RESEARCH ON THE EVENT-DRIVEN SPATIO-TEMPORAL DATABASE FOR LAND SUBDIVISION SYSTEM

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ABSTRACT

The spatio-temporal database for a collaborative decision making system supporting land subdivision is "event-driven". Both various states of spatial objects and the events cause the objects change need to be recorded and manipulated in the database. To achieve this, the authors analyzed the characteristics of events in land subdivision process and studied how events affect the states of spatial objects. An approach was proposed to represent the land subdivision process and a formal specification language was introduced to describe the execution of event sequence. With this approach, events and the causal relations between events and states can be recorded and managed in the spatio-temporal database in a land subdivision system. And a new way for simulating system work-flow was also found.

1 INTRODUCTION

GIS has been used in the urban planning and land management fields for spatial data handling in China since 1990s. Various maps and related attributes are put into spatial databases and people can query, analyze and print these data when they make decisions. In such databases, spatial entities are modeled as points, lines and polygons. Geometric information and attributes are managed separately. Identifiers are used to connect the spatial objects and their attributes. It is the snapshot of spatial entities at certain instant and the static relations among them are recorded and represented in such spatial databases. However, sometimes spatial entities change in shape, location, attributes and spatial relations among each other along with time due to the development of urban construction. People try to extended the traditional vector or raster based data model to describe changes of the spatial objects, such as the space-time cube model, sequent snapshots model, space-time composite model and N1NF model (Langran, 1992; Chen, 1995; Huang, 1997). Such models can represent states of spatial objects at different instants.

Recent years many urban planning and land management agencies begin to build GIS based CSCW (Computer Supported Cooperative Work) system for land subdividing. In such kinds of applications, staffs need to reference not only the states of spatial objects at different instants, but also the reasons cause the objects change, that is the decision behaviors of the land managers. New data might be created by the staffs in each decision process and they should be stored in the spatial database together with the corresponding decision behaviors. So the spatio-temporal database of land subdivision system is "event-driven", where event means the decision behaviors. Both the states of spatial objects in different instants and the events cause them change need to be represented in such spatio-temporal databases.

There have been some initial efforts to describe events in spatio-temporal data model. For instance, Peuquet et al. (1995) proposed an event-based spatio-temporal data model (ESTDM) where an event represents a change in state and the sequence of events through time representing the spatio-temporal manifestation of some process is noted via a time-line called 'event list'. Events in this model represent the change in state, but not the cause of the change. Claramount et al. (1995, 1996) modeled events as a set of processes that transform entities and describe events with object versions. Topologically-based temporal operators are constructed to model and distinguish evolution, succession, production, reproduction and transmission processes of spatial entities. But these operators can access only immediately adjacent entities or versions. The lineage among grandparents and grandchildren can't be checked out. Allen et al. (1995) also considered events as changes of state in objects. The "causal model" they proposed can't represent causal connections between events. Tao Cheng et.al. (1998) represented the changes of natural phenomena as a set of dynamic processes(move, erode, split, etc.). But the reasons cause these processes are excluded. It is obvious that events are now generally used to identify the beginning and end of a state of certain spatial object. Further work need to be done to study the characteristics of complex decision behaviors in land subdivision and represent the causal relations between such behaviors and states of spatial objects in the spatio-temporal databases.

The authors of this paper studied the process of a GIS based CSCW system for land subdivision and an approach was proposed to represent the events and the causal relations between events and states of spatial objects. Here events mean the decision behaviors in land subdivision process. They are not only the identifiers of beginning or end of states of spatial objects, but also the reasons cause the changes. The paper is organized as follows. The next section presents an analysis of events in land subdivision process and a method is proposed for describing events and also the causal relations between events and states. The formal specification of event expression and event operators is given in section 3. Based on a case study, event histories are used to represent the occurrence process of composite events which are consists of sequence of primitive events. Conclusions and future work are summarized in section 5.

