Defining and Representing Temporal Objects for Describing the Spatio-Temporal Process of Land Subdivision

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ABSTRACT

In order to model and represent the spatio-temporal process of land subdivision, the space-time composite model proposed by Langran is extended in this paper. By defining and distinguishing temporal objects and active objects, the geometric and thematic states of land parcels during their lifespan can be represented in the extended space-time composite model and maintained in the land-related spatio-temporal database. The spatio-temporal information concerning the land subdivision could therefore be referenced even after the land parcels completed their function. In addition, time is added at attribute-level in the extended model with non-1NF approach. Time in attribute-level can be considered at two levels; at the attribute value level and at the tuple level.

1. INTRODUCTION

During a process of land subdivision, the geometric components and thematic states of land parcels evolve (or change) over time. Change of parcels in land subdivision has two kinds: spatial and aspatial. During spatial evolution, the geometric components and thematic states of land parcels change. In aspatial evolution, only the attribute values of land parcels differ from before, while the geometric components remain unchanged. Furthermore, geometric change in land subdivision can be divided into two basic types: decomposition and consolidation. For instance, P1001 was the original land parcel at the starting time 1949 as shown in Fig.1. Due to land acquisition or other land development activities, P1001 was decomposed into smaller fragments P1002 and P1003 from 1949 to 1977. P1002 and P1003 were further decomposed into P1004, P1005, P1006 and P1007 during the time period from 1978 to 1983. The geometric components of the parcels P1005 and P1007 remain unchanged during the time period from 1984 to Tnow, but some of their attributes assumed different values over this period, such as the change of landuse due to land transfer or urban development. Moreover, P1004 and P1006 were consolidated and aggregated into a larger parcel P1008 according to permissible land transfer or other land-use options.

The current and historical data of land parcel configuration as well as land subdivision path are useful in planning, monitoring, regulating urban development, such as processing building applications and tracking issued permits [Vrana, 1989; Chen,1992]. In order to maintain the land-related spatio-temporal data and make them accessible to users, many efforts have been made by the academic and user communities to develop computerized LISs with GIS technology [Price, 1989; Langran, 1992; Guo, et. al., 1994]. However, these land parcel data would be maintained by the traditional GISs as a set of snapshots which provide a time-series view of the studied area and obscure the individual object history of land parcels and land transfer events [Langran, 1993a]. In addition, some problems with the expressiveness and consistency of spatio-temporal topology and attribute evolution of the land parcels remain unsolved [Edwards, 1993; Chen, 1994]. So the spatial data models appropriate for describing the spatio-temporal process of the land subdivision and designing the land-related spatio-temporal databases need to be developed.

The method of space-time composite was originally suggested by Chrisman (1983) and was described in detail by Langran and Chrisman (1988). In the compositing, each change causes the changed portion of the coverage to break from its parent object to become a discrete object with its own

