DYNAMIC REVISION OF SPATIO-TEMPORAL DATABASE WITH SIMULATED FEATURES

Yoshihide SEKIMOTO, Ryosuke SHIBASAKI
University of Tokyo, Japan
Center for Spatial Information Science
sekimoto@skl.iis.u-tokyo.ac.jp

KEY WORDS: Database, Revision, Spatio-temporal, Observation strategy, Dynamic processes.

ABSTRACT

Recently many kinds of spatio-temporal data are being repeatedly acquired or generated mainly because of the rapid progress of data acquisition technology in recent times. However, those data are still so limited and "fragmentary" in terms of observation frequency, spatial coverage and thematic accuracy, etc., that we cannot always directly monitor dynamic changes of the spatial objects or features with sufficient spatio-temporal resolution. In order to reconstruct the dynamic changes of spatial objects or features with sufficient spatio-temporal resolution, we have to "integrate" a variety of fragmentary data. In addition, it is also very desirable to revise the reconstructed dynamic changes of spatial objects whenever new observational data are added to the spatio-temporal database. (We call it "dynamic updating".) For this purpose, it is necessary to improve the conceptual model of spatio-temporal data in order to represent observational data and dynamic changes of spatial objects under external disturbances, in addition to the development of integration methodologies. In this study, we executed a sequence of database development from requirement analysis to numerical simulation in database and applied our proposed FEO (Feature/Event/Observation) model as a conceptual framework of the spatio-temporal database which enables dynamic updating of the building database in the simulation level.

1. INTRODUCTION

1.1 Variety of data needs and data acquisition technologies

Geographic Information System (GIS) is expected to be applied to a wide variety of fields, ranging from the conventional ones such as lifeline facility management, fixed property taxation and emergency activity support after disasters to information driven contemporary ones such as traffic monitoring and guidance information provision for Intelligent Transport System (ITS). In these fields it will be required to collect information on phenomena that are changing dynamically, in order to grasp not only the present situation but also to predict the future states of the phenomena. Therefore data with finer spatio-temporal resolution with respect to time, space and attribute will be needed for spatio-temporal database compared with the resolution of existing maps or statistical data.

Because of development in sensor technology or network technology, the technological capability of spatial data collection and measurement is rapidly expanding. For example, there is survey technology to reconstruct three dimensional buildings with textural information almost automatically using laser scan data and CCD image data (Zhao and Shibasaki, 1997). On the other hand, the monitoring technology for the route choice activities of drivers by using automatic vehicle recognition from video data and the real-time positioning technology for monitoring movement of individual persons using Personal Handy-phone System(PHS), are now in operational use. These technologies are expected to contribute to the capture of spatio-temporal phenomena.

1.2 Lack of integration between data acquisition and database development

However, we cannot always obtain data with sufficient spatio-temporal resolutions for a wide variety of applications mentioned above. We often need to estimate or reconstruct dynamic changes of spatial objects by integrating or interpolating various observational data. For example, in the development and updating process of GIS database with conventional aerial photogrammetric method, the use of administrative data on building changes (e.g. building permission) or ground survey data in regions of narrow roads where it is difficult to measure from aerial images would help the development of a more accurate GIS database.

In reviewing existing studies on both acquisition/integration of spatio-temporal data and development/management of database from a viewpoint of how to realize dynamic updating of GIS database, it is found that both studies have been promoted almost separately. In other words, it is often assumed that "edited" or “interpolated” data representing the spatio-temporal phenomena are developed first, and then input into the database. For example, many research works on spatio-temporal database such as Worboys(1990), Langran(1992), Peuquet(1995), Stock(1997), Egenhofer and Golledge(1998), Ohta(1999), have been conducted based on an assumption that complete spatio-temporal data are available to the database.

These approaches or assumptions, however, have problems such as the need for the database to accommodate observational data may be underestimated, which may result in the loss of observational data itself and also in related data such as observational conditions. The loss may cause difficulties in reconstructing spatio-temporal data from the observational data. Furthermore, considering that another spatio-temporal database including both the observational data and feature data is actually needed for the reconstruction process that may be derived from various observational cases, the above approach may result in the duplication in database development.

1.3 Development of a representation model for “extended” spatio-temporal database

To overcome these problems mentioned above, it is essential to integrate the data integration process and the database development/updating process within a unified framework of an "extended" spatio-temporal database accommodating feature data and observational data. To realize the “extended” spatio-temporal database, there are various challenges ranging from the development of a conceptual model representing spatio-temporal changes of features, implementation of database based on this conceptual model, and development of methods for estimating or reconstructing spatio-temporal changes of features.

