THE OBJECTIVE AND IMPLEMENTATION OF DYNAMIC VISUALIZATION OF SPATIO-TEMPORAL GEOGRAPHICAL PROCESSES

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ABSTRACT: The Spatio-temporal data is the description of the time, space, and attribute information of the geographic spatio-temporal process, which reflects the spatio-temporal process information of geographical phenomenon changing with the time on the earth-surface space. The spatio-temporal process information is complex and changing. Thus according to the objective of dynamic visualization of geographic process, a break-through dynamic visualization method was developed in this paper to express the geographical spatio-temporal evolution process intuitively.

KEY WORDS: Spatio-temporal Data, Spatio-temporal Process, Dynamic Visualization

1. INTRODUCTION

The spatio-temporal data is the description of time, space and attributes of the geographic process. The rapid growth of the update period of geospatial data and the new multi-sensor enabled data acquiring devices drive to the accumulation of the geospatial data. On the contrary to that, the management, the expression and the application of the geospatial data is less developed. Whilst, the information of spatio-temporal process consists of multidimensional spatio-temporal data, the geographical spatio-temporal expression oriented dynamic visualization technology and method are required for geospatial spatio-temporal process information to be presented and perceived intuitively. This method is capable to expose the rules of changes and evolution and the trends of the processes, as well as with which it is able to extend the depth and range of the multi-dimensional spatio-temporal data applications.

Visualization technology unifies human and computer in a natural way, providing people the approach of understanding and communication of the spatial information. Comparing to the static frames, dynamic visualization provides the audience the opportunities to repeat the observation and thinking to find the internal rules.With computer graphics and image processing technologies, the dynamic visualization of spatio-temporal data aims to convey changes of space and attribute of the earth surface phenomena in the Time Dimension, which promote the understanding and analysis of the progresses, rules and trends of the geographical spatio-temporal evolutions. In terms of that, on one hand, the research of data organization needs to be enhanced. Moreover, the data structure has been developed from 2 dimensions to 3 dimensions, and also from static to dynamic. On the other hand, strengthening the research on visualization includes the graphics in 2D, 2.5D and 3D, and other forms like the animation as well.

As spatio-temporal process information in the spatio-temporal data set is complex and variable, the objectives and requirements are essential to become the guidelines to facilitate the pertinence and the effectiveness for dynamic visualization of geographical spatio-temporal processes. In general, the research on the dynamic scheduling and the time-mapping of the spatio-temporal realised 3 types of visualization methods, which are the timeline based animation, multi-temporal comparison and entities backtracking.

2. THE OBJECTIVE AND REQUIREMENT OF DYNAMIC VISUALIZATION

The geographical spatio-temporal process is understood as the continuous or discrete process of morphology and properties changes, when the geographical spatio-temporal objects vary along with the long-term period or short-term period. Due to the temporal dimension in spatio-temporal data, the semantic interpreting, data structure, Data Interoperation and data storage are likely to be more complicated, comparing with the conventional spatial data. The dynamic visualization of geographical spatio-temporal process mainly shows the dynamic process which geographical information data evolves over time. As mentioned previously, there are higher requirements for the technological method and the effect of expression of the dynamic visualization than the conventional cartographic visualization or geographic information visualization. The requirements are concluded to four issues as the followings,