2. EVENTS IN LAND SUBDIVISION PROCESS

Land subdivision is a collaborative decision making process executed by a group of urban planners and land managers who are located in different geographic locations (rooms) within the organization. An application submitted by public agencies or private citizens is reviewed by the staffs of the organization according to certain work-flows and regulations. At the end of the reviewing, either a legal permit that prescribes both geometric and thematic states of the land parcel or a notice that inform why the application is rejected will be issued to the applicant. As Fig.1 shows, an applicant submits an application (called a project by the staff) to the land management organization for a parcel of land. The staffs of the organization review this application step by step. Generally three stages have to be gone through, that is site locating, landuse permitting and title registering. Where site locating gives the location of the project, landuse permitting legalizes the property and boundary of the parcel, and title registering issues the title deed. Each stage is executed by different department or working group. And in each department or working group, staffs at different position (e.g. Directors, general office clerks, etc.) have different duty and authorities, such as putting forward draft opinions and confirming the ideas, etc. The various decision behaviors executed by different decision-makers can be viewed as events. The execution of these events might form different states of the land parcel being reviewed, such as the location, landuse boundary and the registered property. From the point of view of information handling, execution of event sequence forms the work-flow of land subdivision system.

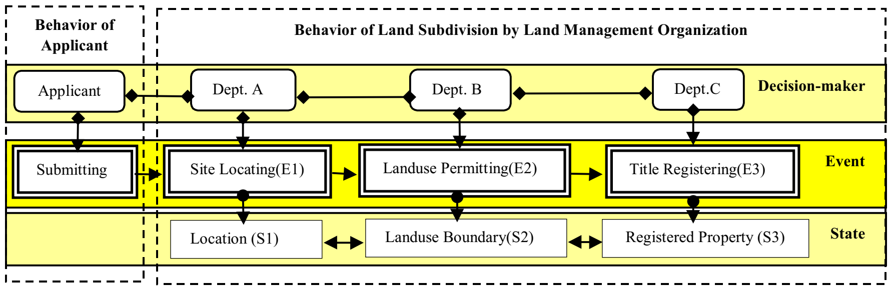
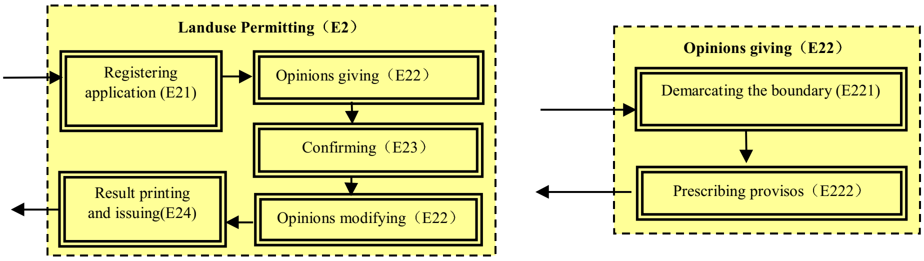


Fig.1 Sequence of events compose land-subdividing process

Events in land subdivision have the following characters:

(1) Events in an event sequence occur orderly. As shows in Fig.1, event E1 occurs before E2. And E3 can not begin until E2 is finished.

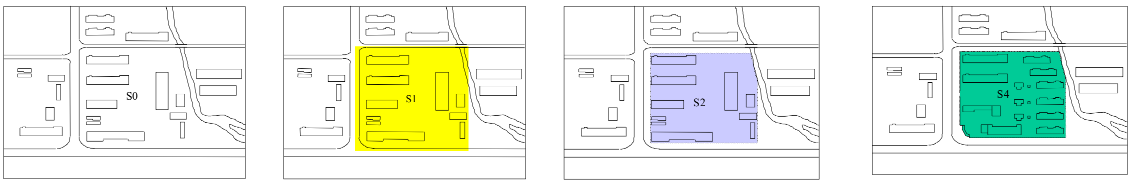
(2) Event is hierarchical. The most prime event is called primitive event. Several primitive events (and other composite events) combined by certain rules form a composite event. The primitive event is defined according to the requirement of application. For instance, the whole land subdivision process in Fig.1is a composite event. It consists of sub-events E1, E2 and E3. Among them E2 is also a composite event which consists of E21~E24 (Fig.2a). Where E21 means the registering application by office clerks; E22 means giving draft opinions by office clerks (including drawing the outline of landuse boundary and assigning attributes); E23 means examining and approving the draft opinions by the director; E24 means printing and issuing the reviewing results. Further more, E22 again can be viewed as a composite event. It can be decomposed into E221(demarcating the boundary of landuse) and E222 (prescribing provisos) (Fig.2b). Of course E221 and E222 can be decomposed into more detailed operations, such as input of a parameter or trigger of the mouse.



