The Identification of Spatial Change Processes based on Set-oriented Space and Topological Space

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Abstract

The identification of spatial change processes is one of the most important topics in spatio-temporal data modeling as a basis for spatio-temporal query and analysis. The paper proposes an approach that applies the spaces where the spatio-temporal objects are embedded to identify the change processes. The primitive relations in change processes in two spaces – set-oriented space and topological space are generated. By combination of these relations with set-oriented tools, many change processes can be identified. Furthermore it can help in understanding the different semantics of 'common-sense' change processes. The identification approach can be used for query operations and spatial reasoning. As an example, a spatio-temporal query operation is designed in principal, and a query example is implemented as an illustration in the end.

1. Introduction

Since Langran (1989) proposed the terminology TGIS - Temporal GIS, it has been widely researched in recent years. Basically the research focuses on the following aspects: (1) how to model the spatial and non-spatial changes? (2) what are the spatio-temporal relations between changing spatial objects? (3) how to make queries to access the spatio-temporal data? (4) how to reason the spatial changes? and (5) how to display and output the data optimally?

Several models have been proposed to handle spatio-temporal data by use of different approaches (Langran and Chrisman 1988, Worboys 1992, 1994, Ramachandran et al 1994, Peuquet and Wentz 1995, Claramunt and Theriault 1995, Raper and Livingstone 1995, Voigtmann et al 1996). While these models try to represent spatio-temporal data in a better manner, the research on spatial, temporal and change relations has been also received high attention. On pure temporal aspects, Allen (1983, 1984) derived 13 relations between single connected temporal objects that were called type-one relation by Roshannejad (1996). Roshannejad discussed type-two relations by introducing two temporal existences of objects. Allen's temporal logic has been widely adopted for derivation of temporal query operators in pure temporal databases (Sarda 1987, Amstrong 1988, Snodgrass 1987, 1992, Wuu and Dayal 1992, Tansel et al 1993) as well as for temporal reasoning (Al-Taha and Frank 1995). In the spatial domain, the spatial query operators have been well established based on topological relations (Egenhofer 1989, Egenhofer and Franzosa 1991) in conventional GIS.

Like conventional GIS in which the spatial relations have to be investigated for query operations and reasoning, understanding of the spatio-temporal change processes is the key to access the underlying databases of the above models in temporal GIS. Change of spatio-temporal objects is very complicated and may have many categories. It can be classified into different categories according to different criteria. For example, from the object-oriented point of view, based on the object identity, it can be classified as identity-preserving and non-identity-preserving. Based on the object components, it can also be classified as identity change, spatial change and non-spatial change. Due to the different properties of change processes, it can be classified as continuous and discrete change.

In spite of its complications, several efforts have been done on this aspect. Claramunt and Theriault (1996) described spatio-temporal change processes in three main classes:

(1) Evolution of a single entity represents basic changes (appearance, disappearance, etc), transformations and movements of that entity.
(2) Functional relations involve spatio-temporal processes between several entities (for example replace and diffusion processes). They convey known dependence links that need to be modeled explicitly in the temporal domain.
(3) Evolution of spatial structures describes spatio-temporal processes involving several spatial entities (for example, split, union and reallocation).

In their model, topologically-based operators are constructed to model the distinguishing *evolution, succession, production, reproduction, and transmission* processes of spatial entities. Hornsby and Egenhofer (1997) analyzed the operations related to change. They offered a classification based on object identity and a set of operations that either preserve or change identity. These operations are applied to single or composite objects, and combined to express the semantics of sequences of change. For example, operation *split* is refined by splitting the single and composite objects into *splinter, divide and secede, dissolve,* respectively.

To identify the qualitative change, we turn to the embedded spaces where a spatial object lies. Worboys (1995) pointed out, the typology of embedding spaces - set-oriented space, topological space, Euclidean space and metric space - is quite useful to analyse the spatial operations. He listed the most useful operations in GIS identified from these spaces for static objects, for which the operations will not change the object itself. For dynamic objects, three general operations are named by *creation*, *destroy* and *update*, which change the objects. Actually these operations are the change processes embedded in set-oriented space. It is also possible to analyse the change processes from all of these embedding spaces. Following this idea, this paper proposes a novel approach to analysing the change process. The basic procedure is to derive the primitive relations in a change process in different spaces, then by combination of these primitive relations we can identify different change processes.

