EVENT-DRIVEN INCREMENTAL UPDATING OF CADASTRAL SPATIAL DATABASE CONSIDERING TOPOLOGICAL INTEGRITY

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KEY WORDS: Incremental Updating; Cadastral Database; Topological Relationship; Consistency; Change; Updating Operators.

ABSTRACT:

In order to update the cadastral database and maintain it's topological consistency automatically (or semi-automatically) during the updating process, an event-driven incremental updating method of cadastral database considering topological integrity is proposed in this paper. In this method, five kinds of cadastral spatial change is divided to five kinds of basic events: node-moving, union, splitting, rectification, and reallocation; The states (including the entities and topology) involved in union, splitting and rectification are analyzed when the parcel including the parcel with one hole; a set of spatial change identification rules used to determine the spatial changes of the entities involved in cadastral event are developed based on the topological consistency rules, the semantic of the entities and the topological relationship between the involved entities before and after change, then the changes of each entity involved in all cadastral spatial change events can be inferred according to these rules; a set of updating operators mapping the spatial changes of each entity to the corresponding identity-based changes of single spatial object are designed and implemented; in order to assure the updating operations can be completely implemented at the correct sequence, the topological integrity can be maintained well, the formal representation of updating process are present. Thus when any cadastral spatial change event occur and submission, an updating program can be triggered automatically to update the cadastral database and maintain the integrity of the spatial data, The approach was implemented using VC^{++} in Oracle10 Spatial and MapX platform, the algorithms are checked by real and simulation data.

1 INTRODUCTION

A cadastral database is normally a parcel based, and up-to-date land information database, which usually includes a geometric description of land parcels (such as location, size) linked to other records describing the nature of the interests (e.g. rights, restrictions and responsibilities) [Stoter & Oosterom, 2006].

Parcels may not overlap and gaps may not occur (forming a planar partition). In order to ensure completeness and consistency, the nodes, edges and faces of land parcels should meet these topological integrity constraints. During the creation of such a spatial cadastral database, a global strategy is adopted to build the topological relationship between parcel objects. And a set of checking and modification processes is performed to assure the consistency.

The situation is different while updating the cadastral spatial database! France cadastre administration concluded a set of authorized cadastral geographical changes: division, merge, rectification, extraction, passage, Reallocation and Expropriation [Claramunt & Libourel, 1999]. All of these cadastral spatial changes just involve one to several parcel objects and their topology, it is noted that about 50% of the update activity is associated with updates to one or two parcels [Effenberg & Williamson, 1996]. So the cadastral spatial change is local, only a few objects involved in a local area need to be updated a time. The global updating operation, which requires that all topological linkages be re-created by detecting all line intersections and then constructing the whole boundaries and polygons, is expensive and unnecessary. An appropriate updating operation should be performed in a local fashion.

Incremental updating methods now exist for atemporal cadastral information system [Langran, 1992]; Cadastral changes (including changes caused by legal actions and spatial changes) happen almost every day in a big city by the daily business. Since the currency of information of land supply is critical for land market decision, the cadastral database update incrementally now in a temporal method by deleting, overwriting the outdated information or store it as a snapshot. “In practice, updating ranges from daily to weekly, monthly, quarterly and even annually, depending on the type of data and the organization of the government” [Vrana, 1989]. Incremental updating is equally well suited to spatial-temporal cadastral database, the difference is that Incremental updating should supersede the out-dated information with new in current view, and still store it in the database. So the updating process just affect several local records and cause the database change gradually over time. All of these are different from the traditional update in an atemporal method or periodic (or batch) model.

Since cadastral updates are caused by the daily business of permits processing, the daily business can be defined as cadastral event causing parcel objects’ change (including spatial and semantic changes, our study focus on spatial change in this paper). Different events cause to different spatial changes, different spatial changes cause to different updating operation. Now in the digital business context, if the updating operation can be triggered by cadastral spatial change business (named as cadastral spatial change event in this paper), the updating operation can be performed daily even hourly or minutely, the currency of information can be achieved to the best. At the same time, introducing cadastral spatial change event can help to analyze the spatial change of the involved objects and help the updating operation. So we study the Event-driven Incremental Updating of Cadastral Spatial database in this paper.

There is a set of topological integrity constraints among cadastral objects, the integrity constraints should be maintained after cadastral updating. The updating operations carried out manually (or interactively) always imply the risk of disturbing the well-defined data consistency. So there is a need to develop an automatic (or semi-automatic) local updating and consistency maintenance method for cadastral database. So in this paper, an event–driven incremental updating of cadastral database considering topological integrity is presented to automate (or semi-automate) the updating process.

Efforts on cadastral system and incremental updating have been done by researchers in recent years. Astle et al. described a standardized cadastral domain model to allow the physical sharing of cadastral data among many implementations [Astle et al., 2006]; The management and query methods of spatio-temporal data on a very large cadastral database have been described [Chen & Jiang, 2000; Oosterom & lemmen, 2001; Oosterom et al., 2002]; The processes to fulfil the cadastral tasks and their formalization have been described [Navratil & Frank, 2004]; Steffen and Frank described a formal model of correctness in a cadastre [Steffen and Frank, 2002]; the topological integrity constraints have been described [Laurini &Thopson,1999]; the issues and methods of 3D Cadastre have been discussed [Stoter & Oosterom , 2006]. Issues of incremental updating have been discussed in detail [Langran, 1993; Cooper & Peled, 2001]; Vrana described the incremental nature of cadastral updates [Vrana, 1989]; Effenberg and Williamson described of the data flows of incremental cadastral update in Australia [Effenberg and Williamson, 1996]; Gombosi et al. proposed an algorithm for determining differences between two sets of polygons using cadastre data sets as experiment data [Gombosi et al., 2003]. Karnes represented a strategy of cadastral location updating in date-forward order, which allows that when an object' s location is updated, it sends a message to objects for which it is a spatial reference to update their own locations [Karnes, 2004].

Following this introduction is the issues and the strategy of Event-driven Incremental Updating of Cadastral Database considering topological integrity. The entities and topology involved in the cadastral events will be proposed in section 3. In section 4, the spatial change identification method of single object will be given. The updating operations facing single objects and the formal representation of the updating process will be presented in section 5. The experiment and conclusion are given in section 6.

