EVENT-DRIVEN INCREMENTAL UPDATING: AN UPDATING APPROACFH OF SPATIO-TEMPORAL DATABASE

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ABSTRACT:

Incremental updating of a Spatio-Temporal Data Base (STDB) means that master spatial data set is updated when any change (geometric or thematic) occurs, the changes can be recorded, updated and provided successively to users. During this process, a set of editing operations is needed to add, delete or amend spatial objects. As traditional manual operations are labor-intensive and even error–prone, it is necessary to develop a method to automate or semi- automate these editing operations. This requires the automatic identification of spatial changes, trigging appropriate editing operations, solving problems of spatial conflicts and checking the consistency of the records. Since the spatial changes are caused by the external events taking place in the geographic world and editing operations are caused by the spatial changes, the editing operations may be directly triggered by the external events. Based on this cognition, a new approach of STDB's automatic incremental updating is proposed. This approach is named as Event-Driven Incremental Updating (E-DIU). The method of E-DIU is based on the relationship among the external events, spatial changes and the internal database operations, the spatial change types of the objects involved in the event are identified by the external event and the topological relationship between the objects before and after the event. The database updating operations are determined by the spatial change types. So the authors analysed the relationship among the external events, spatial changes and the internal database operations at first, then designed a total architecture of E-DIU implementation and described the process of the E-DIU of the master STDB in this paper. An example is given to illustrate this approach in the end of this paper.

1. INTRODUCTION

Nowadays, the 'current view' data of spatial entities is maintained by most traditional GISs and snapshot of the real world could be provided at the request of users. With this background, the updating of this spatial database is to store the all old view in the history database, and update the 'current view' when a change occurs even if only 10% of the objects stored in the database have changed [Langran, 1992; CHEN Jun, 1994]. In this atemporal spatial database, the storage cost is very great, and 'the comparison between states to determine changes which occur in a given time interval will be a tedious task' [Armenakis, 1994; Hornsby, et al, 2000]. Now, it is therefore becoming crucial to add time dimension in spatial database and make temporal data accessible to users. This has result in a very exciting research direction on the development of STDBs.

A number of complex problem arise when extending the spatial databases to include the temporal information, such as the spatio-temporal data model, in efficient storage and access to historical data, incremental updating, etc. Among these problems, incremental updating means that master spatial data set is updated when any geometric or thematic changes occur, the changes are recorded, the updating process can be tracked, and the updates are provided successively to users [Langran, 1993; Cooper, et al, 2001]. The STDBs' incremental updating involves the following 3 stages:

1. The collection of the changed information;
2. The master database' incremental updating;
3. The user database' incremental updating.

In this paper, we mainly study the master database' incremental updating, and assume that the collection of the changed information is independent of the database, which can be transferred to the database system according certain form designed previously. The communication will use standard operating system services. For most spatial data producers, the updating of master spatial data set is carried out by manual and interactive editing. With the geometric or thematic changes from either ground or photogrammtric surveying, it will be determined by data producers which objects should be added, deleted and amended. A large amount of editing operations are needed. As this traditional process is an error–prone and labor-intensive process, automatic execution of these editing operations is desired [Cooper, et al, 2000; Cooper, et al, 2001].

Usually, the process of the automatic updating is like this: when any changes occur and the current view has been transferred to the system, overlap algorithm is done to retrieve the changed objects, then according to the different types of changes previously defined, appropriate operations are executed to update the database records [Beyen, et al., 1998; Badard, 1999; Badard, 2001]. These studies, however, are based on the objects' states; omit the lifespan and the change process of the objects.

When the lifespan and the change process of the objects are must be considered, overlap algorithm is inefficient. For example, there are 5 houses (H0, H1, H2, H3, H4) at T0 and 4 houses (H0, H5, H6, H7) and a road (road 1) at T1 (Figure 1).

Overlap algorithm can determine that there appears a road, disappears a house H2 and H0 continues without any change and the appropriate operations can be done to these objects. But it can't identify the change process of H1, H3, H4 to H5, H6, and H7, can't determine which operations should be done to them. However if we know the change events of these objects, such as demolish H1, H3 and built H5, H6, enlarge H4 to H7, the operations are obvious. So the changing event is very important in the process of updating.