This paper emphases on the approach of identification of spatial change processes. Two spaces are investigated—set-oriented space and topological space. As a consequence, discussion on spatio-temporal modelling is less mentioned in this paper. The structure of the paper is organised in the following way: Part 2 separates the primitive relations in change processes, which are embedded in set-oriented space and topological space. Part 3 formalises the change processes based on set-oriented operations. Part 4 discusses the identification of spatial change processes from different angles. Part 5 analyses comprehensively some ‘common-sense’ change processes based on set-oriented and topological primitive relations. Part 6 gives an example of query operations based on the identification. Part 7 comprises the conclusion and some discussions.

2. Primitive relations in change processes

A change process is the result of events, which cause the change of objects. From the object-oriented point of view, it is a transition from states/objects to other states/objects; that is, spatio-temporal objects will change into other objects or change from states to states during an event. Considering components of a spatio-temporal object, each object has different states and each state has its identity, spatial (which may have different parts), non-spatial and temporal properties. Every state will last a certain period. A state itself can also be regarded as an object. A general spatio-temporal object is then the aggregation of these small objects. For simplicity, we still refer to these 'small' objects as the states in a change process. It should be borne in mind that the changed states may be the beginning states of other spatio-temporal objects.

During a change process, there are some relations between states/objects. Although it acts on a set of objects, it can be identified by decomposing the set from different spaces in which they are embedded. In other words, we can approach the change process of objects from these kinds of relations. Four spaces - metric, Euclidean, topological and set-oriented - are the most important for analysis of a spatial object. All these spaces can be adopted to analyze the change processes of these objects.

The most important procedure of identification of change processes is to derive the primitive relations embedded in these spaces. In general set theory there are three basic constructs: elements or members, sets and membership. A binary relation on a set is any pair of subset of the set. According to Worboys (1995), some of the set-oriented relations between the spatial parts of objects can be refined by topological relations. For example, set-oriented relation *a subset of* can be refined by topological relations *contain* and *cover*, and intersection can be refined by *meet* and *overlap* in topological space. Following this idea, we turn to the topological relations when handling the spatial parts of spatio-temporal objects. Due to the variety of change operations in Euclidean and metric space, this paper just approaches it from general set theory and topological space.

2.1 Primitive relations of change processes in general set-oriented space

2.1.1 Succession relation

During a change process, perhaps the most important relation is the *succession* relation -- a relation between the previous states and its corresponding current states. That is, what changes into what. Suppose *a'* is a member of the current states *C*, *a* is a member of the previous states *P*, then the successive relation Suc(a,a') can be represented as:

$$R = suc_{aa'}(a, a') = \{< a, a' >: a = predecessor(a') \vee a' = successor(a)\}$$

where *predecessor(a') and successor(a)* are two relations to represent the previous state of a'and the next state of a. $Suc_{aa'}(a,a')$ is the primitive relation between *a* and *a'*. If an object has no change, the *succession* will not exist. In case *a* or *a'* is an empty set, the form of *suc()* is $suc(\phi, a')$ or $suc(a,\phi)$.

Using function *id()* to get the identity of a state and leaving the spatial part to the topological relations, then

$$R_{id} = suc_{idid'} < a, a' >= \{< a, a' >: id(a) = id(predecessor(a')) \vee id(a') = id(successor(a))\}$$

The state identity can also be replaced by object identity if needed.

$$R_{oid} = succ_{oid} < a, a' >= \{< a, a' >: oid(a) = oid(predecessor(a')) \vee oid(a') = oid(successor(a))\}$$

2.1.2 Dependency relation

Dependency relation is to denote a special relation during a change process between the current states of objects and the previous states of other objects. As we know, during an event the current states may have some links with the previous states of others. For example, a woman gives birth to a baby. In this example, 'birth' is an event that causes changes of the pregnant lady into a mother and a baby birth. From the baby point of view, the baby has a dependent relation on the lady. The dependency relation reveals this kind of relation. In general it has two possibilities. The first is that the dependent objects have the same domain as its dependency. The second is that the dependent objects have different domain with the links (we suppose that an object has the same domain as its states). In board sense this relation is a kind of 'causal relation' – in which the event causes object changes. In the above case, a baby is born because of the event *birth*. The birth impacts on two objects - the baby and the mother. From the process "baby birth", the baby has the relation with the pregnant lady. Since the process birth itself is dependent on its concrete application, we will not consider this kind of application-dependent process. Only the process dependent on the others, which have the same spatial domain, is considered. In set-oriented space, we have a dependency relation *dep(a,a')* between *a* and *a'*, $b \in P$, $b' \in C$:

$$L = dep_{ba'}(b, a') = \{< b, a' >: (a' = causes(b) \vee b = iscausedby(a')) \wedge \neg suc_{ba'}(b, a')\}$$

Causes() and *Iscausedby()* are two relations, where *b* is the state which is caused by *a'*. That is, the current states may be dependent on several states and one state could cause several objects change.

