TEMPORAL LINKS IN THE COORDINATED MULTIPLE VIEW ENVIRONMENTS APPLIED IN LOCATION SPACE, ATTRIBUTE SPACE AND TIME SPACE

Xia Li and Menno
xia@itc.nl
ITC – International Institute for GeoInformation Science and Earth Observation
PO Box 6, 7500 AA Enschede, the Netherlands

Jan Kraak
kraak@itc.nl
College of Earth Science and Resources
Chang'an University, China

1. Introduction

Many of the most urgent challenges that the world is facing today, such as global climate change, economic development and infectious diseases control require a huge amount of geospatial data to analyze changes and trends in order to support problem solving. These data desire a close look from different angles simultaneously to help users to obtain a deeper understanding. For example, people are not only interested in the place where they are, the time when they arrive at their destination, but also how the relations between these conditions are etc. The elementary questions linked to geospatial data such as "where?", "what?" and "when?" reach an even higher level of relevance. However, data are so complex and diverse that exploring and analyzing relationship in these data becomes increasingly difficult.

Geographic visualization is a powerful data exploration technique, exploiting the ability of current computing technology to dynamically analyze and display large amounts of information (Edsall et al., 2000). According to Shneiderman's (1996) visual information seeking mantra, visualization techniques can be used to obtain an overview of data collections, zoom into interesting sections and filter datasets by comparing the data, and finally obtain details on demand. A specific exploration environment is required to carry out the above tasks. The 'Coordinated Multiple View' (CMV) is a technology to supply an exploratory environment which allows the user to interact with the data not only in terms of an overview and details on demands, but also with different perspectives on it. These exploration visualization (EV) environments are highly interactive systems and relay on the premise that 'insight is formed through interaction' (Roberts, 2005, Roberts, 2008).

It is commonly accepted that spatio-temporal data consist of three components, i.e. location, attribute and time. These three components could be addressed in different views. This can be called triple space, namely the location space, the attribute space and the time space (Li and Kraak, 2008). The three spaces can be represented in a multiple views environment which requires being coordinated in a proper way. A considerable amount of research has been done in the field of CMV to coordinate the views from both the spatial perspective (Roberts et al., 2000, Parkham and Dengam, 2003, Plumlee and Ware, 2003) and the attribute perspective (Carr et al., 1986, Convertino et al., 2003) . Using the time perspective to coordinate multiple views has not been elaborated. This research reconsiders the CMV technology from the time perspective, based on the visual information seeking mantra by Shneiderman (1996). The aim of this approach is to improve the insight in data from the point of view of temporal relationships, whilst not leaving spatial and variable relationships of objects out of consideration.

2. Principle of CMV

Roberts (2008, , 2005) provides an overview discussion on CMV for exploratory geo-visualization. The term 'multiple-views' is all-encompassing: it includes any system which allows direct visual comparison of multiple windows, including visualizations from different display parameters (Roberts, 2008). He states that several aspects should be considered by the developer or user in an exploratory CMV environment, i.e. where is the information displayed, interactive filtering, interactively adapting mapping parameters, navigation, interacting with the environment and coordination.

Roberts' discussion on the CMV focuses on interaction during visualization. He emphasizes the interactive link among multiple views. "Coordinated" is the keyword in the CMV technique. It means: each of the views is linked together in a way such that any user manipulation in one of the views automatically has an effect on the content of any of the other views. For example: a user selects one object in the map view; the record representing the same object in the database will be highlighted in attribute view. In practice the coordination could be supported by brushing techniques (Berker and Cleveland, 1987, Carr et al., 1986). It is also known as highlight technique (Robinson, 2006). It is a direct manipulation technique which allows the user to point on and pick interesting elements for selecting, deleting or adapting them. Recently, CMV techniques got more attention form the perspective of high dimension data (Schlesier et al., 2006, Lamirel and Shehabi, 2006, McDermott et al., 2006), exploratory and coordination techniques (Hoeber and Yang, 2006, Lawrence et al., 2006, Plumlee and Ware, 2003, Andrienko and Andrienko, 2003) and different application systems (Brodbeck and Girardin, 2003, Sifer, 2003, Wraver, 2006, Morrison et al., 2006). However, temporal aspect in CMV environment has not been discussed in detailed.