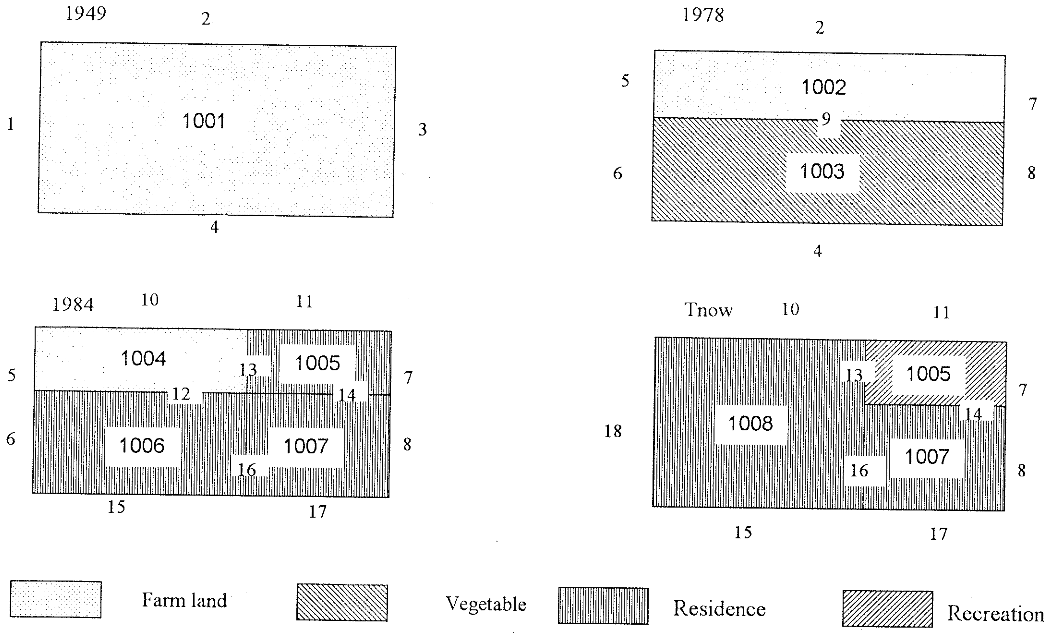

Figure. 1 Temporal states of land parcels during land subdivision

distinct history. By identifying units with coherent histories, the mutation of those units can be described by aspatial attributes. The mechanics of space-time compositing begin with a base map that represents a region's geometry and spatial topology at some starting time. Each database update session generates an overlays. Once accepted for permanent inclusion (having passed error-detection procedures), the overlay is incorporated into the system using the same intersection procedure currently used for polygon overlay [Dongenik, 1980]. New nodes and chains are added to the historical accumulation, forming new polygons that have attribute histories distinct from those of their neighbors. Accessing temporal information stored in the space-time composite is conceptually straightforward. To compile a single time slice from the composite, one has only to 'walk' the history list of each polygon to locate the attribute set that was current at the desired time slice.

But the space-time composite approach suffers two unfortunate side-effects: the representation decomposes into progressively smaller objects, and the identifiers of changed objects must be altered retroactively [Langran, 1992]. These shortcomings make it unsuitable to be used directly in modeling the spatio-temporal process of land subdivision. Therefore, it is extended in this paper by defining and distinguishing temporal objects and active objects.

2. EXTENDING THE SPACE-TIME COMPOSITE MODEL

Space-time composite model begins with the original coverage of polygons which will be decomposed increasingly into smaller segments, and employs the greatest common spatio-temporal units found in the time-slices as discrete database objects [Langran, 1992]. According to this concept, P1005 and P1007 would be the two greatest common spatio-temporal units found in the time-slices stamped with 1992 and T_{now} respectively. It means that in our examples, only P1005 and P1007 would be used as discrete database objects in the space-time composite model. However, the whole spatio-temporal process of the land subdivision could not be modeled and represented with these two parcel objects. First of all, the persistence of land parcels P1001, P1002, P1003, P1004 and P1006 were assumed from the first time they were created until the time they were superseded by another geometric decomposition or aggregation. Although they were not active in T_{now}, but they do have specific lifespan during the spatio-temporal process of land subdivision. The information concerning the geometric and thematic states of these parcels during their lifespan should be referenced even after they finished their function. In other words, these non-active parcels should also be referenced and maintained in the land-related spatio-temporal database. Secondly, an aggregated parcels would not be the common spatio-temporal unit according to the underlying principle of the space-time composite model. For instance, P1008 is one object from the point view of land subdivision; but it is described by P1004 and P1006. Hence, P1008 is not a common unit and can not be represented directly in the space-time composite. In fact, the parcels could not only be carved into smaller segments during the process of land subdivision, but also be consolidated or aggregated into larger parcels. Because in real world, people does regard the consolidated parcel as one object, not the smaller fragments which making up of it.

In order to solve the above problems, we propose to extend the space-time composite model by defining and distinguishing temporal objects and active objects, inspired by the temporal concept of Elmasri et. al(1993). A temporal object in our extended space-time composite model has its specific lifespan and should be referenced at any future time once it is created. An active object is an active temporal object who has specific starting time and has no ending time. According to this definition, P1001, P1002, P1003, P1004, P1005, P1006, P1007 and P1008 are all temporal objects and should be maintained as database objects. At the time Tnow, P1005, P1007 and P1008 are active temporal objects who have no ending time, while P1001, P1002, P1003, P1004 and P1006 are non-active temporal objects with specific ending times. The relationship between temporal objects and active objects in the extended space-time composite model is shown in Fig.2. XY in Fig.2 represent the x, y coordinates of the nodes and edges. Each land parcel that ever existing is database object represented in the extented spatio-temporal composite. Table 1 lists all the temporal parcel objects which need to be referenced in the extended space-time composite model. In addition, some relationships between these parcel objects need to be modeled which would reflect the land subdivision path. For instance, each time a land parcel is splited into two parcels with new identifies and distinct geometric components, there do exist a casual relation between the old parcel and the two new parcels. Modeling such casual relation will allow us to track the history of the subdivision of one parcel or track the parents of one new parcel.

