Cognitive Optimization Techniques of Spatiao-Temporal Dynamic Map

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Abstract. This paper presents three design techniques to optimize dynamic maps for cognitive efficiency. An interactive time legend, which has functions such as play, pause, stop and speed control, can help users to remember, identify and understand the dynamic phenomena in dynamic maps by expressing time information. And a user-defined data filter can help users to reduce the amount of dynamic map information and focus on the phenomena they are interested in. Spatiao-temporal data aggregation can compress the amount of dataset to establish a dynamic map of appropriate time resolution. It can also display the same dataset using different temporal units, such as from year to composite month or composite week, to find the hidden meaningful patterns.

1. Introduction
The world is dynamic. The map as a visual tool for mankind to understand and transform the world is used to describe the state of the geographical phenomenon at a certain moment and express the dynamic characteristics of the geographical phenomenon over time. Due to the limits of the map's breadth and load, static cartographic methods face greater limitations in expressing dynamic spatial-temporal phenomena. Electronic maps and geographic information systems emerged with the rapid development of computer technology and its application in cartography in the 1960s. Mapologist began to make and play dynamic maps through the computer by using the dynamic nature of the electronic map such as Waldo Tobler made a pioneering map of the urban population growth in Detroit in 1970 [1]. The dynamic map introduces time dimensions in electronic maps. Its capacity of information has greatly increased compared with static maps. It reproduces the spatial-temporal evolution process of geographical phenomena through the play of animations. This dynamic expression also meets the human understanding of the dynamic evolution of natural phenomena. Therefore, from the beginning of its appearance, dynamic maps have always been an important means of Spatial-temporal visualization [2].

The main purpose of dynamic maps is to express the transformation and trends of phenomena. Therefore, the role of animation lies in contents and changes of maps. Users need to detect and identify changes quickly and memorize the changes for analysis of features and trends. In view of this, the most important characteristic of cognitive dynamic maps is the large amount of information [3]. If the content (stimulus) of the animation is too much, or the time is long, or the model of the change to be expressed is complex, the information content exceeds the threshold that humans can bear, and it will make the psychological and physiological of the person overloading in the whole cognitive process. This will fail to promote understanding and create confusion.
Barbara et al. [4] proposed two principles of designing dynamic map for this cognitive characteristic: 1) Understanding: Animation must be easily perceived and understood; 2) Expression: The concepts conveyed in the animation should be prominent and distinct. Harrower [5] proposed that the specified frames can be superimposed to contrast the contents of maps, thereby reducing the cognitive load when viewing the map. Mekonnen [6] established a prototype system for dynamic maps analysis of remote sensing images to translucently display the interactively selected content by users outside hotspots, thereby reducing the amount of information in dynamic maps. Robinson [7] highlighted key elements by using the visual variables such as colors, borders, shadows, and ambiguities of graphic symbols to attract the user's attention and improve cognitive efficiency.

It is more and more common to use dynamic maps to express and analyze the spatio-temporal phenomena with the rapid development of Web-GIS and mobile GIS. However, most of the current dynamic maps are simple animated maps, and the static maps of multiple time series are directly mapped to the frames of the computer animation for playback. This may cause too much information to affect cognitive efficiency. This paper proposes three optimization methods for dynamic map design to solve this problem: interactive time legend, user-defined data filter, and spatio-temporal data aggregation. The interactive time legend provides visual representation of temporal dimension information and functions such as play, pause, speed control, time range playback, which can help users to focus on the time of interest. The user-defined data filter only focuses on the content of the data satisfying the user-defined conditions and weaknesses, or not expresses other content so as to reduce the amount of information of the dynamic map to facilitate the user to focus attention on the content of interest for observation and analysis. The Spatio-temporal data aggregation enables comprehensive processing of high temporal resolution data, compressing the dataset to create a dynamic map with appropriate time resolution, and it can also integrate spatio-temporal data at different time periods to help users to discover the evolution of different time periods.

