

An IAES Model for Spatio-temporal Process of Land Subdivision

Jie Jiang^{1,2} Jun Chen¹

¹ National Geomatics Center of China
No.1, Baishengcun, Zizhuyuan, Beijing, 100044
(jiangjie, jchen)@gps.ceic.gov.cn

² China University of Mining and Technology, Beijing
D11 Xue Yuan Road, Beijing, 100083

ABSTRACT In some spatio-temporal process related GIS applications, not only the structural aspects, but also behavioral aspects need to be modeled. A GIS-based CSCW (Computer Supported Cooperative Work) system for land subdivision in urban planning and land administration is such an application. By analyzing the spatio-temporal process of land subdivision in Changzhou Municipality, we found that the states, events, agents and their relations should be taken into consideration for modeling both the structural and behavioral aspects. Traditional GIS models only describe the states of spatial objects and their relations, which are the structural aspects of the process. There also exists some initial efforts to consider behavioral aspects in spatio-temporal process, such as event-based spatio-temporal data model proposed by Peuquet (1995), Claramunt (1995) and 'causal model' proposed by Allen(1995). However, none of them can give out an overall description of the states, events, agents and causal relations among them. An expressive model IAES (Integrated Agent-Event-State) is presented in this paper by the authors to represent states, events, agents and various causal relations among them. In addition, a visual language is designed with formal definitions of agent, event, state and their relations. With this model, both structural and behavioral aspects of spatio-temporal process can be represented explicitly. **KEY WORDS** Process modeling, Spatio-temporal process, Computer Supported Collaborative Work (CSCW), Agent, Event, State, Land Subdivision, Temporal GIS

1. Introduction

GIS has been widely used in various fields. Among them there is one special kind which is used in some organizations to support collaborative decision making. For example, recent year many urban planning and land administration agencies have built GIS-based systems for land subdividing and building reviewing. Such kinds of systems are different from traditional GIS application in that despite being able to manage, query and analyze various spatiotemporal data dynamically, they should also provide the end user with an environment for handling the routing decision making work easily. So what we need to model is the whole spatio-temporal process, including components in the process and their static relations (we call them structural aspects), and dynamic causal relations among those components through which the system functions (we call them behavioral aspects).

Traditional GIS data models can only represent part of the structural aspects, that is states of spatial objects and their static relations. For example the ARC/INFO data model abstracts the geographical entities in real world as point, arc and polygon, and organizes them into coverages, layers or libraries. Although recently some people extended the traditional vector or raster based data model to describe changes of the spatial objects along time, such as the space-time cube model, sequent

snapshots model and space-time composite model (Langran, 1992). Still they take little consideration on the behaviors of organizations or people in spatio-temporal process and can't explain why the spatial objects change. Driven by the need to better understand the effects of man's activities on the natural environment, and with the development of object oriented technique, there have been some initial efforts to describe the behavior aspects in spatio-temporal process. For instance, Peuquet et al. (1995) proposed an event-based spatio-temporal data model (ESTDM) where an event represents a change in state (i.e., change in some property, or attribute, value) and the sequence of events through time representing the spatio-temporal manifestation of some process is noted via a time-line called 'event list'. Claramunt et al. (1995, 1996) proposed another event-oriented approach. It treated time as a complementary and independent facet of spatial and thematic domains. The temporal domain is represented by successive object versions accumulated in temporal structures. Spatial entities and their temporal versions are associated through links that describe the sequence of events and the properties of the spatio-temporal processes involved. However, in these two models, priority was still given to structural aspect because events are defined as changes of states of spatial objects, but not the dynamic behaviors themselves. Allen et al. (1995) developed a model

for representing causal links within a spatio-temporal GIS. The model consists of a number of elements (objects and their states, events, agents, conditions and relations). Where events are considered to be changes of state in objects and an agent may be one of several different types: a person, an animal, or an organization. This model may be used in dynamic system modeling, but the causal connections between agents, or from events to agents and the causal connections between events are excluded. However, none of current models can provide an overview of the system's behavior because they can't explicitly represent all components composing the spatio-temporal process and all essential causal relations among them. [Chen et al, 1998].

