

Integrated Time and Distance Line Cartogram: a Schematic Approach to Understand the Narrative of Movements

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To understand the nature of movement data, we introduce an alternative visual representation looking at paths from different perspectives. The movements and their stops are schematized into lines. These are distorted based on time or distance by applying line cartogram principles to answer specific location- or time-based questions. A prototype consisting of multiple linked views, including the line cartograms and a map, is implemented in a web environment using D3.js. It allows one to explore the nature of single or multiple movements. The option to compare multiple movements gives the solution its unique character. A preliminary evaluation of the product shows it is able to answer questions related to time and space accordingly.

KEYWORDS: movement data; timeline cartogram; distance line cartogram; schematized map; flow map; D3

INTRODUCTION

THE AVAILABILITY OF movement data is overwhelming, and sophisticated analytical and visualization tools are required to understand the nature of the movements and to discover, understand, and explain patterns in space and time (Andrienko et al. 2013). Extensive study programs that look at data from multiple perspectives have been executed (move-cost.info), and many different visual representations are available for displaying movements (www.visualcomplexity.com). The nature of the movement data will determine which representation is most suitable.

Most visual representations contain the path of movement and its direction, as well as qualitative and/or quantitative information. Examples are the flow map, the network map, and the space-time cube. Each of these examples has characteristics which support particular questions. The flow map is useful for showing attribute values in space (Tobler 1987), while the space-time cube, as the name implies, can deal with questions related to time and space (Hägerstrand 1970; Andrienko & Andrienko 2010).

No single map is suitable to answer all questions related to space, time, and attributes. In addition, all can suffer from clutter and overplotting. The former occurs when there is an uneven spatial and temporal data distribution, and the latter in situations where the amount of data to display is large. These problems can only (partly) be solved if one combines analytical methods such as clustering and filtering with highly interactive visualizations (Keim et al. 2010).

The use of multiple and different visual representations in an interactive linked view environment can reveal patterns otherwise missed (Dykes, MacEachren, & Kraak 2005; Roberts 2005). In this paper, we suggest combining several cartographic representations—the timeline, the cartogram, the schematic map, and the flow map—to allow a better understanding of movement data. The result is an integrated linear time and distance cartogram. It does not solve the problem of large data sets, but it does solve some of the clutter and overplotting problems found in other graphic representations, like the space-time cube, and it



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does provide an alternative and insightful way of looking at movement data. Figure 1 shows examples of the four graphic representations that we will combine for a better understanding of movement data.

The *timeline* example in Figure 1a displays three reorganizations of the municipalities in the province of Overijssel, in the Netherlands. Timelines place events in a chronological order. They are mostly used for linear time, but variations exist for cyclic events, such as the seasons. Timelines can be used to answer temporal questions easily: when (*instant*), how long (*interval*), etc. The history of timelines in graphics can be found in Rosenberg and Grafton (2010). Kraak (2005) describes the timelines from a cartographic perspective, while Silva and Catarci (2002) do so from an information visualization viewpoint.

In a *cartogram*, geographic space is replaced by attribute or time space. The size of a geographic unit no longer represents square kilometers, but instead, for instance, shows the number of inhabitants or the production of corn

(Tobler 2004). Alternatively, geographic distances are replaced by travel time (Shimizu & Inoue 2009). Figure 1b shows an example of such a cartogram depicting travel time by train from the Dutch city of Gramsbergen (Ullah & Kraak 2014). Cartograms answer questions in relation to the attribute or temporal distribution of the topic. However, this only works if the user can mentally link the image to the real geography.

Schematic maps simplify reality to emphasize selected aspects of geography via an extreme application of generalization and a fixed design style (Avelar & Hurni 2006; Cabello, de Berg, & van Kreveld 2005). For example, a schematic map might use only vertical, diagonal, and horizontal lines while following a particular set of colors and fonts. Figure 1c shows a detail of one of the most well-known examples of a schematic map, the London Underground map based on an original design by Harry Beck (Garland 1994). An “extreme” kind of schematic map is the so-called *chorem*, proposed by Brunet (1980) and described by Reimer (2010). Schematic maps give a

