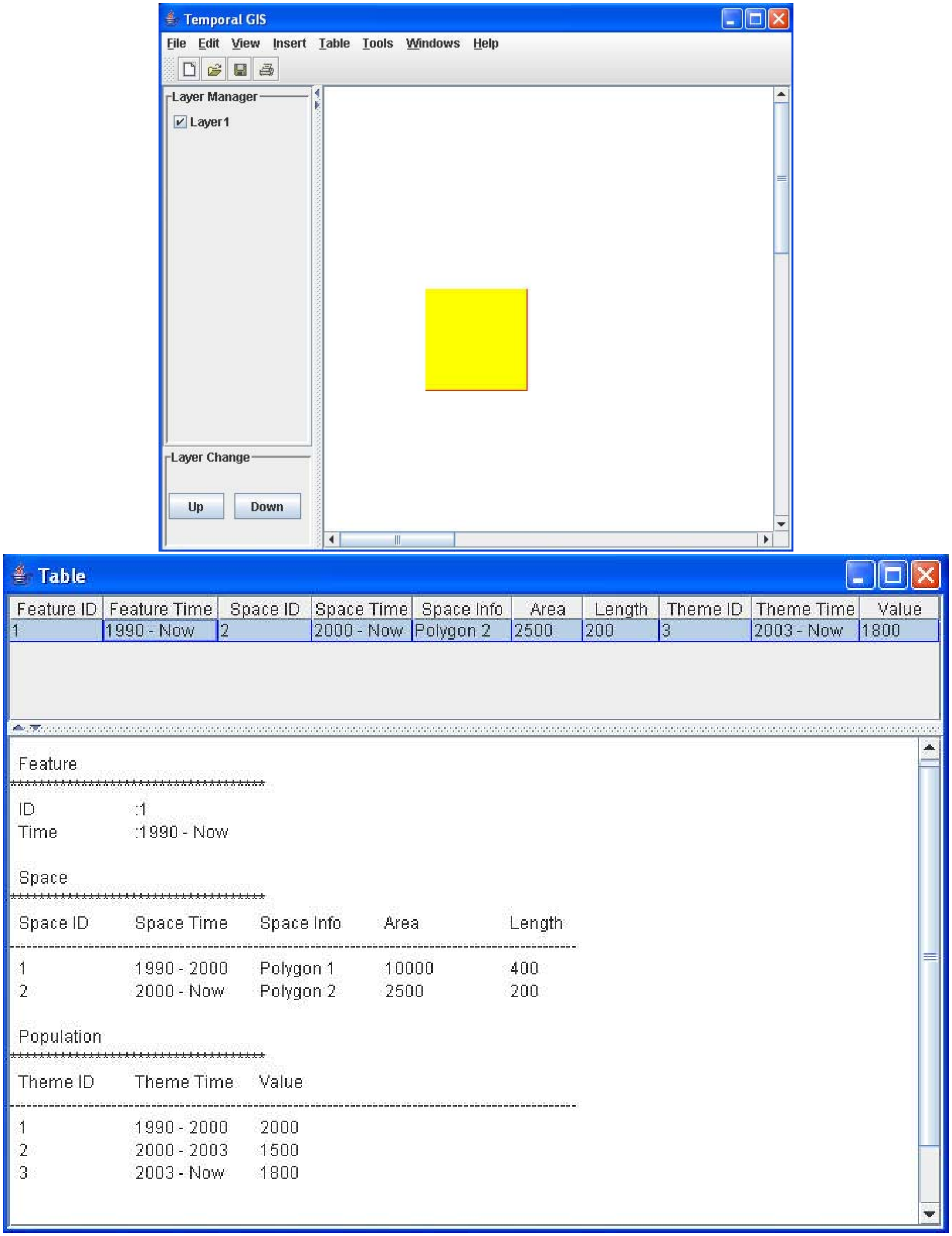


Table1 Feature-based temporal model (ORIGINAL)

<table>
<tr><th colspan="4">Feature</th><th rowspan="2">Space</th><th rowspan="2">Theme</th></tr>
<tr><th>Feature ID</th><th>Feature Time</th><th>Predecessor</th><th>Successor</th></tr>
<tr>
<td>1</td>
<td>1990-Now</td>
<td><table><tr><th>Pres</th><th>Pre Time</th></tr><tr><td>null</td><td>null</td></tr></table></td>
<td><table><tr><th>Sucs</th><th>Suc Time</th></tr><tr><td>null</td><td>null</td></tr></table></td>
<td><table><tr><th>Space ID</th><th>SpaceTime</th><th>Space info</th><th>Area</th><th>Length</th></tr><tr><td>1</td><td>1990-2000</td><td>Polygon 1</td><td>10000</td><td>400</td></tr><tr><td>2</td><td>2000-Now</td><td>Polygon 2</td><td>2500</td><td>200</td></tr></table></td>
<td><table><tr><th colspan="3">Population</th></tr><tr><th>Theme ID</th><th>ThemeTime</th><th>Value</th></tr><tr><td>1</td><td>1990-2000</td><td>2000</td></tr><tr><td>2</td><td>2000-2003</td><td>1500</td></tr><tr><td>3</td><td>2003-Now</td><td>1800</td></tr></table>……</td>
</tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Note: Columns in bold font are temporal data.