

ANALYSIS ON GEOGRAPHICAL CHANGES AND RESEARCH ON SPATIO-TEMPORAL PATTERNS

Yang ping^{a,b} *, Tang Xinming^{a,b}, Wang Huibing^b

^aSchool of Resource and Environment Science, Wuhan University, 129 Luoyu Road, Wuhan 430079, China - yangping_wlu@163.com;

^bChinese Academy of Surveying and Mapping, 16 Beitaping Road, Beijing 100039 - tang@casm.ac.cn ; Wanghb@casm.ac.cn

ThS-6

KEY WORDS: Spatio-temporal Change Analysis, Spatio-temporal Change Pattern, Change Detection, Change Pattern Extraction

ABSTRACT:

As efforts grow to develop spatio-temporal database systems and temporal geographic information systems that are capable of conveying how geographic phenomena change, it is urgent to analyze the impetus and mechanism that the spatio-temporal process happened. The authors proposed a set of universal change patterns for modelling of spatio-temporal processes, which builds a fundamental basis for the representation of dynamic phenomena. Change detection algorithms were also developed and pattern association methods were implemented for the modelling of changing geographical world.

1. INTRODUCTION

The world is changing at every second, from the point view of materialist, all things are in the endless movement, the world is comprises of ever changing and eternal developing material elements. Developing is the creation of new entities, the disappearance of old entities, which is a process that new entities take the places of old entities. Therefore, an profound knowledge of the changes of geographical entities contribute to a better understanding and modernization of the society.

Geographic Information System is an essential tool for people to know the earth. It is establish based on the spatial database, which is destined to provide people with a list of spatial data (Inventory). Since the 1960s, since the birth of geographic information systems, GIS has been developed from two-dimensional system to the current true 3D and virtual reality systems, and operation structure has been undergone from Client/Server to Browser/Server mode, at the same time, the GIS database has been developed from map database to multi-source & multi-dimensional vector and raster databases, from which an system of government decision-making oriented industry applications came into being.

From the perspective view of GIS development trend, the dynamic multi-dimensional network of geographic information system is in the oncoming way. By now geographic information systems is still weak in temporal management. Though some models have been established and several temporal GIS applications had been acted, there is a challenge to overcome. At present, most TGIS manage spatio-temporal data in version mode, which are lacking ability in the management of change information. So far, geographic information systems haven't gotten successful advancement in spatio-temporal analysis, a toolbox for carrying out analysis on both temporal and spatial information is missing.

Currently most geographic information database use static model to store data, no historical connection between the old version data and new version data has been built. But a great many applications such as land planning, land management, effecient use of resources, environmental monitoring need integrated time-series space-time data support. However, besides a small number of applications in cadastral management, few application can be supported by spatio-temporal data.

Firstly, The reason why this situation exist is that current geographic information databases stay in the accumulation stage, time-series data are not abundant. The other reason goes that generalization of change mechanism and change pattern remain weak. Unlike the changes occurred in single space, Temporal GIS hasn't a sound mathematical and theoretical basis. Geographical changes diversify greatly, building a dynamic model for space-time data is complex, it is not easy to implement universal spatio-temporal modeling and analysis.

This authors of this paper propose a set of universal change patterns based on the analysis of characteristics in geographical changes, spatio-temporal change pattens develop from two major categories of No change and Change, gradually a series of patterns including Born, Grow, Shrink, Normal change and Die are derived. compared to previous studies, the proposed change patterns are easy to extend and efficient to implement.

2. RELATED RESEARCH

2.1 Related Concepts

In order to facilitate understanding, first we put forward some basic concepts and explain them.

* Yang Ping, PhD Candidate in Cartography and Geographic Information Engineering of Wuhan Uni, Research interests includes: Spatio-temporal visualization, Geophysical dynamic visualization and Temporal GIS.

Domain: The scope of interesting things or the collection of things. when we study geographic information science, all things including temporal objects, spatial objects and thematic objects are belong to geographical domain.