3. Triple space

Solving a geo-problem can be done based on a set of tasks carried out in an appropriate working environment and with suitable data. In a visual approach, the working environment includes both representation and interaction functions (Li and Kraak, 2008). Peuquet's (1984) discussions on data and user tasks offer a systematic view incorporating both cognition of the human being and computer representation. Figure 1-a present her approach. This 'triad' concept is further extended to a 'pyramid' model (figure 1-b) in which an 'object' is considered as a knowledge component on a higher level (Mennis et al., 2000) (Figure 1b). This theory could be extended to a visualization working environment. Based on the data framework and the user tasks visualization can be approached from three perspectives: location space, attribute space and time space. Here the notion "space" is an abstract notion, not to be mixed with geographic space (Li and Kraak, 2008). Of course there are also graphic representations that combine two or three 'spaces', and these are therefore capable to handle complicated questions (see Figure 1-c). The thematic map can be taken as an example for how the location space and attributes space can be combined to show the variable changes concerning location.

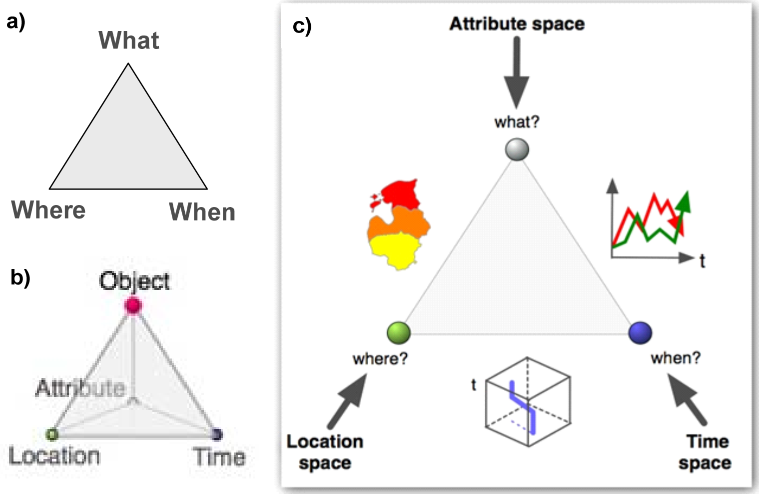

Figure 1 Visualization spaces (c) a view from location-space, attribute-space and time-space. A typical combination of location-space and attribute-space results in maps, the combination of attribute-space and time-space in diagrams and the one of location-space and time-space in a space-time cube (Li and Kraak, 2008); (b) The generic pyramid model of spatio-temporal data based on Peuquet. (a) The triangle model of questions of spatio-temporal questions based on Peuquet

Implementation of triple space should always be supported by the CMV technique. Based on the highly interactive tools, spaces are coordinated with each other to show the different views on data as well as relationships between datasets. In addition, interactive tools available in each window could define or change (refresh) the content visible in the other space. Time can be used as the coordinated link in multiple views not only because all objects behave in a common temporal reference, but also because many user tasks require a temporal action, such as what happens and where is it at a certain time? What objects change with the same frequency? etc. Temporal link is defined as using the temporal data to coordinate the multiple views in this research. With a focus on time space, supported by CMV technology, temporal link in an exploratory environment in triple space will be discussed.

4. Temporal links in triple space

Triple space is a structured CMV environment organized via a systematic view on data and user tasks. It supplies the user with a reasonable clue where to represent data and where it is easier to find the answers to questions, because the corresponding data type is addressed in the relevant space. At the same time, triple space simplifies the activity environment of the user by suggesting a workflow. For example, the user wants to answer the question ‘where did it rain at 5pm yesterday?’ In this case (s)he will define the “5 pm yesterday” in the time space and find the corresponding answer in the location space. Figure 2a shows the relationship between a query plane (the questions), a visualization plane (the interface) and the data plane (data components). The data plane symbolizes the inherent link between data components (location, attribute, time, object) and is the core of the triple space environment. Through the visual plane the user can see the links between the data components. The query plane shows relationships between the questions asked which are displayed in the visual plane. The dotted lines in figure 2a represent the links between components in each of plane linked together. Figure 2b show an example of query process. The person (1) asks question via time space; (2) and get answer in location space and attribute space; (3) the database provides the answer throw visual environment. This process is represented by the gray arrow at both side if the figure 2a.

The next section will focus on time space, discussing how to coordinate the temporal link and what is the requirement for temporal exploration, based on temporal data, temporal user tasks and temporal visualization environment aspects.