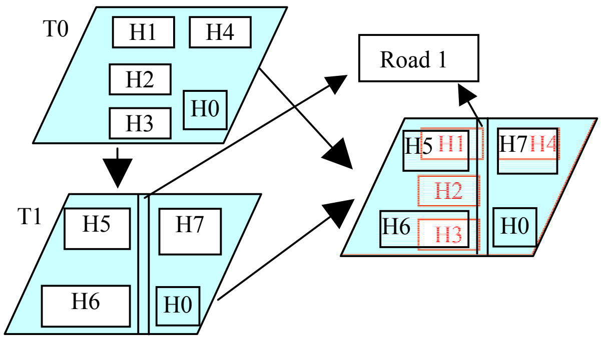

Figure 1. The overlap of the snapshot of T0 and T1

At the same time, 'states, event and evidence are the three main types of TGIS data' [Langran, 1993]. Much work has been done about event, such as the classification of events [SHU Hong, et al, 2000], event-based spatio-temporal data models [Allen, et al, 1995; Claramunt, et al, 1995; Peuquet, et al, 1995; CHEN Jun, et al, 2000; LIN Guang-fa, et al, 2002].

In database field, it is widely recognized that events provide a powerful mechanism for modelling and implementing complex systems. It has been used at operating system and user interface level [Ajit et al, 1998]. Much work has been done about the event specification languages [Gehani, et al, 1992a; Gehani, et al, 1992b; Hasan, 1996] and the event-driven programming [Teisseire, et al, 1994; Ajit et al, 1998; XU Ke, et al, 2000].

Geographic entities may be divided to two types: geometric objects and topological objects [Open GIS Consortium, 2000]. The topological objects are connected with each other. If one object changed, the other objects connecting with it should also be changed in order to maintain the integrity of the data. So the updating process is more complex than the geometric objects. In this paper, We just discuss the updating of the geometric objects.

This paper presents an automatic updating approach of the master spatial database, which is called the Event-Driven Incremental Updating (E-DIU). The foundation of this model is the relationship of the external events, types of spatial change and internal spatio-temporal database dynamic operations. The term *external event* is the causes of state changes (including geometric or thematic of the spatial objects). The term *dynamic database operations* are database operations such as insert, delete, which may change the records in the database. This research is aimed at automating the process of the master STDB's updating by introducing event. In this paper, the spatio-temporal data model is event-based and object-oriented [CHEN Jun, et al, 2000; Raza, 2001].

The remainder of this paper is structured as follows: The relationship among external events, spatial changes and database operations is presented in Section 2. A total architecture of E-DIU implementation is presented in Section3. The process of E-DIU is described in Section 4. An example is given in Section 5. The summary is given in Section 6.

2. RELATIONSHIP AMONG EXTERNAL EVENTS, SPATIAL CHANGES AND DATABASE OPERATIONS

The E-DIU approach is based on the relationship among external updating event, spatial changes, and dynamic database operations. Hence it is described first.

2.1 External Events

An external event is an occurrence in the geographic world (or real world other than computer world), which is the cause of the state changes (including geometric or thematic, attribute) of spatio-temporal entities. The word *external* means the event is outside the realm of the STDB.

		stability	expansion	contraction	displacement	rotation	appear	disappear	reappear	deformation
		1	2	3	4	5	6	7	8	9
Mending	1	✓								
Extension	2		✓							
Partly-demolishing	3			✓						
Movement	4				✓					
Rotation	5					✓				
Building	6						✓			
Demolishing	7							✓		
thematic changing	8	✓						✓	✓	
reconstruct	6–		✓	✓			✓	✓		✓
Earthquake	81	✓		✓			✓	✓		✓
Flood	82	✓		✓	✓	✓		✓	✓	✓
Storm	83	✓		✓	✓			✓	✓	✓
Rainstorm	84	✓	✓	✓				✓	✓	✓
Snowstorm	85	✓	✓	✓				✓		✓

Table 1. The relationship between external events and the change types of single entity

External events are very complicated and may have many categories. It can be classified into different categories according to different criteria. Each STDB application should have its types of external events and categories. In this paper, we divide the external events into two categories: man-activity events and natural events according to if the event has an intentional agent. Man-activity event has one or several intentional agents, which usually occurs when human activity directly changes the geometric or thematic states of artificial entities: buildings, walls, roads, dams and parcels. The geometric man-activity event include the building, demolishing and partly demolishing, mending, extension of the artificial entities, buildings' movement, rotation, and reconstruct of the parcels(land-subdivision). The thematic changing man-activity event refers that the intentional agent doesn't change the geometric attribute but change the thematic attribute, such as change a piece of dry soil to be a parcel of irrigable land. When the attribute is a key to the application system, the STDB will create a new object, otherwise the STDB add a new version to the objects. Natural event usually have no intentional agent, which involve earthquake, flood, storm, snowstorm, volcano-breaking, rainstorm, etc. They also may change the geometric or thematic state of the geographic entities we study (regard). The types of the external events should be capable of extending.

