

NEW VIEWS ON MULTIVARIABLE SPATIO-TEMPORAL DATA: THE SPACE TIME CUBE EXPANDED

Xia Li ^a, Menno-Jan Kraak ^b

^a College of Earth Science and Land Resources Management, Chang'an University, 126 Yanta Street Xi'an, Shaanxi, China 710054 li07816@itc.nl

^b Dept. of Geo-Information Processing, ITC - International Institute of Geo-Information Science and Earth Observation, PO Box 6, 7500 AA Enschede, the Netherlands kraak@itc.nl

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ABSTRACT:

Multivariable spatio-temporal data is used to describe the change of characteristics of objects with time and location, and the change in location of objects is also considered. To analysis of this kind of data, data visualization is one of the effective techniques. This paper presents two new visualization approaches, the Multivariable-Time-Cube (MTC) and Parallel Coordinate Plot-Time-Cube (PTC) and linked to the Space- Time-Cube (STC) to solve the problems of large amounts of multivariate spatio-temporal data.

1. INTRODUCTION

Our dynamic geo-community currently witnesses an increase in the quantity and quality as well as the variability in the availability of spatio-temporal data. This positive trend also stimulates creative action when it comes to dealing with this diverse amount of data. Many computational visual methods and techniques have been developed by information visualization and geo-science community (Dykes et al., 2005). This paper suggests two new approaches, based on Hägerstrand's Space-Time-Cube (Kraak, 2003), to the visualization of changes in multivariable spatio-temporal trajectory data, the Multivariable-Time-Cube (MTC) and the Parallel coordinate plot-Time-Cube (PTC). A STC combines time and space in a natural way. Time is represented along the Z-axis of the cube and can have a continuous or discrete nature. The X and Y axes represent the geography. The classical STC studies deal with the behaviours of human individuals and the position of a person in Space-Time-Cube is a point, following a trajectory through space and time. This trajectory is known as Space-Time-Path (STP).

The STC can handle only a limited number of variables in relation to the trajectory. One could vary its thickness and colour to represent certain qualities or quantities of the trajectory. However, the STC does not offer options to represent additional variables which limit its use when one has to deal with multivariable data. We have opted for a solution in relation to the multiple linked view concept and will discuss graphics that can usefully and efficiently be combined with the STC, and make sure all questions about the multivariable data can be answered. Based on the existing multivariable graphics and STC model, two prototypes have been designed and evaluated in this research.

To analyse the existing methods to visualize multivariable spatio-temporal data, as well as the usability of the new methods, questions related to multivariable spatio-temporal data, and the basic concepts of multivariable spatio-temporal data are discussed briefly. In our approaches we built on the work of Peuquet (1994) who distinguishes three components in spatio-

temporal data in relation to the elementary questions: space (*where*), objects (*what*) and time (*when*) (See the triangle in figure 1). However, the "*what*" component not only indicates the object itself, but also includes the characteristics of the object, and these characteristics are described as multivariable (see *how* in the polygons in figure 1). Here the *how* is distinguished from *what* in to describe multivariable spatio-temporal data. Based on *where*, *when*, *what* and *how* components, the simplest questions about multivariable are addressed as:

1. How → what + when + where
2. What → how + when + where
3. When → where + what + how
4. Where → what + when + how

The above four questions form the foundations of this research, and the more complex questions of multivariable spatio-temporal data can be created by a combination of these four simple questions. So the existing visualization solutions were analyzed based on these four simplest questions. Furthermore the visualization models developed in this research attempt to answer all of these questions and they are also used as to evaluate the prototypes.

2. MULTIVARIABLE-TIME-CUBE

Although the basic questions "what", "when" and "where" can be easily answered by STC, it is limited in dealing with many variables. One solution is to create another cube next to the classic STC. In this cube the X- and Y-axes do not represent the geography but selected variables. The Z-axis represents time as in the STC and also is used to synchronize both cubes. In this situation as displayed in figure 2, the "what", "where", "what" and "how" questions can all be answered. As mentioned before, the movement of an object in Space-Time-Cube is visualized as a trajectory and the X, Y, and Z-axes form a spatio-temporal space (field). All the spatio-temporal questions of the object can be viewed in this space. In Multivariable-Time-Cube, an object is represented also as a trajectory, which indicates the value

change of the variables which are defined on the X and Y axes, and in this case, the X, Y, and Z axes form a multivariable-

temporal space (field), so all the questions of the object about the defined variables can be answered in this space.

