

THE SPACE-TIME CUBE REVISITED FROM A GEOVISUALIZATION PERSPECTIVE

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ABSTRACT

At the end of the sixties Hägerstrand introduced a space-time model which included features such as a Space-Time-Path, and a Space-Time-Prism. His model is often seen as the start of the time-geography studies. Throughout the years his model has been applied and improved to understand our movements through space. Problems studied can be found in different fields of geography, and range from those on an individual movement to whole theories to optimize transportation. From a visualization perspective the Space-Time-Cube was the most prominent element in Hägerstrand's approach. In its basic appearance these images consist of a cube with on its base a representation of geography (along the x- and y-axis), while the cube's height represents time (z-axis). A typical Space-Time-Cube could contain the space time-paths of for instance individuals or bus routes. However, when the concept was introduced the options to create the graphics were limited to manual methods and the user could only experience the single view created by the draftsman. An alternative view on the cube would mean to go through a laborious drawing exercise. Today's software has options to automatically create the cube and its contents from a database. Data acquisition of space-time paths for both individuals and groups is also made easier using GPS. Today, the user's viewing environment is, by default, interactive and allows one to view the cube from any direction. In this paper an extended interactive and dynamic visualization environment is proposed, and demonstrated, in which the user has full flexibility to view, manipulate and query the data in a Space-Time-Cube. Included are options to move slider planes along each of the axes to for instance select, or highlight a period in time or location in space. Examples will be discussed in which the time axis is manipulated by for instance changing world time for event time (time cartograms). Creativity should not stop here since it has been shown that especially an alternative perspective on the data will sparkle the mind with new ideas. The user should be allowed to for instance let the x- and/or y-axis be represented by other variables of the theme studied. Since the cube is seen as an integral part of a geovisualization environment the option to link other views with other graphic representation does exist.

1. INTRODUCTION

Our dynamic geo-community currently witnesses a trend which demonstrates an increased need for personal geo-data. This need for geo-data is based on a strong demand driven data paradigm. Individuals move around assisted by the latest technology which requires data that fits personal needs. They want to know where they are, how they get to a destination and what to expect there, and when to arrive. The elementary questions linked to geospatial data such as 'Where?', 'What?' and 'When?' become even more relevant. This is further stimulated by technological developments around mobile phones, personal digital assistance, and global positioning devices. The location-question becomes essential and is not limited to navigation. Next to the demand for location based services one can witness an increase in use of for instance mobile GIS equipment in fieldwork situations. Next to the increased (personal) geo-data needs, the above technology also proves to be a rich new data source, since these devices can easily collect data. However, the implications on privacy have to be discussed, and should not taken for granted [1]. Interests in exploratory and analytical tools to process and understand these (aggregate) data streams are increasing. Geographers see new opportunities to study human behaviour and this explains the revival in the interest in Hägerstrand's time geography [2].

From a visualization perspective the Space-Time-Cube is the most prominent element in Hägerstrand's approach. In its basic appearance the cube has on its base a representation of the geography (along the x- and y-axis), while the cube's height represents time (z-axis). A typical Space-Time-Cube could contain the space time-paths of for instance individuals or bus routes. However, when the concept was introduced the options to create the graphics were limited to manual methods and the user could only experience the single view created by the draftsman. An alternative view on the cube would mean to go through a laborious drawing exercise again. Today software exists that allows to automatically creating the cube and its contents from a database. Developments in geovisualization allow one to link the

(different) cube views to other alternative graphics. Based on the latest developments in geovisualization, this paper presents an extended interactive and dynamic visualization environment, in which the user has full flexibility to view, manipulate and query the data in a Space-Time-Cube. The aim is to have a graphic environment that allows for creativity via an alternative perspective on the data to sparkle the mind with new ideas and to solve particular geo-problems.