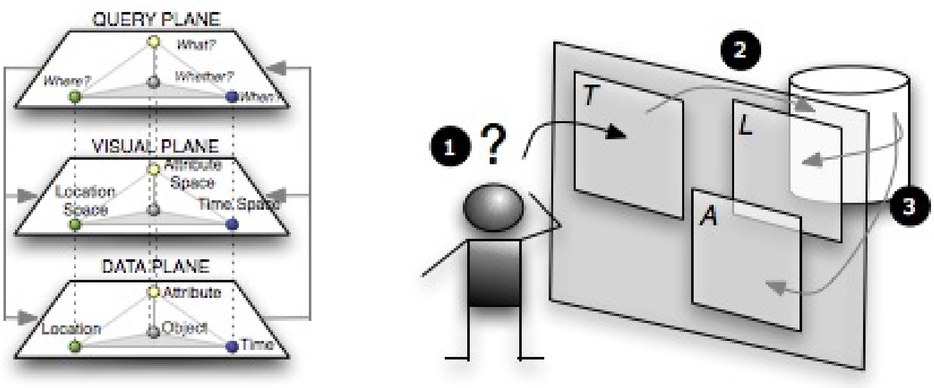

Figure 2 the theory framework of CMV environment in triple space

Temporal data

Temporal data has been topic of study for many years (Frank, 1994, Peuquet, 1994, Goralwalla et al., 1998, Langran, 1992, Peuquet, 1998). These different studies reveal notable similarities, particularly in relation to the notions of linear and cyclic time, the granularities of time, discrete and continuous time, instant and interval time, and the absolute and relative time. These characteristics have to be addressed in time space. For example, 12am is an absolute instant point in both linear and cyclic time. 5 hours on 1st January 2002 is an absolute time interval; 5 days after is a relative interval time; first week of this spring is in cyclic time; the first day of each month in this year is in different granularities of cyclic time. Furthermore, logical operations such as “and”, “or” and “not” which is discussed by Chen (2004) are necessary to define temporal links as well, for example, first week but not on Monday.

Similar to a map the user who often gets lost during navigation and orientation, the time space users might experience same. The reason for this is that time is often shown at different scales. Those differences can be quite large. Analogue to location space, one needs function like zoom in /out and pan to navigate. Furthermore, creating to a focus and keeping a overview context are necessary in time space for navigation purposes.

Temporal user tasks

Andrienko and Andrienko (2003) discussed the temporal user tasks based on two kinds of questions:

- When➔what+ where+object
- What+ where +object➔ When

To answer the first question, both the instant and interval of time should be selected in time space, and the results are shown in the linked views: the status of the object in the attribute space and the position in location space. To answer the second question, the location and a certain value of the object should be identified as a result the temporal characteristics and distribution will be shown in time space. Because temporal coordinated elements are focused, the first question will be elaborated. To answer more complicated questions, coordinated elements should be jointly identified. The flowing combinations exist:

- When+where: what is the object and what happens at a certain location at the certain time
- When+what: what is the object and where does a certain situation happens at that certain time
- When+object: what happens where with the object at a certain time
- When+where+what: what object exist with a certain value in a certain location and at a certain time
- When+what+object: where is the object with a certain value at a certain time
- When+where+object: what is the value of the object of a certain location and at that certain time

To identify the above combinations coordinated elements in triple space, the logic operations should work not only in time space but also in location space and attribute space. For example, the moment of appearance of object “a” in afternoon at location “A” and in the morning at location “B”. However, it is easy for user to get confused about which link exists. Therefore, an overview of the current coordinate links has been shown in a separate window.

Temporal visualization

To discuss the temporal coordinated elements in the time space, a temporal visualization environment has to be discussed specifically. This environment includes temporal representation and temporal interactive tools.

The timeline is a popular temporal visualization to represent linear time. The time wheel is a design to show the cyclic characteristics of time. However, the representation of time by a timeline (linear time) or a time wheel (cyclic time) does not always result in satisfying solutions, because a lot of phenomena have both linear and cyclic characteristics. The time wave (Li and Kraak, 2008) is one potential solution to represent both linear and cyclic nature of the data, often even at different levels of granularity. It is a combination of the timeline and the time wheel. In this paper, the time wave will be the instrument in time space to discuss the temporal coordination in triple space. This section will briefly introduce the time wave. The time wave (Figure 3) is developed along the x-axis, which represents the characteristics of the timeline (dashed line below the time wave). The wavelength represents one period of time which symbolizes one cycle of the wheel. In its basic form the period corresponds with a certain time-unit, for instance a year or a day.