2 THE STRATEGY OF EVENT-DRIVEN INCREMENTAL UPDATING OF CADASTRAL DATABASE CONSIDERING TOPOLOGICAL INTEGRITY

Incremental updating means that the master spatial data set is updated when any geometric or semantic changes occur, the changes are recorded, the updating process can be tracked (or the different versions can be tracked), and the updates are provided successively to users [Langran, 1993; Cooper & Peled, 2001]. The incremental updating of STDB involves 3 stages as follows: ① the collection of changed information; ② the changed information transfer to the core database, and incremental update the core database; ③ updates transferring to the user and incremental updating of user database [Zhou, et. al, 2004]. Ideally, the collection of changed information can be driven by the events, the transfer of changed information can be continuous (wirelessly), and change-only; the core database should be spatial temporal database referencing in time of both occurrence and database; the update transferring to the user also should be change-only information with metadata.

In the analogue era, cadastral update is incremental, local with the history data holding by hard-copy. In cadastral system, the occurrence of any changes (including geometric or semantic) must be confirmed by the government's ***"change- register business"*** or giving the owner with ***"Land-use certificate"*** and the certificate are preserved as hard-copy. In the digital era, Incremental updating methods now exist for atemporal cadastral information system [Langran, 1992], by deleting, overwriting the outdated information or store it as a snapshot. Incremental updating is equally well suited to spatial-temporal cadastral database, the difference is that incremental updating should supersede the out-dated information with new in current view, and still store it in the database and protecting the integrity of all the involved objects to improve the efficiency of the storage and spatio-temporal analysis, While the updating and maintenance process is more difficult than the former two methods.

Now, let us take an example (as Fig.1 shows) to illustrate the nature of the incremental updating of cadastral spatial database. In Fig.1, the node M moves to N, which leads to parcel A, B, C change to parcel A′, B′, C′; bound line a, b, c change to e, d, f. Now the incremental updating of spatio-temporal database is as follows: ① the changed information (including the change area and the coordinate of N) is submit to the database manager; ②the database manager extract the current data of the corresponding area before change to the workspace, choose the moving node M and input the coordinate of N; ③ the database manager rebuild the new objects A′, B′, C′, e, d, f, create these records in the spatial database, delete the out-dated objects A, B, C, a, b, c and M by defining the dead-time of these objects interactively and maintain the integrity of these objects, all these operations should be performed in the workspace; ④ database manager submit these changes to the database.

From this example, we can conclude that the updating of cadastral database is local and incremental. Usually there are more than 10000, boundary lines and parcels in a big city, accordingly there are more than 10000 records in the spatial database, while one cadastral spatial change event usually just involve one to several points, boundary arcs and parcels. As Fig.1 shows, there are 17 points, 15 boundary arcs and 6 parcels, at least there are 38 records in the database. While just 1 point, 3 boundary arcs and 3 parcels involved in the node-moving event, and just 7 records need to update. So the updating is local and incremental. As there is a set of topological integrity constraints among cadastral objects at the same time, the integrity constraints should be maintained during the cadastral updating. They also can be used to determine the change type of the involved entities.

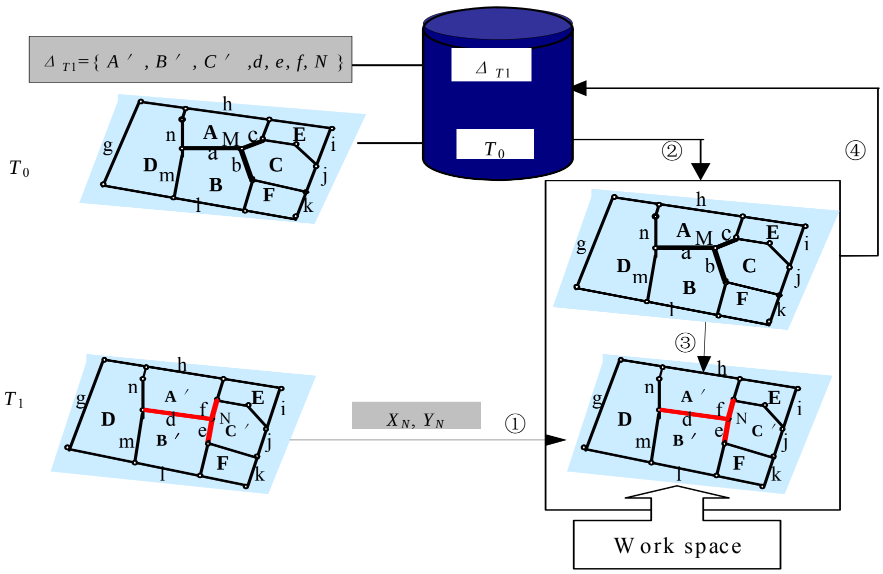


Fig.1 An example of the incremental updating of cadastral database

As each cadastral event produces different changes to the involved objects, causes to different updating operations, the local updating and maintenance operations should be designed and implemented based on the cadastral event. So there is a need to analyze (or conclude) the types of cadastral events and the spatial changes involved in them, to analyze the original change entities (such as M in Fig.1), linkage change entities (such as a, b, c, A, B, C in Fig.1) in each kind of spatial change; develop some basic operations (such as node-replacing, co-boundary′ deletion, etc) to build new entities (such as d, e, f, A′, B′, C′); The change types (such as appearance, disappearance, expansion and contraction, etc) of the involved entities should be determined based on the topological consistency rules with semantic constraints; corresponding operators (such as creation, deletion, spatial-modification, etc) should be designed and implement to realize the local updating of spatial database. The strategy of Event-driven Incremental Updating of Cadastral Database considering topological integrity is given in Fig.2.