We also leave the spatial relation between the current states with dependent objects (states) to the topological relations. Then the set-oriented relation between identities:

$$L_{id} = dep(a', b) = \{< a', b >: (id(a') = id(causes(b)) \vee id(b) = id(iscausedby(a'))) \\ \wedge \neg suc(a', b)\}$$

During the change processes, the dependent object may or may not change.

(1) Dependent objects have no change:

$$D_{no} = ind(b, b') = \{< b, b' >: (\exists a \in P \exists a' \in C\ suc(a, a') \\ \wedge dep(a', b) \wedge \neg suc(a', b) \wedge b = b')\}$$

(2) Dependent objects change:

$$D_{ch} = dep(b,b') = \{<b,b'>: \{\exists a \in P \exists a' \in C\ suc(a,a') \wedge dep(a',b) \wedge \neg suc(a',b) \wedge suc(b,b') \wedge \neg equal(b,b')\}\}$$

where *equal()* is a set operation.

2.2 Primitive relations in topological space

Topology investigates characteristics of geometry that remain invariant under certain transformations (topological mappings or homeomorphisms) (Kainz, 1995). The topological space is defined based on open sets. Let **X** be a set. A *topology* on **X** is a collection $\Im$ of subsets of **X** that satisfies the three conditions: (1) the empty set and **X** are in $\Im$, (2) $\Im$ is closed under finite intersections, and (3) $\Im$ is closed under arbitrary unions (Kainz 1995, Egenhofer 1991). In a topological space, a rectangle is equivalent to a circle. The fundamental primitives like *interior, boundary* and *exterior* have been used to model spatial relations. The 4-intersection approach is generalised using the mutually exclusive components of a subset by (Egenhofer 1989, Egenhofer and Franzosa 1991) to derive the topological relations between two simple regions. The relations between two simple regions are: *disjoint, contain, inside, equal, meet, cover, coveredby and overlap*. The 9-intersection approach (Egenhofer and Herring, 1990), in which *exterior* of a set is defined to identify the relations, allows for more relations when the objects are embedded in a space of higher dimension, e.g. a line in R^2. Kufoniyi (1995, in Molenaar 1998) analysed 19 relations between region and line, 22 relations between line and line, and 3 relations between region and point, 3 relations between line and point and 2 relations between point and point. Since intersection between the exterior of one subspace with the interior, boundary and the exterior of the other subspace cannot differentiate some relations, it was revised by introducing the *Voronoi region* that was called V9I model (Chen et al 2000). In their model, 13 relations between area/area, 8 relations between line/line, 13 relations between line/area, 3 relations between point/point, 4 relations between point/line and 5 relations between point/area were identified.

Spatio-temporal relations are in general the relations between any spatio-temporal objects. It can be decomposed into spatial relations and temporal relations, respectively, by mapping states onto the same time or the same plane. Among these relations, an important topological relation is the relation between two spatial objects/states before and after an event. In this situation, the temporal topology is limited into two conditions: *MeetWith* and *MetBy* out of *13 temporal relations*. We can consider that these relations belong to the spatial relations since the time is already fixed. Based on 4-intersection approach, we can distinguish 8 different topological relations between two states before and after an event. These relations can be adopted as the primitive relations for the identification of change processes.

Assuming:
(1) The change from polygon into line, point, and vice versa, is neglected; (2) The polygons are simple polygons without holes; (3) $a = precedessor(a'), a' = successor(a)$ Then the change process between two states before and after an event is (figure 1):