2. Interactive Temporal Legend

The dynamic map introduces the time dimension in the map. In addition to viewing and reading the dynamic changes in the map during the dynamic map playing process, the user needs to understand the time when the change occurred. Therefore, a time legend needs to be designed to match the dynamic map to the time at which the Information is expressed. A good time legend needs to answer at least the following three questions:

1) What is the time corresponding to the current frame during dynamic map playing process? (e.g. August 10, 2014)
2) What is the total time in the dynamic map? (e.g. August 1 to August 20, 2014)
3) What is the position of current time in the overall time of the dynamic map? (as in half of the total time.)

Figure 1 shows a typical linear time legend. This legend expresses time as a directed line segment. The start points and end points of the line segment respectively correspond to the start time and end time of the dynamic map, and the cursor that moves from left to right on the line segment expresses the current time during the animation playing, and the played time period is shown in blue. This time legend can quickly answer the above questions.

![Figure 1. Linear temporal legend](image)

In addition to expressing time information, another important function of the time legend is to interactively control the dynamic map in the time dimension in the environment of electronic maps and GIS. The dynamic maps have greatly increase the amount of information compared with static maps and the contents are constantly updated during the playback process. The users need to memorize the contents of each frame to identify and understand. This cognitive manner creates a
greater psychological burden on users. Adding a control function of interactive animation on the time
legend is one of the effective ways to solve this problem.

Figure 2 shows an interactive time legend. It can express the start time, end time, and current time
of the animation and include the following functions:

1) The legend includes functions such as play, pause, advance one frame, and back one frame of
the animation. The user can pause at any time during the animation playback, so that there is enough
time to memorize and cognitive the interested frames in maps;

2) The timeline is designed as a time slider with a scale. The user can drag the cursor to switch to
any frame, and it facilitates the user to disturb the time sequence to compare the contents of the map at
different times;

3) With the customizing the starting and ending time function of the animation, the user can select
the interested time period to the animation segment playback for key cognition.

4) With the speed control function of animation playback, the user can select different speeds to
play the animation and cognitive the dynamic content at different speeds.

![Interactive temporal legend](image)

3. Interactive Data Filtering

The amount of information people can remember and understand within a certain period of time is
limited. If there are too many changes in dynamic maps, and the amount of information exceeds the
threshold that people can bear, it will fail to promote understanding and create confusion. Therefore,
dynamic maps should provide users with interactive screening of data content. They only express
contents that satisfy user-defined conditions and not express other contents, so as to reduce the amount
of information on dynamic maps and the user can be concentrated on observing and analyzing the
content of interest.

Figure 3 shows the differences between two consecutive frames in Shandong Aerosol Dynamic
Map. The map expresses the monthly average aerosol optical depth (AOD) of the area by the grid
color. The closer the color is to red, the greater the optical thickness is. The closer the color is to blue,
the smaller the optical thickness is. This map has not been screened for content resulting in the large
information capacity. It can be found that the Shandong Province is covered by grids of different
colors in the map. And it is difficult to find the key areas of change between two frames. In contrast,
the content of the map is screened in Figure 4. It only shows the area where optical thickness is greater
than 0.15 that is with more suspended particles in the air. The user can quickly detect and capture the
important areas of the two frames for comparison and analysis during animation playback because the
amount of map information is effectively reduced in the map.
4. Spatio-Temporal Data Aggregation
The simplest method for making dynamic maps by using spatio-temporal data is to directly map them onto frames of computer animations. For example, map of time 1 = frame 1, map of time 2 = frame 2, and so on. The problem of this simple dynamic map is that:

1) The resolution of data time may not match the time resolution of dynamic map
The time resolution is a parameter that describes the degree of detail of the time variation and it’s the smallest unit of time that can be divided [43]. The temporal resolution of spatio-temporal data may not match the temporal resolution of the dynamic map that needs to be made. In this case, the data
cannot be directly used to create a dynamic map. For example, in order to study the evolution of aerosols in a certain region within 3 years, the dynamic map will reach 1000 frames or more by directly obtaining the inversion result of aerosol optical thickness data using the MODIS data collected in days. It will be difficult to meet the needs of analysis because its playing time is too long and the amount of information is too large.