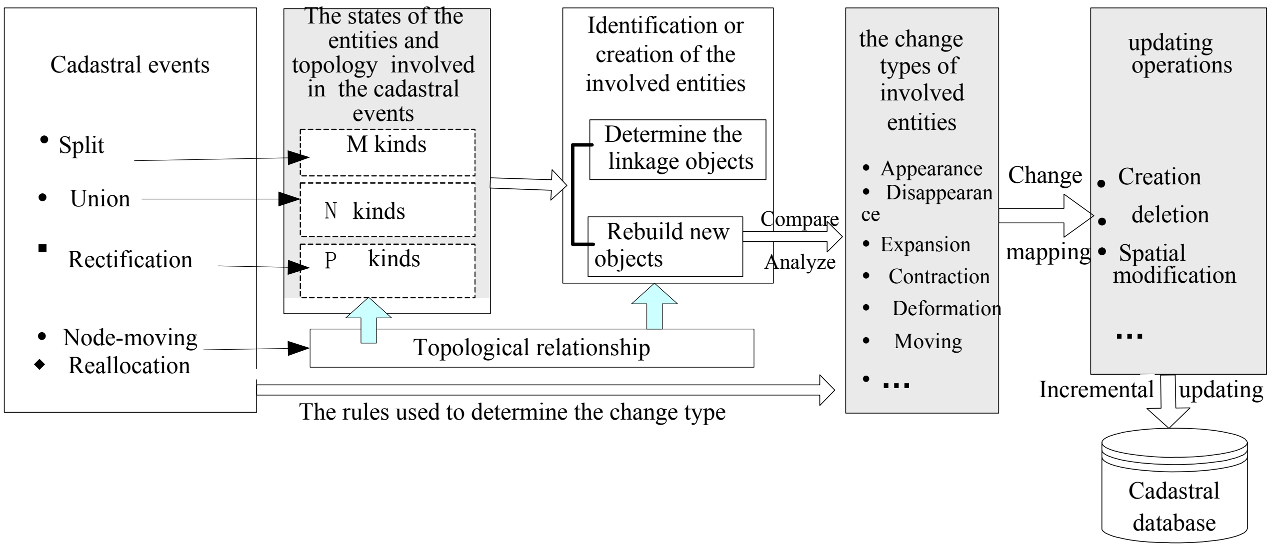


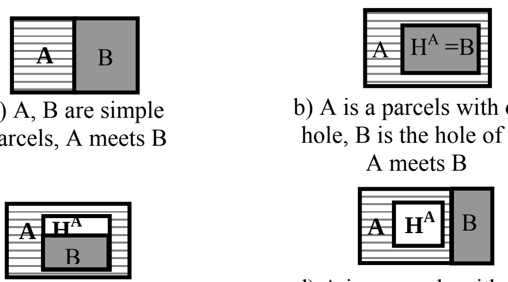
Fig. 2 The strategy of Event-driven Incremental Updating of Cadastral Database considering topological integrity

From the existing reference, it can be concluded that there are 5 kinds of basic cadastral spatial change events cause to topology change: node-moving, union (merge), split (division), rectification (modification of the common border) and reallocation [Claramunt &Thériault, 1995; Claramunt & Libourel, 1999], during the updating of these events, the topological integrity should be maintained. Through analyzing, we find that if the involved parcels are simple parcels, the involved entities and the topology between them before and after the event is well-known (such as node-moving, as Fig.1 shows), the spatial change types (such as appearance, disappearance, and so on) of each involved entity can be determined by the determination rules, the updating and maintenance operations can be driven by the cadastral event directly. While when the involved parcel includes a complex parcel (such as a parcel with one hole, or several holes, in this paper just the parcel with one hole is discussed), as the involved entities and the topology between them before and after event is unknown, the spatial change of each involved entity can't be determined, so the corresponding updating operation can't be done. So in this paper, at first we'll discuss the entities and the topology involved in each kinds of cadastral spatial change events (including before and after event). Then we'll develop a set of spatial change identification rules to determine the spatial change of each entity; then in order to automate (or semi-automate) the updating process, there should be a set of updating operators to transfer the entities′ change to the database. Further more, in order to assure the updating operations can be completely implement at correct sequence, and the topological integrity can be maintained during the updating, formal representation of this process is need.

3 THE ENTITIES AND TOPOLOGY INVOLVED IN THE CADASTRAL EVENTS

The entities and topology involved in each cadastral event will be analyzed in this section. As the parcels involved in node-moving are simple parcels, the entities and topology involved in it before and after change can be determined by the topological relationship to the moving-node, the state is clear, needn't analyzed; usually there are many entities involved in reallocation, the number of the original change entities is uncertain, the linkage change entities and new creating entities are difficult to be identified in advance, so the entities and topology involved in it are difficult to classified. So just the entities and topology involved in union, split and rectification will be analyzed in this section.

The changes involved in union, split and rectification usually include two parcels with meeting relations. Parcels usually include two basic cases: simple parcel and a parcel with one hole, there are two kinds of meeting relations: contiguity at the sides (arcs), or corners (vertices); the relations contiguity at corners usually are not involved in union, split and rectification; the relations contiguity at sides may include meeting at one side, two sides, three sides, et al. in theory. However we limit our study at the basic meeting relationship (contiguity at one side), as it is sufficient to general use. There are four kinds of basic meeting relations (as Fig.3 shows) at this level: a) A, B are simple parcels, A meets B; b) A is a parcels with one hole, B is the hole of A, A meets B; c) A is a parcels with one hole, B is a part of the A' hole, A meets B; d) A is a parcels with one hole, B is a simple parcel, A meets B at the exterior border [ZHOU, et al 2003]. So the subdivisions of cadastral events should be done based on these four kinds of meeting relations. The



a) A, B are simple parcels, A meets B

b) A is a parcels with one hole, B is the hole of A, A meets B

c) A is a parcels with one hole, B is a part of the A' hole, A meets B

d) A is a parcels with one hole, B is a simple parcel, A meets B at the exterior border

Fig3 4 kinds of meet relations between two

cadastral topological Relationship model based on Euler-number [ZHOU, et al., 2006] will be used to formalize the subdivisions, in which the shape of the parcel can be identified by its Euler-number, such as the Euler-number of simple parcel C is 1, denoted as Eul (C) =1; the Euler-number of a parcel with one hole C is 0, denoted as Eul (C) =0.

3.1 The Entities and Topology Involved in Union

In this paper, union denotes that two parcels A and B (A is adjacent to B at one side) unite to a parcel C. There are four kinds of adjacency relations between A and B (as Fig.3 shows), and the parcel C may be a simple parcel or a parcel with one hole. So there are eight possibilities from these combinations, as Fig.4 shows. In fact, not all of the eight possibilities exist in union. It is concluded that at least the states Fig.4-a, b, c and d exist in union at this level. The following propositions show that these four states are the only states that can occur at this level.