(1) Expand: *coveredby(a, a')*

(2) Shrink: *cover(a, a')*

(3) Enlarge: *containedby(a, a')*

(4) Reduce: *contain(a, a')*

(5) Meet: *meet(a, a')*

(6) Separate: *disjoint(a, a')*

(7) Equal: *equal(a, a')*

(8) Deform: *overlap(a, a')*

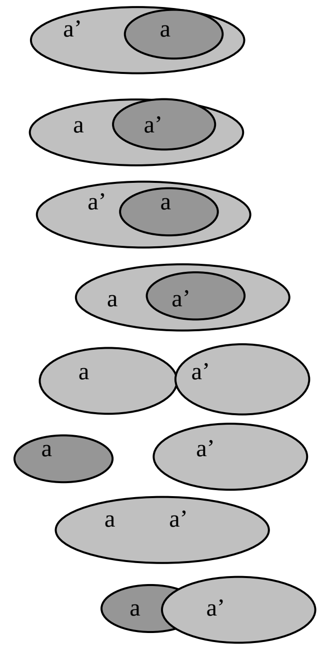
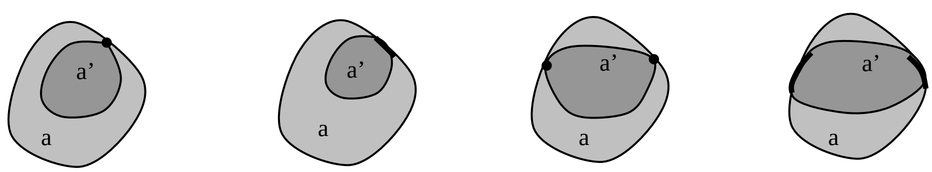


Figure 1. Eight primitives of change processes in topological space

The dimension and number of intersections are not discussed. This consideration can cause too many relations. For example, there is a variety of *shrink* (figure 2).



(1) *a* shrinks into *a'* with 1-point intersection

(2) *a* shrinks into *a'* with 1-line intersection

(3) *a* shrinks into *a'* with 2-points intersection

(4) *a* shrinks into *a'* with 2-lines intersection

Figure. 2 Number of intersection in *shrink* relation

3. Identification of change processes by general set-theory

Based on the set-oriented tools introduced in section 2.1, we can formulate the set-oriended change processes. Since the processes are based on the subsets of states, the formula in section 2 has to be extended from elements into subsets.

3.1 Creation

Creation is the process that generates new objects. For all elements in *suc(a,a')*, denote *SA* the set of states that will change and *SA'* the set of states what are changed into. The general creation can be formalised as:

$$P_1 = \{< A, A' >: A \subset SA \wedge A' \in SA' \wedge |A| = 0 \wedge |A'| > 0 \\ \wedge (\forall a \in A \forall a' \in A' \, suc(\phi, a'))\}$$

The general process creation only needs the set-oriented tool *asubsetof* and the *cardinality* property. The number of new objects may be one or many. This can be reflected by refining the cardinal number.

Creation of one object

$$P_2 = \{< A, A'>: A \subset SA \wedge A' \in SA' \wedge |A| = 0 \wedge |A'| = 1$$
$$\wedge (\forall a \in A \forall a' \in A' suc(\phi, a'))\}$$

Creation of several objects

$$P_3 = \{< A, A'>: A \subset SA \wedge A' \in SA' \wedge |A| = 0 \wedge |A'| > 1$$
$$\wedge (\forall a \in A \forall a' \in A' suc(\phi, a'))\}$$

The change process in which some objects are created dependent on other objects can be formulated by adding the primitive relations *dep()* and *ind()*. The creation dependent on other objects is:

$$P_4 = \{< A, A'>: A \subset SA \wedge A' \in SA' \wedge |A| = 0 \wedge |A'| > 1$$
$$\wedge (\forall a \in A \forall a' \in A' : \exists b \in P \exists b' \in C \ \ ind(b, b'))\}$$
$$= \{< A, A'>: A \subset SA \wedge A' \in SA' \wedge |A| = 0 \wedge |A'| > 1$$
$$\wedge (\forall a \in SA \forall a' \in SA' : \exists b \in P \exists b' \in C$$
$$suc(\phi, a') \wedge dep(a', b) \wedge \neg dep(a', b) \wedge b = b')\}$$

The independent creation of objects can be simply formulated by:

$$P_5 = \{< A, A'>: A \subset SA \wedge A' \in SA' \wedge |A| = 0 \wedge |A'| > 1$$
$$\wedge \forall a \in A \forall a' \in A' (suc(\phi, a') \wedge \forall b \in P \ \neg dep(a', b))\}$$

If one wants to know the object created by replication or generation, then the following formula can be adopted:

$$Replication = \{< A, A'>: A \subset SA \wedge A' \in SA' \wedge |A| = 0 \wedge |A'| = 1 \wedge$$
$$(\forall a \in A \forall a' \in A' : \exists b \in P \exists b' \in C \ \ suc(\phi, a') \wedge$$
$$dep(a', b) \wedge \neg dep(a', b) \wedge |\{b\}| = 1))\}$$

However, in the above example, we cannot tell the difference between identical replica (reproduction) and generation (there is some difference between original objects and generated objects). To make this kind of difference, the geometric transformation like *shift* should be introduced.