In this paper, we overview a procedure of building database development in section 2. In section 3, we analyze our requirement to the system in the context of building database development. In section 4, we design our database system using our previously proposed FEO Framework for dynamic updating of spatio-temporal database. In section 5, we demonstrate an example of simulated feature data and observational data with the proposed model and of reconstructing dynamic changes of features.

In some fields, systems or methods to estimate the dynamic changes of features from various kinds of observational data are investigated based on specific characteristics of feature and methods of observation. For example, Oneyama and Kuwahara (1997) in the field of traffic engineering, Shibasaki and Huang (1996) in the field of land use. But these investigations have started only recently and have not spread to the other fields. The investigations of conceptual model as a more general model will be expected to contribute to the evaluation of each existing integration method or database management, exploration of new fields, and further development of each method.

2. PROCEDURE OF BUILDING DATABASE DEVELOPMENT

In this section, we consider a procedure of development of building database. In system engineering fields, some frameworks or design patterns have been developed. For example, Rumbaugh(1991) is famous for objected-oriented modeling and design. Anyway we can find common phase between these methods. Moreover collection of spatial data about real world is more important in spatial database system. After this section, therefore, we develop our database system based on the procedure below(Figure 1).

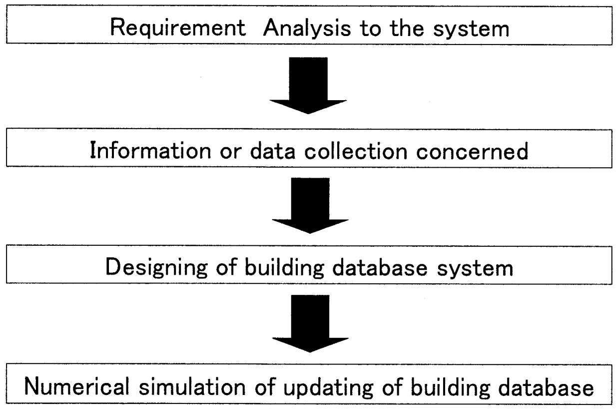

Figure 1. Procedure of building database development

At first, Requirement of our system should be analyzed because system varies depends on the requirement. Then we collect related information or data, and design our database system based on the analyzed requirement and collected information. Furthermore the system is implemented and numerical simulation of updating of database have been done.

3. PROBLEM AND REQUIREMENT ANALYSIS TO BUILDING DATABASE SYSTEM

In this section, we arrange our problem and requirement to the building database system. Ultimately we want to reconstruct real world spatially and temporally as accurate as possible. In this case, we want to reconstruct spatio-temporal changes of buildings in urban area. This is the problem to be solved. And then, requirement depends on the obtained information. In this study the assumption is that we can collect several information for this simulation problem solution as follows.

--- Observation data; Aerial photo, Acceptance of building application/permission

--- Feature model; Spatio-temporal data model about building

--- Event structure; Structure of urban development project which affect the buildings

In this study, our requirement to the system is defined as follows.

--- Variance of reconstruction accuracy according to the state of observation

--- Extraction of event which affects to the feature using known event structure

4. DESIGNING OF BUILDING DATABASE SYSTEM

In this section, we design the building database system based on the requirement analysis. We applied our FEO(Feature/Event/Observation) Model as a framework for developing spatio-temporal database. FEO Model is a conceptual model to represent both feature data and observational data in an "extended" spatio-temporal database(Sekimoto and Shibasaki, 2000) (Figure 2).

In the building management, FEO Model is applied and Database design is described as follows(Figure 3).