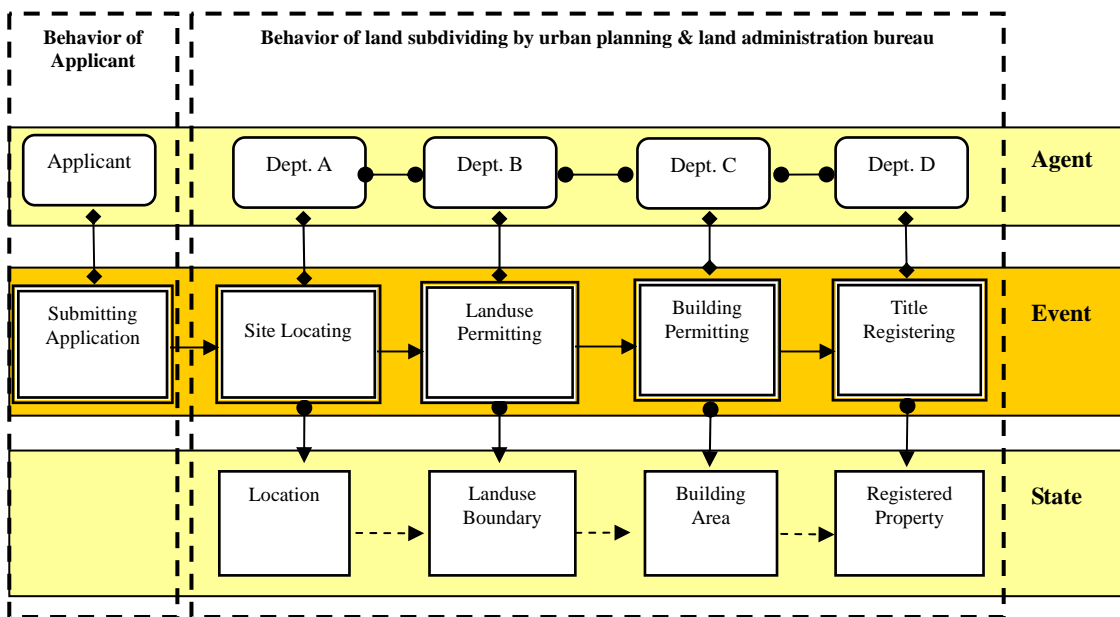
An expressive model IAES (Integrated Agent-Event-State) is proposed in this paper, which can explicitly elucidate all the components in spatio-temporal process and causal relations among them. In section 2, the spatio-temporal process is analyzed based on the case study of land subdividing system in urban planning and land administration bureau of Changzhou Municipality, Jiangsu Province, which is one kind of GIS-based CSCW (Computer Supported Collaborative Work) system. Three kinds of components are described, which are agent, event and state. The system functions through various relations among the three components. In section 3, a visual language is designed and formal definitions of agent, event, state and various relations are given. Further investigation is also discussed in this paper.

Land subdivision in an urban planning and land administration agency is a collaborative decision making behavior by a group of urban planners and land managers who are located in different geographic locations (rooms) within the organization. In different levels of position, persons or workgroups review applications submitted by public agencies or private citizens according to certain work-flows and regulations. As the results of the reviewing behavior, legal permits are issued to applicants that prescribe both geometric and thematic states of land parcels.

We use the example from the urban planning and land administration bureau of Changzhou Municipality, Jiangsu Province, to illustrate how this spatio-temporal process is carried through. Firstly, public agencies or private citizens submit an application (called a project by the staff) for a parcel of land. Then the application need to be reviewed step by step in the bureau. Generally four stages have to be gone through, that is site locating, landuse permitting, building permitting and title registering. Where site locating gives the location of the project, landuse permitting legalizes the property and boundary of the parcel, building permitting gives detail rules of construction within the parcel and at the end of reviewing, title registering issues the title deed.

As Fig.1 shows, from the point of view of behavior modeling, the whole process is the behavior of the bureau and it is consists of sequences of sub-behaviors. We call the various behaviors events, and the executant of each event agent. Affected by the events, spatial objects change in both spatial aspect and in attribute, thus have different states.