Feature: the minimum unit that can be divided in domain layer.
 Entity: entity is collection of a group of elements and the relevant information.

Process: process is a concept that is to understand the natural world and the related the happened changes.

Spatio-temporal process: a subset of process, which is used to describe the integral change both in temporal and in spatial.

Event is the transition of an object from one state to another in a change. It is the mutation of an object that produces a new object version (state). Events are the states where start and finish times fall in the same chronon (Roshannejad 1996).

State is a line segment that represents the duration of a condition. While an event is a point that terminates that condition and begins the next, it forms a zero-dimensional boundary between two one-dimensional segments. The inter-relationship between event and state of one object is drawn in Figure 1

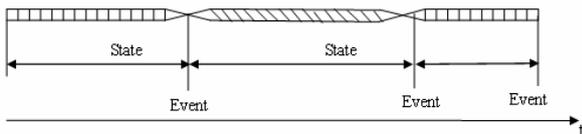


Figure 1 State and event of an object

2.2 Spatio-temporal Process The Analysis of Spatio-temporal Change Pattern

Since geographic information system has been introduced, many efforts have been made on the spatio-temporal process or change pattern, scholars in this domain have done great work in this field:

Yuan (1996) summarized six types of change patterns which includes: attribute changes, static spatial distribution, static temporal changes, dynamic spatial changes, mutation of a process, and movement of an entity. These change types cover almost all aspects of space-time changes, but are not based on a systematical theory, certain repetitive kind of change exists in these classification, therefore it is not a basic spatio-temporal change pattern.

Christophe Claramunt, etc. (1997) proposed a design for change pattern which are compatible for several spatio-temporal models from three hierarchy perspective view of design. Change processes on single entity and the relevant entities were researched in their work, they proposed a lot of change patterns including the Stability, Deformation, Expansion, Contraction, Rotation, Translation, Succession, Permutation, Re-Allocation, Split and Union more than 10 kinds of space-time processes, new change patterns could be derived from the combination of the basic processes. Claramunt have done beneficial work for the design of spatio-temporal patterns, however, it is a theoretical framework without practical implementations and evaluation results.

Kathleen Hornsby, etc. (2000) presents an approach to spatio-temporal knowledge representation based on the explicit description of possible changes to geographical phenomena modelled at a high level of abstraction as identifiable objects. Starting with a set of basic types of change with respect to the existence and non-existence of objects with identity, a methodology is presented that systematically builds on these fundamental concepts and derives further types of change that are possible. The set of change operations that results can be found in most scenarios of geographical change. This change-based model provides a better understanding of the set of possible alterations to which an object can be subject as it evolves over space and time and enables the extension of spatial data models and the development of GIS query languages that incorporate such semantics of change. However, no explicitly spatial information has been incorporated in this change model, therefore this model has obvious shortcomings, it can not be well used for real time changes in process modeling.

Luo Nianxue etc. (2004) proposed a set of unified object identification operation model on the basis of work of Kathleen Hornsby, they introduced 5 basic operations including Create, Destruct, Freeze, Resume and Developing existence, more operations were derived from the combination of basic operations. Luo also defined complex change concern two or more objects, three pairs of forms including Split & Merge, Attach & Detach and Aggregate & Segregate were defined, compared with the previous definition, the model can be applied to manage many special geographical phenomena such as freeze, mortgage and alternation of parcel, which had efficient application in cadastral management. Since the change patterns are comparatively simple, this model isn't a universal model.

Looking at the above study, although spatio-temporal processes attracted many efforts of world wide scholars, there is rare spatio-temporal change pattern for modeling both space and time, no satisfying solution have been acquired for the management and visualization of spatio-temporal data. The author of this paper try to establish a integral spatio-temporal change patterns for the real implementation.