1. Dynamic effect: The major haracteristic is to present the changing process of spatio-temporal data, which reflects the temporal trend, sequence and cyclicity of dynamic phenomena, bring with the dynamic effect. As this dynamic effect is an approximation effect by the selection and interpolation of the spatio-temporal process according to the timeline, consistent with the human perception of the dynamic phenomena process.
2. Interoperability: The process of interaction between men and computers means men involve and control the dynamic visualization as needed. However, the interpretation and presentation do not rely on the computer program instructions, which is the demand of scientific visualization development. Interoperability provides the measure and method for people to observe and make sense of the spatio-temporal geographic processes. Therefore, researching and developing many multi-channel and multi-interface of the human-computer interaction are crucial to increase the effectiveness of communications and understanding of the human-computer information.
3. Traceability: Spatio-temporal data contain substantial historical information, which indicates the value of spatio-temporal data differing from the static and fresh data. As such, back tracking the historical status of spatio-temporal data is the basic requirement of the dynamic visualization. One of the role which dynamic visualization plays is to represent the historical scenes, and the other function of it is to compare the different historical status, which allow people to understand to historical status and the changes happened.
4. Smoothness and fluency: To achieve the dynamic visualization, access and dispatch the spatio-temporal data from the database in real time is required, as well as to display the corresponding temporal data according to the temporal changes. Hence to search and retrieve data in a high efficient way is the guarantee to the fluency of the dynamic visualization, which improves the user experience.

3. DYNAMIC SPATIO-TEMPORAL DATA SCHEDULING

3.1 Headings Spatio-temporal Culling

Spatio-temporal dynamic visualization technologies require the search and acquiring data needed in high efficiency. The requirements from 4 aspects mentioned above ultimately are the need of scheduling the spatio-temporal data rapidly in order, which based on the reasonable and high-efficient spatio-temporal data organization and management.

In visualization of the conventional spatial database, the data retrieving is enabled by the spatial location culling. When the window position changes, the corresponding spatio-temporal data is able to be culled from the spatio-temporal database and visualized according to the spatial location of the window. In the spatial-temporal database, spatial location based culling can be adapted to the time dimension, that is, according to the current window time to cull the corresponding spatio-temporal data from the database.

The spatial range of the visualization window is determined by the spatial coordinates, which can be formulated as the equation,

$$S_{now} = \{(X_{\min}, Y_{\min}, Z_{\min}), (X_{\max}, Y_{\max}, Z_{\max})\}$$

where S_{now}= spatial range of the visualization window
X, Y, Z = object spatial coordinates

The temporal attribute of spatial data can be described by the self-defined temporal coordinates(T_0,$\triangle$T),where T_0 is the initial point of the temporal coordinates, which is the current database time of the spatio-temporal database, and $\triangle$T is the temporal coordinate unit, which is also the granularity of the changes of time with a reverse direction along the timeline. So the current window time (T_{now}) can be defined as the equation,

$$T_{now} = T_0 - \mathrm{n} * \Delta T, (n = 0,1,2,3..., n)$$

where T_{now}= current window time
T_0 = current database time
$\triangle$T= temporal coordinate unit

The determining of spatial intersections from the spatial data and the window spatial range can provide the culling for the spatial range. In the temporal based culling, the visualization window time is a single time point, which has to be transited to the determination that whether the valid time period have spanned over the visualization window time. The above can be describe by the result of the relationship between T_{now} and the valid time duration of a spatio-temporal object i：

$$T_{now} \in \{VTB(i), VTE(i)\}$$

where T_{now}= current window time
VTB=the beginning of valid time
VTE=the end of valid time

If the equation is proved to be true, the object i is satisfied to the culling conditions, at the time of which, this object data will be retrieved and visualized.

3.2 Spatio-temporal Buffer

During the roaming or playing the animation, the current visible range is moving with the movement of viewpoint or the changes of the current window time. In order to promote the loading efficiency of the dynamic data and to achieve the smoothness of scene roaming and animation playing, the scene region can be logically divided to current visible region, buffer region and invisible region. By the use of current view frustum and current window time, though the spatio-temporal culling mechanism, it is convenient to get determine the current visible region of the scene. The buffer of the scene data is composed by spatial buffer domain and temporal buffer domain jointly. Spatial domain is constructed on the basis of current visible region, enabled by block-organized strategy. While the spatial area like a sub-block at each direction are expanded to be the spatial buffer domain. Nevertheless, in the temporal domain, at the current window time, loading or preloading the data spatial region, and extending a temporal granularity spatial region alongside the timeline can be taken as the temporal buffer domain.