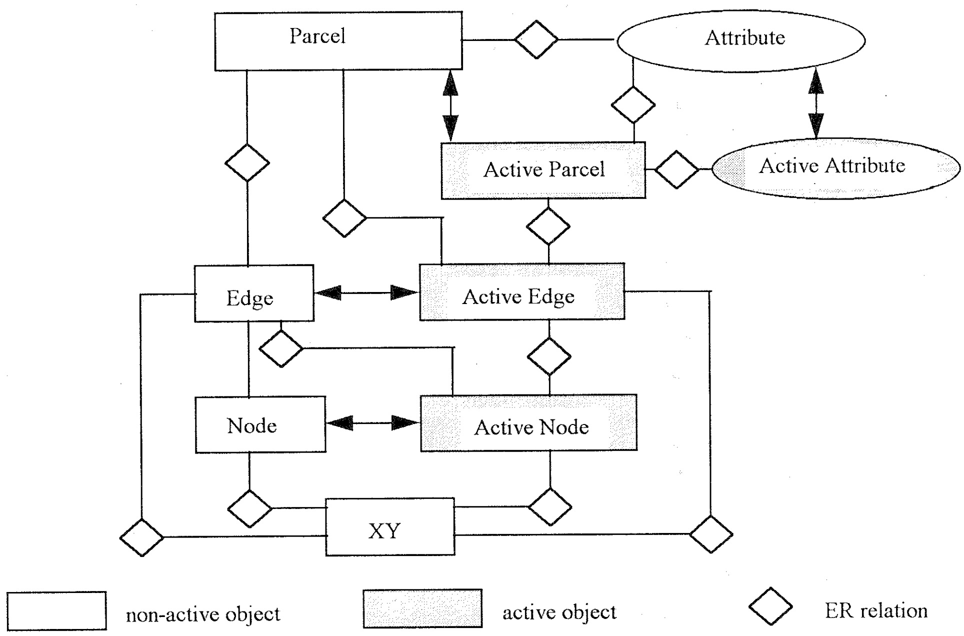

Figure.2 Temporal objects in Extended Space-Time Model

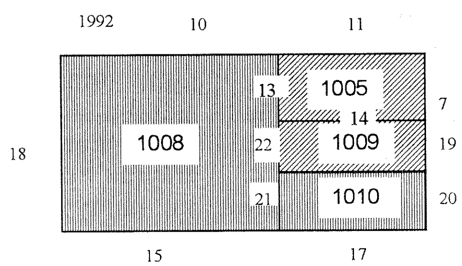

Fig.3 Further evolution of Parcel P1007

Object ID	Owner	Landuse	Area (km^2)	Tax Receipts	Ts	Te
1001	Mao,C.	Farm	4320	1110	1949	1977
1002	Chen, P.	Farm	2020	700	1978	1983
1003	Wang,H.	Vegetable	2300	1200	1978	1983
1004	Chen, P.	Vegetable	1200	700	1984	1992
1005	Yang, M.	Residence	820	1300	1984	1990
1005	Yang, M.	Recreation	820	1600	1991	–
1006	Li, H.	Residence	1500	2250	1984	1992
1007	Tang, Y.	Residence	800	1200	1984	1990
1007	Li,T.Y.	Residence	800	1200	1991	–
1008	L,H.	Residence	2700	4000	1993	–