(a) (b)

Fig.2 Hierarchical Events

(3) There exist causal relations between events and states of land parcels. A state of the parcel, including the shape, location, attributes and spatial relations between each other, begins with an event and ends with another event. For example, S0 in Fig.3a is the initial state of a land parcel. After site locating E1 the location of the parcel S1 is formed (Fig.3b). That means E1 creates S1 and ends S0 at the same time. Then E2 modifies S1 and creates landuse boundary S2 (Fig.3c). S3 is the boundary of registered property confirmed by E3 (Fig.3d). These different states of a land parcel correspond to each other. It should be noticed that not all events operate the spatial objects directly. For example, only E22 in E2 directly modifies the shape, location or attribute of S1 (Fig.2).



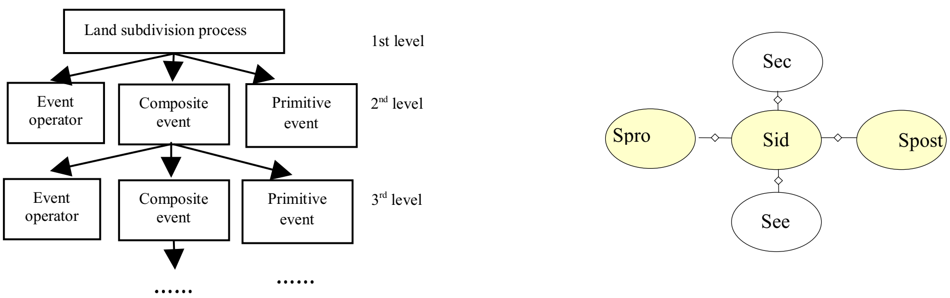
(a) Initial state S0 (Before E1)　(b) Site Location S1 (Created by E1)　(c) Landuse Boundary S2 (Created by E2)　(d) Registered Property S3 (Confirmed by E3)

Fig.3 Events change the states of spatial objects

Based on above analysis, we propose following approach to describe events and causal relations between events and states.

(1) The land subdivision process is a hierarchical composite event that consists of primitive events (and other composite events) and event operators (Fig.4a). An event can be described with a tuple (Eid, Ea, Epro, Es, Epost), where Eid is identifier of the event; Ea is attribute of the event; Epro is precondition of the event occurrence; Es is subsequence effects of the event occurrence. The id is a character string representing hierarchy and generalization. For instance, E2 in Fig.2 is a composite event, the sub-events of E2 are E21,E22, ……, E24. The sub-events of E22 are E221, E222, …….

(2) A state of a spatial object can be described by a tuple (Sid, Sec, See, Spro, Spost), where Sid is identifier of the state; Sec is the event that create the state; See is the event that end the state; Spro is the previous state; Spost is the post state. The landuse boundary in Fig.3c can be represented as (S2，E22，E3，S1，S3). This tuple describes not only the relation between spatial object and the related events, but also the corresponding relations between different states (Fig.4b).



(a)Structure of land subdivision event　　(b) Describing state of spatial object

Fig.4 Structure of land subdivision event and causal relations between events and states

3. EVENT EXPRESSIONS FOR LAND SUBDIVISION EVENTS

Formally representation of events and the process of their occurrence is essential for managing events and causal relations between events and states in the spatio-temporal database. In studying of active database and object-oriented database, Gehani et al.(1992a, 1992b), Claramunt et al.(1996) and Motakis et al.(1995) proposed the definition of event operators and event pattern language (EPL). Based on their achievements, we use the event expression to represent the events in land subdivision process. And several event operators are also used according to the characteristics of land subdivision, including OR、AND、ANY、SEQ、A、P、NOT、FIRST.

An event expression consists of primitive events (or composite events) and event operators. A primitive event name itself is an event expression. A composite event is also an event expression. For example, let E1, E2 event name, ∇ is an event operator. Then E1∇E2 is an event expression, means E=E1∇E2. Because an event E (either primitive or composite) occurs at an instant of time, it is a Boolean Function in the time domain. Given by

$$E(t)=\begin{cases}\text{T(rue) if an event of type E occurs at time point t}\\ \text{F(alse) otherwise}\end{cases}$$

The definition of event operators is as follows:

① OR operator (∇): Disjunction of two events E1 and E2, denoted E1∇E2, occurs when E1 occurs or E2 occurs. Formally $E(t) = (E1\nabla E2)(t) = E1(t) \vee E2(t)$

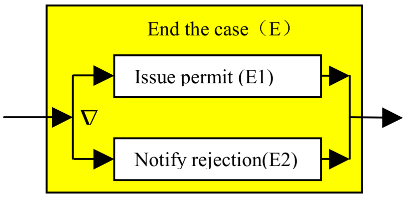


Fig.6 OR Operator

As Fig.6 shows, the result of a landuse permitting is either issuing a permit (E1) or notifying the rejection (E2). As long as one of E1 and E2 is executed, the case is ended (E). $E(t)=E1\nabla E2(t) = T$。

② AND operator (Δ): Conjunction of two events E1 and E2, denoted （E1ΔE2）, occurs when both E1and E2occur, irrespective of their order of occurrence.