2.2 Types of Spatial Change

Understanding the spatio-temporal entities' types of spatial change is very important in the updating of spatio-temporal data. Since Aristotle (2, 000 years before) distinguished four kinds of change: generation / corruption (appearance / disappearance), increase / decrease (quantitative change), alteration (qualitative change), locomotion (change with respect to place) [Couclelis, H., 1998], much effort has been done on this aspect. For example, three main classes described spatio-temporal change processes by Claramunt and Theriault (1995) are accepted widely by the society of TGIS. They are the evolution of a single entity, functional relationships between several entities, the evolution of spatial structures involving several entities. From the object-oriented point of view, Evolution of a single entity constitutes an indispensable foundation for TGIS. The functional relationships between several entities and the evolution of spatial structures involving several entities can be represented through the evolution of a single entity's evolution. Claramunt and Theriault proposed three categories to describe evolution of a single entity: a) basic processes: appearance, disappearance and spatial stability to allow representation of attribute variation without spatial effects; b) transformation processes involving change in shape or size: expansion, contraction and deformation (i.e. shape modification without size change), c) movement processes involving only positional change: displacement and rotation [Claramunt, et al, 1995]. Comparing Aristole' s four kinds of change and Claramunt' s three main classes change processes, it is not difficult to find that they are almost equal except *reconstruct* including in Claramunt' s change processes. From this, we can conclude that the kinds of change process cognised by human being are stable and the basic spatial change can be the link between the external events and internal database operations.

However, these studies have omitted an important change type: reappear. In geographic history, there usually had something, but for some reasons, it disappeared, and afterward, it has appeared again. We call this change process as reappear. For example, there had a river, because of the drought, the river became a dry channel for years, with the weather becoming well, the dry channel become a river again, this process may be called reappearing.

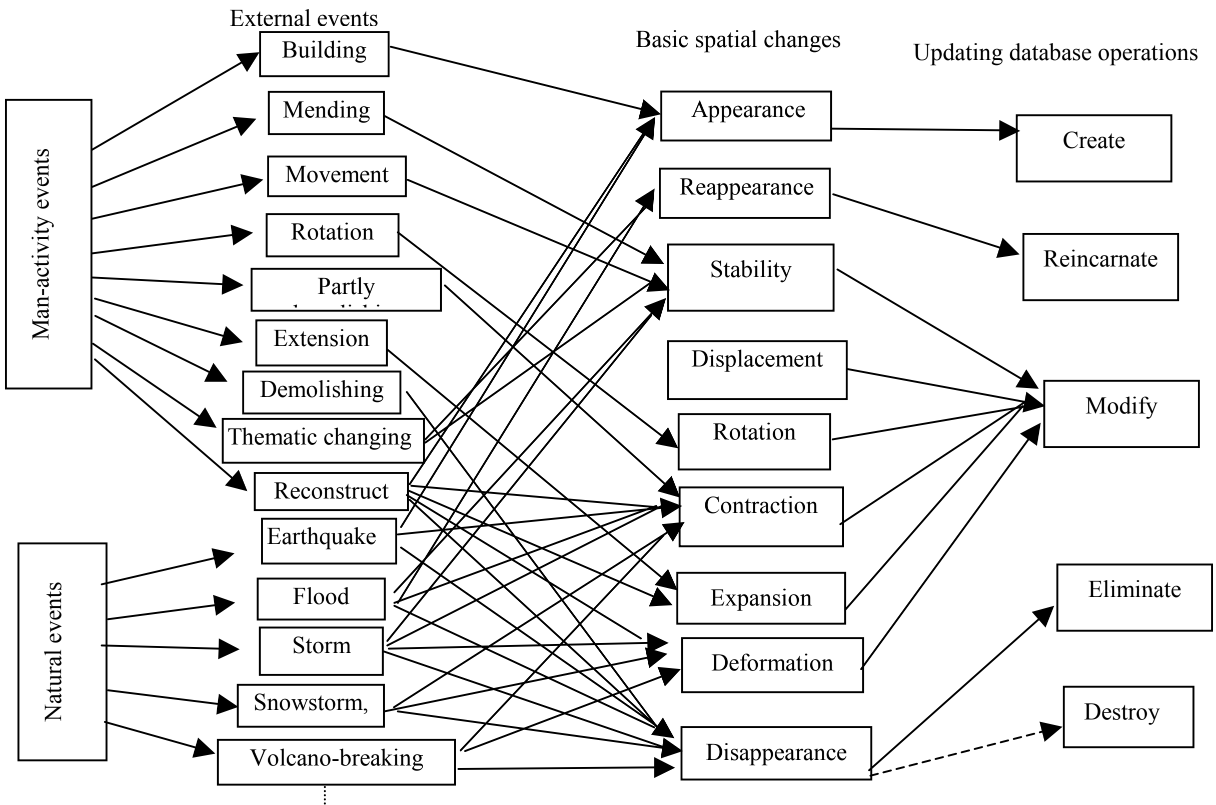

Figure 2. The relationship among external events, basic spatial changes and internal database updating operations

