Mathematical and Computer Modelling 51 (2010) 1343–1350

Contents lists available at ScienceDirect

Mathematical and Computer Modelling

journal homepage: www.elsevier.com/locate/mcm

A event-based change detection method of cadastral database incremental updating

Y.T. Fan, J.Y. Yang, C. Zhang*, D.H. Zhu

College of Information and Electrical Engineering, China Agricultural University, 17 Qinghua East Road, 100083, PR China

ARTICLE INFO

Keywords:
Incremental updating
Change detection
Incremental information
Changing information
Event information
Cadastral database

ABSTRACT

Event information reflects reasons for cadastral entities changes, and constitutes incremental information together with changing information. However, the existing change detection methods of incremental updating haven't realized the event information detection so far. To address this issue, taking parcels as an example, a new change detection method including event semantics is proposed and used in cadastral database incremental updating. In the method, parcel event knowledge rule database is established through selecting the three factors *inheritance relationship*, *topology relationship* and *attribute relationship* as prerequisites. On the basis of detecting changing information, the event information is deduced by calculating different values of the above factors according to the established parcel event knowledge rules. A prototype system is designed and realized, and its experimental results show that the method can accurately deduce the changing information of parcels and their corresponding event information. In addition, the detection method also provides a solution for realizing the automation of cadastral database incremental updating.

1. Introduction

In order to avoid low efficiency, high data errors rate and other problems caused by artificial interactional operation, the automation of cadastral database incremental updating is gradually becoming a hot topic of research in the cadastral area. The access to incremental information is the focus of the whole incremental updating process because incremental information contains not only changing information describing new cadastral entities, but also event information reflecting reasons for cadastral entities changes and deciding the subsequent updating operations [1,2]. Therefore, the automatic access to incremental information is the key to realizing the automation of incremental updating. To realize the automation, scholars have put forward many solutions. The two most typical updating processing approaches of realizing the automation are the one based on local topological linkage, and the one based on change detection.

The updating processing approach based on local topological linkage is to introduce actively maintaining functions based on topology relationship in the editing process of present data and respectively design automatic updating processes based on local topological linkage for different types of cadastral events so as to reduce the human–computer interaction operation in the process of processing changing information [3–7]. The approach has better realized automatic processing of changing information and maintained the data consistency but the process is based on the premise that people determine event information, in other words, operators need to manually select event types before executing the automatic processing of changing information. Thus, the processing approach has not completely solved the problem of the automatic access to incremental information and can be regarded as a semi-automatic updating approach.

The updating processing approach based on change detection is to make spatial overlay of updating data and status quo data in the corresponding field for extracting change information according to snapshot updating data in the local field

* Corresponding author.
E-mail address: zhangchao_bj@163.com (C. Zhang).

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doi:10.1016/j.mcm.2009.11.007

Table 1
The relation between inheritance relationship and parcel events.

Types of inheritance relationship	Types of event
$1:1$	Boundary adjustment, attribute change, no change
$1:N$	Segmentation
$N:1$	Mergence
$N:N$	Boundary adjustment, complex change
$M:N$	Complex change

and determine different change types of cadastral entities for updating by using different processing strategies [8–11]. In the processing approach, both changing information and event information can be automatically obtained through change detection, which is a fully automatic updating approach. However, up to now, the research on the approach has not been deep enough and only limited to the information extraction stage. Based on this, the issue of making the event information detection has become the bottleneck of realizing automatic updating. Therefore, this paper, taking parcels as an example, designs a change detection method of event-based cadastral database incremental updating. The method, selecting *inheritance relationship*, *topology relationship* and *attribute relationship* three factors as prerequisites, establishes parcel event knowledge rule database, deduces types of changing events after obtaining changing information according to the established knowledge rules and finally realizes the event information detection.