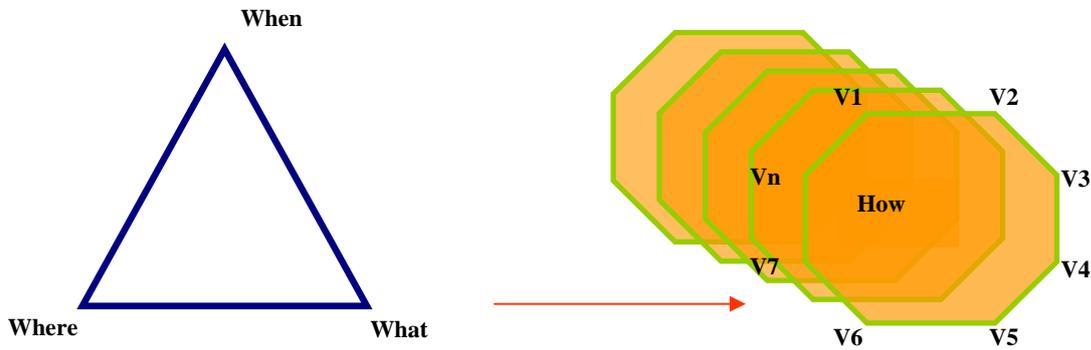


Figure 1 Concept of multivariable spatio-temporal data. Left the basics of geospatial data “where”, “when” “what” and right the multivariable extension with “how”, in which “what” refers to the object, “where” indicates the location, “when” is the time and the “how” refers to the thematic attributes of an object.

In Space-Time-Cube, at a certain time, an object is a point which indicates the position according to the geo-space reference and time reference. Similarly, at a certain time, the object is also a point in Multivariable-Time-Cubes, and the position of this point indicates the value of the object for the two variables which are defined at that time, and the slope of the trajectory indicates the speed of the change. It should be mentioned that, in Space-Time-Cube, the X and Y axes form a continuous space and the X, Y variables are inseparable. However, in Multivariable-Time-Cube, the X, Y axes can be defined as any variable, so the relationship between the two axes may be meaningful or not, and it is based on the user’s definition. Figure 2 shows an example of Multivariable-Time-Cube. In a STC the result of projecting the trajectory on the

bottom in Space-Time-Cube is the footprint of an object path. In a MTC the projection of the trajectory on the bottom, as well as on the cube’s sides are also meaningful. The projection on the bottom shows how the variables of the object change with time and the relationship between the two variables in two axes, a kind of ‘scatterplot’. Figure 2-a, c shows that the projection of the trajectory as a polyline which indicates the change of the variables. The slope of the line segments indicates decrease or increase of the value of the variables, while the speed of change is defined by the line gradient. A vertical or horizontal section indicates that the variable doesn’t change. The projection of the trajectory on the cube’s sides (figure 2-b, c) show how the variable change with the time.

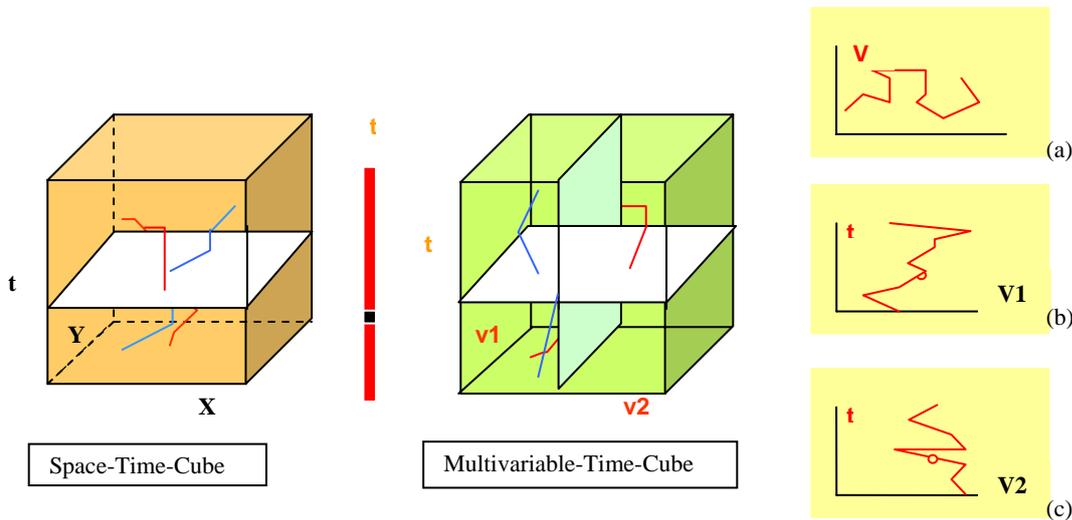


Figure 2. Multivariable-Time-Cube model.