3. ANALYSIS ON CHANGE OF GEOGRAPHICAL FEATURES

It has become clear that the traditional visual variables, which we will call the static visual variables from here on, do not suffice in describing the added means of expression we have in dynamic visualization of spatio-temporal processed through cartographic animations. To this end six "new" visual variables including moment, duration, frequency, order, rate of change, synchronization have been introduced by DiBiase et al. (1992) and MacEachren (1994). These will be called the dynamic visual variables from here on.

Research by DiBiase et al. (1992) and Koussoulakou & Kraak (1992) has shown that visual variables can indeed be used on the individual frames of an animation in such a way that these images effectively communicate the cartographic message to the user, while the movement of the animation gives the message an extra dimension and "new energy". Furthermore, the findings of Koussoulakou & Kraak (1992) showed that using animated maps helped users grasp the contents of a message in a more effective manner compared to using traditional static maps or map series.

3.1 Impetus of Change

The impetus of change occurred to geographical entities vary greatly, sometimes it may come from internal factor within the object itself, sometimes it will be triggered by external factors. Sometimes the impetus is easy to discern, sometimes the reason is vague to clarify. The impetus of spatio-temporal is so complex that it makes the modeling of spatio-temporal data become complicated. Since geographic information systems are application-oriented, the actual storage schema of changes and the reason of change vary greatly. For example, when people want to establish a global climate change information system, it is necessary to keep record of the relationship between glacier and temperature. Some information systems care about the result of change without knowing the reason for change.

The analysis on the impetus of change is benefit to the modeling of geographic information, different kinds of temporal geographic information systems need different kinds of data. Currently most spatio-temporal database store the results of geographical change without take the reason of change into account. For instance, a land-use dynamic monitoring system, only records the original state and the latest state of objects, the reasons for the change are not in consideration. However, in cadastral management system, the land legitimacy proof are required, while the proof is an thematic information.

Change happened to spatial features different one from another, a spatio-temporal process corresponding to each change. Take a cadastral registration in a cadastral management system for example, registration process includes a number of stages: a public announcement, the ownership investigation, ownership confirmation, fixing boundary points, cadastral mapping, ownership registration, issue certification and so on. Each of these processes can be divided into a number of steps, take cadastral survey and mapping for instance, first of all, acquisition of high-resolution images, then, controlling survey, boundary point measurements, a boundary line measurements, map sheet manufacture, ownership registration, then the formation of land parcel.

Take the surveying of boundary point as a sub-process, there are several stage contained, which are survey plan, survey implement, survey record, data computing, result output, etc. A figure(Figure 2) was drawn for this explanation:

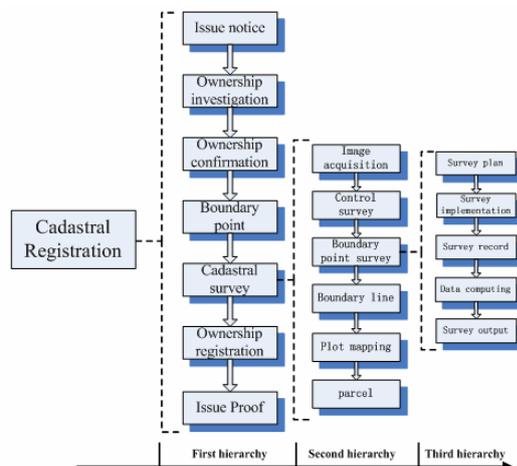


Figure2. Gradually Hierarchy of Cadastral Registration Classification

When we analyzing the process of spatio-temporal change, not only the one-time change should be researched, but also periodically change must be taken into account.

A common phenomenon happen in cadastral management information systems exists like the following: one parcel A separate from a bigger parcel B, then A merge parcel C to form a new parcel D, after some time, parcel A separate from the newly born parcel D, which remain the initial properties.

We can see from the above analysis of change process, spatio-temporal change pattern is complicated and hard to completely define, we must refine universal change patterns from all spatio-temporal process.

Conclusions can be drawn from the above analysis:

- 1, spatio-temporal changes are semantics based, there has no change for change only.
- 2, spatio-temporal changes are complicated, the definition of change highly dependent on the demand.