Proposition 1. It is assumed that H^C and H^A aren't NULL in Fig.4, then for union Fig.4-e, f, g and h cannot occur.

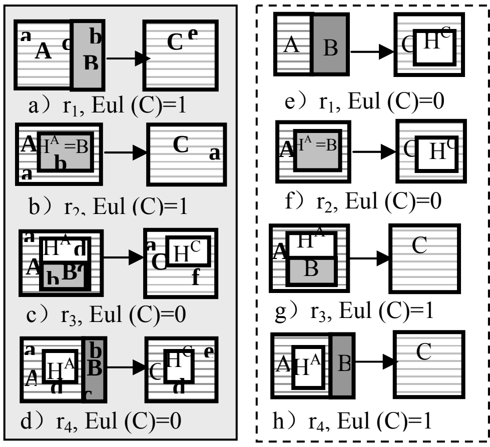


Fig.4 the entities and topology involved in union

Proof. It is an axiom that if region A and region B unite to region C, the area of A plus the area of B should be equal to the area of C. In Fig 4, as H^C and H^A aren't NULL, the cases of e, f, g and h can't meet this axiom, area (A) + area (B) ≠ area (C). Such as in Fig 4-e, f, area (C) = area (A) + area (B)- area (H^C); in Fig 4-g, h, area(C)= area (A) + area (B)+ area (H^A). This implies that all the area of A plus the area of B is not equal to the area of C in Fig 4-e, f, g and h, cannot occur.

In Fig.4, a) simple parcel A and B unite to a simple parcel C, the boundary of C is a∪b; b) A is a parcel with one hole, B is the hole of A, A and B unite to a simple parcel C, the boundary of C is a; c) A is a parcel with one hole, B is one part of the hole, A and B unite to C, C also is a parcel with one hole and it's boundary is a∪f; d) A is a parcel with one hole, B is a simple parcel which meets A at c, the exterior boundary of A, A and B unite to C, C also is a parcel with one hole and it's boundary is e∪d.

3.2 The Entities and Topology Involved in Split

In this paper, Split denotes the division of a parcel A into 2 parcels: B and C. The parcel A may be a simple parcel or a parcel with one hole. There also may be four kinds of adjacency relations between B and C, as Fig.5 shows. Thus there also may have eight possibilities from the combinations, as Fig.5 shows.

It is concluded that at least Fig.5- a, b, c, d and e exist in split at this level. The following propositions show that these five states are the only states that can occur at this level.

Proposition 2. It is assumed that D isn't NULL in Fig.5, then for split Fig.5-f, g and h cannot occur.

Proof. It is an axiom that if region A divides to region B and region C, the area of A should be equal to the area of B plus the area of C. In Fig 5, as D isn't NULL, the cases of f, g and h can't meet this axiom, area (A) ≠ area (B) + area(C). Such as in Fig 5-f, area (A) + area (D) = area (C) + area (B); in Fig 5-g, h, area (A)= area (B) + area (C)+ area (D). These imply that all the area of A is not equal to the area of B plus the area of C Fig.5-f, g and h, cannot occur.

In Fig.5, (a) A is a simple parcel, it is divided into 2 simple parcels: B and C; (b) A is a simple parcel, it is divided into two parcels: B and C, B is a parcel with one hole, C is the hole of B; (c) A is a parcel with one hole, it is divided into two parcels: B and C, B also is a parcel with one hole, C is a simple parcel, B meets C at its exterior border; (d) A is a parcel with one hole D, it is divided into two parcels: B and C, B and C are parcels each with one hole, the closure of C is the hole of B, D is the hole of C, the boundary of B is a∪c, the boundary of C is c∪b; (e) A is a parcel with one hole, it is divided into two parcels: B and C, B also is a parcel with one hole, C is a simple parcel, it is one part of B's hole, the boundary of B is a∪d∪c, the boundary of C is d∪e.

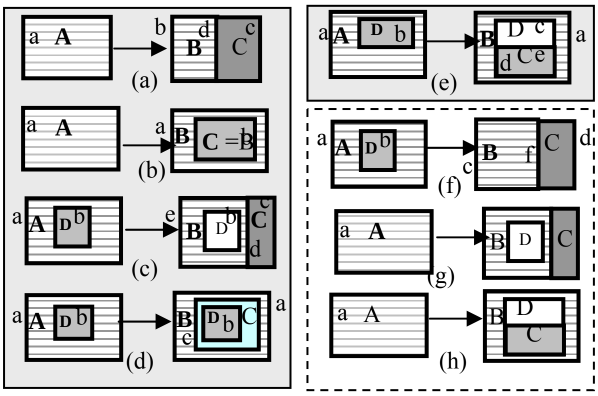


Fig. 5 the entities and topology involved in split

3.3 The Entities and Topology Involved In Rectification

The modification of the common border always occurs at two parcels with adjacency relations. It is assumed that the parcels before modification are A and B, after modification are A′ and B′. There are four meeting relations between A and B, A′ and B′ separately, as Fig.3 shows. So there are 16 possibilities from these combinations. By anatomising the possibilities, it is concluded that at least the subdivisions a, b, c, d, e, f, g and h exist in the modification of the common border at this level in Fig.6. The following propositions show that these eight states are the only states that can occur at this level.

Proposition 3. It is assumed that C isn't NULL in Fig.6, and then Fig.6-i, j, k, l, m, n, p and q cannot occur.

Proof. It is an axiom that if region A and region B after modification of their common border become to A′ and B′, the area of A plus the area of B should be equal to the area of A′ plus the area of B′, area (A) + area (B) = area (A′)+ area (B′). In Fig 6, as C isn't NULL, the cases of Fig.6-i, j, k, l, m, n, p and q don't meet this axiom, area (A) + area (B) ≠ area (A′)+ area (B′). Such as in Fig 6- i, j, p, q, area (A) + area (B) + area (C) = area (A′)+ area (B′); in Fig 6- k, l, m, n, area (A) + area (B) = area (A′)+ area (B′) + area (C). These imply that the subdivisions i, j, k, l, m, n, p and q (as Fig.6 shows), all the area of A plus the area of B is not equal to the area of A′ plus the area of B′, cannot occur.