The left cube is a Space-Time-Cube, and right cube is a Multivariable-Time-Cube (MTC). The red and blue polylines indicate the objects, the same colour indicates the same object, and the red vertical strip indicates the time synchronism link. The diagrams on the right represent the different projections of the trajectory in the MTC.

Looking at Figure 2 and table 1, it is possible to get answers to all the basic questions given at the end of the introduction. The table also addresses several combinations.

Component	STC	MTC
What	Trajectory	Trajectory
When	T-plane	T-plane (V1-V2 plane)
Where	A vertical line	
How		A vertical line
How+when		Intersection of time plane and the vertical line
What+when	Intersection of trajectory and T-plane	Intersection of trajectory and T-plane
What+how		Intersection of trajectory and the vertical line
When+where	Intersection of time plane and the vertical line	
What+where	Intersection of trajectory and the vertical line	
When+how		Intersection of time plane and the vertical line
What+when+where	Point	
What+when+how		Point

Table1. The basic questions answered in a STC & MTC (see also figure 2).

3. PCP-TIME-CUBE

Although the MTC offers to possibility to deal with multiple variables the number is still limited. The Parallel Coordinate-Time-Cube (PTC) does allow many variables. It is based on the original Parallel Coordinates Plots (PCP) as defined by Inselberg (1985), and which effectively visualizes patterns in multiple variables. Each object or geographic unit is representing by a set of line segments connecting vertical lines representing the different variables. Each line passes the line at a position that indicates the object's value for that variable.

PCP is 2D graph and the time dimension (Z-axis) can be added to PCP. This result is called PCP-Time-Cube. In a PTC the Z-axe represents time just as in the STC and the MTC. The X-axis represents the different variables and the Y-axis the (normalized) range of each of the variables. In both Space-Time-Cube and PCP-Time-Cube, an object is represented by a polyline. Although the polylines have different meanings in PCP and STC (the value of an object at different attributes versus the trajectory of the object in both space and time), they identify the objects. Figure 3 show an example of basic PTC model. Any horizontal plane is a classic PCP graphic to address the multivariable value for all objects at the certain time; it is called T-PCP plane and is shown in the upper-right diagram in figure 3. Any vertical plane which include one variable axis, results in a diagram of a variable value against time (figure 3 lower-right diagram) and is called V-time plane. The change of an object along V1 with time is visualized as a polyline, which must be on the V1 time plane. The polyline on

the T-PCP plane indicates the value of the object at the certain time; it is called T-object-variables line. The polyline on the V-time plane indicates the change of certain variable with the time, and it is called V-object-time line. The intersections of T-object-variable lines and the V-object-time lines are vertex of the surface, and these vertexes identify a state of an object at a time: "what+when+how". For one object, all the T-object-variable lines and the V-object-time lines form one multifaceted surface, which identifies the object. Then different objects are represented as different surfaces in PCP-Time-Cube (see figure 3 the blue surface).

As mentioned before, two planes are used to address the multivariable-temporal data: one is T-PCP plane which is the same as PCP graphic, and the other is V-time plane which addresses a variable with time. However, one problem that should be noticed is that the values of the line segments between the vertical lines, i.e. the variables, are meaningless in the T-PCP plane. They are only used to link all useful points to identify one object. In V-time plane, all the line segments on the polyline, which identify one object, are meaningful; they indicate the value of the object at different times. Therefore, in object surface, the skeleton of the surface (red line in PCP-Time-Cube, see figure 3) can also be used to identify one object.

The PTC also allows for answering most of the basic questions. For the STC functionality looks at table 2.