2. Agents, Events and States in The Land Subdividing Process



So there are three kinds of elements in land subdiv-

Fig.1 Sequence of events composed land-subdividing behavior

iding process, that is agent, event and state. Where agents means departments or persons who have the ability to make decisions in land subdividing process. Agents are hierarchical, they cooperate with each other in the land subdividing process. One agent can execute one or more events. Events represent various behaviors made by agents. They are also hierarchical, an event can be decomposed into sub-events. An event may be triggered by an agent or another event with or without certain preconditions. States are the results of events and different states of one parcel coexist in the database for querying and analyzing. Historical states and causal relations between different versions also need to be maintained. Among the three components, the events are the most important because agents have to act through them and states are results of them.

There are various relations among agents, events and states. Actually, the system functions through these relations. The following five kinds of relations are the most important for behavior modeling.

2.1. Relations Between Agents and Agents

(i) Hierarchical: An agent may consist of sub-agents. Father agent may supervise its son agents.

(ii) Collaborative: It's a dynamic process with actions such as require, reject, accept and inform.

2.2. Relations Between Events and Events

(i) Hierarchical: An event may be decomposed into sub-events.

(ii) Ordinal: An event begins with the ending of other events.

(iii) Synchronous: More than one event can occur at the same time.

(iv) Mutually exclusive: Some events cannot happen at the same time because of limitation of resource or other reasons.

2.3. Relations Between Agents and Events

(i) Participate in: Agents participate in events. One event can only have one agent, but one agent can execute many events.

2.4. Relations Between States and States

There exist two kinds of spatial objects in land subdividing process. That is midway results and final results (as shown in Fig.2). Different spatio-temporal relations exist in these two kinds of objects.

(i) Temporal topology: The temporal topology

exists between midway results of the same project, and between final results of different projects. In addition, there is also temporal topology between different versions of the final results of the same project.

(ii) Spatial relation: Spatial relations exist among all states of all objects.

(iii) Evolving: One state in a project develops from its previous state.

2.5. Relations Between Events and States

(i) Causal relation: Occurrence of events causes the states of spatial objects change.

3. An IAES Model for Describing the Spatio-Temporal Process

Based on above analysis, we propose an integrated agent-event-state (IAES) model intending to describe all the three components and relations among them.

3.1. Graphical Representation

A visual language is designed to describe the agents, events and states, as well as relations among them. As Fig 3 (a) shows, we use different container symbols to represent the three components. The round corner rectangle represents agent, double rim rectangle represents event and mongline rectangle represents state. And we also use different connector lines to represent different kinds of relations, except for the spatial topology and temporal topology that will be represented by formal methods. The hierarchical levels are also shown (Fig.3 (b), (c)).

We present an example to illustrate how this method might be used in spatio-temporal process modeling. Figure 4 shows a hierarchical model in land subdividing, where only limited parts of the whole model and two levels of generalization are represented due to the space of page.

3.2. Formal Description

3.2.1. Agent

Agents can be divided into different workgroups according to roles they play in decision making process. One agent may belong to several workgroups. There are three kinds of agents: managing agent, operating agent and application agent. This typology and their hierarchical relations define status and authority of various agents.

(1) Managing agent: They make decisions and control other agents' behavior. They can query information and give their own opinion on projects

to instruct operating agents what to do and how to do, but they can't modify the states of spatial objects directly. Directors or deputy directors in the