The formulation of destruction change is similar to the creation formula provided $|A|=0$ is replaced by $|A|>0$ and $|A'|>0$ by $|A'|=0$ and $suc(\phi, a')$ by $suc(a, \phi)$.

3.2 Update

The general formula of *update* only involves the succession, cardinal number and equality relations.

$$P_6 = \{< A, A'>: A \subset SA \wedge A' \in SA' \wedge |A| > 0 \wedge |A'| > 0$$
$$\wedge (\forall a \in A \forall a' \in A' \ suc(a, a') \wedge \neg equal(a, a')\}$$

This formula is also the basis to refine the change processes by topological relations. We will discuss it later. There are several cases of basic updates.

(1) Update with some objects' creation

In this process, the created objects must be dependent on the previous states of updated objects, otherwise this process can be regarded as two processes: update and creation.

$$\begin{aligned} P_7 = \{ < A, A' >: A \subset SA \wedge A' \in SA' \wedge |A| > 0 \wedge |A'| > 0 \\ \wedge (\forall a \in A \forall a' \in A' \; suc(a, a') \wedge \neg equal(a, a') \\ \wedge \exists ca' \in A' \, suc(\phi, ca') \wedge \exists b \in P \; dep(ca', b)) \} \end{aligned}$$

(2) Dependent update on unchanged objects

$$\begin{aligned} P_8 = \{ < A, A' >: A \subset SA \wedge A' \in SA' \wedge |A| > 0 \wedge |A'| > 0 \\ \wedge (\forall a \in A \forall a' \in A' : \exists b \in P \, \exists b' \in C \, \neg suc(a', b) \wedge \\ \wedge suc(a, a') \wedge dep(a', b) \wedge id(b') = id(b) \wedge equal(b, b')) \} \end{aligned}$$

(3) Independent update

$$\begin{aligned} P_9 = \{ < A, A' >: A \subset SA \wedge A' \in SA' \wedge |A| > 0 \wedge |A'| > 0 \\ \wedge (\forall a \in A \forall a' \in A' : \forall b \in P \forall b' \subset C \; suc(a, a') \wedge \neg dep(a', b)) \} \end{aligned}$$

(4) Dependent update on changed objects

$$\begin{aligned} P_{10} = \{ < A, A' >: A \subset SA \wedge A' \in SA' \wedge |A| > 0 \wedge |A'| > 0 \\ \wedge (\forall a \in A \forall a' \in A' : \exists b \in SA \exists b' \in SA' \, \neg suc(a' b) \wedge suc(b, b') \\ \wedge \neg equal(b, b') \wedge suc(a, a') \wedge dep(a', b)) \} \end{aligned}$$

4. Identification of spatial change processes

4.1 Identification by Combination

We have seen that based on the set-oriented relations, some qualitative change processes can be identified. By combination of set-oriented and topological relations, many qualitative change processes can be identified.

(1) Enlarge

The set-oriented function for spatial operations can be refined by the topological relations. The formula P_6 is also the basis to accommodate these topological relations. For example, we can formulate the *enlarge* process:

$$\begin{aligned} Enlarge = \{ < A, A' >: A \subset SA \wedge A' \in SA' \wedge |A| > 0 \wedge |A'| > 0 \\ \wedge (\forall a \in A \forall a' \in A' \; suc(a, a') \wedge enlarge(a, a')) \} \end{aligned}$$

(2) Grow

The grow process is usually defined as the current states being larger than the previous states. The P_6 can be adjusted by union of some topological relations:

$$Grow = \{< A, A' >: A \subset SA \wedge A' \in SA' \wedge |A| > 0 \wedge |A'| > 0$$
$$\wedge (\forall a \in A \forall a' \in A' \; suc(a, a') \wedge (enlarge(a, a') \vee expand(a, a')))\}$$

4.2 Identification of composite change process

The change process can be broken into simple change process and composite change process. A simple change process acts on objects at only one continuous time while the composite change process acts on certain objects at several times. The combination of simple change process can be adopted to form more complicated processes.