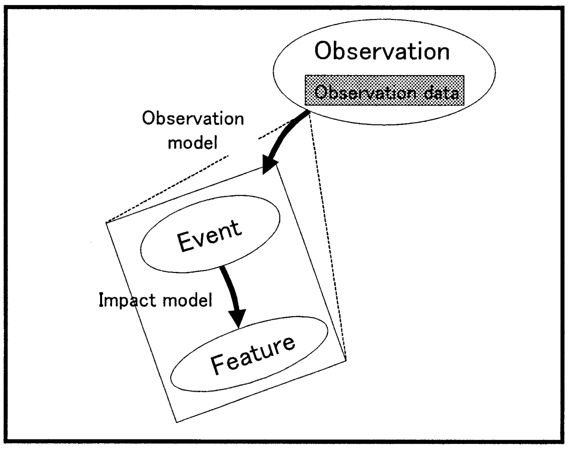

Figure 2. Outline of FEO Model

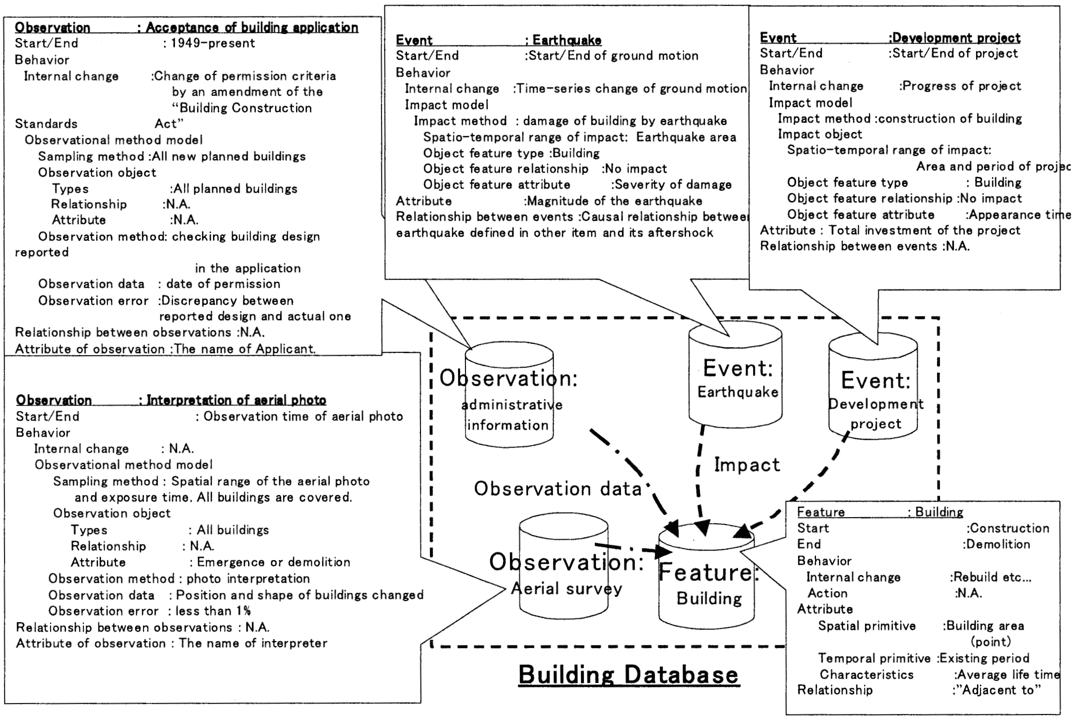

Figure 3. An application example to building database design

5. NUMERICAL SIMULATION OF UPDATING OF BUILDING DATABASE

5.1 Numerical simulation procedure

In this section, numerical simulation of updating of building database is performed. The procedure is described with figure 4 as follows.

Step1: Model assumption

At first we assume the models. Actually we assume that there are 50 buildings in one area and they are observed for about 10 years (4,000days).

Step2: Generation of real world and true data

Then based on these models, simulation data of real world representing the state of each building is generated everyday.

Step3: Generation of observation data

At the same time a part of simulated data is obtained with some errors as observation data. In this case observation data is aerial survey data and administrative information data as we mentioned before.

Step4: Estimation of true data

At last we estimate the state of each feature and the parameters of models from observation data and prior knowledge of feature. The emergence/demolition time of each building is estimated so that the likelihood of observation data becomes

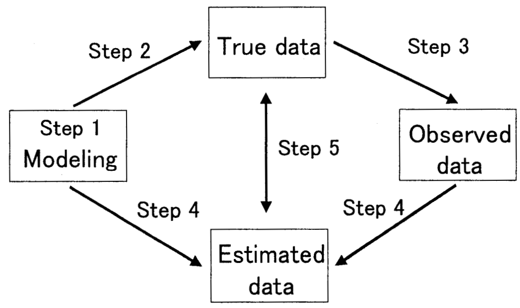

Figure 4. Structure of simulation calculation

maximum to the assumed model. Moreover genetic algorithm(GA) is used for estimation.

Step5: Verification of estimated value

We repeat simulation calculation of Step1-4 for ten times in order to test the variance of estimated the state of feature.

Step6: Control of observation

We calculate the variance of estimated parameter of model in order to check the accuracy of estimation when we control the observation situation. Actually we control the number of aerial survey.

Step7: Extraction of Event

We cannot always observe an occurrence of event directly. Therefore we calculate the variance of estimated event occurrence time by doing the same process in the case of existence of event, which aims to test whether event, we cannot observe directly, can be estimated from observation data on feature. We use development project as event and estimate its starting time.