When status changes of the geographic objects evolved in the buffer domain from the invisible domain to the buffer domain, the pre-load work is necessary to be proceeded for the smoothness and fluency of the scene roaming and the animation play.

4. TIME MAPPING

One of the key issues of the dynamic visualization of geographic spatio-temporal process is the expression of the time dimension of the geographic entities, which relates to the human feeling and cognation of the dynamic changes. Different people have different temporal descriptions of the geo-entity and geo-phenomena, such as the ways in using the Gregorian calendar or Lunar calendar, as well as using the age of timing or the dynasty of timing. The timing unit differs, for instance from hour to second and from hour to day,…,etc. Thus those drive to the tense pre-processing to the data presented by the plenty of timing, which is critical to realize the general storage of valid time(VTB,VTE)and transaction time(TTB,TTE) of the geo-entities or geo-phenomena at the same temporal reference system.

The consistent storage makes it is possible that the valid time of geo-entity and geo-phenomena be converted to the quantitative numerical data. However, it will result in the loss of the diversity of the temporal expressions, because the temporal data has been involved in to the precise processing computation of the spatio-temporal changes. Considering the specific application environment, user from various domains has his or her unique habit of description of time. In terms of that, it is suggested to avoid using the valid time at the user level directly in the numerical form to describe the temporal information in a geographic world. Whilst, through the time mapping database designed in this paper, the mapping relations conform the valid time to the time descriptions of the user habits as the indication time.

The span period of valid time stored in the database varies, which can be decades or a few seconds. During the dynamic visualization process of the changes on spatio-temporal data, the system is unlikely and unnecessary to visualize the spatio-temporal process according to the real time. However the playing time can be mapping scalable according to the valid time span and its granularity. Adapting the concept of the map scale, the time scale concept is adopted to scale the valid time to the playing time, while it scales to the indication time reversely for the user to read and identify. The valid time is the same as the indication time. Besides, the indication time can be transited to other forms of time and representation methods by the time expression conversions. For instance, the conversion from timing in the Gregorian calendar in database storage is implemented to the timing by dynasty/age as the indication time. A example of the general method is illustrated in figure 1.

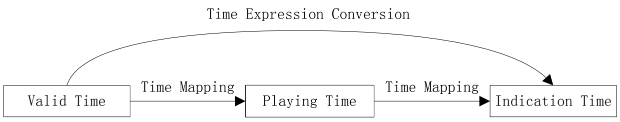

Figure 1. Time mapping

5. DYNAMIC VISUALIZATION METHODS FOR SPATIO-TEMPORAL PROCESSES

In accordance with the objective requirements of dynamic visualization, explorations were conducted to the visualization method of the geographic spatio-temporal process, and as well as several visualization methods were designed and implemented.

5.1 Timeline-based Animations

Timeline-based animations can illustrate the processes of geo-entities' changes in the region intuitively with positive order or the invited order of the timeline by assigning certain time spans, which is one of the intuitive and effective way to research on the spatio-temporal process changes.

In the implementation of timeline-based animations, the user need to assign a initial indication time(ITB),end indication time(ITE) and the actual playing time of the animation(PT),taking advantage of time mapping database, it is possible to map the indication time to the valid time format(VTB,VTE) and store in the database. Then by specifying the time duration for the whole changing process and its direction of the timeline for playing, those can be taken part to the spatio-temporal culling computation. If the actual playing time of the spatio-temporal process simulation is determined, the current time scale can be expressed as TS=(VTE-VTB)/PT. While, using the process valid time(VTB,VTE) and the time scale(TS), any current window time corresponding to arbitrary playing time can be calculated trough the equation T_{now}=VTB+PT *TS, based on which, any correspondent scene of the arbitrary playing time derives from the spatio-temporal culling mechanism.