The paper is organized as follows. In Section 2, based on the above three factors, we analyze characteristics of different cadastral events and establish the cadastral change event knowledge rule database; in Section 3, we introduce the method of obtaining changing information (the spatio-temporal changing binary relationship) and describe the whole change detection processes; in Section 4, some experimental results by the prototype system are presented; in Section 5, the most relevant conclusions are summarized.

2. Cadastral change event knowledge rule database

Changes of cadastral entities are often caused by corresponding events, the generation of entities, changes of their states and the disappearance of entities are triggered by specific events. According to the different changes caused by events, events can be classified into two types: one causing spatial characteristic changes and the other causing attribute characteristic changes. The former can also be classified into newly added event, extinction event, segmentation event, mergence event, boundary adjustment event, complex change event and so on. The latter mainly refers to changes of obligees, used land attribute, functions and so on, but the geometric position does not change. Cadastral changes, taking parcels as the focus, which possess ‘blanket’ characteristic, therefore, the events causing parcel changes mainly include five types: segmentation event, mergence event, boundary adjustment event, complex change event and attribute change event [3,12].

Based on parcel change characteristics before and after events, this paper selects *inheritance relationship*, *topology relationship* and *attribute relationship*, three factors as prerequisites, and establishes parcel event knowledge rule database, among which inheritance relationship is regarded as the main prerequisite, the other two as assistant prerequisites. When the main prerequisite cannot determine events types, assistant ones are needed. In addition, the event knowledge rule database will provide evidence for change detection of subsequent event information.

2.1. Inheritance relationship

In the study, inheritance relationship is used to describe the number ratio of parcels with genetic relationship before and after change. Considering various circumstances, the corresponding relations between inheritance relationship and parcel events have been obtained and shown in Table 1. Among them, the unique corresponding relations between some inheritance relationships and events exist, such as $1:N$ corresponding segmentation event, $N:1$ corresponding mergence event and $M:N$ corresponding complex change event. However, $1:1$ and $N:N$ two typical inheritance relationships cannot only determine event types.

2.2. Topology relationship

Topology relationship reflects invariants in the spatial continuous variation and is one of the most important spatial relationships including disjoint, meet, intersection, inclusion, overlap and so on. As for those events that cannot be determined through the inheritance relationship, the paper will add topology relationship into the knowledge rules as a prerequisite to support the deduction of results. The following will make further discussion on $1:1$ and $N:N$ two typical inheritance relationships, respectively.

2.2.1. $1:1$ inheritance relationship

The events to which the $1:1$ inheritance relationship corresponds may be boundary adjustment event, attribute change event or unchanged event. The boundary adjustment event refers to the addition or deletion of boundary points. Attribute