organization may be considered as managing agents

(2) Operating agent: They assist in decision ma-

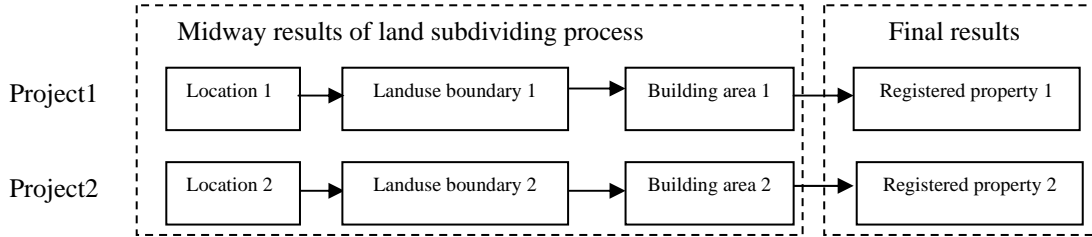


Fig.2 Two kinds of spatial objects in land subdividing process

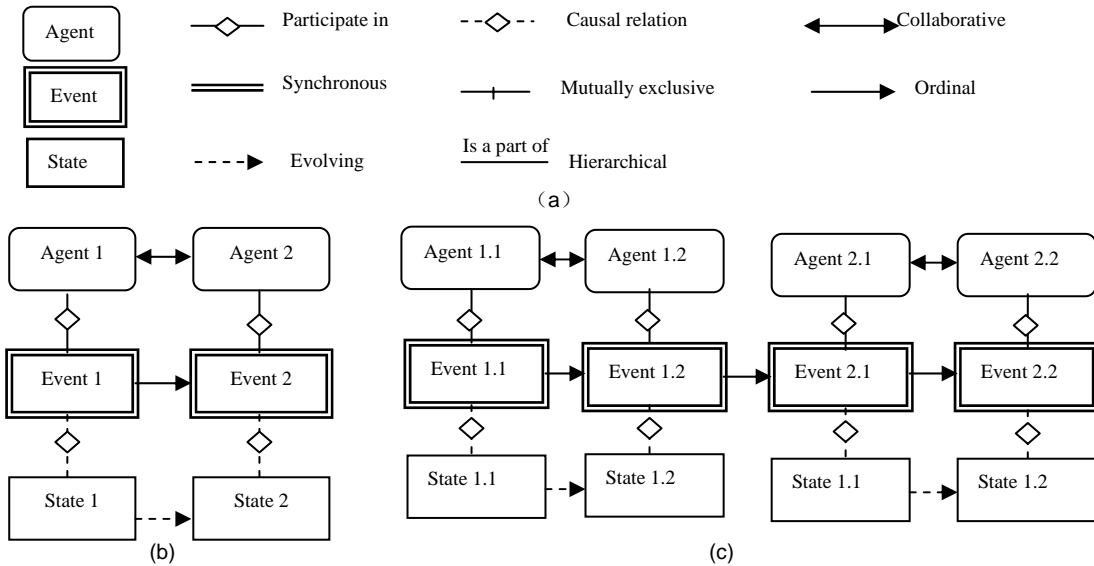


Fig.3 Visual language describing agent, event, state and relations among them

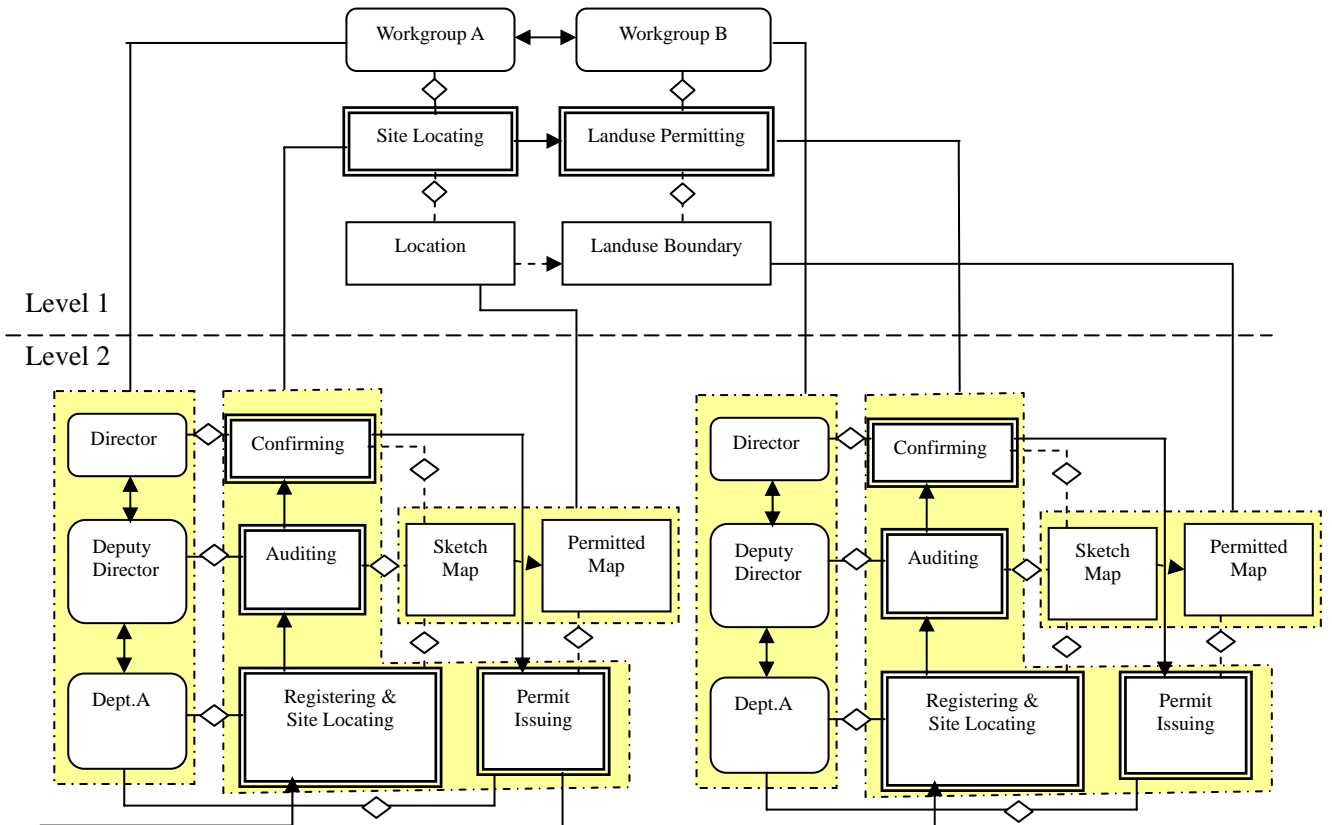


Fig.4 Example of a hierarchical model for land subdividing, showing two levels of generalization

king. They can give draft statements on projects, create spatial objects and modify their properties. The operating agents correspond to clerks in the organization.

(3) Application agent: They can only query information about projects. Usually they are those applicants who want to know how the reviewing process is going on and what are the results of their applications.

3.2.2. Event

Definition 1: Let M_i , F_j , A_k represent managing agent, operating agent and application agent respectively. Where i , j , k is the serial number of each agent and represents the workgroup it belongs to. Tuple $COOP(A_k1, A_k2)$ defines the collaborative relation between A_k1 and A_k2 .

Definition 2: Agent can be described with a tuple (Aid, F, S, T, R, C) , where Aid is identifier of the agent; F is exterior character of the agent; S is state set of the agent; T is event set of the agent; R is resource of the agent; C is restriction relating to T and R .

- (1) F describes type, ability, property and interface with external;
- (2) S describes different states of agent;
- (3) T describes events the agent executes;
- (4) R describes data the agent handles;
- (5) C describes limitation to agent from R and T ;

Definition 3: 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; Es is subsequence effects of the events.

Definition 4: Eid is identifier of the event, where id is a character string representing hierarchy and generalization. For instance, $E1$ is an event, its sub-events are $E11$, ..., $E1n$. And sub-event of $E1i$ are $E1i1$, ..., $E1im$. Other relations can be represented as follows:

- (1) (1).Ordinal relation: $PRE(E_i, E_j)$ means that E_i cannot begin until E_j finished.
- (2) (2).Synchronous relation: $CONCUR(E_i, E_j)$ means E_i and E_j happen at the same time.
- (3) (3).Mutually exclusive relation: $NOT(E_i, E_j)$ means E_i and E_j cannot happen at the same time.

3.2.3. State

Definition 5: State is described by a tuple $(Sid, Sec, See, Spro, Spost)$, where Sid is identifier of the

state; Sec is the event create the state; See is the event end the state; $Spro$ is the previous state; $Spost$ is the post state.

As to the spatial topology and temporal topology among states, we may use the methods proposed by M.J.Egenhofer, (1990-1993) and Hong Shu (1997). And we will not discuss it in detail in this paper.

4. Further Investigations

An IAES model is proposed for describing spatio-temporal process in a GIS-based CSCW system. Based on the example from urban planning and land administration bureau of Changzhou Municipality, the land subdivision process is analyzed and a visual language is proposed for describing elements in the process and relations among them. Formal definitions of agent, event, state and various relations are also given. The model expressive, and all the three components in spatio-temporal process and causal relations among them are explicitly represented. However, the spatio-temporal process in such systems is very complex and what we proposed here is just a primary model. There are lots of works remain to do, including quality control of the model (such as integrality and consistency checking, semantics overlapping eliminating, etc). In addition, to make the system operational, we should study how to organization the spatio-temporal data reasonably and develop efficient methods to implement spatio-temporal query.

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