Ts : starting time, Te : ending time , – : still active and has no ending time

Table 1: Temporal parcel objects in the process of land subdivision

Edge	Left_P	Right_P	Ts	Te
1	0	1001	1949	1977
2	0	1001	1949	1977
	0	1002	1978	1983
3	1001	0	1949	1977
4	1001	0	1949	1977
	1003	0	1978	1983
5	0	1002	1978	1983
	0	1004	1984	1991
6	0	1003	1978	1983
	0	1006	1984	–
7	1002	0	1978	1983
	1005	0	1984	–
8	1003	0	1978	1983
	1007	0	1984	–
9	1002	1003	1978	1983
10	0	1004	1984	1991
	0	1008	1992	–

Edge	Left_P	Right_P	Ts	Te
11	0	1005	1984	–
12	1004	1006	1984	1991
13	1004	1005	1984	1991
	1008	1005	1992	–
14	1005	1007	1984	1991
	1005	1009	1992	–
15	1006	0	1984	1991
	1008	0	1992	–
16	1006	1007	1984	1991
	1008	1007	1992	–
17	1007	0	1984	–
18	0	1008	1992	–
19	1009	0	1992	–
20	1010	0	1992	–
21	1008	1010	1992	–
22	1008	1009	1992	–

Explanation:

0 : the outside polygon; – : still active and has no ending time;

Left_P: left polygon of the edge; Right_P: right polygon of the edge;

all horizontal lines' direction are up ↑ ; and all vertical lines' direction are right → .

Table 2. Changed spatial contiguity of temporal parcel polygons

It is evident that representing the above temporal parcel objects requires alteration of the spatial topology stored in the space-time composite. After adjusting or subdividing lot lines, new geometry for parcel boundaries would be formed and the topological elements of some parcel polygons would also be updated. The changed spatial contiguity of each parcel polygons is shown in Table 2. On one hand, each edge is used to make up two parcel polygons for a specific time interval, but it might be used in the sequential time period of its lifespan to make up different temporal parcel polygons. For instance, edge 5 was to make up P1002 and P1004 from 1978 to 1991 and from 1992 to Tnow respectively. On the other hand, the edges of a given temporal parcel polygon might be changed during its lifespan. For example, P1008 is made up of edges 10, 13, 16, 15, 18. If P1007 is splited into P1009 and P1010 as shown below in 1992, then P1008 is made up by edges 10, 13, 22, 21, 15, 18 from 1992 on.

Because edge 16 is splited into edges 22 and 21. In fact, the spatial contiguity relations between edges and parcel polygons might change over time. In other words, there do exist spatio-temoral contiguity relations (such as the contiguity relation between the temporal polygons and temporal edges) which need to be modeled in our extended space-time composite model.

3. ADDING TIME AT ATTRIBUTE-LEVEL TO TEMPORAL OBJECTS

It can be seen from Table 1 and Table 2 that each temporal object has a list of attribute values stamped with the time intervals when these attributes are valid. In fact, when a new parcel object is created, a new attribute tuple representing its distinct attributes would be appended. Any geometric or thematic change of the parcel object would cause the current tuple be stamped with an ending time and a new tuple would be appended if the object remains active. The distinct history and attribute evolution of the temporal objects could be reflected and referenced with these temporal attribute sets which are 'current' at a particular points over some period of real-world time. It is therefore essential to add time to the attribute sets and chain (or link) them along the time axis.

There are three basic approaches for adding the real-world time to attribute sets when they are handled in a related DBMS (RDBMS), i.e., adding time on a new version of a table, on a new version of tuple or on a new version of an attribute [Transel, 1986; Navathe, et.al., 1989; Ling, et.al., 1992; Langran, 1992; Raafat, et.al., 1994]. Adding time to a new version of table is highly redundant and individual object histories are obscured. Langran pointed out in 1992 that 'the tuple-level versioning' permits better temporal resolution than the relation-based approach and at lower storage costs, and most of the relational theories and algebra apply, but the problems with expressiveness, consistency, and joins across time do exist; attribute-level versioning is obviously compact but requires alternate relational algebra to manage [Langran, 1992]. It was proposed by Chen in 1994 to adding time at attribute-level in the space-time composite model which permits a more logical and non-redundant representation of the spatio-temporality. However, the derived relations are of non-1NF (non-First Normal Form) relations which could not handled directly by traditional relational DBMS and relational algebra. The conceptual issues on the data construct and temporal object used for managing in the temporal attribute sets with non-1NF approach were examined by the author [Chen, 1994].