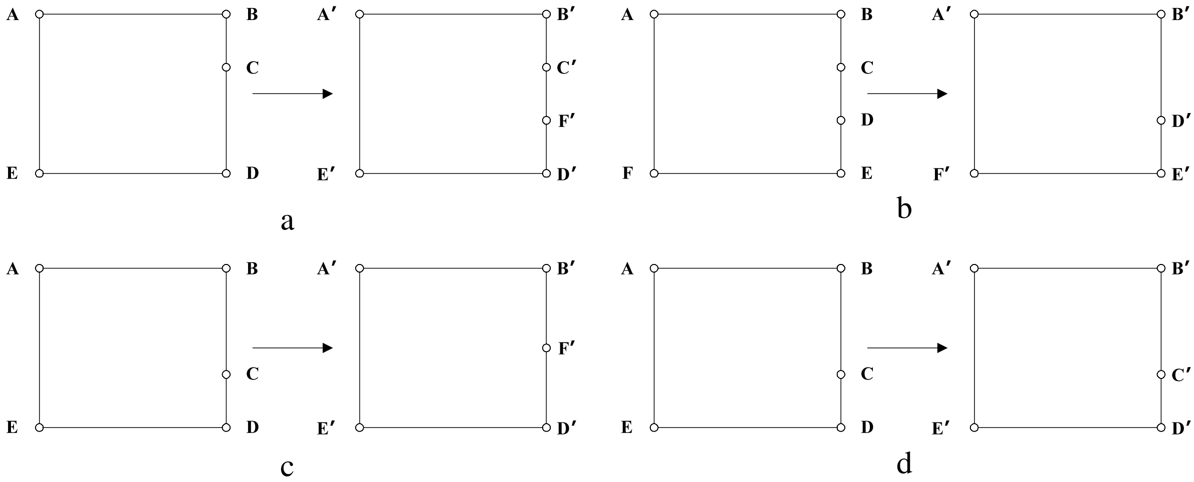

Fig. 1. The topology relationship between boundary points of relevant parcels with 1 : 1 inheritance relationship.

change and unchanged events cannot affect spatial characteristic changes of parcels, thus the topology relationship between boundary points of parcel intersection before and after changes do not change and is regarded as equality relationship. On the contrary, as for boundary adjustment event, not every boundary point before and after changes has its own equality relationship boundary one. Four cases will be shown in Fig. 1.

(1) In the case shown in Fig. 1(a), the remaining boundary points have their own boundary ones with equality relationship except the boundary point $\{F'\}$ after change. This case can be regarded as newly added boundary point in boundary adjustment event.

(2) In the case shown in Fig. 1(b), the remaining boundary points have their own ones with equality relationship except the boundary point $\{C\}$ before change. This case is regarded as deletion boundary point in boundary adjustment event.

(3) In the case shown in Fig. 1(c), the remaining boundary points have their own ones with equality relationship except the boundary point $\{F'\}$ after change and the point $\{C\}$ before change. Such case can be regarded as the co-existence of newly added boundary point and deletion boundary point in boundary adjustment events.

(4) In the case shown in Fig. 1(d), all boundary points have their own ones with equality relationship. In such a case, boundary adjustment does not happen.

To sum up, in order to further distinguish three types of events with 1 : 1 inheritance relationship, it is necessary to determine the topology relationship between boundary points of parcel intersection before and after changes. Its determinant condition can be defined as for every boundary point before and after changes, whether its corresponding one with equality relationship exists in the boundary ones after and before changes'. When the condition is not satisfied, it is a boundary adjustment event; or else, it is an attribute change event or unchanged event.

2.2.2. $N : N$ inheritance relationship

The events to which $N : N$ inheritance relationship corresponds are boundary adjustment or complex change. The boundary adjustment event refers to moving public boundary lines (or points). As for boundary adjustment event, parcels in which changes happen have public boundary line (or point) and boundary adjustment event only refers to moving those public boundary lines (or points) and the mutual topology relationships between those parcels in which changes happen are unchanged before and after change. However, as for complex change events, the mutual topology relationships between those parcels in which changes happen will be changed because segmentation event and mergence event happen together. In the paper, the researcher, taking Fig. 2 as an example, illustrates how to use topology relationship to distinguish event types with $N : N$ inheritance relationship.

(1) In the case shown in Fig. 2(a), parcels $\{A, B, C\}$ meet in the public boundary point P before change, parcels $\{A', B', C'\}$ still meet in the public boundary point P' after change and their mutual topology relationships before and after change remain unchanged. In such a case, it is regarded as boundary adjustment event.

(2) In the case shown in Fig. 2(b), parcels $\{A, B, C\}$ before change meet in the public boundary point P and parcels $\{A', B', C'\}$ after change still meet in the public boundary point P', but parcels $\{A, C\}$ meeting in the point are changed into parcels $\{A', C'\}$ meeting in the line, that is, topology relationship of the parcels are changed. In such a case, it is regarded as complex change event.

(3) In the case shown in Fig. 2(c), neither parcels $\{A, B, C\}$ before change nor parcels $\{A', B', C'\}$ after change meet in the public boundary line (or point), although their mutual topology relationships remain unchanged before and after change. In such a case, it is regarded as complex change events.