2.3 The Relationship between Spatial Changes and External Events

The relationship between external events and the change types of single entities is showed in table 1. Table 1 shows that the relationship between external events and the change types may be 1:1 (such as mending, extension and part-demolishing, movement and rotation, demolishing, building), and 1:m (earthquake, flood, storm, rainstorm, snowstorm, volcano-breaking). According to this, we divide the external event into simple event and composite event. Simple events refer 1:1 events, which may cause only one type spatial or thematic change of one or several objects. Composite events refer 1:m events, which may causes several types of change on the objects (a part of or the whole involving in the event scene). Reconstruct is one type of composite event, but because it's operands are topological objects, the updating process is more complex than the other external events, and we will not discuss it in this paper.

2.4 Dynamic Database Operations

Database operations may be classified as static operations and dynamic operations, static operations define operations and relationships that do not make essential changes to the operand objects, such as select, query event; while dynamic operations change the state of one or more of the operands, such as insert, delete or modify [Worboys, 1995; Raza, et al, 2000]. In this paper, we just discuss the dynamic STDB operations.

Several efforts have been done on this aspect, Ale RAZA and Wolfgang Kainz proposed 4 kinds of dynamic STDB operations, create, delete/destroy, kill and reincarnate [Raza, et al, 2000]. Based on the three states (existence, non-existing with history, and non-existing without history) of a single entity in database, K. Hornsby and M. Egenhofer proposed single entity's nine identity-based change operations: continue non- existence without history, create, recall, destroy, continue existence, eliminate, forget, reincarnate, continue non-existence with history [Hornsby, et al, 2000]. From the object-oriented STDB management point of view, this paper argues that seven primitive dynamic database operations are powerful to a single spatio-temporal object's dynamic behaviour. The seven dynamic events form a set of primitive dynamic operations of STDB.

In this paper, we assume that time is one dimension, and the interval time stamp [start. end] represents the entity's life span $\{(T_{start}, T_{end}) \mid T_{start} \leq T_{end}\}$, All objects with [start. *] time stamps are called active objects (usually, active objects means the objects still exist in the real world), all objects with [start, end] time stamps are called inactive objects (inactive objects are not existing in the real world). The seven dynamic events are defined as follow:

Create: The task of this operator is to add a new record of an active object in the database. This operator specifies the stamp [start. *] of the spatial objects.

Destroy: The task of this operator is to permanently delete the spatio-temporal active objects from the database. Therefore, they are no longer available for any types of operations (static or dynamic). In STDB, almost all history objects should be reserved in the database for some time, so usually this operation should be limited to use.

Modify: The task of this operator is to modify the properties (including thematic and spatial properties) of the active or inactive objects in the database. In STDB, the operator 'modify' means add a new version of the operand to the database.

Eliminate: This operator transmits an active object in the database to an inactive object by defining the upper bound of the time interval.

Recall: The task of this operator is to add a new record of an inactive object in the database with the stamp [start, end].

Forget: The task of this operator is to permanently delete the spatio-temporal inactive objects from the database.