5.2 Model assumption

We talk about model assumption in Step1. But its detailed formularization is omitted in this paper because of space. See Sekimoto and Shibasaki(2000) if you have some interests.

Feature

Start/end of feature correspond to the construction/demolition of the building. Changes of building and actions to the other buildings are not be considered. Shape of the building is simply represented as a point (Figure 5b). The building is assumed to have some characteristics such as average life, and the distribution of life(from construction time to demolition time) is under the normal distribution around average life (Table 1). Furthermore we don't consider the relationship between buildings like "adjacent to".

Table 1. Parameters of feature

Average life of building	Variance of life of building
700 (days)	200 (days)

Event

We consider development project as event which affects to building feature. Development project also has start/end time. Moreover it has impact model to the building and its range can be represented in figure 5a. Impact model has some impacts to the construction/demolition time of building shown in Figure 5e (To be precise, occurrence probability of construction/demolition of building is assumed to be increasing in the term of event in Table 2).

Table 2. Parameters of event

Ratio of occurrence probability of building (in development project term / in usual term)	Start time of development project	End time of development project
10	1000(days)	1100(days)

Observation

We consider 1) interpretation of aerial photo and 2) Acceptance of building application as observation.

1) Interpretation of aerial photo

Range of sampling model in interpretation of aerial photo can be represented as Figure 5c and all buildings are included in the range. The existence of building is judged as shown in Figure 5f, and interpretation error that we think there is a building in spite of no existence, can be represented probabilistically (Table 3) .

Table 3. Parameters of observation (Aerial photo)

Measurement time	Observation error (that no building observed in spite of actual existence)	Observation error (that building observed in spite of no existence)
400,800,1200,1600(days)	5(%)	1(%)

2) The understanding of building by administrative information

Range of sampling model in acceptance of building application can be represented in Figure 5d corresponding to each building, and construction/demolition time is observed with normal distribution error like Figure 5g and Table 4.

Table 4. Parameters of observation (Administrative information)

Observation error variance of construction time	Observation error variance of demolition time
30(days)	20(days)

Figure 5 illustrates the relationship between feature, event and observation.

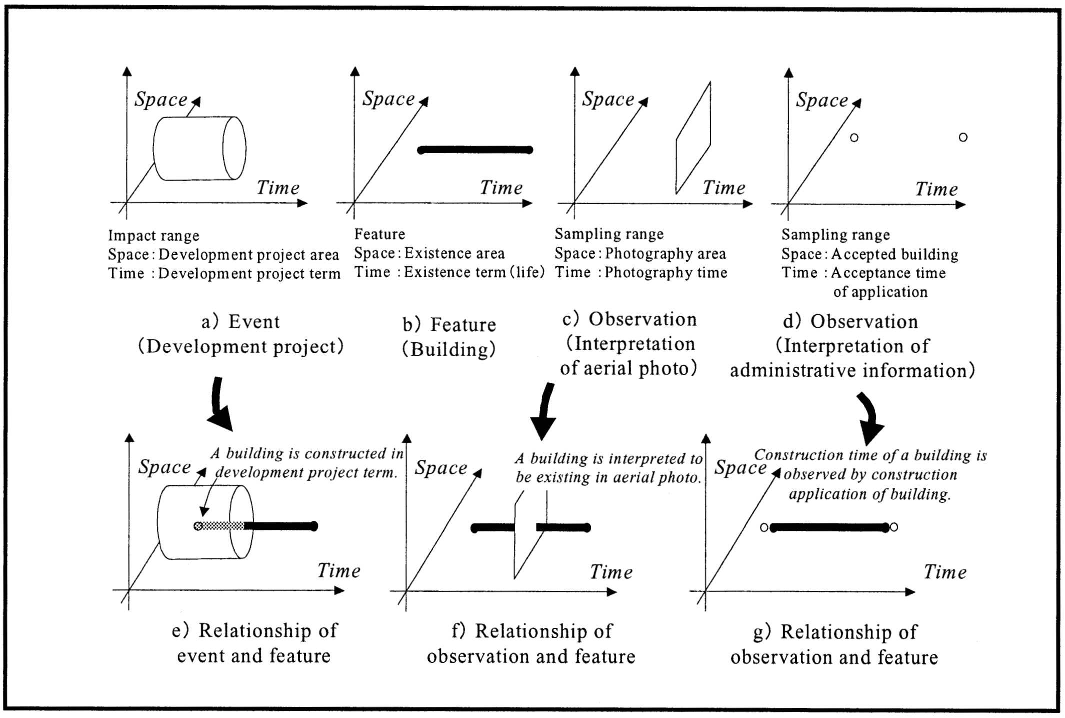

Figure 5. The relationship of feature, event and observation in the management of building