(4) In the case shown in Fig. 2(d), parcels $\{A, B, C\}$ before change do not meet in the public point, but parcels $\{A', B', C'\}$ after change meet in the public boundary point P'. Besides, disjointing parcels $\{A, C\}$ are changed into parcels $\{A', C'\}$ meeting in the point and their topology relationships changed. In such a case, it is regarded as complex change event.

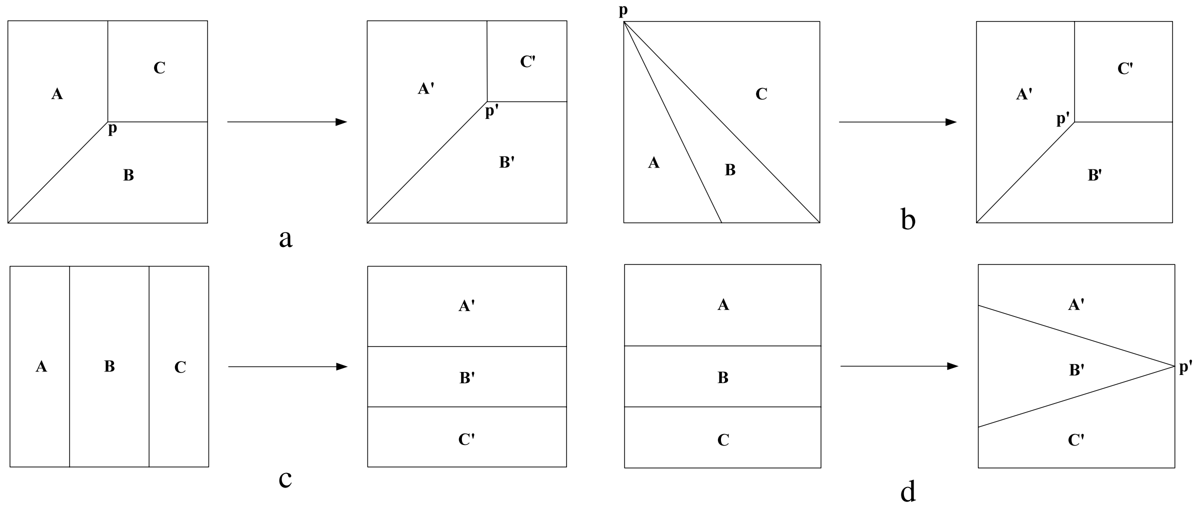

Fig. 2. Comparison between boundary adjustment events and complex change events.

Table 2
Parcel event knowledge rules.

Premise			Conclusion (types of events)
Inheritance relationship	Topology relationship	Attribute relationship	
	Change	\	Boundary adjustment
1 : 1	No change	Change	Attribute change
	No change	No change	Unchanged
1 : N	\	\	Segmentation
N : 1	\	\	Mergence
N : N	No change	\	Boundary adjustment
	Change	\	Complex change
M : N	\	\	Complex change

Note: '\' indicating that there is no need to determine the these factors.

To sum up, when topology relationship is used as the prerequisite to distinguish events with N : N inheritance relationship with others, two conditions are needed to be satisfied.

(1) The topology relationships among all parcels on which change have influence: calculate topology relationships among all parcels before and after changes respectively and determine whether they meet in the public boundary line (or point).

(2) The mutual topology relationships between parcels on which change have influence: calculate their mutual topology relationships between parcels before and after changes respectively and determine whether their all topology relationships remain unchanged.

Values of the above two conditions both can be 'yes' or 'no', therefore, in all, there are four kinds of situations: (yes, yes) indicating boundary adjustment event in Fig. 2(a) ; (yes, no) indicating complex change event in Fig. 2(b); (no, yes) indicating complex change event in Fig. 2(c); (no, no) indicating complex change event in Fig. 2(d). The further analysis shows: when the value of the first condition is 'no', it can be a sufficient condition to deduce complex change event so as not to verify the second condition; while when the value of the first condition is 'yes', the second condition must be verified. From the above analysis, it is shown that using topology relationship can uniquely determine types of events with N : N inheritance relationship with others.