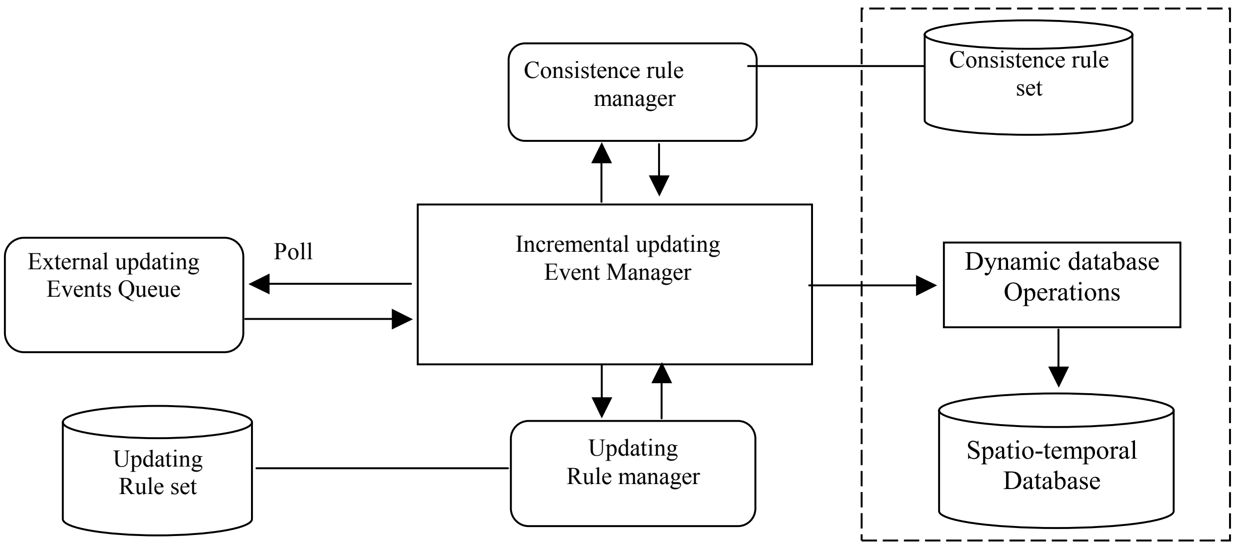

Figure 3. The implementation architecture of event-driven incremental updating

Reincarnate： This operator turns an inactive object in the database into an active object, which means that the properties of the inactive object were copied to form an active object with the timestamp of (start, *).

The dynamic database operations used in the updating process usually include create, reincarnate, modify, eliminate and destroy.

2.5 The Relationship among External Events, Basic Spatial Changes and Updating Database Operations

Figure 2 shows the relationship between the basic spatial changes and the updating database operations are m: 1. It means that if the spatial change types are known, the updating database operations will be determined easily. The relationship between some external events and the basic spatial changes is 1: 1, some is 1: m. 1:1 external events, which are called simple events, can drive the appropriate database updating operations directly. 1:m external events, which are called composite events, may drive a segment of change types identification program to identify the involving objects' change types at first, then trigger the appropriate database updating operations.

External events are capable of extending. When an external event is added, if the event is a simple event, it is sufficient to define the according type of spatial change; if it is a composite event, except defining the types of spatial change, the identification program also must be given.

3. AN ARCHITECTURE OF E-DIU IMPLEMENTATION

Based on the relationship among external events, basic spatial changes and updating database operations, the authors propose an updating approach of STDB, namely E-DIU. In order to implement this updating approach, a total architecture of E-DIU implementation is designed. This architecture is composed of the external event queue, STDB, three managers (event manager, updating rule manager and consistence rule manager), and two rule sets (updating rules and consistence rules). Figure 3 shows this architecture.

3.1 The External Updating Events Queue

The external updating events queue is a queue to store the state-changing events timely or according to certain prior mechanism. When a surveyor transmits the changed information (including geometric, thematic, event and survey information) according to certain scheduled form to the system, the system manager stores this information in the external updating events queue to wait being polled by the incremental updating manager. The external updating events queue is defined (in language C) as follows:

```
typedef struct ext-event / the definition of external-event /
{ char ev_name;  / external-event name /
int ev_type; / external-event type /
int ev_id; / external-event identity /
date event-time; / the time when the external-event happened /
geometry ev_spatial_property;  / the spatial-property of an external event. /
…; / the other properties /
    } ext-event;
typedef struct Eventqueue / the definition of event queue  /
{int   head；  / the head of the event queue /
int tail；  / the tail of the event queue /
ext-event ev[maxext-event];  / event queue /
} Event-queue.
```

3.2 Managers

There are three managers in this architecture (figure 3); in fact they are three different executable programs. The responsibility of the incremental updating event manager is to manipulate the whole event-driven incremental updating process, such as poll external events from the external updating events queue, notify the rule system, notify the STDB. The updating rule manager is responsible for notifying the updating rule system about occurrences of external events and gets back the expression of the STDB operations. The consistence rule manager is responsible for checking the records consistence according to the consistence rule.

3.3 The Rule System

The rule system includes two sets of rules, consistency rules and updating rule. Consistency rule set is the set of the rules of the spatio-temporal topological consistency rules for the objects of the STDB; it is beyond the scope of this paper. The updating rules are such rules that determine the behaviours of the STDB to update the database's records according to the external event types.