2) Implicit cyclic evolution characteristics in spatio-temporal data are difficult to reflect

Spatio-temporal phenomenon often has cyclical evolution characteristics. According to statistics of traffic accidents in a place, the frequencies of traffic accidents from 2 pm to 4 pm are higher, and the consequences of traffic accidents from 8 pm to 10 pm are much more serious. A simple dynamic map is conducive to reflecting the development trend of the phenomenon in the entire data cycle by expressing spatio-temporal data in a linear time series manner, but often masks its cyclic evolution characteristics in some small cycles (such as days, weeks, and months).

This paper solves the above problems by means of time data aggregation. For question 1), the time resolution of the dynamic map should be matched with the time scale of the analyzed spatio-temporal problem. For example, the time scale can be millions of years or even hundred millions of years when studying the spatial-temporal evolution of geological phenomena, and the time resolution should be one million years or less when making dynamic maps, so as to avoid the dynamic maps being too lengthy and the information volume being too large, which affects the cognition of the entire spatio-temporal process. The spatio-temporal data needs to be aggregated to reduce its time resolution and satisfy the mapping requirements of the dynamic map when the time resolution of the empty data is higher than the time resolution of the dynamic map. Spatio-temporal data aggregation is generally performed in units of time in the time dimension. For example, data with a time resolution of one hour can be aggregated by day, and data with a time resolution of one day can be aggregated by week or month. Spatio-temporal data aggregation algorithms are generally statistical methods such as mean, sum, maximum, minimum, standard deviation, variance and so on. The temporal resolution of aerosol optical thickness of the dynamic map is one month which is shown in Figure 3, and the data is obtained by aggregating the data for several days within the month using arithmetic mean method.

For Question 2), the spatio-temporal data should be aggregated according to different time periods (such as days, weeks, months, and years) in order to discover the cyclic evolution characteristics of spatio-temporal data over these time periods. The dynamic map should provide users with the function of interactively select aggregation cycles.

Figure 5 shows a dynamic map of China's air disasters from 1982 to 2010. The locations of the crash are represented by the position of the dotted symbols. The possible causes of the air disaster are represented by the color of the dotted symbols, which are mainly divided into man-made, mechanical stoppage, weather and other four major categories. The map can express the linear and dynamic data of air disasters by year as shown in Figure 5a. It can also aggregate data by the cycle of 1 year including 12 months, 1 week including 7 days and 1 day including 24 hours to express phenomenon such as the hour is used as a unit in Figure 5b, the air disaster data that occurred at 0 o'clock in all 29 years is collectively expressed on the map frame of 0 o'clock, and the air disaster data that occurred at 1 o'clock is collectively expressed on the map frame of 1 o'clock and so on. This dynamic map can help users analyze the distribution of air disasters over different time periods, answering spatio-temporal issues such as "Which month was the most likely to cause air disasters due to weather?" or "Is it more likely that a plane disaster caused by a mechanical stoppage occurred on Mondays than Fridays?"

Spatio-temporal data aggregation is an important part of dynamic map designing. For one thing, it can comprehensively process high time resolution data and compress data volume to create a dynamic map with appropriate time resolution, and for another thing, it can also integrate the spatio-temporal data according to different time periods to help the user to discover the evolution of different cycles.
5. Conclusion

Dynamic maps use computer screens to quickly update new features of content, expressing spatio-temporal processes through map content that changes over time. This method has greatly expanded the map’s information capacity to meet the demand for mapping of large amounts of spatio-temporal information. At the same time, this dynamic expression over time is consistent with the development of spatio-temporal phenomena and cognitive habits of human.

Most of the current dynamic map design the time-series static maps directly onto the frames of the computer animation and play them at a fixed speed. This simple dynamic map has poor interactivity, less cognitive efficient and visual confusion caused by large amounts of information. In order to improve the cognitive efficiency of dynamic maps, this paper proposes three optimization methods for dynamic map designing:

1) An interactive time legend, which has functions such as play, pause, stop and speed control, can help users remember, identify and understand the dynamic phenomena in dynamic maps by expressing time information.

2) A user-defined data filter helps users reduce the amount of dynamic map information to focus on the phenomena they are interested in.

3) Spatio-temporal data aggregation can compress the amount of dataset to establish a dynamic map of appropriate time resolution. It can also display the same dataset using different temporal units to find the hidden meaningful patterns.

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