4. ORGANIZING TEMPORAL OBJECTS IN THE EXTENDED SPACE-TIME COMPOSITE

By distinguishing and organizing temporal objects and active objects, the geometric and thematic states of land parcels during their lifespan can be represented in the extended space-time composite model and maintained in the land-related spatio-temporal database. The spatio-temporal information concerning the land subdivision could therefore be referenced even after the land parcels completed their function.

As discussed above, change of parcels in land subdivision has two kinds: spatial and aspatial. During spatial evolution, the geometric components and thematic states of land parcels change. In aspatial updating, only the attribute values of land parcels differ from before, while the geometric components remain unchanged.

4.1 Data Construct of Aspatial Temporal Object

In the non-1NF approach proposed by Chen in 1994, aspatial attributes are divided into three types: static attributes, synchronous time-varying attributes and asynchronous time-varying attributes. Static attributes keep 'static' during the lifespan of the temporal object, synchronous time-varying attributes change over time synchronously, and asynchronous time-varying attributes alter respectively.

The following data construct is used for representing the non-1NF relations

$$\{ID, <Sj_1, Sj_2, ..., Sj_m, Tj>, \{<Vi_1, Vi_2, ..., Vi_n, Ti>\}\}$$

Where (Sj_1, Sj_2, ..., Sj_m, Tj) is a list of static attributes and Tj=(Tjs, Tje). {<Vi_1, Vi_2, ..., Vi_n, Ti>} is a list of synchronous time-varying attributes. When i_n = 1, Vi would be an asynchronous time-varying attribute. Following this definition, Table 1 and Table 2 can be stated respectively as :

[Parcel_ID,(Area, Own, Ts_1, Te_1),
< Name, Ts_2, Te_2>, < Use, Ts_3, Te_3>]

[Edge_ID, < LeftPoly, RightPoly, Ts, Te>]

4.2 Data Construct of Spatial Temporal Object

Spatial evolution in land subdivision has two basic types: decomposition and consolidation. Aspatial updating and spatial updating differs greatly on the number of 'parents' and 'sons' also called 'history'

