DYNAMIC CARTOGRAPHIC REPRESENTATION OF SPATIO-TEMPORAL DATA

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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 important to associate the spatio-temporal process with a vivid representation. The paper propose a way for visualization base on dynamic symbol base, by which represent the spatio-temporal process in a more vivid and visually way. The authors propose a new classification of spatio-temporal change pattern, which builds a fundamental basis for the representation of dynamic phenomena. Dynamic visual variable of dynamic symbol for the display of changing spatial-temporal objectives will be discussed, a framework will be designed and implemented for the dynamic visualization.

1. INTRODUCTION

1.1 Development in Spatio-temporal Modelling

Our planet is dynamic. Changes occur constantly in all the components of the earth's system: its lithosphere, hydrosphere, biosphere and atmosphere. Although human interest in the world's dynamics is not new, in the past major factors that inhibited the study and understanding of these changes were the limited availability of large temporal data sets and a lack of suitable methods and techniques to discover patterns, relationships and trends in such data.

Spatio-temporal databases aim to support extensions to existing models of Spatial Information Systems (SIS) to include time in order to better describe our dynamic environment.

In the past two decades, a large project called CHORONOROS had been carried out by several agencies in European countries, the objective of is to study the design, implementation, and application of spatio-temporal database management systems (STDBMS). CHOROCHRONOS covering issues related to the ontology, structure, and representation of space and time; data models and query languages for STDBMS; graphical user interfaces for spatio-temporal information; query processing algorithms, storage structures and indexing techniques; and architectures and implementation techniques for STDBMSs were researched under the network. As a result, several prototype STDBMS were developed in the project to demonstrate the innovations of more theoretical work. Finally, applying STDBMS in realistic problem settings guided the research throughout the project.In China, A dynamic fundamental geographical information database is undertaken construction, a large mount of 1:250000 scale map sheets have been tested for the management of multi-version spatial data.

1.2 Visualization of Spatio-temporal Data

In order to present the contents of the data collection or the results of queries, most modern database systems provide the user with visualization tools. Some of the standard tools for spatial database systems include browsers, plotters and map displays. Most of these, however, are poorly adapted to display dynamic and/or temporal information. Therefore, alternative graphical presentational techniques must be investigated to successfully communicate geographical processes.

To establish guidelines for spatio-temporal visualization, we must first determine our expectations and goals. To this extent, Kraak and MacEachren review aspects of visualizing dynamic processes. Augmenting an existing definition, they define a temporal map as "a representation or abstraction of changes in geographic reality: a tool (that is visual, digital or tactile) for presenting geographical information whose locational and/or attribute components change over time".

Spatio-temporal data can be graphically represented in many ways. Vasiliev (1997) proposed a framework for graphic representation in static maps; Andrienko et al. (2003) attempted to do the same in an exploratory context, focusing on interactive and dynamic visualization of spatio-temporal data. Foundation for the visualization formalization was laid by Bertin in 1967 (see Bertin, 1974). His semiological framework has been further elaborated and extended. Among the main developments in the visual domain (see also Schlichtmann, 1999) is research on effects of combinations of variables (e.g. Spiess, 1970). Morrison (1974) and MacEachren (1994a, 1995)

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have argued that the variables colour (including saturation) and texture are composites rather than primitives, and they defined the different components.

Furthermore, new variables such as transparency and fuzziness or crispness of symbol edges have been distinguished and applied to represent characteristics of data and of metadata (MacEachren, 1994a; van der Wel et al., 1994). Adaptations to Bertin's way of linking the variables to data have been suggested as well (e.g. Geels, 1987; MacEachren, 1995; Morrison, 1974). Kraak (1988) investigated depth cues, i.e. variables that can be used to simulate the third dimension on a 2-D surface, while DiBiase et. al. (1992) and MacEachren (1994b) proposed dynamic variables for animated representations, together with suggestions for their use.