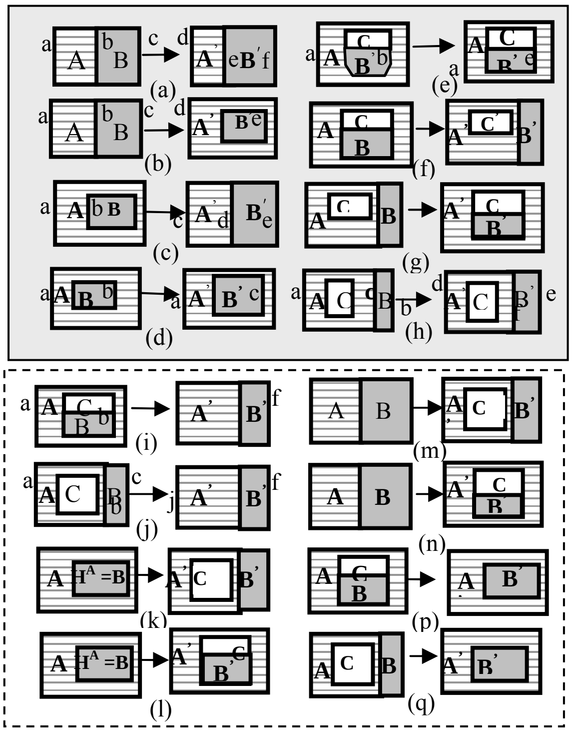


Fig.6 the entities and topology involved in rectification

In Fig.6, (a) A, B, A′ and B′ are simple parcels; (b) A and B are simple parcels, A′ is a parcel with one hole, B′ is the hole of A′; (c) the modification occurs between a parcel with one hole A and it's hole B, while after modification, A′ and B′ become simple parcels; (d) the modification occurs between a parcel with one hole A and it's hole B, after modification, A′ also is a parcel with one hole and B′ also is a simple parcel; (e) A is a parcel with one hole, B is one part of the hole of A, after modification, the relation between A′ and B′ is similar to the relation between A and B; (f) the relation between A and B is similar to (e), while after modification, A′ is still a parcel with one hole, B′ become a simple parcel meeting at the exterior boundary of A′; (g) A is a parcel with one hole, B is a simple parcel, A meets B at it's exterior border, after modification, A′ is still a parcel with one hole, B′ become one part of the hole of A′; (h) the relation between A and B is similar to (g), while after modification, A′ also is a parcel with one hole, B′ also is a simple parcel, and A′ still meets B′ at it's exterior boundary.

4 SPATIAL CHANGE'S IDENTIFICATION OF THE ENTITIES INVOLVED IN CADASTRAL EVENT

A single spatial entity includes nine basic changes: appearance, disappearance, stability, reappearance, displacement, rotation, expansion, contraction and deformation [ZHOU Xiaoguang, etc, 2004]. As a parcel is a zone on the earth with fixed boundary, owner and land -using, parcel and its boundary usually don't include move, rotation and reappearance phenomenon. So the changes of cadastral entities just include six basic cases: appearance, disappearance, stability, expansion, contraction, and deformation. Stability means there is no spatial change, usually used to present the change of the attribute, it is easy to identify, and will not be discussed in the following.

It is assumed that A is an appearance entity, B is a disappearance entity, X is an entity before change, Y is an entity after change which coming from X (including expansion, contraction, and deformation). Then the spatial change of the entities can be denoted as: appearance (A), disappearance (B), expansion (A, B), contraction (A, B), and deformation (A, B).

In order to identify the spatial changes of the involved entities (including the linkage entities and the new built entities), a set of identification rules should be developed. The change of spatial entity usually is captured by the change of the same entity's property (including spatial and attribute property), key-property change means an entity's appearance or disappearance, non-key-property change means a new version of the same entity. In cadastral system, ownership is the key-property of parcel, if the ownership is changed, new parcel should be created in spite the boundary is changed or not; the spatial property is the key-property of boundary [RAZA, 2001]. The spatial-property change can be identified by the topological relationship between the objects before and after the change. In cadastral system the topological integrity constraints is the foundation of the spatial database quality, which should be hold during the updating process. So the spatial entity's change identification rules should be concluded based on the attribute property, topological relationship and topological integrity constraints. There is a set of topological integrity constraints between the cadastral entities at the same time as follows:

There are no free - standing points and boundaries, as Fig.7- (a) shows.
There are no dangling boundaries, as Fig.7- (b) shows.
There are no cross and extending boundaries, as Fig.7- (c) shows.
There are no overlapping and missing parcels, as Fig.7- (d) shows.

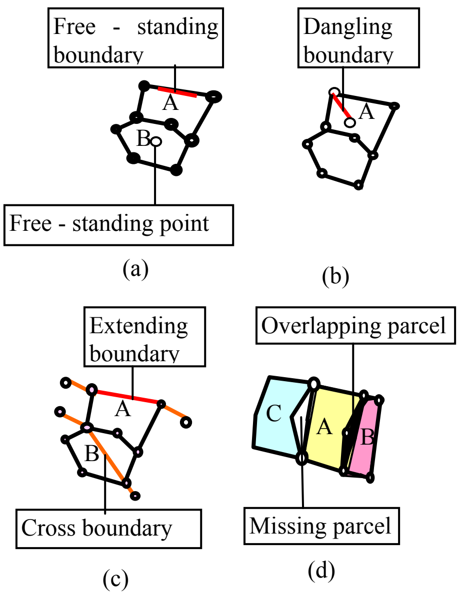


Fig.7 The topological integrity constraints between cadastral entities

4.1 The Identification Rules for Parcel

It has been proved that five kinds of topological relationships: disjoint, touch, contains, cross, and overlap, forming a small exclusive and complete set of topological relationships between two entities [Clementini, et al., 1993]. In this set, "equal" relation is not identified explicitly, but implied in contains, so the small complete set of topological relationships should be six kinds of relationships [CHEN Jun, 1999]. As the cross relation is not fit to area objects, five basic relationships: disjoint, touch, contains, overlap, and equal, form the small complete set of topological relations for parcel. As the interior of parent-child parcels isn't empty, among the five basic relationships, only "contain", "overlap", and "equal" are the three possible relations for parent-child parcels. Let X be one of the set of parent parcels: P^0, Y be one of the set of children parcels: P^1. Contain relationship includes "Y contains X" and "X contains Y", while the result of the spatial change is different, so "Y contains X" and "X contains Y (Y inside X)" are identified in this paper, as Fig.8 shows.