During playing, in order to achieve the effective expression of geographical spatio-temporal process and as well to reduce the jumps emerge from the entity changing process in the expressions. This paper conducted the implementation based on the general features of various types of geo-entities, and adapted abstraction approach to design a number of animation models qualified for the typical changing processes. For instance, from the bottom to the top, the changing process of the constructions in figure 2 was abstracted to the rising animated model, while the gradual change feature of the terrain was abstracted to the gradient animated model,…,etc.

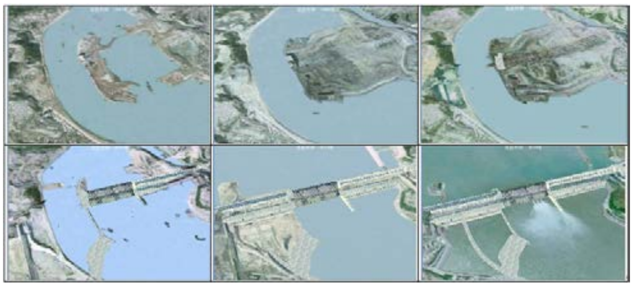

Figure 2. Screenshots of the timeline-based animation process sequential frames

5.2 Multi-temporal Comparison

There are significance meanings for people to use multi-temporal comparison for the research on the regional development and changes. Users specify a series of time points for pre-comparison, after that, from multiple view point, the differences among each geo-entity in one region but in various tense can be detected and shown intuitively.

Based on the spatio-temporal culling mechanism, Focused on every time (represented as t) which the user specify, firstly, the solution is to build a spatio-temporal version database generated from the restructure of current status database, historical information database and process information database. Secondly, the visualization of version data is implemented. When the user confirm the time comparing points, if the total number of point is represented as n, there will be n scene data be created relevantly. Thirdly, by assigning each scene data a single viewport for its visualizing, it is possible to display different scene data at different temporal tense at one time. Meanwhile, all the viewports provide the roaming and observation function for the multi-temporal data controlled by a unified browser from the same view angle and position, which the developments and changes of the same region can be recognized and compared. Some results from the implementation are illustrated in figure 3.

Figure 3. Bi-viewport visualization examples from the multi-temporal comparison

5.3 Entity Historical Backtracking

The historical backtracking of entities aims at the geographic entity, querying the way and the state of existence of certain geo-entity in all time range base on a unique search condition of the geo-entity(i.e. entity ID),which is a method to visualize the historical changes of a certain geo-entity intuitively and directly.

This paper identified the geo-entity by the unique entity identifier of the spatio-temporal object. During the entity historical backtracking process, appointing a unique identifier of a certain geo-entity at a given period, by means of the search of the databases of history information and process information in the spatio-temporal database and reconstructing of the existence status of the geo-entity in each period, the data of the status of this geo-entity in any period is visualized in the panels in chronological sequences, which visualize the time-varying changes and the trends of the changes of the entity in a simple and intuitive way. Implementation results are shown in figure 4.

Figure 4. Entity Historical Backtracking

6. CONCLUSIONS

This paper proposed the objective and requirement of the dynamic visualization of geographic spatio-temporal visualization, and also conducted the data scheduling and time mapping mechanisms for the dynamic visualization. Whilst based on the objective driven principles, this paper developed a multi-dimensional visualization method to directly reflect the geographic spatio-temporal process evolution, which also achieved the timeline-based animation, multi-temporal comparison and entity backtracking methods, that was a breaking to the limitations of the convictional visualization method for the single spatio-temporal status.

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8. ACKNOWLEDGEMENTS

The research project described in this paper is funded by International S&T Cooperation Program of China (project No.2011DFG23339), and National Key Technology R&D Program(project No.2011BAB01B04) ,as well as the Open Fund from Key Laboratory of Geospatial Information Engineering, National Administration of Surveying, Mapping and Geoinformation(NASG).