2.3. Attribute relationship

The above analysis indicates that, as for events with 1 : 1 inheritance relationship, using topology relationship can distinguish boundary adjustment event, but still cannot distinguish attribute event and unchanged event. Therefore, the researcher adds attribute relationship into prerequisites to determine attribute changes when spatial characteristics are unchanged. In fact, the process of determining attribute relationship is relatively simple. As long as travel attributes of parcels before and after change and make attributes comparison one by one, the conclusion can be obtained. For unchanged event and attribute change event to which 1 : 1 inheritance relationship correspond, introducing attribute relationship can distinguish them.

In conclusion, taking *inheritance relationship*, *topology relationship*, *attribute relationship* three factors as the prerequisite and adopting different values can deduce the types of all parcels. The specific knowledge rules will be shown in Table 2.

3. The change detection method

In the paper, the researchers classify the change detection of parcels into two kinds: changing information detection and event information detection, between which the latter is based on the former. In the study, the changing information detection is used to not only determine new parcels after changes through spatial overlay operation, but also obtain spatio-temporal changing binary relationships, that is, to determine the parcel sets with genetic relationship before and after changes; while the event information detection is to use parcel event knowledge rules to deduce event types after calculating values of three factors *inheritance relationship*, *topology relationship*, *attribute relationship*.

3.1. The spatio-temporal changing binary relationship

Definition 1. The two sets *PU* and *PE* represent the parcel updating data set and the parcel status quo data set respectively, their spatial areas are the same, and *pu* and *pe* represent objects of the parcels in the two sets, respectively. Thus, the set *PU* and the set *PE*, respectively, are expressed as formula (1) and formula (2), and their relationship as formula (3):

$$PU = \{pu|pu \in PU\} \tag{1}$$

$$PE = \{pe|pe \in PE\} \tag{2}$$

$$PU_s = PE_s. \tag{3}$$

Definition 2. The power sets of set *PU* and set *PE* are expressed as formula (4) and formula (5) respectively:

$$P(PU) = \left\{X_i|X_i \subseteq PU, 1 \leq i \leq 2^{|PU|}\right\} \tag{4}$$

$$P(PE) = \left\{Y_j|Y_j \subseteq PE, 1 \leq j \leq 2^{|PE|}\right\}. \tag{5}$$

Definition 3. The Cartesian product *F* of the power sets of *PU* and *PE* is binary relations, and is expressed as formula (6):

$$F = P(PU) \times P(PE) = \{\langle X, Y\rangle|X \in P(PU) \wedge Y \in P(PE)\}. \tag{6}$$

Definition 4. A pair of binary relations $\langle X, Y\rangle$ in the Cartesian product F, x is an element of the power set X and y is an element of the power set Y. For all elements x and y, if only '$x = X$ & $y = Y$', then the condition '$x = y$' is satisfied. In such a case, the binary relation $\langle X, Y\rangle$ is the spatio-temporal changing binary relationship.

Definition 5. The restrictions of $P(PU)$ and $P(PE)$ on F are respectively expressed as formula (7) and formula (8):

$$F \uparrow P(PU) = \{\langle X, Y\rangle|\langle X, Y\rangle \in F \wedge X \in P(PU)\} \tag{7}$$

$$F \uparrow P(PE) = \{\langle X, Y\rangle|\langle X, Y\rangle \in F \wedge Y \in P(PE)\}. \tag{8}$$

Based on the above definitions and the spatial intersection characteristics of parcels with genetic relationship before and after changes [13–15], the following three theorems can be deduced.