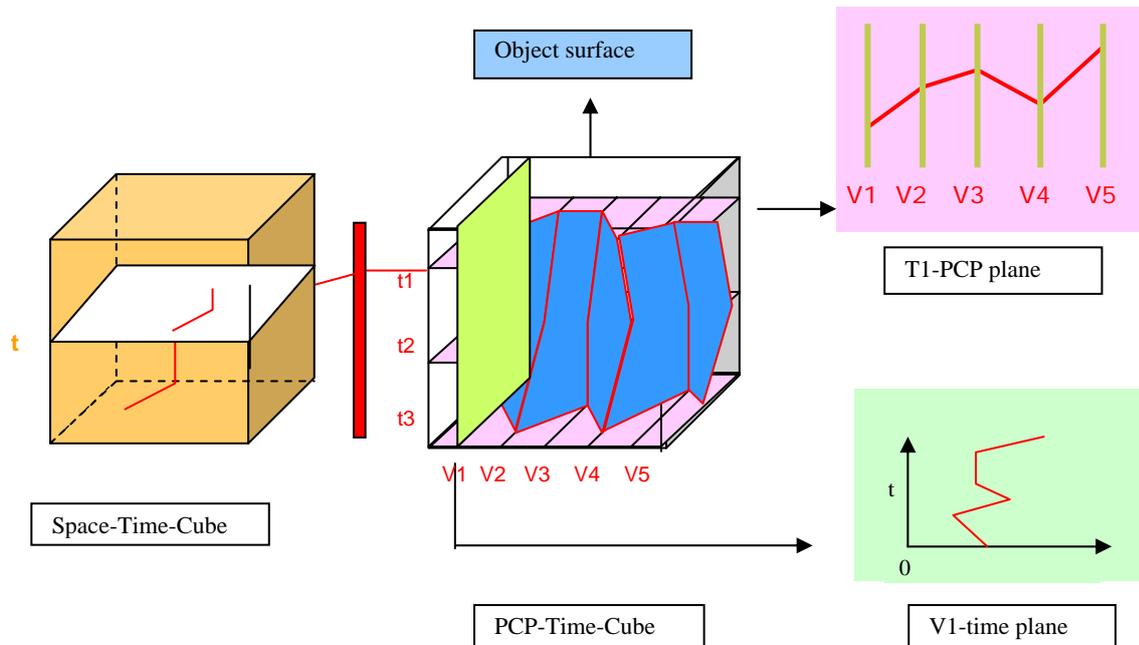


Figure 3. The Parallel-coordinate-plot Time Cube Model (PTC). On the left a STC link to PCP-Time-Cube and on the right the views are vertical plane and horizontal plane from the PTC.

Question	PTC
What	Surface
When	T-PCP plane
How	V-time plane
What+when	Surface + T-PCP plane =T-object-variable line
What+how	Surface +V-time plane=V-object-time line
What+when+how	T-object-variable line+ V-object-time line= vertex point

Table 2. The basic questions answered in PTC (see also figure 3)

4. USABILITY EVALUATION AND CONCLUSION

In this research, the STC is combined with two new designs (the MTC and PTC) to improve insight in multivariable spatio-temporal data. But do the new designs work? Based on the designed models, the prototypes were developed to attempt to address multivariable spatio-temporal questions (determined from a literature review) through the case study conducted in ArcScene environment. The prototype was used in a short preliminary test has been conducted to get a first impression of the MTC and PTC's usability. An evaluation based on a focus group and a questionnaire revealed that a small group of test persons could handle MTC and PTC. Some of the key remarks were:

- Most of participants can understand PCP-Time-Cube and Multivariable-Time-Cube.
- PTC is effective to visualize multivariable spatio-temporal data.
- The MTC is more flexible and efficient.
- Labels are very important in 3D models, especially in PTC.
- Useful interactive tools to help user finding interested information from multivariable spatio-temporal data include the 2D graphic, to play the cubes and their synchronisation mechanism are required.

These two models are prospective solutions for multivariable spatio-temporal data visualization using the combination of Space-Time-Cube and multivariable graphic. They are all three-dimensional graphics, which on the one hand offers extra opportunities to display extra information, but on the other hand is more complex and un-familiar to some users. A good interface and the right functionality to query and view the cubes and their data are very important and no doubly useful.

Due to the time constraints the evaluation was limited and needs to be expanded. The geo-visualization environment of prototypes should be further improved and the usability of the environments functionality should be discussed. In addition, the new models should be further compared with existing visualization solutions for multivariable spatio-temporal data, and more objective evaluation should be done with larger sample of users to get better evaluation results.

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