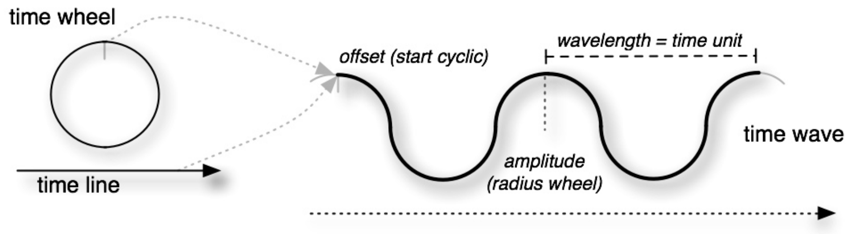

Figure 3 Time wave, composed from the timeline and the time wheel

Based on the different representations, interactive tools should be design properly. As mentioned in the section on temporal data, it is possible to select instants and intervals both in linear and cyclic time, and at different granularities. Both timeline and time wheel have their strengths and weaknesses as basic structure of time space. For example, cyclic characteristics are difficultly selected at a time line (first week of each month); continue linearly time interval is difficult to select at a time wheel, different granularities are difficult to select both on a timeline or time wheel. With the time wave, these weaknesses can be limited, because the time wave holds both continuous linear and cyclic characteristics. It is possible to embed different temporal granularities in a single time wave to represent the different temporal granularities. The different waves with different wavelengths and amplitudes are nested into each other based on their temporal scale, to show for instance a year with seasons and months. Therefore, the time wave not only deals with the nature of time, e.g. its continuous passing, but can also handle cyclic phenomena at different granularities. Figure 4 shows a prototypical CMV environment with location space, attribute space and time space.

Triple space is implemented as CMV and as such supports exploration as an interactive and iterative process. This exploration requires a close combination of the temporal representation and temporal interaction in the time space. After the temporal distribution is shown in temporal representation, zoom to or select interesting temporal characteristics, such as irregular time intervals. The corresponding results will be shown as map and diagram representation in the location and attribute space respectively. This is typically an iterative process and could include action directed from location and attribute space effecting the representation in time space.

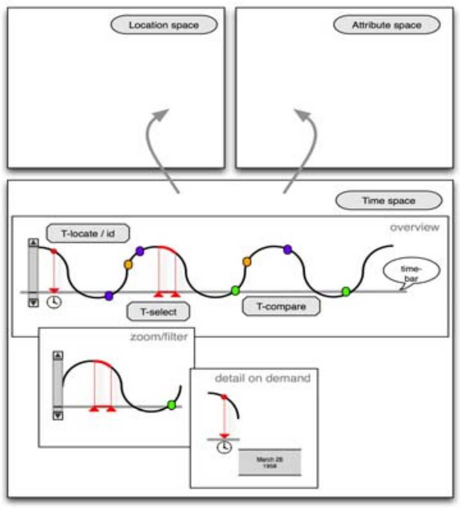

Figure 4 A prototypical CMV environments with location space, attribute space and time space

5. Case study

Data for this case study has been collected by the Institute of Hydrogeology and Environmental Geology (CAGS). It deals with data of eleven observation stations in Mudanjiang city Heilongjiang province, China. There are three attributes: precipitation, surface temperature, soil temperature (10cm below). Observations are available at half hour intervals from 1995 to 2002. The data has been collected with the objective to detect the relationship between precipitation, atmosphere temperature and soil temperature.

Figure 5 shows a CMV environment of triple space. This environment was realized in uDig with plug-in written in Java. Based on discussion in last section, a map represents location space. Attribute space could contain PCPs, scatter plots or bar graphs. The time wave acts as both representation and interaction tools in time space. Since the data covers a long period (seven years) and is very detailed (a value every half hour), a temporal overview view is used as shown in the center of the figure 5. An overview of the current links between the spaces is shown in the view with the data pyramid (in the middle of right side of figure 5).