2. HÄGERSTRAND'S TIME GEOGRAPHY

Time-geography studies the space-time behaviour of human individuals. In their daily life each individual follows a trajectory through space and time. Hägerstrand's time geography sees both space and time as inseparable, and this becomes clear if one studies the graphic representation of his ideas, the Space-Time-Cube as displayed in Figure 1. Two of the cubes axes represent space, and the third axis represents time. This allows the display of trajectories, better known as Space-Time-Paths (STP) - see figure 1.II. These paths are influenced by constraints. One can distinguish between capability constraints (for instance mode of transport and need for sleep), coupling constraints (for instance being at work or at the sports club), and authority constraints (for instance accessibility of buildings or parks in space and time). On an aggregate level time geography can also deal with trends in society. The example in Figure 1.I shows the author's movements through the city of Enschede on a Thursday. The vertical lines indicate a stay at the particular location which are called 'stations' – in Figure 1.I home, pool, work & restaurant. At this observation scale stations are equal to no-movement. However, if one would zoom in on those stations it is very likely one would observe movement, since people meet for activities such as sport or lectures. The time people meet at a station creates so-called 'activity bundles'. The near horizontal lines indicate movements. The Space-Time-Path can be projected on the map, resulting in the path's footprint. Another important time-geography concept is the notion of the Space-Time-Prism and is schematically displaying in figure 1.III. In the cube it occupies the volume in space and time a person can reach in a particular time-interval starting and returning to the same location (for instance: where can you get during lunch time). The widest extent is called the Potential Path Space (PPS) and its footprint is called Potential Path Area (PPA). In the diagram it is represented by a circle assuming it is possible to reach every location at the edge of the circle. In reality the physical environment (being urban or rural) will not always allow this due to the nature of for instance the road pattern or traffic intensity.