Formally, $(E1\Delta E2)(t) = (\exists t1)(((E1(t1) \wedge E2(t)) \vee (E2(t1) \wedge E1(t))) \wedge t1 \le t)$

For example, when a staff accept a case, he must register the application (E1) and give his opinion (E2) first. And then transfer the case to the director for confirming (E). This means that E can't occur until both E1 and E2 occur.

③ ANY operator: The conjunction event, denoted by ANY（m,E1,E2,…,En）where m≤n, occurs when m events out of the n distinct events specified occur, ignoring the relative order of their occurrence. Formally,

$$ANY(m,E1,E2,\ldots,En)(t) = (\exists t1)(\exists t2)\ldots(\exists tm\text{-}1)\,(Ei(t1) \wedge Ej(t2) \wedge \ldots \wedge Ek(tm\text{-}1) \wedge El(t)$$
$$\wedge (t1 \le t2 \le \ldots \le tm\text{-}1 \le t) \wedge (1 \le i,j,\ldots,k,l \le n) \wedge (i \ne j \ne \ldots \ne k \ne l))$$

④ SEQ operator (;): Sequence of two events E1 and E2, denoted E1;E2, occurs when E2 occurs provided E1 has already occurred. This implies that the time of occurrence of E1 is guaranteed to be less than the time of occurrence of E2.

Formally, $(E1;E2)(t) = (\exists t1)(E1(t1) \wedge E2(t) \wedge (t1<t))$

⑤ Aperiodic operator (A): The aperiodic operator A allows one to express the occurrences of an aperiodic event within a closed time interval. Expressed as A(E1,E2,E3), where E1, E2 and E3are arbitrary events. The event A is signaled each time E2 occurs within the time interval started by E1 ad ended by E3. Formally,

$$A(E1, E2, E3)(t) = (\exists t1)\,(\forall t2)(E1(t1) \wedge E2(t) \wedge (t1 \le t) \wedge ((t1 \le t2 < t) \rightarrow \sim E3(t2)))$$

⑥ Periodic operator (P): A periodic event is a temporal event that occurs periodically. Denoted as P(E1,TI,E3), where E1 and E3 are events and TI is a time interval specification. P occurs for every TI interval, starting after E1 and ceasing after E3. Formally,

$$P(E1,TI,E3)(t) = (\exists t1)\,(\forall t2)(E1(t1) \wedge (t1 \le t2 \le t) \rightarrow \sim E3(t2))$$
$$\wedge (t=t1+i*TI \text{ for some integer } i \ge 1)$$

This operator can be used to monitor the work process. That is to detect the process and give out instructions at certain time interval.

⑦ NOT operator ($\neg$): Denoted $\neg$（E2）[E1,E3], the NOT operator detects the non-occurrence of the event E2 in the closed interval formed by E1 and E3. Formally,

$$\neg(E2)[E1, E3](t) = (\exists t1)(\forall t2)(E1(t1) \wedge \sim E2(t) \wedge E3(t) \wedge ((t1 \le t2 \le t) \rightarrow \sim E2(t2) \vee E3(t2))))$$

⑧ FIRST operator ：FIRST(E) occurs when the first event in E occur.

4. REPRESENTATION OF COMPOSITE EVENT OCCURRENCE

The event expression describes the instant behaviors. To represent the process of event sequence occurrence, we need use the event history proposed by Chakravarthy et.al.(1994). We denote an occurrence of an event Ej by e_j^i, where i indicates the relative time of occurrence with respect to other occurrences of the same event. A set of all primitive event occurrences is called global event history and is denoted by H. A set of the occurrence of the primitive event E present in the global history H is called primitive event history and is denoted by E[H]:

$H=\{\{e_j^i\}|$ for all j, primitive event $\{e_j^i\}$has occurred at instance i relative to events Ej }

$Ej[H]=\{\{e_j^i\}|$ for all i, $\{e_j^i\} \in H\}$

Composite events are represented as a set of constituent event occurrences within which the order of event occurrences is preserved. Composite event history of a composite event E that has n constituent events E1, …, En is E[H] = $E1[H] \overset{+}{\cup} \ldots \overset{+}{\cup} En[H]$, where $\overset{+}{\cup}$ is an operator that computes the merged-Cartesian product.