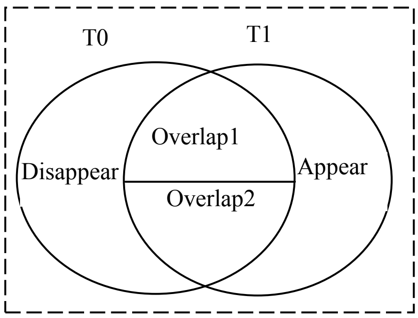

Figure 4. Relation between data sets

The general updating rules in this framework are assumed to be the form: 'on external event-type do action', the event-type may be represented by the external-change code. In order to construct the relationship between external event and the database operations conveniently, we give each change category and each external event a number code (which is less than 100, showed in table 1), such as '8107' means the objects' disappearing caused by earthquake. To simple external event, the action is an updating database event (table 2).

To composite external events, the action is more complex. The key issue is to identify the spatial change types. In order to simplify the question, in this paper, we assume that the objects in the scene of the composite external events are geometric objects (discrete objects), not include topological objects. The objects involving a composite event may be divided to three classes: overlap, disappear l and appear.

Definition 1: the Overlap objects is a set of such objects that the objects of T0, which intersect the same kind objects of T1, is not null, and the objects of T1 which intersect the same kind objects of T0 is not null.

external event	event-code	database event	database action
Mending	101	modify	add a new version of the operand in the database
Extension	202	modify	add a new version of the operand in the database
Partly-demolishing	303	modify	add a new version of the operand in the database
Movement	404	modify	add a new version of the operand in the database
Rotation	505	modify	add a new version of the operand in the database
Building	606	create	add a new record of the operand in the database
Demolishing	707	eliminate	replace the operand's updown time with the event time

Table 2. The rules of simple external events

Overlap= $\{objects_{T0}: (object_{T0} \cap object_{T1} \neq \emptyset)\} \cup \{objects_{T1}: (object_{T1} \cap object_{T0} \neq \emptyset)\}$,

$\Rightarrow$ disappear = datasetT0 – Overlap,
appear = datasetT1- Overlap,

The set of overlap also can be divided to 2 parts: overlap1, overlap2.

Definition 2: overlap1 is a set of the objects of T0, which is equal to the same kind objects of T1 (such as H0 in Figure 1); overlap2 is the overlap subtracts overlap1 (such as H1 H3 H4 H5 H6 H7 in Figure 1).

Overlap 1 = {objects: $Objects_{T0} = objects_{T1}$}
Overlap 2 = overlap - overlap1

The objects of the overlap1 are stable without any spatial change. To the objects of the overlap 2, we should analyse details to determine the types of spatial change according to the external event-type, and the state relationship between the objects of T1 and T2.

4. THE PROCESS OF EVENT-DRIVEN INCREMENTAL UPDATING

Whenever an external updating event is polled, the following actions are triggered automatically: (1) A record of the external event is inserted in the event table, (2) according to the event-type, the event manager can determine the external event is simple event or composite event. (3) To composite event, the segments of T0 (from the spatial database) and T1 (from the external event spatial property) will be copied to workspace by the event manager. (4) The datasets of T0 and T1 will be compared, and will be divided to four parts: disappear, appear, overlap1, and overlap2. (5) The updating operation expressions will be formed according to the appropriate rules in the updating rule set. (6) The database updating operations are executed to update the records in the database. (7) The consistence of the updating records will be checked by the consistence manager according to the consistence rules. If there is no problem in the new data sets, the updating process ends; if there are some problems, the conflicts will be marked, and the operator will deal with them interactively. To simple event, because the operand is illustrated by the spatial property of the external events, the steps of 3 and 4 may be omitted; the updating manager can directly execute the step 5. Thus the searching time will be cut. Usually many updating activities are triggered by simple external events. All of these actions are triggered by the external updating event. So we called the whole updating process as external event-driven updating.

5. AN EXAMPLE

The change process of figure 1 is as follow: There are 5 houses (H0, H1, H2, H3, H4) at T0, in order to build the road, H1, H2 and H3 were demolished, two houses H5, H6 and a road were built, then H4 was extend to H7. The corresponding database operations are as follow (Table 3): eliminate H1, H2 and H3, create H5, H6 and road 1, and modify H4 (add a new version of H4 with H7 as it's spatial property). So we can get the snapshot of T1: 4 houses (H0, H5, H6, H7) and a road (Figure 1). The process is very simple. In this architecture, we distinguish world time/valid time and transaction time / database time, so the four events can transact at the same time, but with the sequence of the happening of the events.

event-id	event-type	event-code	database event	operand
1	Demolishing	707	eliminate	H1, H2, H3
2	Building	606	create	H5, H6
3	Building	606	create	road 1
4	Extension	202	modify	H4 to H7

Table 3. The example of event-driven updating

6. CONCLUSIONS

In this paper, a new type of automatic updating approach for the master STDB, called Event-Driven Incremental Updating (E-DIU) has been described. This paper has analysed the relationship among the external events, spatial changes and the internal database operations, designed a total architecture of E-DIU implementation and described the process of the E-DIU of the master STDB. As a by-product, this approach also has an advantage of enabling a simple event directly trigger a database updating operation without searching referring objects. Though this approach is presented for the master spatial database' incremental updating, it also adapt to the user database' s incremental updating, and the transferred information is 'change-only'. At the same time, since the event information is stored in the database, the querying of causal relationship and reasoning based on the causal relationship are capable.