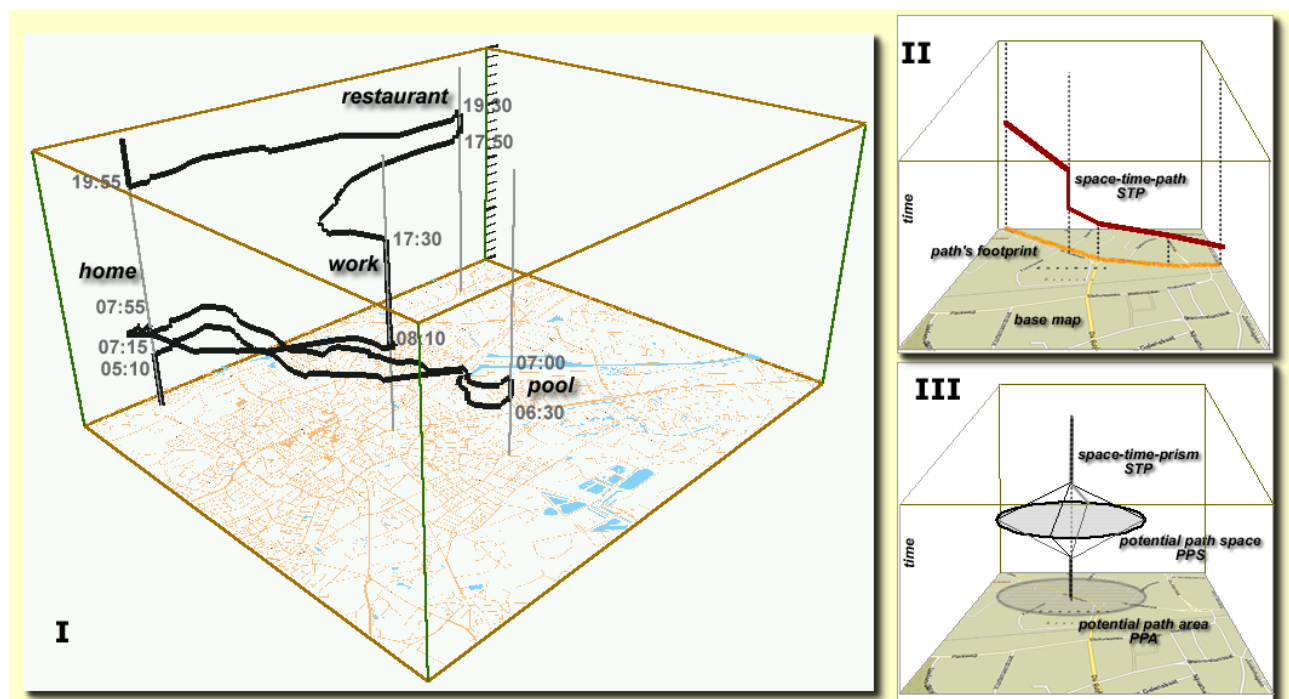


Figure 1. The space-time cube: I. An example of the author's travels on an average Thursday in Enschede, the Netherlands. II. The space-time cube's basics: a Space-Time Path and its footprint. The vertical line in the path represents the time a person remains at the same location, called station. III. A Space-Time-Prism (STP) indicates the locations that can be reached in a particular time interval (the Potential Path Space (PPS)). The projection of the PPS on the map results in the Potential Path Area (PPA).

During the seventies and eighties Hägerstrand's time-geography has been elaborated upon by his Lund group [3, 4]. It has been commented and critiqued by for instance Pred [5], who in his paper gives a good analysis of the theory, and summarizes it as "the time geography framework is at one and the same time disarmingly simple in composition and

ambitious in design.” As one of the great benefits of the approach he notes that it takes away the (geographers) over emphasis on space and includes time and pay attention to people. Recently Miller [6] in a homage to Hägerstrand worded this as a shifting attention from a ‘place-based perspective’ (our traditional GIS) to a more people based-perspective (time-geography). The simplicity is only partly through, because if one considers the Space-Time-Cube from a visual perspective it will be obvious that an interactive viewing environment is not easy to find. Probably that is one of the reason the cube has been used only sporadically since its conceptualisation. Although applications in most traditional human-geography domains have been described, only during the last decade we have witnessed an increased interest in the Space-Time-Cube. Miller [7, 8] applied its principles in trying to establish accessibility measure in an urban environment. Kwan [9, 10] has used it to study accessibilities differences among gender and different ethnic groups. She also made a start integrating cyberspace into the cube. Forer has developed a interesting data structure based on taxels (‘time volumes’) to incorporate in the cube to represent the Space-Time-Prism [11, 12]. Hedley [2] created an application in a GIS environment for radiological hazard exposure. Improved data gathering techniques have given the interest in Time geography and the Space-Time-Cube again a new impulse. Recent examples are described by Mountain and his colleagues [13, 14] who discuss the data collection techniques by mobile phone, GPS and location based services and suggest visual analytical method to deal with the data gathered. The Space Time-Path or geospatial life lines as they are called by the Hornsby & Egenhofer [15] are object of study in the framework of moving objects.

From a visualization point of view the graphics created are often of an ad-hoc nature. This paper tries to systematically look at what is possible today?

3. GEOVISUALIZATION

During Hägerstrand’s the era - the time before Geographic Information Systems - paper maps and statistics were probably the most prominent tools for researchers to study their geospatial data. To work with those data, analytical and map use techniques were developed, among them the concepts of time-geography. Many of these ideas can still be found in the commands of many GIS packages. Today GIS offers researchers access to large and powerful sets of computerized tools such as spreadsheets, databases and graphic tools to support their investigations. The user can interact with the map and the data behind it. This capability adds a different perspective to the map, as they become interactive tools for exploring the nature of the geospatial data at hand. The map should be seen as an interface to geospatial data that can support information access and exploratory activities, while it retains its traditional role as a presentation device. There is also a clear need for this capability since the magnitude and complexity of the available geospatial data pose a challenge as to how the data can be transformed into information and ultimately into knowledge. A visual environment for the Space-Time-Cube will definitely contribute to improve our insights and understanding in geospatial-temporal data generated from human behaviour.