(1) Reincarnation

Reincarnation is a change process in which the previous objects were destroyed and it is regenerated again (Figure 3). Denote *PA* the previous states of states *A*, *SSA* the set of all previous states.

$$Re = \{< A, A' >: A \subset SA \wedge A' \subset SA' \wedge |A| = 0 \wedge |A'| > 0 \wedge (\forall a \in A \forall a' \in A' \; suc(a, a')\} \cap$$
$$\{< A, PA >: A \subset SA \wedge PA \subset SSA \wedge |PA| > 0 \wedge |A| = 0 (\forall a \in A \forall pa \in SSA \; suc(pa, a)\}$$

Figure.3 reincarnation process

(2) Continuous expanding

Continuous expanding is a change process in which the next states are always larger than the previous ones:

$$Expand = \bigcap_{n=1}^{m} \{< A_{n-1}, A_n >: |A_{n-1}| > 0 \wedge |A_n| > 0 \wedge (\forall a \in A_{n-1} \forall a' \in A_n \; suc(a, a') \wedge$$
$$\wedge (expand(a, a') \vee enlarge(a, a')))\}$$
$$where \; A_n \subset SA_n$$

The process in section 3 and 4.1 can be also extended for composite change processes provided by adding union or intersection operations.

4.3 Identity dependent change processes

Identity dependent change is that during a process, the object identity will change or not. It can be modeled by adding function *oid()* to solve this problem. For example, supposing *splinter* is a special split process (the general split process will be discussed in section 5), in which several object identities are unchanged, then

$$
\begin{aligned}
Spliter = \{ &< A, A' >: A \subset SA \wedge A' \subset SA' \wedge |A| = 1 \wedge |A'| > 1 \wedge |A'| > |A| \\
&\wedge (\forall a \in A \forall a' \in A' \quad suc(a, a') \\
&\wedge \neg equal(a, a') \\
&\wedge \exists c' \in A' \ oid(c') = oid(predecessor(c')))) \}
\end{aligned}
$$

5. Understanding the semantics of change processes

As we know, spatial changes are quite dependent on their semantics. Different users may have their own understanding and their own definitions. This approach will help us not only in identification of change processes, but also in understanding the essence of 'common-sense' change processes. We will list some as examples.

5.1 Split

The process split has different meanings. It can be referred to as (1) one split into more, no matter the location relation between the previous and the current objects. (2) several into more. (3) the extent of the previous object is preserved as that of the current object, the number of objects changes, for example, 2 objects split into 3 where the extent keeps the same. (4) the only one object split into several while the extent remains the same (Figure 4).

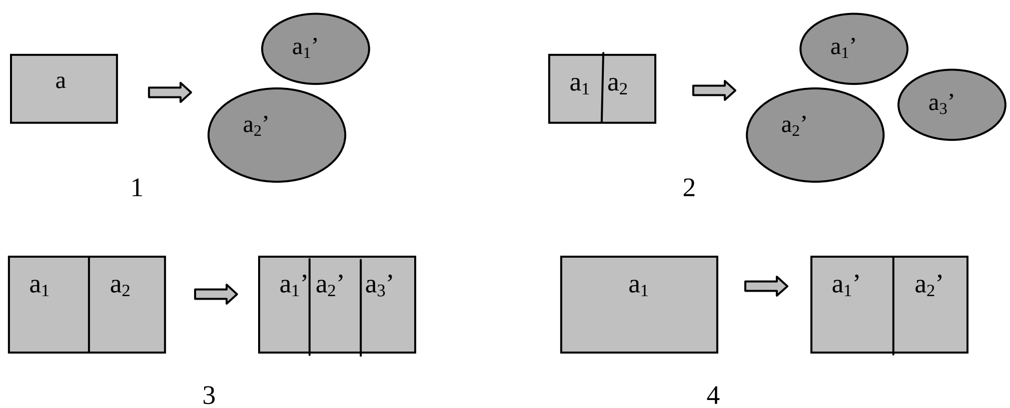


Figure 4 Different kinds of 'common-sense' change process split

Split 1: this change can be regarded as the special case of formula P_6 only replacing *|predecessor(A')|>=1* by *|predecessor(A')|=1*.

$$
\begin{aligned}
Split_1 = \{ &< A, A' >: A \subset SA \wedge A' \subset SA' \wedge |A| = 1 \wedge |A'| > 1 \\
&\wedge (\forall a \in A \forall a' \in A' suc(a, a') \\
&\wedge \neg equal(a, a') \}
\end{aligned}
$$

Split 2:

$$
\begin{aligned}
Split_2 = \{ &< A, A' >: A \subset SA \wedge A' \subset SA' \wedge |A| > 0 \wedge |A'| > 1 \wedge |A'| > |A| \\
&\wedge (\forall a \in A \forall a' \in A' suc(a, a') \\
&\wedge \neg equal(a, a') \}
\end{aligned}
$$