There are several areas for further research in this context. To composite event, one type of external event may associate with several types of change process of the geographic entities. The identification of these change types is the foundation of the automatic updating of these change processes. To topological objects, because the change of them is independent, construct the relationship between the external events of these objects and the database operations is still a challenge. In addition, there is much work to implement E-DIU.

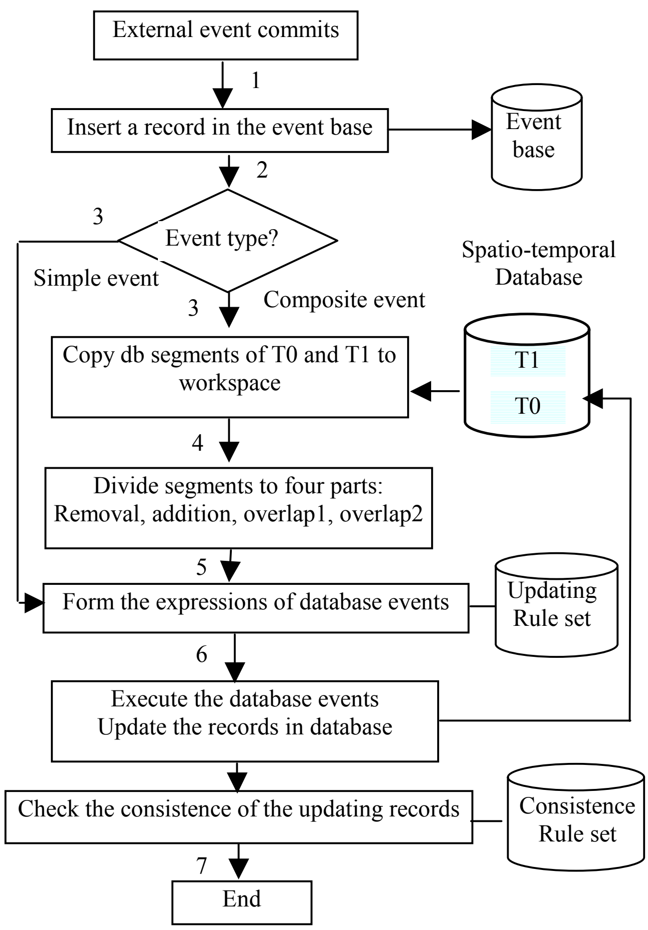

Figure 5. The process of event-driven incremental updating

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REFERENCES

Ajit, K.P. and Arie, S., 1998. An architecture and construction of business event manager. O.Etzion, S.Jajodia, and S.Sripada (Eds). *Temporal Databases-Research and Practice*. Spring-Verlag Berlin, Heidelberg, pp.257-280.

Allen, E., Edwards. G and Yvan B., 1995. Qualitative causal modeling in temporal GIS. Andrew. U and Frank, K. W. *Spatial Information Theory-A Theoretical Basis for GIS.* Springer-Verlag, New York, pp. 397-417.

Badard, T., 1999. On the automatic retrieval of updates in geographic databases based on geographic data matching tools. *ICA / ACI 1999 - Proceedings /Acte.* Ottawa, Canada, pp. 1291-1300.

Beyen, J. and Brussels, J. H., 1998. Updating topographic databases with arc info; client – fitted creation of change – only information. *GIS-between Visions and Applications, International Archives of Photogrammetry and Remote Sensing*, Stuttgart, Germany, Vol. 32-B4, pp. 59-64.

CHEN Jun, 1994. Managing GIS temporal attributes with Non-1NF approach. *Proceedings of Integration, Automation and Intelligence in Photogrammetry, Remote Sensing and GISs*, Wuhan, China, pp. 338-347.

CHEN Jun, JIANG Jie, 2000. An event-based approach to spatio-temporal data modeling in land subdivision system for spatio-temporal process of land subdivision. *Geoinformatica,* 4(4), pp. 387-402.