Given a global event history H, the event history for a composite event formulated using the operators defined in previous section can be computed.

① $(E1\nabla E2)[H] = \{e \mid e \in E1[H] \cup E2[H]\}$

② $(E1\Delta E2)[H] = \{\{e^i, e^j\} \mid \{e^i, e^j\} \in ((E1[H]\overset{+}{\cup}E2[H]) \cup (E2[H]\overset{+}{\cup}E1[H]))$ and $t\_occ(e^i) \le t\_occ(e^j)\}$

③ ANY(m,E1,E2,…,En)[H]=
$\{\{e^i,e^j,\ldots,e^k\} \mid t\_occ(e^i)<t\_occ(e^j)<\ldots<t\_occ(e^k)$ and $|\{e^i,e^j,\ldots,e^k\}|=m\le n$ and $\{e^i,e^j,\ldots,e^k\}\in P(\text{element})\}$

Where P is the power set and element is a member of the set:

$$E_{\pi 1}[H]\overset{+}{\cup}E_{\pi 2}[H]\overset{+}{\cup}\ldots\overset{+}{\cup}E_{\pi m}[H]$$

Each πI can be any i from 1 to n.

④ (E1；E2)[H] = $\{\{e^i,e^j\}\} \mid t\_occ(e^i)<t\_occ(e^j)$ and $\{e^i,e^j\} \in E_1[H]\overset{+}{\cup}E_2[H]\}$

⑤ A(E1,E2,E3)[H] = $\{\{e^i,e^j\}\} \mid t\_occ(e^i)<t\_occ(e^j)$ and $\{e^i,e^j,e^k\} \in E_1[H]\overset{+}{\cup}E_2[H]\overset{+}{\cup}E_3[H]\}$

⑥ P(E1,TI,E3)[H]=

$\{\{e^i,t\}\} \mid$ for all $\{e^i,e^k\} \in E_1[H]\overset{+}{\cup}E_2$ and $t\_occ(e^i)+j*TI$ for integer $j \ge 1$ and $t \le t\_occ(e^k)\}$

⑦ $\neg(E_2)[E_1,E_3][H] = \{\{e^i,e^j\} \mid \{e^i,e^k\} \in E1[H]\overset{+}{\cup}E3[H]$ and $\wp(E_2, t\_occ(e^i), t\_occ(e^k)) = \varnothing\}$, where function $\wp$ is a collection of all event occurrences of E2 within the time interval (t-occ(e^i),t-occ(e^k)).

$$\wp(E, start\_time, end\_time) = \{e \mid \{e\} \in E[H] \text{ and } start\_time \le t\_occ(e) \le end\_time\}$$

We use the example in Fig.2 to illustrate the computation of a composite event. The composite event E2 can be expressed as E2= ((E21ΔE22); E23; (E22ΔE24)) . This expression means E2 occurs according to the following sequence. Firstly the office clerk registers the application (E21) and gives his draft opinion (E22). Then the case is transferred to the director for confirming (E23). After that the case returns to the office clerk again. The clerk modifies the boundary and provisos according to the director's opinion (it's the same operation with previous E22), then prints and issues the permit to the applicant (including the final provisos and landuse boundary)(E24). Among them only E22 change the state of land parcel directly. E21,E23 and E24 occur once and E22 twice (Fig.5). The primitive event history is:

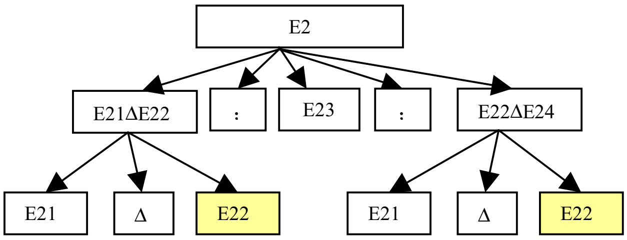


Fig.5 Structure of E2

$E21[H]= \{\{e^1_{21}\}\}$,
$E22[H]= \{\{e^1_{22}\},\{e^2_{22}\}\}$
$E23[H]= \{\{e^1_{23}\}\}$,
$E24[H]= \{\{e^1_{24}\}\}$