Characteristics of geographic data can also be represented by signs or signals for modes of perception other than sight. Vasconcellos (1993) made an attempt to define tactile equivalents of Bertin's graphic variables for visually disabled people. More recently, Griffin (1999) added kinaesthetic variables (e.g. resistance, friction) for application in fully immersive Virtual Environments. Barend Köbben described preliminary tests for evaluating the perceptual properties of dynamic visual variables. By the comparison of six kind dynamic visual variables, included moment, duration, frequency, order, rate of change and synchronization, they gave out that dynamic visual variables would only render favorable results in the use of cartographic animations.

These developments show that the framework for the representation of geodata by perceptual variables, originally founded by Bertin, is a dynamic construct that is still evolving (Blok, 1998, Fairbairn et al., 2001; MacEachren, 2001). Important reasons for ongoing developments are increasing insight and progress in technological advancements. It is clear that the representation framework is not a fixed construct; it will be further extended and adapted. Blok developed the framework by integrating the former visual variables into four categories: moment of display, order, duration, frequency, gave out the relationships between the dynamic visualization variables, provided interactions options from a design perspective, made the utilization of the variables from a user perspective, and tested the effects of the using interactions of various dynamic visualization variables (blok,2005).

Such as we know, Amounts of work have been done on the evolving of the Bertin's framework, but more should be done for further research. The goal of this paper is to propose a new framework which can visualize the spatio-temporal processes refer to each classification of temporal phenomena. By the utilizing of dynamic symbol base, a methodology for dynamic visualization of changing geographic data will be carried out.

2. SPATIO-TEMPORAL CHANGE PATTERN

2.1 What is Imply in Spatio-temporal Data?

As we know, the world we are living in is an ever changing planet, information about changing are contained in the dataset that collected in different version. Spatio-temporal database destined to describe and manage historical geographical phenomena. However, describing real-world evolution is a complex task. One may observe the status of entities before and after a change occurs, these are facts and consequences. An event is a set of related changes leading to a new status. Events may be observed without knowledge about the mechanisms leading to change. However, we postulate that change happen when a set of active entities or forces transform their environment. Most of the time these transformations do not occur at random because they are constrained to previous status and obey to evolution laws (causal relationships). Discovering these laws is the ultimate goal of science (explanation).A knowledge of Spatio-temporal Process in necessary for visualization of the dynamic data

2.2 Spatio-temporal Process

Various models of change have been developed by mathematicians, geographers, philosophers, and computer scientists. Kathleen Hornsby presented an approach to spatio-temporal knowledge representation based on the explicit description of possible changes to geographic phenomena modeled 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 was presented that systematically built on these fundamental concepts and derived further types of change that were possible. This change-based model provided a better understanding of the set of possible alterations to which an object can be subject as it evolved over space and time and enabled the extension of spatial data models and the development of GIS query languages that incorporate such semantics of change. Although no explicitly spatial information has been incorporated in this model of change, it has been shown that tracking changes to an object's identity over periods of existence and nonexistence, gives useful insights into the behavior of an object over time that are relevant to many cases of spatio-temporal change. Christophe Claramunt proposed a standard way of designing STPs, aimed valid for every data model that supports the time and space dimensions. He presented a taxonomy of basic STPs, extended the spatio-temporal processed in two ways, and derived a complete classification, including endogenous approach and exogenous processes, consisted of Translation, Succession and Permutation, Re-allocation, Split and Union, Production, Reproduction and Transmission. introduced related database modeling issues, expressed three design patterns in a spatio-temporal object-relationship data mode (Christophe Claramunt 1997) .

2.3 Qualitative Representation of the evolving spatial entities

Qualitative reasoning, which is widely used to define spatial relationships, must therefore be extended to the temporal dimension to provide a set of well-defined, homogeneous spatio-temporal relationships.

The evolution of an independent spatial entity involves changes in its size and shape as well as movement processes. The multi-linear evolution represents changes of a set of spatial entities that are of the same spatial type and that covers the same area, the identified processes are the split of a spatial entity and the unification or re-allocation of several spatial entities.

The properties of topological spaces have been extensively used as a mathematical support for GIS design. They provide a formal support for the expression of spatial relationships (Alexandroff 1961). A temporal metric assigns values to things in time and measures duration whereas a temporal topology allows the study of properties which are preserved under all continuous transformations.