$Split_2$ can be identified by grouping several adjacent objects where all objects have change *$split_1$*. In figure 5 there are two *$split_1$* changes. They can be grouped together as one *$split_2$* change. That is,

$$Split_2 = \bigcup \{split_1\} \wedge \{\exists a_1 a_2 \in split_1(SA)\ Meet(a_1, a_2) \vee Metby(a_1, a_2)\}$$

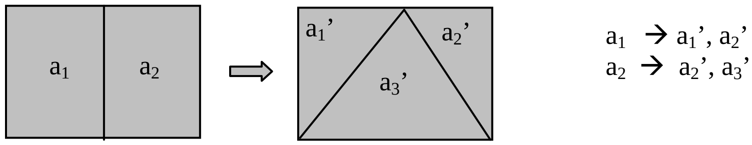


Figure 5. A *$split_2$* can be regarded as two *$split_1$* changes

Split 3:

$$\begin{aligned} Split_3 = \{< A, A' >: A \subset SA \wedge A' \subset SA' \wedge |A| > 1 \wedge |A'| > 1 \wedge |A'| > |A| \\ \wedge (\forall a \in A \forall a' \in A'\ suc(a, a') \\ \wedge \neg equal(a', a) \\ \wedge euqal(\sum a', \sum a)\} \end{aligned}$$

Split 4: is the special case of formula $Split_3$, provided replacing $|A| > 1$ by $|A| = 1$.

In *$split_3$*, since there is a different size of subset *A*, the *$split_3$* could include several levels of split. For example, in figure 6, 2 objects split into 3 can be regarded as 4 objects split into 6.

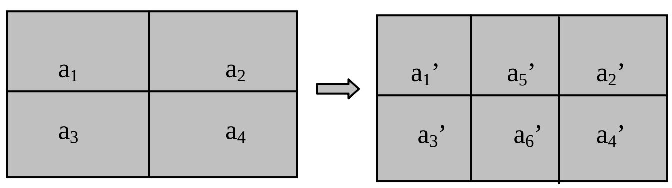


Figure 6. Different levels in split 3

To our understanding, the process $split_1$ and $split_2$ are because of the users lacking the support of spatial information system. $Split_3$ and $split_4$ are split processes. $Split_3$ is a general split process in space and $split_4$ is a special case of split, which can be called *subdivision*.

Process *aggregation* is the inverse process of split. Only functions *predecessor()* and the current states *C* have to be changed into *successor()* and the next states *N* respectively.

5.2 Exchange

Exchange is the process that changes between objects. It can be circular as well as non-circular (Figure 7). Furthermore, there are dependent relations between the objects. That is, that the object *a* changes into *a'* is because of the existence of the object *b*. If object *b* does not exist, the exchange cannot happen and vice versa.

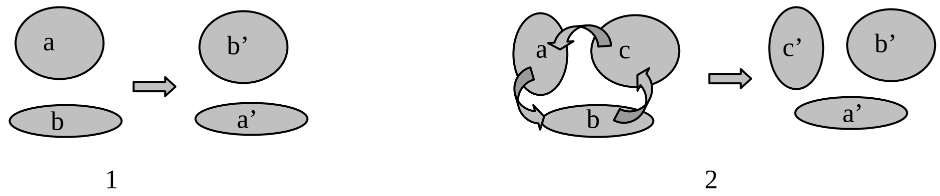


Figure 7 the exchange process (1- general,2 - circular exchange)

The general exchange process is:

$$\begin{aligned} Exchange &= \{< A, A'>: A \subset SA \wedge A' \in SA' \wedge | A |> 1 \wedge | A'|> 1 \\ &\wedge (\forall a \in A \forall a' \in A' \; suc(a, a') \wedge \neg equal(a, a') \\ &\wedge \exists b \in A \exists b' \in A' \; dep(a', b) \wedge equal(a', b) \wedge equal(b', a))\} \end{aligned}$$

The circular exchange process is:

$$\begin{aligned} Exchange_{cir} &= \{< A, A'>: A \subset SA \wedge A' \in SA' \wedge | A |> 2 \wedge | A'|> 2 \\ &\wedge (\forall a \in A \forall a' \in A' \; suc(a, a') \wedge \neg euqal(a, a') \\ &\wedge \exists b, c \in A \exists b', c' \in A' \; dep(a', b) \wedge dep(b', c) \wedge dep(c, a') \\ &\wedge equal(a', b) \wedge equal(b', c) \wedge \neg equal(c', b) \wedge equal(a', c))\} \end{aligned}$$