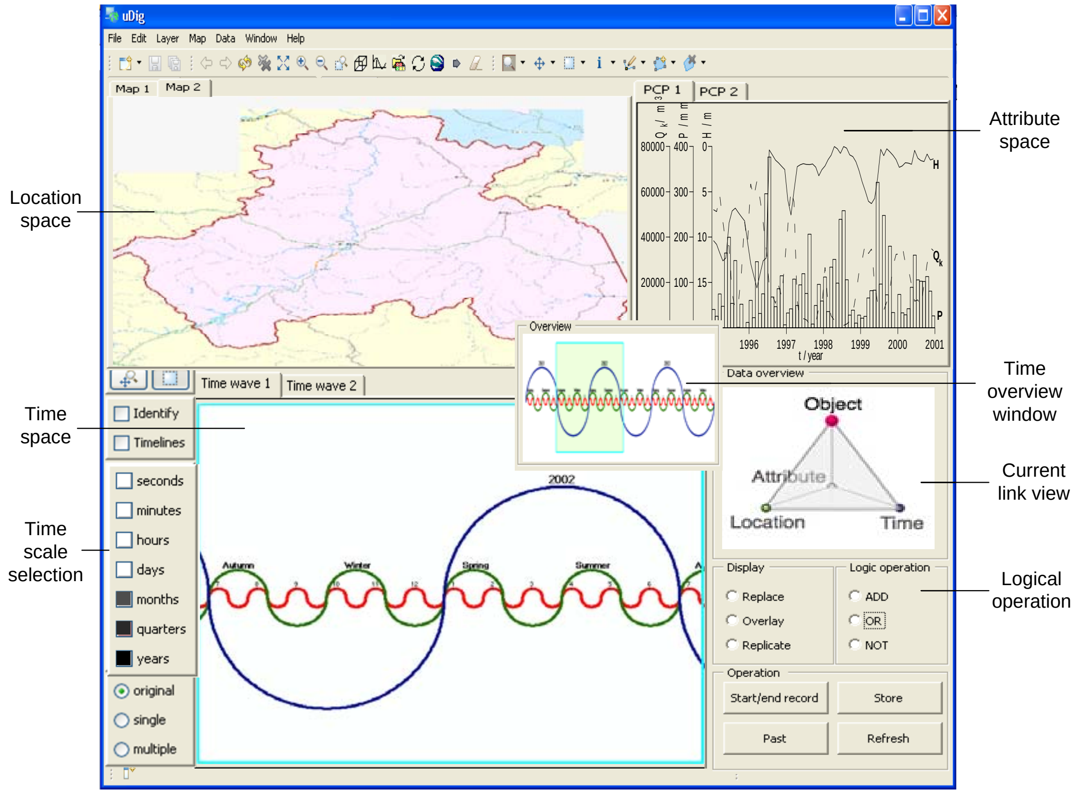

Figure 5 a CMV environment of triple space

Multiple temporal granularities are shown as multiple time waves in time space. The temporal data could be shown with time wave. With a mouse click, a time instant or interval could be selected. Based on the nature of the temporal questions, a wave unit can be selected by the time scale at the left. After selection, the time wave will adapt to the chosen unit.

To view the correlation between three variables, the temporal relationship, attribute relationship and spatial relationship can be shown in corresponding spaces directly. Supported by CMV techniques, these relationships can be further explored. For example, the temporal distribution of the highest value for each attribute at several locations will be shown by selecting the corresponding location and highest value of each attribute. Based on this environment, iterative exploration can be executed. For example, after showing the temporal distributions of soil temperature and surface temperature in time space, time delay of soil temperature to surface temperature can be selected. The selected delay can be used as a time parameter for a statistical model. According to this parameter, the calculated value can be shown and compared to the value of the other attribute in attribute space.

6. Conclusions and discussions

Triple space structure the data, visualization and interaction of the user in an efficient way. It supports the user in finding answers and thinking process systematically. The link related the user tasks closely. To deal with the temporal user tasks, temporal link is useful and necessary.

Defining the temporal link in time space could help user to identify or selection the time instant and/or interval at different granularities and show the spatial and attribute characteristics in the other spaces. To define a useful temporal link, different views of time have to be considered, such as linear versus cyclic, continuous versus discrete, instant versus interval and granularities. For complicate questions, the combined temporal links should be addressed and supported the logical operation.

Since exploratory tasks executed as an iterative process, the temporal representation and temporal interactive function should work together in time space to interact with spaces. Each of the spaces needs an overview window after using zoom function. An overview of current links is needed to keep track of relation between the data components. Further research activities include:

- Usability evaluation of the prototype with the coordinate links.
- Further study on temporal links and the temporal user task in detailed.

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