Theorem 1. *For any $X_i \in P(PU)$, under the restriction of F on X, $F \uparrow X_i = \{\langle X, Y\rangle|\langle X, Y\rangle \in F \wedge X = X_i\}$, at least a pair of binary relationship $\langle X_i, Y_j\rangle$ is satisfied $X_i \subseteq Y_j$.*

Theorem 2. *For any $Y_j \in P(PE)$, under the restriction of F on Y, at least a pair of binary relationship $\langle X_i, Y_j\rangle$ is satisfied $Y_j \subseteq X_i$.*

Theorem 3. *In the set F, at least a pair of spatio-temporal changing binary relationship $\langle X_i, Y_j\rangle$ can be found.*

Based on the above definitions and theorems, the iterative process of a pair of spatio-temporal changing binary relationship will be illustrated below.

(1) Iterative initial value: expressed as formula (9).

$$p_0 = \{p|p \in PU\}. \tag{9}$$

(2) Iterative equation: according to Theorems 1 and 2, each p_{i-1} can find a p_i, and then $p_{i-1} \subseteq p_i$ is satisfied. It is expressed as formula (10).

$$p_i = \begin{cases} p_{i-1} \cap PE & i \setminus 2 \neq 0 \\ P_{i-1} \cap PU & i \setminus 2 = 0. \end{cases} \tag{10}$$

(3) Iterative control conditions: according to Theorem 3, at least a pair of $\langle p_{i-1}, p_i\rangle$ can satisfy iterative control conditions, which is expressed as formula (11).

$$p_i - p_{i-1} = \phi. \tag{11}$$

If iterative control conditions are satisfied, go to Step (4); otherwise return to Step (2).

(4) Iterative result: $\langle p_{i-1}, p_i\rangle$ is a spatio-temporal changing binary relationship.