6. Elementary implementation for query operations

The identification of change processes has several applications like understanding different semantics in change processes, designing spatio-temporal query operators and spatio-temporal reasoning. Based on the above analysis, it can be perceived that it is impossible to list all spatial change processes and then to design the spatio-temporal queries. To query objects in change processes, we can turn to a middle way. On the one hand, we can form the most useful operators for general uses. On the other hand, we can generate the primitive functions for more flexible use. We have designed an elementary spatio-temporal model called Spatio-temporal Object-oriented Model (STOOM) for the Chinese Cadastral Information System. The model is state-based where the current states of objects are stored in the main database and the old states are stored in the historical database and they are linked by a link table. The identity of states and objects are explicitly expressed in the link table. Several unary operations have been designed like *getprevious(), getnext(), getcurrent(), getdependent(), getextent()* from set-oriented space. For example, the operation *getsuccession()* represents the relations between the current states and their previous states. Its result is an object composed of two lists which are the previous states and its corresponding current states respectively. The operation *getlink()* has a similar function. The topological primitive relations include the eight topological relations. The set-oriented tools are *count(), disjoint(), equal(), union(), intersection(), difference()*.

Based on the above functions, some useful change processes can be constructed to retrieve the objects like *iscreated(), isupdatedby(), updatedinto(), issplitby(), splitinto()*. For example *isdestroyed()* can be described as:

Parcel.getsuccession().getpreviouslist.count > 0 and parcel.getsuccession().getnextlist.count = 0

Several query operators have been implemented. For example, we can retrieve all parcels before subdivision (figure 8):

Select parcel.subdividedinto()

In figure.8 the gray color is the result of this example which is implemented based on ArcView by Avenue programming. The details of the implementation are neglected in this paper.

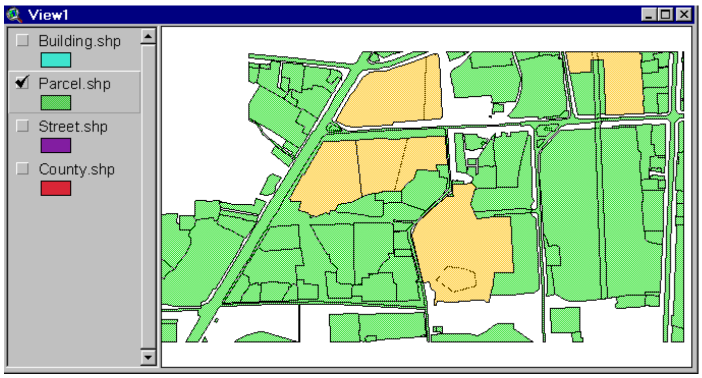


Table8

AREA	PERIMETER	PARCEL_	PARCEL_ID	SOURCE	FROMTIME	TOTIME	STARTTIME	STOPTIME
35839	1048	8	104016		19911016	19930412	19911101	19930428
97151	1419	125	107005		19911016	19970809	19911021	19970810
61922	1065	203	104001		19931116	19951115	19941117	19951118
90341	1460	207	107001		19920402	19950101	19920403	19950102
46202	970	208	107001		19950102	19961001	19950103	19961002

Figure 8 Sample Query results

To retrieve spatial objects by use of primitive relations, the statement *For Each … In* is necessary. However, this is not yet finished in the implementation.

7. Summary and Discussion

This paper mainly discusses the approach for the identification of change processes. Basically we can identify the change process of spatio-temporal objects from its embedded spaces. Two embedding spaces – set-oriented and topological space- are discussed to derive the different primitive relations in a change. By combination of these relations in change process, theoretically all changes can be identified. The paper identifies the primitive relations in set-oriented space and topological space. In set-oriented space, there are two primitive relations: *succession* and *dependency*. In topological space eight primitive relations can be generated based on 4-intersection models. By use of them, a lot of change processes are identified. The identification, which is mathematically formalised, can greatly help us in designing the spatio-temporal query operators.

The above identification of qualitative change processes is based on set-oriented and topological relations and their combination. The geometric transformation (mainly it is quantitative) is not considered. By adding these transformations, more spatial change process can be differentiated. For example, if we add the relation as following:

$$Dis = \{ < A, A' >: A' = A + \Delta \}$$

Where Δ is a vector. We can tell the difference between such as generation and replication. However, because of its variety, it is impossible to list all of them. Despite its complexity, we can approach it from several aspects such as distance, direction, size, shape and so on. We will discuss it in the future research.

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