The above trend in mapping is strongly influenced by developments in other disciplines. In the 1990s, the field of scientific visualization gave the word “visualization” an enhanced meaning [16]. This development linked visualization to more specific ways in which modern computer technology can facilitate the process of “making data visible” in real time in order to strengthen knowledge. The relations between the fields of cartography and GIS, on the one hand, and scientific visualization on the other, have been discussed, in depth [17] and [18]. Next to scientific visualization, which deals mainly with medical imaging, process model visualization and molecular chemistry, another branch of visualization that influenced mapping can be recognized. This is called information visualization and focuses on visualization of non-numerical information [19]. From the map perspective, a synthesis of the above trends results in geovisualization. Geovisualization integrates approaches from scientific visualization, (exploratory) cartography, image analysis, information visualization, exploratory data analysis (EDA) and GIS to provide theory, methods and tools for the visual exploration, analysis, synthesis and presentation of geospatial data [20]. In this context, it is required that cartographic design and research pay attention to human computer interaction of the interfaces, and revive the attention for the usability of their products. Additionally, one has to work on representation issues and the integration of geo-computing in the visualization process. As such, maps and graphics are used to explore geospatial data and the exploration process can generate hypotheses, develop problem solutions and ultimately construct knowledge.

In a geovisualization environment, maps are used to stimulate visual thinking about geospatial patterns, relationships, and trends. One important approach here is to view geospatial data sets in a number of alternative ways, e.g., using multiple representations without constraints set by traditional techniques or rules. This should avoid the trap described by Finke [21] who claim that “most researchers tend to rely on well-worn procedures and paradigms...” while they should realize that “...creative discoveries, in both art and science, often occur in unusual situations, where one is forced to think unconventionally.” This is well described by Keller and Keller [22], who in their approach to the visualization process suggest removing mental roadblocks and taking some distance from the discipline in order to reduce the effects of traditional constraints. Why not choose an alternative mapping method? For instance, show a video of the landscape next to a topographic map accompanied by a three-dimensional map, or use a cartogram instead of a choropleth map. New, fresh, creative graphics could be the result. New methods might also offer different insights and would probably have more impact than traditional mapping methods. It is the above approach that will be applied to

Space-Time-Cube. An interactive visual environment will be proposed with an emphasis on alternative graphics that are connected to the cube via multiple linked views.

4. SPACE TIME CUBE AND GEOVISUALIZATION FUNCTIONALITY

Here it is assumed that a better (visual) exploration and understanding of temporal events taking place in our geo-world requires the integration of geovisualization with time-geography's Space-Time-Cube. Prominent keywords are interaction, dynamics and alternative views which each have their impact on the viewing environment proposed. Interaction is needed because the three-dimensional cube has to be manipulated in space to find the best possible view, and it should be possible to query the cube's content. Time, always present in the Space-Time-Cube automatically introduces dynamics. The alternative graphics appear outside the cube and are linked and should stimulate thinking new insights and explanations. This section will systematically discuss the functionality required in such environment. One can distinguish functions linked to a basic display environment, those linked to data display and manipulation in the cube and those related to linked view. The functions are all based on the questions: What tasks are expected to be executed when working with a Space-Time-Cube?