A judge on change of object in the four-factor model: the object, object properties, object or attribute the status of the property value logical result:

Change (O) = F (O, P, S, R, Tn). (n=0 to N)

Which O means Object, P means objects' properties, S means the state attributes, R property value means the logical computation result, Tn means the temporal information which is often represented in spot time. In other words, the geographical changes of objects are concerned with object, object properties, time and state property. A algorithm can be developed for the detection of change by the above regulations. In different spot time, maybe some of the aspects are different from the previous time, then it can be recorded by database, and each kind of change can be associate the defined spatio-temporal change pattern.

In the following section, spatio-temporal change patterns are to be proposed for the implementation of dynamic representation of spatio-temporal data.

2.4 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:

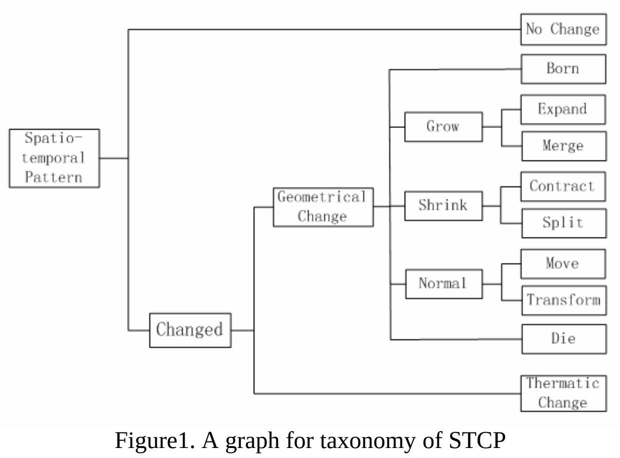


Figure1. A graph for taxonomy of STCP

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.

3. DYNAMIC VARIABLES AND TEMPORAL MAPPING

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 Four Implemental Dynamic Variables

In this paragraph, in order to get an implemental framework of dynamic visualization for the STP, we chose Moment, Duration, Order and Frequency for the representation of temporal aspect of objects, there are the reasons for the choice:

3.1.1 Moment

In most time, we look process time as a continuous variable, however, each process can be divided into discrete time pieces, we call it MOMENT, The moment that an element in the map changes during a STP can be used for temporal as well as non-temporal animations. e.g. every procedure has a begin time and end time, some key remarkable MOMENT are often record in spatio-temporal database.

3.1.2 Duration

From the Start to the end, the time span that between two different MOMENT is named DURATION, we can also name it after from one specific state to another state of objects or phenomena, The last time always is an important item in the geographic information, e.g. how long will be typhoon last.

3.1.3 Order

Order is used to differentiate change sequence among several spatio-temporal changes, sometimes we use a frame according to a specified spatio-temporal process, The order of change is similar to the topological relationship or spatial neighborhood, in one hand ,the sequence of the frame can be represented by ORDER, in the other hand, order also refers to the order of phases in a series of changes in the spatial domain.

3.1.4 Frequency

Frequency refers to the number of times that a phase is repeated in a series of changes in the spatial domain. It is also used to determine how the frame for representing the STP to be repeated, since a lot of phenomena reoccurs according to a regular time, here the frequency can conceptualize this phenomena very well.

Altogether, the variable mentioned above may not sufficient to describe all the STP representing the objects and phenomena, however it can build a implemental framework for a practical implementation.

3.2 Temporal Mapping

There are at least three kind of time for the spatio-temporal object, Real World Time, Database Time and Display Time. when dealing with a temporal process a direct relation between display time and world time exists. World Time is the time scale of reality, the moment an event takes place in the real world. Examples of these processes are those of the Dutch coastline from Roman times until today, boundary changes in Africa since the Second World War, or the changes of yesterday's weather. Time units can be seconds, weeks, or years.

In order to represent the spatio-temporal process in a dynamic (animated) way, the mapping from Real World Time to Display Time is necessary, because it is impossible to display a time sequence change according to actual time. Figure2 show a relation between Real World Time to Display Time, T1 and T2 are world time, Display time T1' and T2' are derived through a mapping. All this time are recorded in the Database time, that means that Database Time is a complete record temporal variable aggregation. Not only the transactional time but also the Real World Time and Display Time are derived from it.