According to previous definition,

$$(E21\Delta E22)[H]=\{\{e^i,e^j\}\mid\{e^i,e^j\}\in((E21[H]\overset{+}{\cup}E22[H])\cup(E22[H]\overset{+}{\cup}E21[H]))\text{ and }t\_occ(e^i)\le t\_occ(e^j)\}$$

$$=\{\{e^1_{21},e^1_{22}\},\{e^1_{21},e^2_{22}\}\}$$

$$(E22\Delta E24)[H]=\{\{e^i,e^j\}\mid\{e^i,e^j\}\in((E22[H]\overset{+}{\cup}E24[H])\cup(E24[H]\overset{+}{\cup}E22[H]))\text{ and }t\_occ(e^i)\le t\_occ(e^j)\}$$

$$=\{\{e^1_{22},e^1_{24}\}\{e^2_{22},e^1_{24}\}\}$$

$$E2[H]=((E21\Delta E22);E23;(E22\Delta E24))$$

$$=\{\{e^i,e^j\}\}\mid t\_occ(e^i)<t\_occ(e^j)\text{ and }\{e^i,e^j\}\in((E21\Delta E22)[H]\overset{+}{\cup}E23[H]\overset{+}{\cup}(E22\Delta E24)[H])\}$$

$$=\{\{e^1_{21},e^1_{22},e^1_{23},e^1_{22},e^1_{24}\},\{e^1_{21},e^1_{22},e^1_{23},e^2_{22},e^1_{24}\},\{e^1_{21},e^2_{22},e^1_{23},e^1_{22},e^1_{24}\},\{e^1_{21},e^2_{22},e^1_{23},e^2_{22},e^1_{24}\}\}$$

This result means there are four possible occurrences of the event E2, that is $\{e^1_{21},e^1_{22},e^1_{23},e^1_{22},e^1_{24}\}$ 、 $\{e^1_{21},e^1_{22},e^1_{23},e^2_{22},e^1_{24}\}$ 、 $\{e^1_{21},e^2_{22},e^1_{23},e^1_{22},e^1_{24}\}$ 和 $\{e^1_{21},e^2_{22},e^1_{23},e^2_{22},e^1_{24}\}$ respectively. But only the second one $\{e^1_{21},e^1_{22},e^1_{23},e^2_{22},e^1_{24}\}$ makes sense in practice. Restriction and detection mechanism should be introduced to select tenable result (The authors will discuss this topic in other papers). Thus we can get the value of E2(t) by computing the occurrence of E21~E24.

5 CONCLUSIONS

An approach was proposed in this paper, which can describe the events and causal relations between events and states of spatial objects in the land subdivision process. This approach might be used in a GIS based CSCW system for land subdivision to fulfill thefollowing tasks:

(1) Record and manage events that cause the states of land parcel change in the spatio-temporal databases. The state of a land parcel is linked with the events that create or end it. Other events are connected with this state through event expressions and event histories. An additional advantage of this approach is that the dependence of the spatio-temporal database to the work flow of the system is reduced because only part of the events out of the event sequence are connected directly to the spatial objects in the databases.

(2) Provide a radically new way for the system procedure controlling. The work-flow (event sequence) of a land subdivision system might change due to re-engineering or adjustment of the land management organization. Current systems usually use control-flow and data-flow to represent the execution of work-flow and the procedure of data processing. In this technique a control table is defined in the database according to the work-flow. Each decision event corresponds to a field in the table. When an event occurs, the field is updated accordingly and the spatial objects in the database are modified consequently. In case the work-flow of the system change, the control table has to be modified and the schemas of the spatio-temporal database evolve. This makes troubles for system maintenance and also spoils the flexibility of the system. Generally, no matter how the work-flow of the land subdivision system changes, some basic operating units hold the line, such as E21~E24 in our previous example. With the approach proposed in this paper, only these primitive events are managed by the database. The occurrence patterns and results of composite event can be computed through the occurrence of the primitive events. When the work-flow change, what we need to do is just modify the event expression of the composite events. The database schemas can keep unchanged. This provides a new way for simulating system work-flow and it might also be useful for CASE tool design.

Further study will focus on some key technology for implementation of the spatio-temporal database of land subdivision, such as the specification of structural schema and behavior schema, the restriction condition of event occurrence and the detection mechanism, data organization and index mechanism, etc. And a prototype system is also under consideration.

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