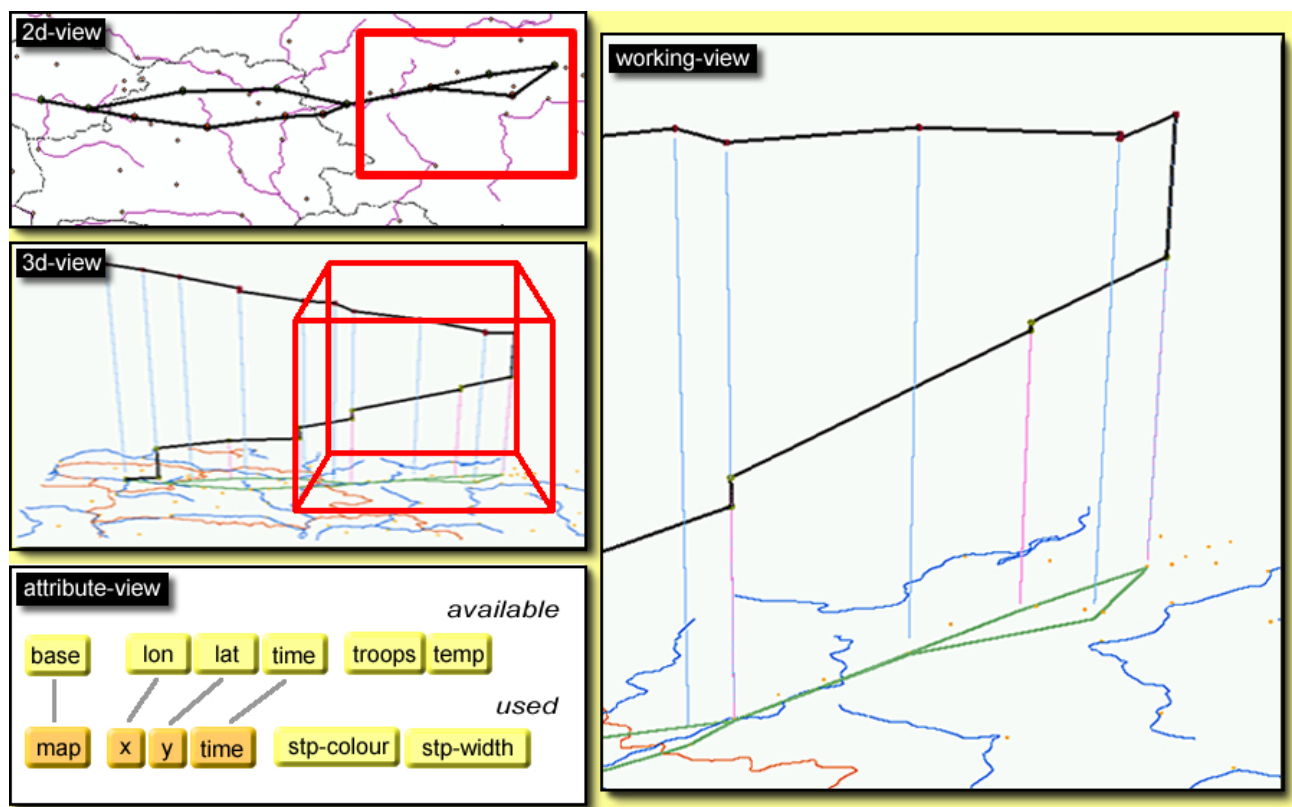


Figure 2. The Space-Time-Cube's basic viewing environment. The working view shows the details of the data to be studied. The 2D and 2D view assist the user in orientation and navigation. The attribute view offers the user options to define which variable will be displayed in the cube. The data displayed in the figure represent Napoleon's 1812 march into Russia.

In a viewing environment has a main or working view, as can be seen in Figure 2. Additionally three other optional views are shown. These views help with orientation and navigation in the cube, as well as with the selection of the data displayed. The 2D view shows the whole map of the study area with a rectangle that matches the base map displayed in the working view's cube. Similarly, the content of cube in the 3d view corresponds to the content of the Space-Time-Cube. The situation in Figure 2 results after zooming in on a particular area. The views are all linked, and moving for instance the rectangle in the 2D view will also result in a different location on the overview cube in the 3d view and a different content of the working view. The attribute view shows the variables available for display, and allows the user to link those variables to the Space-Time-Cube's display variables. These include a base map, variables to be displayed along the cubes axis (x, y, and time) and variables linked to the Space-Time-Path – its colour and width. The user can drag any of the available variables onto the display variables. However, a few limitations exist. Since we deal with a Space-Time Cube a spatial (x or y) and time component must always be there. It is possible though that different time variables exist of which one should be selected by the user. For instance time could be given in years but also according particular historical events like the reign of an administration. The base map is displayed optionally. The x or y could be

used for display with another variable. In the case of the Napoleon data displayed in Figure 2 the y could be interchanged by the number of troops, as was suggested by Roth discussing the SAGE software [23].