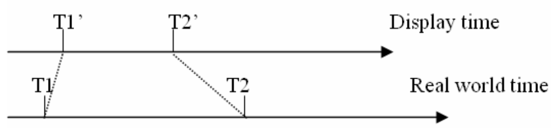


Figure 2. Mapping from Real World Time to Display Time

3.3 Combination of Traditional and Dynamic Variables

Barend Köbben and Mustafa Yaman have carried out a preliminary test for evaluating the perceptual properties of a series of dynamic visual variables, The test results shows that the dynamic visual variable moment appears to be not very useful for cartographic animations unless in combination with the static visual variable colour and some other variables. Perhaps the most important conclusion has to be that selection, which is so important in making cartography a strong tool for communication, can not be effectively attained by using dynamic visual variables alone. The traditional variables in order to accompany dynamic variables are as follows:

The SIZE of an area on a map may be changed to show changes in value, it represents the size modifications of the objects during a specified time interval. For example, the sizes of countries are made proportionally larger or smaller to depict the amount of oil or coal reserves. An animation can be used to transform the map of oil reserves into the map of coal reserves to show the differences in location of the reserves.

SHAPE represents a unique character of each object, sometime the shape can tell much of the quality of a object. An area on a map can be made to change in shape. The shape (and size) of Greenland varies as a result of the influence of a map projection. An STP can be used to blend between the two shapes to accentuate the effect of the different projections.

COLOUR is used to concept the calorific properties that objects to be represented. A color transition of sptio-temporal objects means from one colour to another during a specified time interval for a certain number of iterations. The colour animation can be used to highlight objects of interest on a map. The blinking of point symbol give a sense of stressing.

OPACITY represents the animation visibility, in other words, the transparency of the objects from one degree of transparency to another during a specified time interval. The typical usages

of the opacity animation are blinking to draw attention, fade-in to make objects progressively appear, and fade-out to make objects progressively disappear.
DIRECTION represents the direction change of the objects from a starting angle to an ending angle during a specified time interval. Objects may be modified with direction change in terms of a position point. The direction animation is used to represent the symbols with the obvious arrow or direction.
Another variable DENSITY is often used to represent the degree of scatter or assemble of spatio-temporal objects, density became larger if the objects became more collective, whereas it became smaller when the object scatter sparsely.

By assigning the traditional variables with dynamic variables, the combination of them become flexible to visualize changing phenomenon and altering objects. Then a framework is needed to be created for this combination, which based on the dynamic symbol base.

4. DYNAMIC VISUALIZAITON BASED ON DYNAMIC SYMBOL BASE

Above we have mentioned many aspects of dynamic symbol, which is used to visualize the spatio-temporal process, in this section, the dynamic symbol base is proposed to establish an strategy for the implementation of dynamic symbol.

The strategy are proposed to define a procedure which can make a multi-versioned data into a dynamic visualization. First , the Spatio-temporal association will be used to build a historical relationship between different spatio-temporal data, then different Spatio-temporal processes are got and the mapping of time are derived, based on the dynamic symbol base, temporal symbol and non-temporal are created by the combination of dynamic variables and dynamic variables. Thus dynamic visualization can be displayed by a control over the time-series dynamic map through a visual interface.

4.1 Spatio-temporal Association

On the basis of the classification of spatio-temporal processes, adopting a series of algorithms for detecting changes between different data versions through geometry and thematic characteristics of spatio-temporal objects, different kinds of STP will be derived from the association. A time mapping algorithm will be used to get the relationship between real world time and display time as well.

4.2 Utilization of Dynamic Symbol Base

Here we propose a dynamic symbol base for the implementation of dynamic visualization, which provides a methodology rather than a concrete entity for the application. Apart from offering a base for the traditional mechanism for static geographical data, the dynamic symbol base built up a framework for two kinds of dynamic symbol as Figure 3:

4.2.1 Temporal Symbol

Lots of spatio-temporal processes are successive procedures that can be displayed in a continuous representation, in the paper, we adopt temporal symbol to visualize such kind of successive processes. By the combination of dynamic variables and traditional variables such as colour, size, opacity and so on, the process can be displayed well. For example, urbanization can be showed vividly by temporal gradually size-changed polygon, etc.
An example of the temporal symbol is the addition of subsequent map layers, which leads the viewer through a theme, to help understand spatial and contextual coherence. This leaves this types of cartographic animations, which are the core of the classification presented here. It is the relation between spatial data's components and display time which distinguishes them from each other.