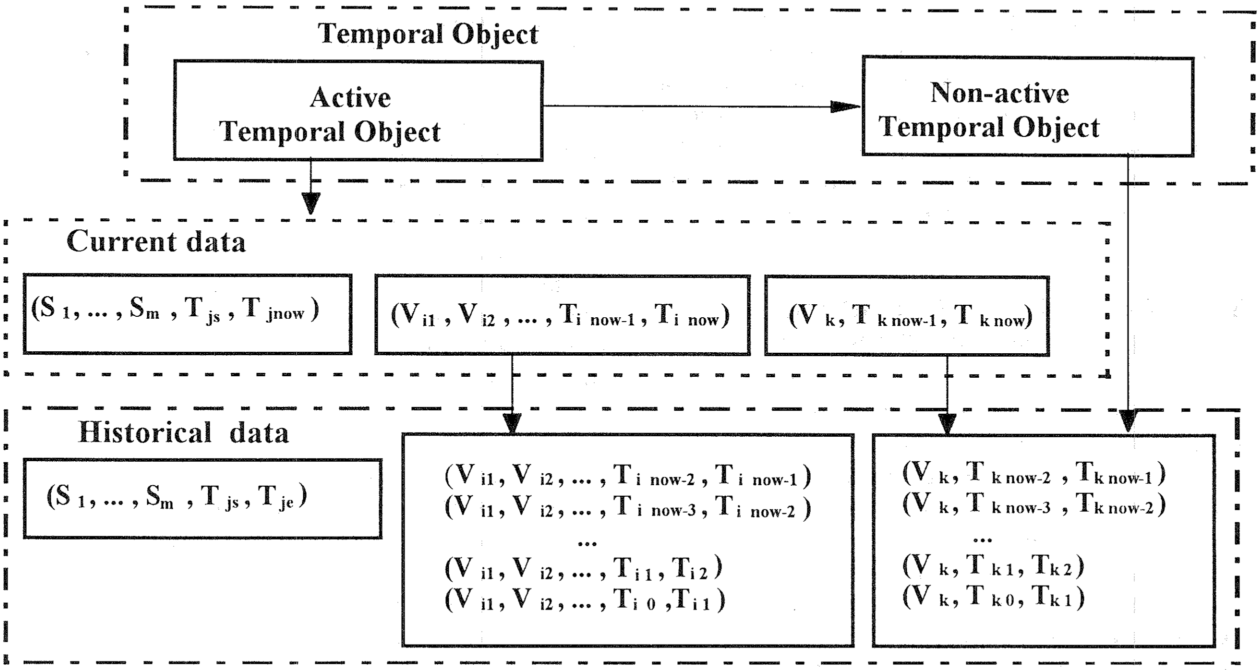

Fig.4 Temporal aspatial data in the non-1NF model

Record_No	ID	...	Ts	Lh
1	1005	...	1984	2
2	1007	...	1984	3
3	1008	...	1992	4

Table 3. Current database

Record_No	ID	L
1	1002	2
2	1003	3
3	1004	4
4	1005	-1
5	1006	5
6	1007	-2
7	1008	-3

L < 0: the parcel is in current database;
L > 0: the land parcel is historical database;

Table 4. Future index database

Record_No	ID	...	Ts	Te	Lh	Lf	Numof Son
1	1001	...	1949	1977	0	1	2
2	1002	...	1978	1983	1	3	2
3	1003	...	1978	1983	1	5	2
4	1004	...	1984	1991	2	7	1
5	1006	...	1984	1991	3	7	1

Table 5. History database

and 'future' of the 'current' parcel. There is only one 'parent' and one 'son' active land parcel has no 'son' in aspatial updating. But in land decomposition or consolidation, there are more than one 'sons'or 'parents' So, we can not treat spatial change in the same way we treat aspatial change. The following data construct is used to represent the spatial temporal object:

Current data: {ID, ..., Ts, Lh}
History data: {ID, ..., Ts, Te, Lh, Lf, NumofSon}
Future index: {ID, L}

Where '...' stands for attributes of the land parcel. Lh is record_number of its 'parents' in history database. And Lf is the record_number of its son's index in future index database. Since records in the current database would be deleted when they became history, we need L to maintain the correct linkage. NumofSon shows how many sons it has. All sons' index are recorded sequentially in the future index database. In decomposition, NumofSon is greater than 1; but in consolidating , NumofSon is 1.

According to this definition, we can get Tables describing the process of land subdivision in Fig.1 at the time Tnow.

From Table 5, we know that temporal land parcel P1001 was valid from 1949 to 1977, its parent is not recorded in the temporal database (Lh = 0). And P1001 decomposed into P1002 and P1003, which are the first (Lf = 1) and second record in Table 4. Furthermore, we can read that P1003 is the fourth record in history database.

Also, we know P1008 is an active object with no ending time and no future at Tnow. From Lh = 4, we track its history P1004, the fourth record in Table 5. Since P1004's NumofSon equals 1, P1008 is consolidated from several parcels. So Lf of the fifth record, the next record of P1004, is compared with that of P1004. Because they both equal 7, then the fifth record (P1006) is also P1008's history.

Generally speaking, with the three databases, the spatio-temporal information concerning the land subdivision could be referenced.

4.3 Organize Spatial and Aspatial Attributes in the Extended Space-Time Composite

In the process of land subdivision, a parcel changes its ID only when its geometry changes. So time in attribute-level can be considered at two levels; at the attribute value level and at the tuple level. Times at tuple level, the first level, defining the geometric and static thematic states of land parcels, while time at attribute value level, the second level, representing the dynamic thematic states of land parcels. In order to reference a temporal land parcel, tuple level is firstly located, then the attribute value level.

5. SUMMARY

It has been becoming crucial for more and more GIS application projects now to add time dimension in GISs and make temporal data accessible to users [Gagnon, et.al; 1992; Langran, 1993b; Al-Taha, et.al., 1994]. In the case of land subdivision, one of the fundamental issues is to develop a descriptive formalism for the time-related spatial phenomena which can be used to help specify and structure spatial-temporal databases. The space-time composite model proposed by Langran was extended in this paper by defining and representing temporal objects and active objects. Further development and implementation of the extended space-time composite model for land subdivision is current under investigation by the author's research group at LIESMARS.

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