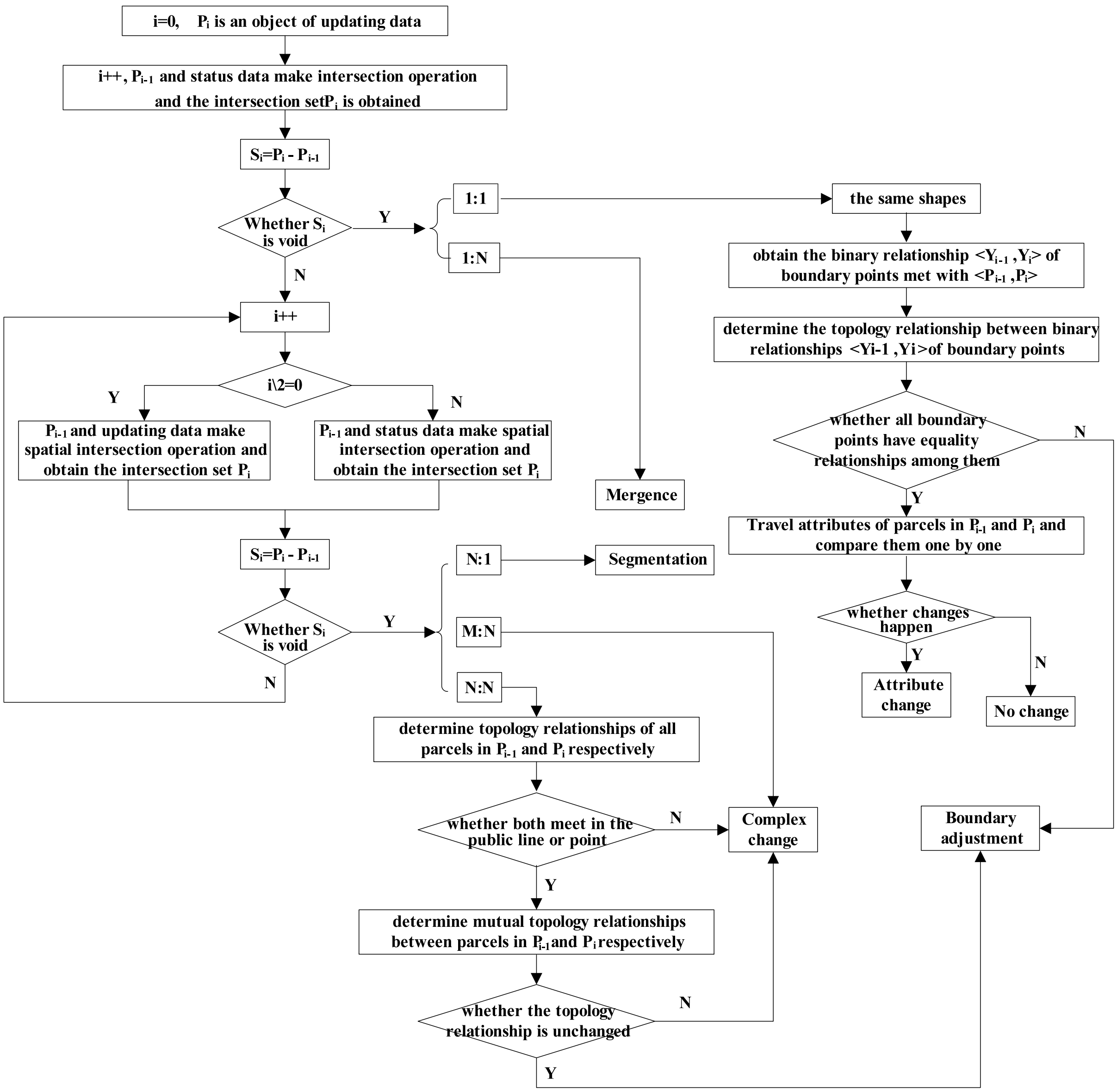

Fig. 3. The change detection process of event-based cadastral incremental updating.

3.2. The overall change detection process

In conclusion, the change detection method, taking parcels as an example, is composed of obtaining the spatio-temporal changing binary relationship and determining event types. The specific detection process will be shown in Fig. 3.

4. Case study

Based on the above proposed change detection method including event semantics, researchers also design and develop a prototype system of cadastral changes. The prototype system not only can be used to detect spatio-temporal changing binary relationship before and after change, but also deduce all types of events included in the cadastral event knowledge rules.

Taking the parcel change processes shown in Fig. 4 as an example, the paper provides related test results of the prototype system. As shown in Fig. 4, four types of events happen from T0 to T1: (a) boundary adjustment, that is, the public boundary point of parcels {3, 4, 7, 8} is moved; (b) complex change, that is, parcels {9, 10, 13, 14} are changed into the ones {17, 18, 19, 20, 21}; (c) mergence, that is, parcels {5, 6} are merged into the parcel {22}; (d) attribute change, that is parcel {1}. From T1 to T2, three types of events happen: (a) segmentation, that is, the parcel {22} is divided into the parcels {23, 24}; (b) boundary adjustment, that is, the public boundary line of parcels {11, 12} is moved and new boundary points

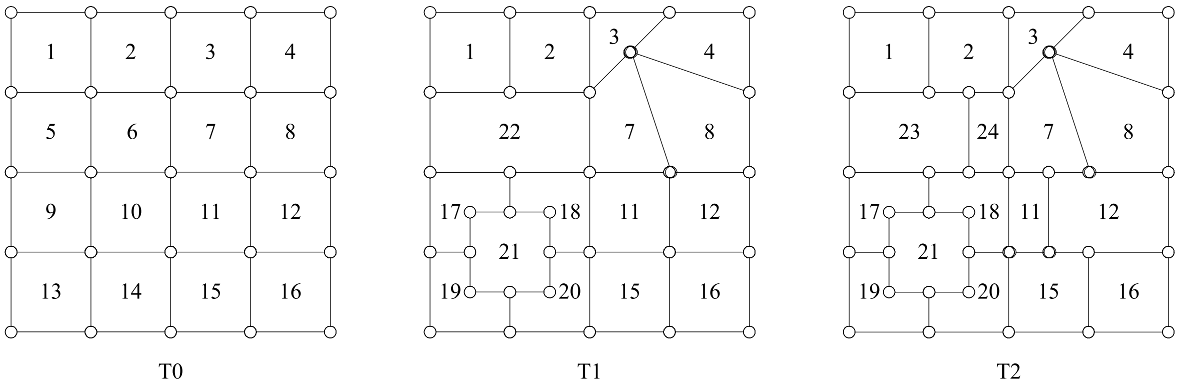

Fig. 4. Sample of parcel changes.