4. MODELLING OF CHANGE OF GEOGRAPHICAL ENTITIES

4.1 Domain Selection

At the beginning of the establishment of spatio-temporal model, we should get the domain that the geographical changes happen within. Especially in the spatial domain, we should take which field that change occurred into account. Take the new road birth as an example, if this is happened in transportation field, the new born road is creation, however, if this is occurred to land use apartment, this change is defined as a displacement of land use which the farmland or wasteland changed into highway.

4.2 Feasibility and Necessity of Change Modelling

Modelling of change of geographical entities same, it is difficult to do with moving information. Since moving objects change its location during the geographical change, so it can be regarded as a problem within spatio-temporal databases, it characteristics are continuous change in spatial information with the temporal sequence.

In this paper, only non-discrete entities are modeled, the features are static, the change that moving entity over time in geographic space will be regarded as a special situation

5. BASIC SPATIO-TEMPORAL CHANGE PATTERNS

5.1 Domain and Feature Layer

From the point of view of geographic information modeling, it is common to classify features into different layers by the domain scope that the features in accordance with. For example, hydrological features, topographical features, residential area, border, transportation features, Vegetation are often organized in different feature layers in fundamental geographic information systems, sometimes even point features, line features and polygon features are organized in different layer. Feature layer is the research domain in this case, by defining the interesting research domain, people can easily concentrated their efforts on the very thing that they want. Therefore different definition of domain leads to different layer organization in GIS.

Before we define a set of universal spatio-temporal change pattern, it is necessary to determine the interesting domain, a series of feature layer can be derived as a result of this process. Take for cadastral management for example, after the interesting domain determination, parcel and land use feature layer were derived as a result.

5.2 Spatio-temporal Change Pattern

In this paper, we propose a practical classification of Spatio-temporal change pattern, abbreviated as STCP. For the reason of actually implementation, we get used to the conception of Layers, Such as we know, Layers are widely used for the construction of geographical data, when we construct the spatio-temporal data storage in the database, there are three features patterns, includes points, lines and polygons within a layer, for each geographical object or phenomenon, it is able to represent in the three patterns of features. On the basis of three patterns, classification corresponding each pattern is proposed to describe the process of change of spatio-temporal objects. Hence we draw up a spatio-temporal process taxonomy which is used for the taxonomy of STCP by the analyzing of essence of phenomena change, it can be showed in the following graph:

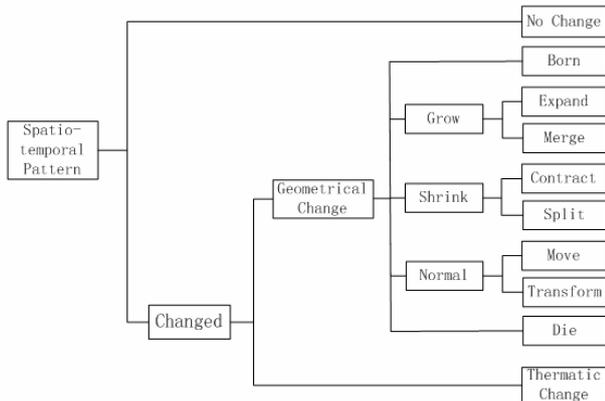


Figure3. A graph for taxonomy of STCP

The procedure that from start to end has no difference except the time variable has been changed, we name it a **No Change** process, this process is easily ignored, but in the real database, the record about this information is solidly stored in the Spatial-temporal database.

Apart from the process of No Change we propose a detail definition of the spatio-temporal change patterns, transformation occurred during the Spatial-temporal process could be reflected in many ways, in the paper, we plan to classified them in two aspects, one of them occurred in the geometric aspect, we give it a name **Geometric Change**; Another can be happened in thematic way, which can be named after **Thematic Change**, the reason for this classification lies in a logical design pattern of database, there is a common way for the data storing strategy that the geometric data and property data are separately deposited but with a weak relation by the using of key.