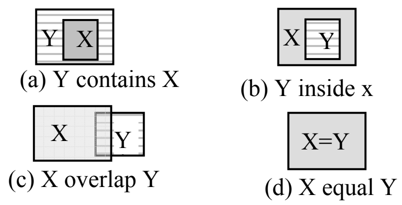


Fig.8 Topological relations between parent-child parcels

Let O_X be the owner of X, O_Y be the owner of Y, O^0 be the owners set of the parent-parcels, O^1 be the owners set of the child-parcels, f_D $(A \cap B)$ denote the dimension of $A \cap B$. As ownership is the key-property of parcel, we have therefore gotten the identification rules for parcel:

Rule (1): if ((Y contains X) and (O_X=O_Y)) then Expansion（X, Y）
If "Y contains X" and the owner of X is equal to that of Y, then it can be inferred that X expansion to Y.

Rule (2): if ((Y inside X) and (O_X=O_Y)) then Contraction（X, Y）
If "Y inside X" and the owner of X is equal to that of Y, then it can be inferred that X contraction to Y.

Rule (3): if ((Y overlap X) and (O_X=O_Y)) then Deformation（X, Y）
If "Y overlap X" and the owner of X is equal to that of Y, then it can be inferred that X deformation to Y.

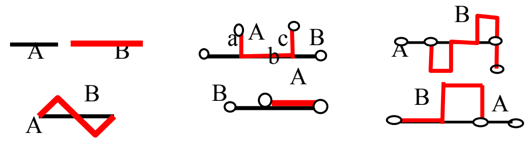
Rule (4): if f_D $(Y \cap P^0)$=2 and $(O_Y \cap O^0 = \varnothing)$ then Appearance (Y)
If the dimension of Y intersection the set of parent parcels P^0 is two, and the owner of Y (O_Y) intersection of the owners set of the parent-parcels O^0 is empty, then it can be inferred that Y is an appearance parcel.

Rule (5): if f_D $(X \cap P^1)$=2 and $(O_X \cap O^1 = \varnothing)$ then Disappearance (X)
If the dimension of X intersection the set of child parcels P^1 is two, and the owner of Y (Q_Y) intersection of the owners set of the child-parcels Q^1 is empty, then it can be inferred that X is a disappearance parcel.

4.2 The Identification Rules for Boundary

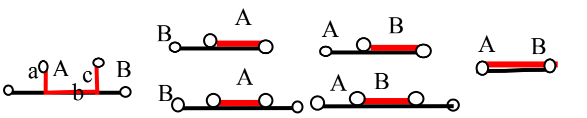
As presented above, the spatial property is the key-property of boundary and the topological integrity constraints for boundary include: there are no free - standing, dangling, cross and extending boundaries. In the following the identification rules for boundary will be concluded based on the spatial property and the topological integrity constraints.

Let L^0 be the set of boundaries before change, L^1 be the set of boundaries after change, A is one boundary of L^0, B is one boundary of L^1, $f_D(x)$ denotes the dimension of x, the value of f_D usually include: "-1" denotes the intersection is empty, "0" denotes that the intersection is 0-dimensional objects (points), "1" means the intersection is 1-dimensional objects (lines). When the intersections include points and lines at the same time, let f_D be equal to "4". There are three kinds of topological relationships between A and B, as Fig.9 shows. In Fig.9, (a) "$f_D(A \cap B) \le 0$" denoted that A disjoint to B, or A touch (or intersect to) B at point (or points); (b) "$f_D(A \cap B) = 1$" means that A intersects B at a line (or lines); (c) "$f_D(A \cap B) = 4$" means that A intersects to B at point (or points) and a line (or lines). To the second case, A intersects to B at a line (or lines), according to the topological relationship between the result of the intersection and the operands (A or B), it also can be subdivided to four possibilities, as Fig.10 shows. In Fig.10, (a) the intersection isn't equal to A or B; (b) the intersection is equal to A, not equal to B; (c) the intersection isn't equal to A, but equal to B; (d) the intersection is equal to A and B. We have therefore gotten the change identification rules as follows:



(a) $f_D(A \cap B) \le 0$ (b) $f_D(A \cap B) = 1$ (c) $f_D(A \cap B) = 4$

Fig.9 Examples of topological relationship between the boundary lines before and after changes



(a) $A \cap B \ne A$, $A \cap B \ne B$ (b) $A \cap B = A$, $A \cap B \ne B$ (c) $A \cap B = B$, $A \cap B \ne A$ (d) $A \cap B = A$, $A \cap B = B$

Fig.10 The subdivision of the intersection at 1-dimensional objects

Rule (1): if $((f_D(A \cap L^1)) \le 0)$ then Disappearance（A）; if $(f_D(B \cap L^0) \le 0)$ then Appearance（B）

If A is disjoint to all the boundaries in L^1, or the intersection of A and L^1 is a point (or points), then A is a disappearance entity; If B is disjoint to all the boundaries in L^0, or the intersection of B and L^0 is a point (or points), then B is a appearance entity.

Proof: It is assumed that A is not a disappearance boundary, but is an unchanged boundary remained in L^1, then it can be inferred that A must be one case of free-standing boundary ($A \cap L^1 = -1$), dangling boundary (or can be divided to several dangling boundaries) and cross boundary ($A \cap L^1 = 0$), contradicting the topological integrity constraints that there are no free-standing boundary, dangling boundary and cross boundary. So A is a disappearance boundary; for the same reason, if $f_D(B \cap L^0) \le 0$, then B must be an appearance boundary.

Rule (2): if $((f_D(A \cap B) = 1)$ and $(A \cap B \ne A)$ and $(A \cap B \ne B))$ then (Disappearance(A) and Appearance(B))

If the intersection of A and B is a line, and the line is not equal to A or B, then it can be inferred that A is a disappearance boundary and B is an appearance boundary.

Proof: it is assumed that A isn't a disappearance boundary and B isn't an appearance boundary, divided A to a, b, c three segments, as Fig. 10-a shows, according to Rule (1), a, c should be disappearance objects, b remain unchanged, then b must be a free-standing boundary, contradicting the topological integrity constraints that there are no free-standing boundary. So A is a disappearance boundary and B is an appearance boundary.