A Space-Time-Path will be automatically displayed as soon as the x, y and time variables have been assigned in the attribute view. As with most software dealing with maps it is possible to switch information layers on and off. In the cube a footprint of the Space-Time-Path is automatically displayed for reference and measurements as is displayed in figure 3.I. Any of the cube's axes can be dragged into the cube to measure time or location. Drop lines can be projection on the axis for the same purpose. Since we deal with the display of the third dimension the option to manipulate the cube in 3d space is a basic requirement. Rotating the cube independently around any of its axis is possible. Also introduced is a spinning option that allows one to let the cube automatically rotate around a define axis with the purpose to get an overview of the data displayed. Since users will be curious one should be able to query the Space-Time-Path as shown in figure 3.III. In this example the system responds with an overview of available data on the segment selected. Via the attribute view the user can change the variable attached to the axis or the Space-Time-Path on the fly. For selection purposes it is also possible to use multiple slider planes along the axis to highlight an area of the cube.

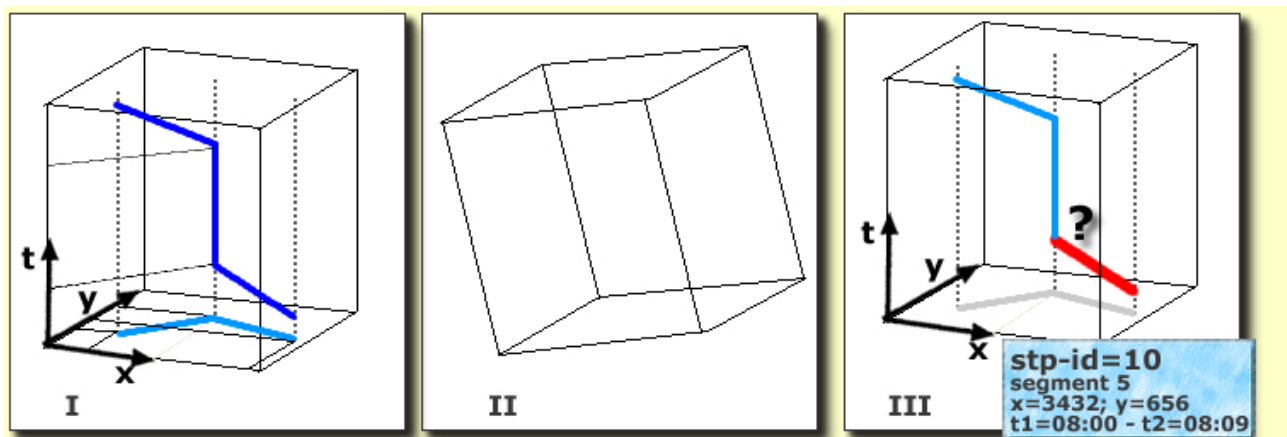


Figure 3. Basic functions available in the Space-Time-Cube's viewing environment:
I. reference and measurement; II. manipulation in 3D space; III. select and query.

5. APPLICATIONS AND EXTENDED FUNCTIONALITY

The Space-Time-Cube is most suitable for the display and analysis of paths of (multiple) individuals, groups or other objects moving through space. However, other possibilities exist, and it could also be used for real-time monitoring. To illustrate this let's consider an orienteering event. The aim for participants in an orienteering run is to navigate (run) as quickly as possible via a set of check points from start to finish with help of map and compass. Different variation of these type of event exist, but in this example we consider an event where the participants leave with a certain time interval in between and have to follow a predefined route along the check points. The participants all carry a special mobile phone that transmits an SMS message every so many minutes (participants are not issued with a GPS because this takes away their chance to get lost). This approach allows the organisation to monitor the runners' positions during the race. The cube will contain vertical lines for each check point (stations), and based on the SMS messages and the arrival at the check point the paths of all runners can be generated and displayed near real-time. The base map displayed in the cube could be enhanced with a digital terrain model to be able to judge the influence of the terrain on the race. After the race the Space-Time-Cube viewing environment would allow the participants to analyse their run after the race and once could even use the cube as an animation environment to replay the orienteering event as a whole or for individual runners. The cube can also be used to animate for instance the urban growth in a region. Each frame will be displayed as a (transparent) 'base map' at the relevant time, and would allow for analytical operations via the measurement tools as displayed in figure 3.I.