Refer to the **Geometric Change**, we propose a furthermore classification which comprising pattern **Born**, **Grow**, **Shrink**, **Normal Change** and **Die**, In order to deal with change concerning two or more objects, we proposed Expand and

Merge for the Grow pattern, and Contract and Split for the Shrink pattern.

For **Born**, for each spatio-temporal object, the creation is the most and the very beginning step during it's life circle, it is an opposite process of DIE, means that a newly objects exist after a death of others, also has many instances.

For **Grow**, there exists two situations, a common phenomenon that a spatio-temporal object enlarge it's size due to a lot of reasons, we name **Expand** to represent this kind of process. Another issue is occurred among two or more objects, a growing space occupied by an object, this object is comprised by two or more objects, these spatio-temporal change patterns named after **Merge** which can be derived by the ID number it correspond to.

For **Shrink**, We propose the **Contract** to describe when a object decreasing it's space that occupied in the geo-spatial way, as a result of **Contract** process, geometrical area or volume reduced in a computable way, **Contract** is a original process. As for two or more, We propose **SPLIT** as a basic change pattern for the description of change occurred involving several spatio-temporal objects, for the **Split** process, at the beginning, there is one object has an integral part of geometric properties, in the end, newly born objects have been created, as a result, the space the occupied by the original objects has been reduced through this process.

Normal change is a special change pattern which is distinct from the above process, the size or space has not been changed but other characteristic features such as shape, location and object Id become different. It is a comprehensive change that can be reflected in many geometrical aspects, there is a example, for the **Split** change, if the space has not changed during the process, it turned into **Normal change** instead of Shrink. If a object change it location as a whole body, normal change happened in this case.

The Last process we name it **Die**, the process is regarded as a termination of a spatio-temporal objects, The **Die** process can be described in such a way, the identity of the object has change into another or the geometry has vanished, the process is a creation of the new objects, leading to the contrary process of **Born**.

The classification of STP change pattern do benefit for the representation of changing data, and built a fundamental basis for the visualization of STP, in the following paragraph, numerous variables will be utilized for the displaying of the STP, with respect to each process under the framework proposed here.

6. CHANGE DETECTION AND AUTOMATED CHANGE

6.1 Spatio-temporal Change Pattern Detection

There are many methods are used to detect temporal and spatial variation , we proposed two space-time change detection methods as following:

1) Geometry based spatio-temporal matching method: by using a algorithm that comparing the geometrical characteristics of two versions of data, we can judge whether the objects' feature has changed or not.

2) Property based change detection method: by comparing the thematic information of different version of data, some rules are created for the comparing, then we can get the information whether the objects changed or not

6.2 Automatic Extraction of Change Pattern

Through spatio-temporal change detection, we can discover whether the changes in time and space, However, a further process should be carried out on determine which kind of change pattern are the change correspond to, aim to this, we develop a spatio-temporal association method to extract the defined pattern.

7. CONCLUSION

The paper discussed the patterns of change in the spatio-temporal domains, including the impetus and process of change, analysis on the possibility and feasibility were also introduced, a set of universal spatio-temporal change patterns were defined, and change detection and pattern association were introduced for the real implementation.

The change patterns proposed in this paper provide a solution for the modeling of geographical change, more evaluation should be implemented for widely use of introduced ideas in this paper.

ACKNOWLEDGEMENT

The authors wish to thank China National High-tech R&D Program (Project No.:2006AA12Z214) and China National Fundamental Surveying & Mapping Project: (Project No.:1460130524207) and Chinese Academy of Surveying & Mapping Basic Scientific Research Project: (Project No.:G7724) and Digital Mapping & Land and Resource Application Engineering State Bureau of Surveying and Mapping Open Fund Project (Project No.: GCWD 200703) for financial support.