Rule (3): if $((A \cap B) = A)$ and $(A \cap B \ne B))$ then (Disappearance (A) and Appearance (B))

If the intersection is equal to A, not equal to B, then A is a disappearance boundary and B is an appearance boundary.

Proof: it is assumed that A isn't a disappearance boundary, but is an unchanged boundary remained in L^1 or extending to B, then A must be a free-standing boundary (if it remained in L^1), or B should be split to several parts as the history and the other semantic attributes are different each other, each part of B must be free-standing boundary or dangling boundary, contradicting the topological integrity constraints that there are no free-standing boundary and dangling boundary. So A is a disappearance boundary and B is an appearance boundary.

Rule (4): if $((A \cap B) = B)$ and $(A \cap B \ne A))$ then Contraction（A, B）

If the intersection isn't equal to A, but equal to B, then the spatial change is a contraction to B.

Proof: it is assumed that A isn't contracted to B, but is an unchanged boundary remained in L^1, then A must be a extending boundaries, contradicting the topological integrity constraints that there are no extending boundary. As Fig. 10-c shows, the spatial of B is one part of A, it's history and the other attributes are inherited from A, so B is contracted from A.

Rule (5): if $((f_D(A \cap B) = 4))$ then (Disappearance(A) and Appearance(B))

If the intersections include points and lines, then A is a disappearance boundary and B is an appearance boundary.

Proof: it is assumed that A isn't a disappearance boundary, but is an unchanged boundary remained in L^1 or deformation to B. If it remained in L^1, then A should be split to several parts, some of them must be free-standing boundaries, the other of them must be dangling boundaries; if it deformation to B, then B should be split to several parts as the history and the other semantic attributes are different each other, each part of B must be free-standing boundary or dangling boundary, contradicting the topological integrity constraints that there are no free-standing boundary and dangling boundary. So A is a disappearance boundary and B is an appearance boundary.

It is assumed that the degrees of all nodes in Fig.4, Fig.5, Fig.6, aren't larger than three, named that the adjacencies of the involved entities' closure are streets. Based on the rules presented above, we can determine the spatial changes involved in union, split, and modification between the common border, showed in Fig.4, Fig.5, and Fig.6. So, let us examine the Fig.4. Suppose the owner of C is different from that of A and B in Fig.4, it can be inferred that: in Fig.4-a, the parcel A, B, and the boundary a, b, c are disappearance entities, parcel C and boundary e are appearance entities, the spatial of e is equal to a∪b; In Fig.4-b, the parcel A, B, and the common boundary b are disappearance entities, parcel C is an appearance entity, boundary a is unchanged; In Fig.4-c, the parcel A, B, and the boundary b, c, and d are disappearance entities, parcel C and the boundary f are appearance entities; In Fig.4-d, the parcels A, B, and the boundaries a, b, and c are disappearance entities, the parcel C and the boundary e are appearance entities, the spatial of e is equal to a∪b. According to the same methods, we can get the spatial changes of the involved entities in Fig.5 and Fig.6.

While not all nodes in union, split and modification of the common border aren't larger than three, not all of the adjacencies of the involved entities' closure are streets, the changes of the exterior boundaries (the boundary of the closure) still needs to be discussed.

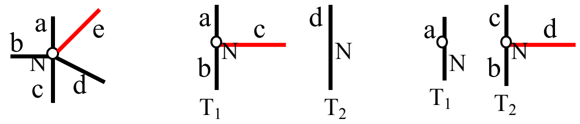
4.3 The Changes of the Exterior Boundaries

Union, split and modification of the common border usually accompany the insertion, deletion and modification of the boundaries. There are two kinds of basic boundary: simple boundary and ring boundary. Insertion, deletion and modification of the ring boundary usually don't cause the change of the exterior boundaries, so in this paper, only the change of simple boundary are discussed.

It is clear that when insertion or deletion a boundary, the degree of the beginning and ending node is the foundation to the spatial change of the exterior boundary. In this paper, the degree of a node means the number of the arcs connected to the node. 1) When the degree of a node is larger than three, insertion or deletion a boundary, usually doesn't cause the spatial change of the other boundary connected to it, as Fig.11 (a) shows, before change the degree of N is 4, in spite of insertion or deletion an arc (such as insertion e or deletion d), the other boundary connected to it (such as a, b, c) needn't to change; 2) if the degree of a node is three before change, when insertion a boundary, the other boundary connected to it needn't to change, while deletion an arc connected to it, it will be a shape point, the left two boundaries connected to it should be united to one boundary, as Fig.11 (b) shows, The degree of N is three, after deletion c, a and b should unite to d, and according to the rules mentioned above, a and b are disappearance entities, d is an appearance entity; 3) if the point after inserting a boundary (after connecting an arc to the node), the degree is equal to three, it can be inferred that the vertex isn't a node before insertion, the spatial change of the exterior boundary include splitting the boundary to two segment at this node, as Fig.11 (c) shows, the degree of N is two, after insertion d, a split to b and c, the change type the entities are a contract to b and c, Contraction（a, b）and Contraction（a, c）.

5 UPDATING OPERATION

In order to transfer the spatial changes of the involved entities to the spatial temporal database in cadastral events, a set of updating operations should be performed, so a set of updating operators should be designed; as there are several updating



(a) The degrees of N are larger than three | (b) The degree of N is three, after deletion c, a and b unite to d | (c) The degree of N is two, after insertion d, a split to b and c

Fig.11 the changes of the exterior boundaries

operations involved in each cadastral event, missing any operation or improper submission may cause the topological integrity problem, the performance process needs formal description.

5.1 The Updating Operators Based on Change - Mapping

The spatial entities are stored as objects in cadastral database, the changes of the entities should be transferred to the change of the corresponding objects, updating operation should be the bridge mapping the change of spatial entities to the change of the objects.