Claramunt, C. and Thériault, M., 1995. Managing Time in GIS An Event-Oriented Approach. Clifford, J. and Tuzhilin, A. (eds.). *Recent Advances on Temporal Databases.* Springer-Verlag, Zurich, Switzerland, pp. 23-42.

Cooper, A. & Peled, A., 2000. The international Cartographic Association's Working Group on Incremental Updating and Versioning. *ICA/ISPRS Workshop on Incremental Updating and Spatial Databases,* Amsterdam, pp. 1-9.

Cooper, A. & Peled, A., 2001. Incremental Updating and Versioning. *The 20th International Cartographic Conference (ICA),* pp. 2806-2809.

Couclelis, H., 1998. Aristotelian Spatial Dynamics in the Age of Geographic Information Systems: Spatial and Temporal Reasoning in Geographic Information Systems, Max. J. Egenhofer, Reginald G. Goliedge, New York Oxford, Oxford University Press, pp. 109-118.

Armenakis, C., 1994. Estimation and organization of spatio-temporal data. Proceedings of the Canadian Conference on GIS.

Gehani, N. H., Jagadish, H. V. and Shmueli, O., 1992a. Composite event specification in active databases: model & implementation. *Proceedings of 18th VLDB Conference,* Vancouver, British Columbia, Canada, pp. 327-338.

Gehani, N. H., Jagadish, H. V. and Shmueli, O., 1992b. Event specification in an active object--oriented database. *Intl. Conf. on Management of Data (SIGMOD)*, San Diego, California, pp. 81--90.

Langran, G., 1992. Time in Geographic Information Systems. Taylor & Francis.

Langran, G., 1993. Issues of implementing a spatiotemporal system. *International Journal of Geographical Information Systems*, 7 (4), pp. 305-314.

Hasan, M. Z., 1996. The Management of Data, Event, and Information Presentation for Network Management (A thesis presented to the University of Waterloo in fulfillment of the thesis requirement for the degree of Doctor of Philosophy in Computer Science Waterloo, Ontario, Canada).

Hornsby, K. and Egenhofer, M. J., 2000. Identity-Based Change: A Foundation for Spatio-Temporal Knowledge Representation. *International Journal of Geographical Information Science,* 14 (3), pp. 207-224.

Hornsby, K., and Egenhofer, M. J., 2000. Identity-Based Change: A Foundation for Spatio-Temporal Knowledge Representation. *International Journal of Geographical Information Science*, 14 (3), pp. 207-224.

LIN Guangfa, FENG Xue-zhi, WANG Lei, DU Jin-kang, 2002. An Event-centric Object Oriented Spatiao-temporal Data Model. *ACTA GEODAETIA et CARTOGRAPHIC SINCA*, 31(1), pp. 71-76 (In Chinese).

Open GIS Consortium, 2000. The OpenGIS™ Abstract Specification,Topic 1: Feature Geometry (ISO 19107 Spatial Schema), Version 5, Edited by Dr. John R. Herring, http://www.opengis.net/

Peuquet, D. J. and Duan, N., 1995. An event-based spatiotemporal data modal (ESTDM) for temporal analysis of geographical data. *International Journal of Geographical Information System, 9(1),* pp. 7-24.

Raza, A. and Kainz. W., 2000. Designing operators for an object–oriented spatio-temporal data model. *The International Archives of Photogrammetry and Remote Sensing*, Amsterdam, Vol. XXXIII, Part B4, pp. 863-870.

Raza, A., 2001. *Object-Oriented Temporal GIS for Urban Applications*. ITC. Publication.

SHU Hong. Gold, C. and CHEN Jun. 2000. Various Events Involved in Spatio-temporal Databases. *International Archives of Photogrammetry and Remote Sensing,* Amsterdam, Netherlands, *Vol. XXXIII*, Part B4, pp. 971-978.

Tang Xinming and Kainz, W., 2001. The Identification of Spatial Change Processes based on Set-oriented Space and Topological Space. *Proceeding of the 20th international Cartographic Conference (ICC2001)*, Beijing, China, pp. 2718-2732.

Teisseire, M., Poncelet, P. and Cicchetti, R., 1994. Towards Event-Driven Modeling for Database Design. *Proceedings of the 20th VLDB Conference,* Santiago, Chile, pp. 285-296.

Worboys, M. F., 1995. GIS: *A Computing Perspective*. Taylor Francis.

XU Ke, WU Jian-ping, FAN Xiao-bo, 2000. Design and Implementation of Border Gateway Protocol BGP-4 Based on Event-Driven Programming. *Journal of Software*, 11(11), pp .1516-1521(In Chinese).