In Figure 4 the Space-Time-Cube is used to visualize another running event, but here additional views are linked to the cube environment. The working view and the 2D view show a path based on GPS data acquired during a fitness run. Highlighted in both views is a section of the run for which detailed information is shown in the linked views. These are a GPS data file showing the track history and a video displaying the path's environment. The dot in the working view and 2d view indicate the position of the runner represented by the current video-frame and highlighted record in the GPS-log. For analytical purposes one could add the other paths of similar runs and compare the running results in relation to the geography. To expand this one geographic analysis one could also use a digital terrain model as base map and see how the terrain might influence running speed. This example shows how multimedia elements can be linked to the cube. However, one can easily think of other linked views as well. With many available variables these could –when

relevant- be displayed in a in a parallel coordinate plot which could be used as an alternative variable view and allow for linking the variable with the cube's axes or the Space-Time-Path.

Another discipline that might benefit from the Space-Time-Cube approach is archaeology. Complex relations between artefacts excavated at particular times found from different historical period at different location could be made visible in the cube. The location of a find will be presented be a vertical line that has a colour/ thickness at the relevant time period, possibly indicating uncertainty. Since most finds will be point locations paths are not necessarily available in the archaeological version of the cube. However, the possibility to play with the different time scales related to history, geology, archaeology etc makes it possible to for instance discover the spread of a civilisation or the influence quarry in the spread of particular artefacts. It could assist in prediction where interesting location could be found.