5.3 Estimation

Estimation of building is described roughly based on the assumed model. Firstly likelihood of the state of each building can be represented as a function having parameters of feature, event and observation model and several observation data. Multiplying each likelihood leads to the likelihood of state of all buildings to parameters of each model and all observation data. Unknown parameters are estimated so that likelihood becomes maximum. In this study accuracy of estimation becomes much worse in the case of increasing the number of unknown parameters, therefore unknown parameters are given as mentioned before (Table 1,2,3,4) and construction/demolition time, that is, the state of each building is estimated. It means that the number of parameters to be solved is 100(=50*2).

5.4 Result

Genetic Algorithm (GA) is probabilistic searching method derived from evolution of creature, and is appropriate to the problem whose solution is not established or is inefficient. In this paper, we assume the parameters of GA by trial and error as the following Table 5. Consequently we can determine the parameters.

Table 5. Parameters of GA

Evaluation criteria	The number of gene	The number of individual	The number of generation	Mutation rate
Occurrence probability	100	200	1000	0.02

Table 6 shows the result of Step 5, that is, average variance of estimated emergence / demolition time when we have twice observation by interpretation of aerial photo. Moreover the result is the sample average of simulation for 10 times. Table 7 shows the result of Step 6, and it means the decrease of variance of estimated value when the number of observation increases. Finally Table 8 is the result of Step 6, that is, variance of estimated start time of development project, and an extraction of event can be confirmed.

Table 6. Variance of estimation of the state of building

Average variance of estimated emergence time	Average variance of estimated demolition time
193(days)	277(days)

Table 7. Decrease of variance by the increase of the number of observation

The number of observation	Average variance of estimated emergence time	Average variance of estimated demolition time
1	272(days)	360(days)
2	193(days)	277(days)
4	97(days)	120(days)

Table 8. Extraction of event

Variance of estimated start time of development project	104(days)

6. CONCLUSIONS

In this study, we aim to realize more intelligent spatio-temporal database which can estimate, reconstruct and predict the dynamic phenomena in the real world from various data as one type of next generation GIS. As a conceptual basis, we applied our proposed FEO model and showed how the model can be applied to building database design as an example. Spatio-temporal database based on FEO model enable us to integrate many existing estimation/reconstruction methods and models as well as a wide variety of observational data.

Future works will be devoted to the following topics;

(1) Implementation test of database system based on our framework and its feed back to the improvement of our framework.

(2) Development of observation models for observation methods commonly used in several major application fields. (e.g. aerial survey, traffic monitoring etc.)

(3) Comparison and improvement of reconstruction methods based on FEO framework.

REFERENCES

Egenhofer, M. and Golledge, R. (eds.) (1998). "Spatial and temporal reasoning in geographic information systems", *Oxford University Press*, New York.

Langran, G. (1992). *Time in geographic information systems*, London: Taylor and Francis.

Ohta, M. (1999). "The Spatiotemporal Schema for Geographic Information Systems", *Theory and Applications of GIS*, 7(1), 37-44 (in Japanese).

Oneyama, H. and kuwabara, M. (1997). "Estimation of Time Dependent OD Matrices from Traffic Counts", *Traffic Engineering*, 32(2), 5-16.

Peuquet, J.(1995). "An event-based spatiotemporal data model (ESTDM) for temporal analysis of geographical data", *International Journal of Geographical Information Systems*, **9**, 7-24.

Rumbaugh, J. (1991). *Object-oriented modeling and design*, Prentice Hall.

Sekimoto, Y. and Shibasaki, R. (2000). “Conceptual data modeling for dynamic updating of spatio-temporal database”, *Advances of GIS (Proceedings of Spatial Data Handling)*, in preparation.

Shibasaki, R. and Huang, S. (1996). "Spatio-temporal Interpolation by Integrating Observational Data and a Behavioral Model", *Advances of GIS (Proceedings of Spatial Data Handling)*, 251-265.

Stock, O. (eds.) (1997). *Spatial and temporal reasoning*. Netherlands: Kluwer Academic Publishers.

Worboys, M. (1990). "Object-oriented data modeling for spatial databases", *International Journal of Geographical Information Systems*, **4**, 369-383.

Zhao, H. and Shibasaki, R. (1997). "Automated registration of ground-based laser range image for reconstructing urban 3D object", *ISPRS*, **32**, Part3-4W2, 27-34.