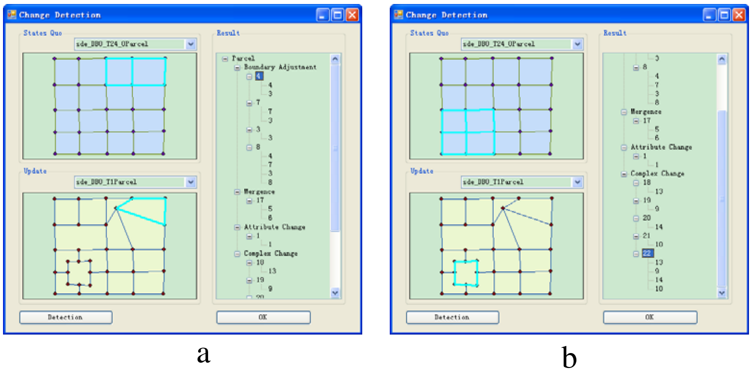

Fig. 5. Examples of parcel change detection at T1: (a) moving public boundary point in boundary adjustment; (b) complex change.

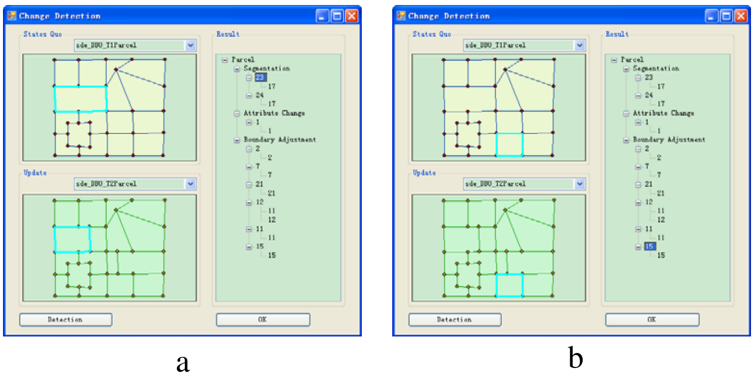

Fig. 6. Examples of parcel change detection at T2: (a) segmentation; (b) adding new boundary point in boundary adjustment.

appear in parcels {2, 7, 15, 18}; (c) attribute change, that is parcel {1}. Input the above parcel snapshots at T0, T1 and T2 into the prototype experimental system, and the detection results at T1 and T2 can be obtained respectively. Figs. 5 and 6 provide some detection results at T1 and T2 respectively.

5. Conclusion

(1) Based on characteristics of parcel changes before and after various types of events happen, the paper takes three factors *inheritance relationship*, *topology relationship* and *attribute relationship* as prerequisites and establishes the parcel event knowledge rule database. Moreover, after detecting spatio-temporal changing binary relationships before and after changes, the cadastral event information is deduced by calculating different values of the above three factors in binary relations according to the established parcel event knowledge rules, the experimental results shows that the above research idea is feasible.

(2) Realizing the automation of cadastral database incremental updating plays an important role in improving the efficiency of updating and maintaining the quality of spatial data, the change detection method proposed in the paper has organically combined changing information with event information and has realized automatic detection of the above two types of information, thus it provides a solution for realizing the automation of cadastral database incremental updating.

It should be noted that, during the updating processes of the cadastral database, parcel changes can cause changes to related boundary lines and points. For maintaining the consistency of data before and after changes, further research on change detection of boundary lines and points should be carried out.

Acknowledgments

This research is funded by the National High Technology Research and Development Program of China titled The technique of the patch-oriented culture type precision.

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