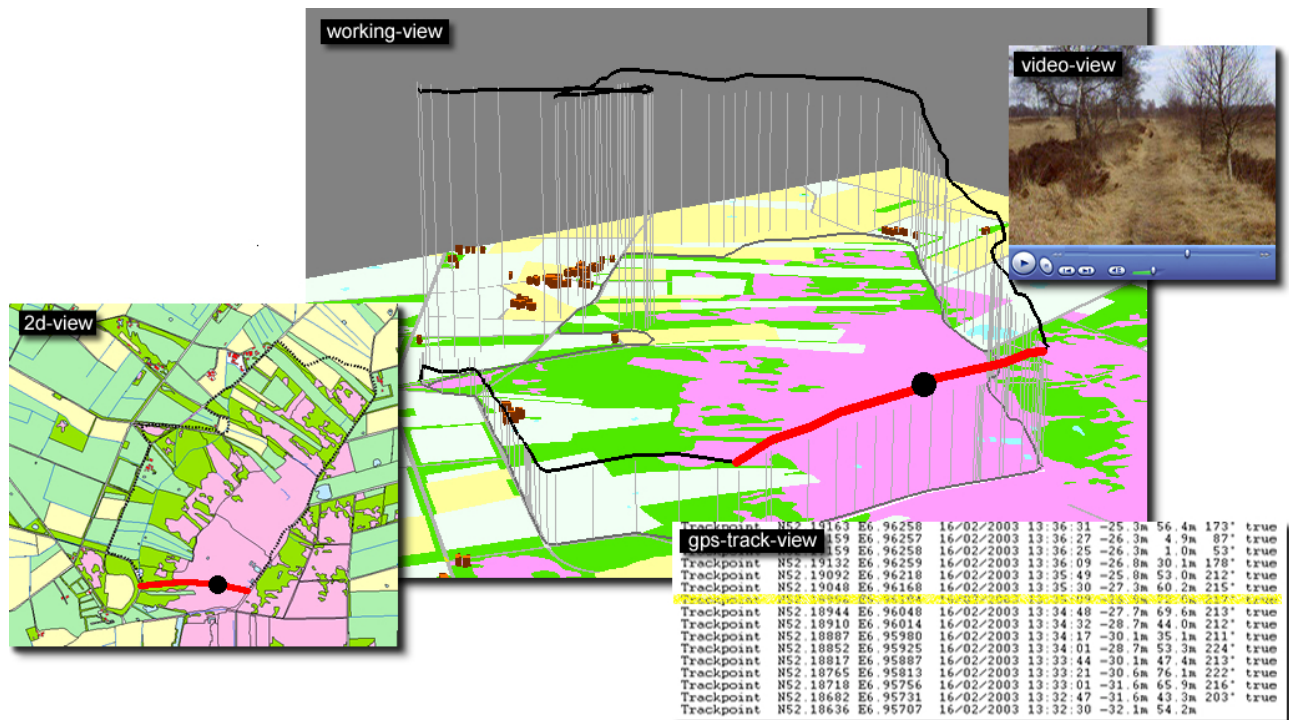


Figure 4. A run in the Aamsveen, Enschede displayed in the Space-Time-Cube viewing environment. Next the 2D view and the cube's working view a video view and a GPS track view are linked. Both the video view (the visible frame) and GPS track history (the highlighted coordinate) show the location of the runner at the black dot's in both map views.

The Space-Time-Cube offers good visual opportunities to study the relation between time and space and additional variables. Especially the option to swap variables along the cubes axes makes it a strong tool. However, as shown in for instance Figure 4 the additional views can clarify the nature of the displayed Space-Time-Path. Alternative graphics might also be required to enhance the understanding of the data on Napoleon's march into Russia as displayed in Figure 2. Figure 5 shows some of the views that could be added. It displays three graphics, a map, a diagram, and a time-cartogram. The data represented are the first twenty days of Napoleon's retreat from Moscow[24]. In the maps each dot represents the position where the army camped after a day's march. The lines represent the march. The army did not cover the same distance every day and even stayed at the same location for multiple days. This becomes clear when we look at the diagram. The diagram holds a map-line (top) and a time-line (bottom). The short vertical lines along these lines represent camps. The units along the map-line are kilometres and along the time-line days. In the time-cartogram the camps have been position on equal distances, where distance represents time. The line representing a days march in the time-cartogram have the same orientation as the corresponding segments in the map.

6. PROBLEMS AND PROSPECTS

This paper has discussed the option to visually deal with the concepts of Hägerstrands Space-Time-Cube based on the opportunities offered by geovisualization. The functionality of a Space-Time-Cube's viewing environment with its multiple linked views has been described. However, many questions remain and are currently subject of further research. Among those questions 'How many multiple linked views can the user handle?', 'Can the user understand the cube when multiple Space-Time-Paths are displayed?', 'How should the interface look like?' All these questions deal with usability aspects of the cube's viewing environment.

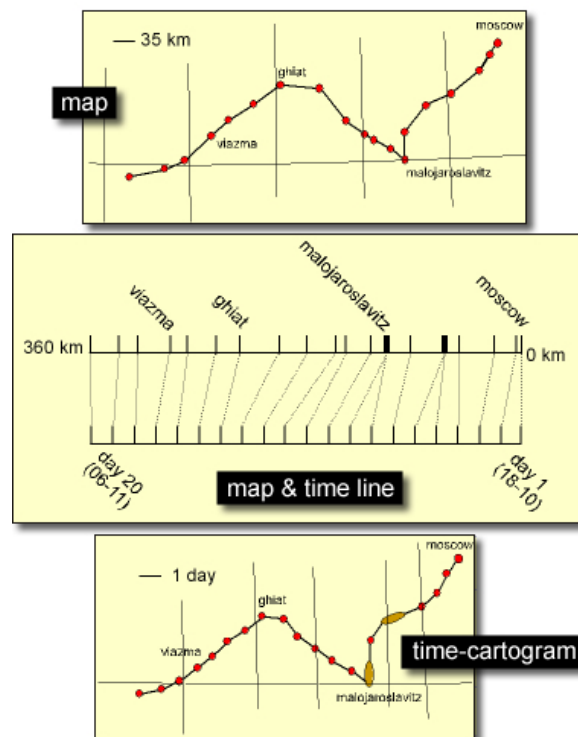


Figure 5. Additional views linked to the Space-Time-Cube: The Space-Time-Path in a map, in a diagram with a map-line and a timeline, and in a time-cartogram. Data represented are the first twenty days of Napoleon's retreat from Moscow.

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