REFERENCES

Koussoulakou, A. and Kraak, M.J., 1992. Spatio-Temporal Maps and Cartographic Communication, *The Cartographic Journal*, 29(1), pp.101-108.

Abraham, T. and Roddick, J. F., 1999, Survey of spatio-temporal databases, *GeoInformatica* 3(1), pp.61-99.

Köbben, B., Yaman, M.,1996. Evaluating Dynamic Visual Variables. In: Ormeling, F.J.,Köbben, B., Perez Gomez, R. (eds.): *Proceedings of the Seminar on Teaching Animated Cartography*. International Cartographic Association, Utrecht pp. 45-51.

Kraak, M.J. and Klomp, A., 1995. "A Classification of Cartographic Animations: Towards a Tool for the Design of Dynamic Maps in a GIS Environment". The Seminar on Teaching Animated Cartography, Spain, <http://cartography.geog.uu.nl/ica/Madrid/kraak.html>.

Masuoka, P., Acevedo, W. , Fifer, S., Foresman, T. Tuttle, M., 1996. Techniques for visualizing urban growth using a temporal GIS database .*Presentation at the*

ASPRS/ACSM Annual Convention and Exhibition, Baltimore, MD, pp.22- 25.

ZHU Guorui, 2004. *Cartography*. Wuhan University Press, pp.34- 35.

AI Tinghua, 1998. Dynamic symbol and dynamic map. *Journal of Wuhan Technical University of Surveying and Mapping*. 23(1),pp.47-51

TANG Xinming, WU Ian, 1999. Spatio-Temporal data model and Geographic Information System Frame. *Remote Sensing Information* 01,pp.4-8.

WU Lixin, SHI WenZhong., 2003. *Principles and Algorithms of GIS*, Science Press ,Beijing, pp.154-156.

Huang Xingyuan, HU Peng, 2001. Tutorial of GIS. *Wuhan University Press*, pp.204- 206.

Vasiliev, I.R., 1997. Mapping Time. Monograph 49, *Cartographica* 34.2.

Andrienko, N., Andrienko, G., Gatalsky, P., 2003, Exploratory spatio-temporal visualization: an analytical view. *Journal of Visual Languages & Computing* 14, pp. 503-541.

MacEachren, A.M., 1994a. Some truth with maps: a primer on symbolization & design. Washington D.C.: *Association of American Geographers*.

MacEachren, A.M., 1994b. Time as a Cartographic variable. In: H. Hearnshaw & D. Unwin, eds., *Visualization in GIS*. London: Wiley & Sons, pp. 115-130.

DiBiase, D., MacEachren, A.M., Krygier, J.B. & Reeves, C., 1992. Animation and the role of mapdesign in scientific visualization. *Cartography and Geographic Information Systems*, 19(1), pp. 201-214, 265-266.

Vasconcellos, R.,1993. Representing the geographical space for visually handicapped students: acase study on map use. In: P. Mesenburg, ed., *Proceedings of the 16th International Cartographic Conference*, Cologne, German, International Cartographic Association, 2(1), pp. 993-1002.

Griffin, A. 2003, An empirical study of interactive maps in the context of a geographical simulation model. In: Cartographic renaissance. *Proceedings 21st International Cartographic Conference, Durban, South Africa*. International Cartographic Association, pp 358-364.

Dykes, J.,1996. Dynamic maps for spatial science: a unified approach to cartographic visualization. In: D. Parker, ed., *Innovations in GIS 3*. Bristol, Pennsylvania: Taylor & Francis, pp. 177-187.

El-Geresy, B.A., Abdelmoty, A.I. and Jones, C.B., 2000. Episodes in Space: Qualitative Representation and Reasoning over Spatio-Temporal Objects. *International Journal on Artificial Intelligence Tools*, IJAIT, World Scientific Publishing, 9(1), pp. 131-152.

Koussoulakou A. and Kraak M.J., 1992. Spatio-Temporal Maps and Cartographic Communication, *The Cartographic Journal*, 29(1), pp.101-108.