As section four mentioned, cadastral entity include six kinds of changes: appearance, disappearance, stability, expansion, contraction and deformation. Let X be the set of the change of cadastral entity:

X=｛appearance, disappearance, stability, expansion, contraction, deformation｝ (1)

Hornsby & Egenhofer proposed that there are nine identity-based changes of single spatial object: continue non-existence without history, create, recall, destroy, continue existence, eliminate, forget, reincarnate, and continue non-existence [Hornsby & Egenhofer, 2000]. As "non-existence without history" doesn't exist in database, so in fact there are eight identity-based changes. Let Y be the set of identity-based changes of single spatial object:

Y=｛create，recall，destroy，continue existence，eliminate，forget，reincarnate，continue non-existence｝ （2）

There is a map from X to Y (f: X→Y) does the following: for every p ∈ X it gives you an element of Y, denoted f(p), and called the image of p.

f：X→Y ={< appearance, create>, <disappearance, eliminate>, <stability, continue-existence>, <expansion, continue-existence>, <contraction, continue-existence>, <deformation, continue-existence>} （3）

In set theory, if the map (f：X→Y) is single-valued: for each x in X, there is at most one image point y in Y, then the map from X to Y can be realized by operators. In this paper, the map from the cadastral spatial entities' change to the corresponding identity-based change is defined as updating operator.

In Eq. (3), all of the image point of ‵stability′, ‵expansion′, ‵contraction′and ‵deformation′, is ‵continue-existence′. Among these, ‵expansion′, ‵contraction′and

‵deformation′cause the geometry component modification of the corresponding object, ‵stability′cause the semantic component modification of the corresponding object. As there are much difference between geometry-modification and semantic –modification at data collection, handling, and updating performance, in this paper, two updating operators: geometry-modify and semantic–modify are designed to handle the geometry component modification and semantic component modification respectively. So four updating operators are used to map the cadastral spatial entity change to the corresponding identity-based object change in this paper, as Fig.12 shows.

It is assumed that time is one dimension, and the stamp interval time [start, end] denotes the entity's life span {(start-time, end-time)│ start-time ≤ end-time}, All objects with [start-time, *] time stamps are called as active objects (usually, active objects means the objects still exist in the real world), all objects with [start-time, end-time] time stamps are called as inactive objects (inactive objects are not existing in the real world, named history objects). In this paper, the object-oriented data model and object version management are used, the four updating operators are defined as follows:

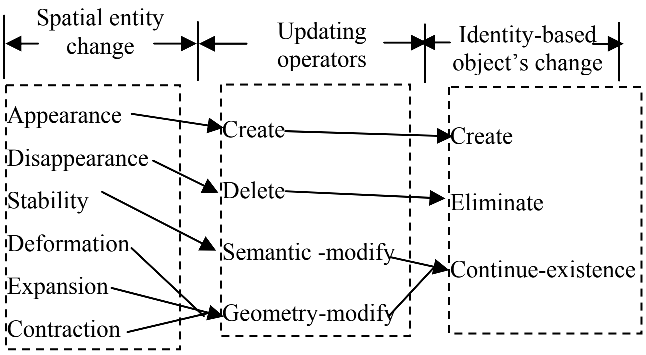


Fig .12 Updating operators based on change mapping

Create (X): This operation maps an appearance process to the database; its task is to add a new record X of an active object in the database. This operator specifies the stamp [start-time, *] of the new one.

Delete (X): This operator transfers an active object in the database to an inactive object by defining the upper bound of the time interval: [start-time, end-time].

Semantic -modify(X, X′): The task of this operator is to modify the semantic properties of an active object in the database. In STDB, in order to store the history information, this operator usually makes the object as an inactive object with the stamp [start-time, end-time] and add an active object with the same spatial and temporal properties but changed semantic properties correspondingly.

Geometry-modify(X, X′): The task of this operator is to modify the spatial properties of an active object in the database. In STDB, the operator means to make the object as an inactive object with the stamp [start-time, end-time] and add an active object with the stamp [start-time, *] and changed spatial properties correspondingly.

5.2 Formal Representation of the Updating Process

As mentioned above, there involved several spatial entities' changes in each cadastral event (or the sub-event), each updating process needs implement several updating operations, if there are some errors about the sequence (or the submission) of the updating operations, the topological integrity problem may be caused. Therefore the updating process needs formal representation.

In this paper, the Event Pattern Language (EPL) developed in active database is adopted in the formal representation of the updating process. Where an updating operation (such as create or delete), defined as a primitive event, a whole cadastral event updating process as a composite event, the composite events are represent by EPL [CHEN Jun &IANG Jie, 2000]. The updating process of the node - moving (as Fig.2 shows) can be represent as follows:

$$E = \text{delete}(N)\ \Delta\ \text{delete}(a)\ \Delta\ \text{delete}(b)\ \Delta\ \text{delete}(c)\ \Delta\ \text{create}(N')\ \Delta\ \text{create}(d)\ \Delta\ \text{create}(e)\ \Delta\ \text{create}(f)\ \Delta\ \text{Geometry-modify}(P_1, P_1')\ \Delta\ \text{Geometry-modify}(P_2, P_2')\ \Delta\ \text{Geometry-modify}(P_3, P_3') \quad (4)$$

Where "Δ" denotes AND operator, E denotes composite event, Eq. (4) means that E can't occur until all the primitive events occur. Thus the topological integrity errors caused by the missing any operation or improper submission can be avoided.

6 THE EXPERIMENT AND CONCLUSION

Based on the above model and design, an incremental updating of cadastral database prototype system was implemented using VC^{++} in Oracle9i Spatial and MapX platform. The automatic (or semi-automatic) incremental updating of the cadastral events (including node-moving, union, split, **rectification**) is implemented, active and automatic (or semi-automatic) topology maintenance has been realized. Real and simulated cadastral data (based on a sheet of 1:1000 real digital cadastral map, simulating the five kinds of basic cadastral events and the entities and topology involved in union, split, and **rectification**), as Fig.13 shows, was used to examine the models and methods presented in this paper. It can be concluded that:

(a) Simulated cadastral data before updating

(b) Simulated cadastral data after updating

Fig.13 The experiment of the incremental updating based on topological linkage

1) Event-driven incremental updating of cadastral database based on topological relationship is an efficient and effective updating method, which can avoid the topological integrity error-prone, and reduce manual labor during updating operation in time.

2) The incremental updating method presented above is based on the topological relationship, as the topological relationship is sensitive to spatial data quality, the location error and uncertainty may cause the determination error of topological relationship, so in this method, error tolerance mechanism should be introduced in the design and implementation of this kind of system.

Further study will focus on checking and correcting the topological integrity error in existing spatial database and developing change-only information's collecting and committing system.

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ACKNOWLEDGEMENTS

This research was supported by the National Natural Science Foundation of China under grant No. 40337055 and No. 40571122.