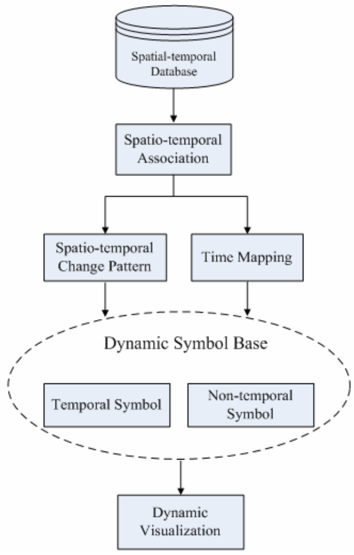


Figure 3 A Framework for Dynamic Visualization Base on Dynamic Symbol Base

4.2.2 Non-temporal Symbol

A number of phenomenon are not so strictly related to the whole process of apatio-temporal objects, however, some character at specific moment need to be highlighted. Non-temporal symbol is not strictly linked with world time, the display time of it is applied to explain spatial relations by presenting individual images in logical sequence. Some techniques will be used to demonstrate highlights or emphasis of spatio-temporal processes, such as the blinking and flashing of point symbol. Another example of this is to show a data set in different graphic representations, such as an isoline map, an smooth statistical surface or a dot map to provide the viewer a comprehensive impression of the same data set.

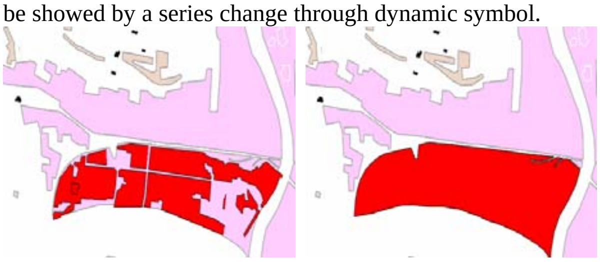
4.3 Visual Interface for Dynamic Control

For the user of a dynamic symbol, it is important to have tools available that allow for interaction while viewing the animation. Seeing the animation play will often leave users with many questions of what they have seen. Just a re-play is not sufficient to answers questions like 'What was the position of the coastline in the north during the 15th century?' Most general software to view animations already offer facilities such as 'pause', to look at a particular frame, and '(fast-) forward' and '(fast-) backward', to go to a particular frame. More options have to be added, such as a possibility to directly go to a certain frame based on for instance a temporal query, or the ability to re-ordering individual frames based on a attribute query. This becomes especially relevant if we realize that animation will not only be used to present spatial data, but will be increasingly used in an exploratory environment. In such an environment the animation is just one of the alternative view one has available to study the data at hand (Dykes et al., 2005).

We designed a visual interface that help users to manipulate the process of displaying, through which people can play back and query some details of the Spatio-temporal process. A speed control function of the process also provided for different velocity analysis. User can get a vivid impression of the change that had happened from the data which are stored in the spatio-temporal database.

4.4 Test and Analysis

A test of the implementation of the framework is carried out based on the residential expansion of a city of BAOJI in the northwest of shananxi province in China. The following graph diagram shows Entity-based spatial-temporal process displaying based on dynamic symbol base. An urban growing process can be showed by a series change through dynamic symbol.



T1 T2

Figure 4 Time series change showed by temporal symbol

5. CONCLUSION

Dynamic Symbol offers the user the opportunity to see and query changes spatial patterns. Depending on the nature of the data one can apply different design techniques, or change the viewpoint on the data. Dynamic Symbol will offer a better insight to mapped phenomena. However, this will only work when the user environment has the proper options for interaction. In an exploratory environment the dynamic symbol will be one of the strong alterative views on the data that supports knowledge discovery.

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