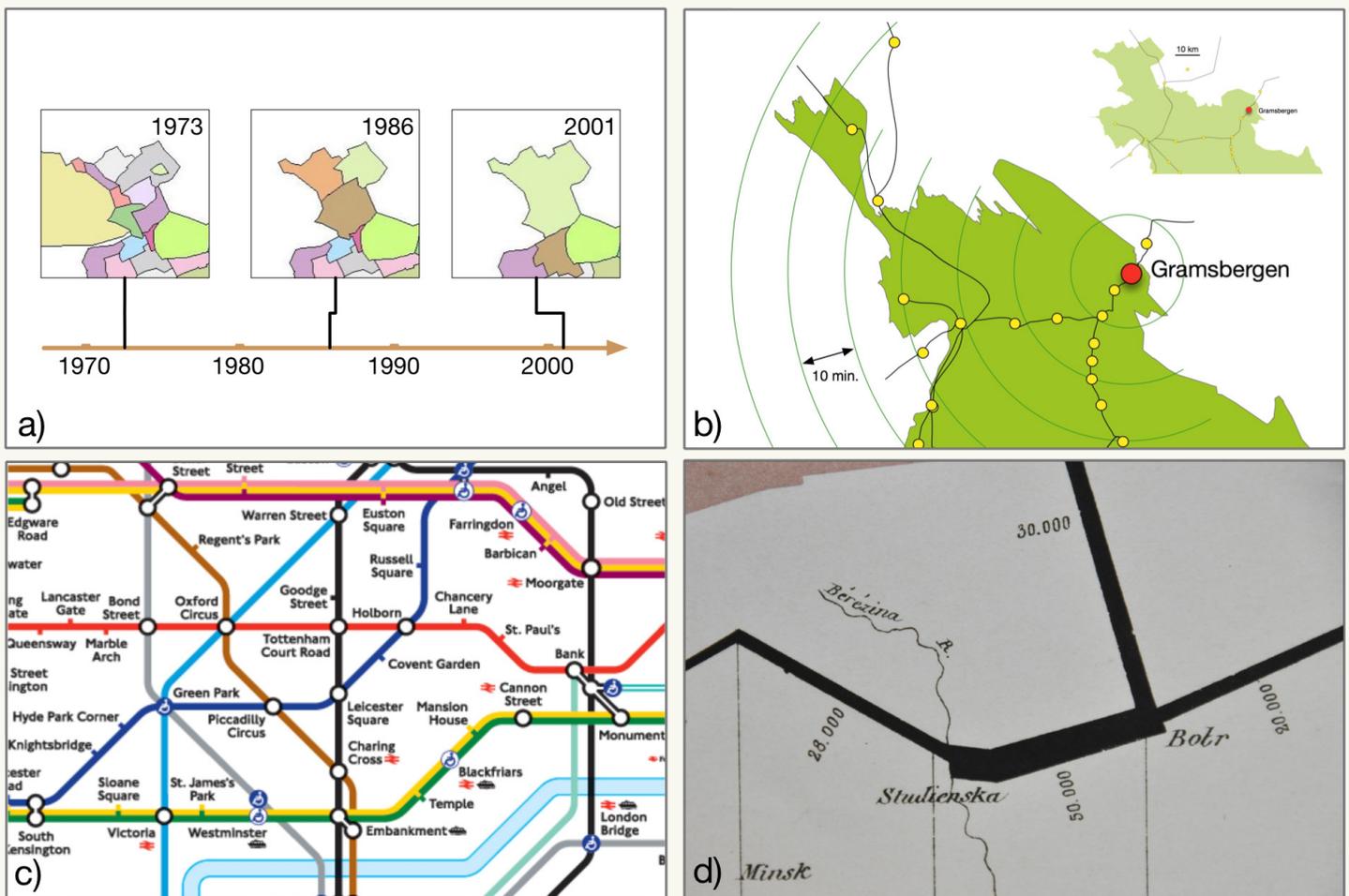


Figure 1: Graphic representations that we will combine include a) a timeline, b) a cartogram, c) a schematic map, and d) a flow map.

quick insight into the selected topic, and depending on the design, can answer generic questions about location, attribute, and time.

A *flow map* shows the path and volume of movement, such as the number of people or amount of goods transported. Location and attribute information can be clearly deduced from these maps. However, even though time is

inherently incorporated, it is not always explicit (Johnson & Nelson 1998). Figure 1d shows a detail of Charles Joseph Minard’s map of Napoleon’s invasion of Russia, where the width of the line symbols represents the number of troops in Napoleon’s army (Kraak 2014). A flow map can answer questions related to the *where*, the *what*, and often the *when* of movement.

THE INTEGRATED TIME AND DISTANCE LINE CARTOGRAM

FIGURE 2 EXPLAINS the integration of these different cartographic representations. Basic data are paths (x, y, and time), such as a GPS-track, and stops located along those paths (Figure 2a). Stops are an essential element of the linked time and distance line cartogram. The distortions on the timeline or the distance line are defined in between stops. In some situations, these stops are given: for example, towns along the roads, bus stops, or control points during an orienteering race. In other situations, stops have to be derived from the path. In that case, GPS-tracks describing the path are the data source, and stops can be determined based on a spatial and temporal threshold (a defined range and minimum duration). Algorithmic solutions to this problem have been proposed by Palma et al. (2008) and Spaccapietra et al. (2008), among others.

In the schematization process, the track is transformed into a straight line, representing the total distance traveled. The stops are then added to their proper location on the line. In the next step (Figure 2b), a timeline—of the same length as the distance line—is plotted parallel to this distance line. The units on the timeline are in proportion to the total time traveled. In the Figure 2b example, the unit is one minute. On the timeline, the stop durations are separately coded and linked to the stop on the distance line. This figure gives a generic overview of the relation between time and distance, and shows that neither is equally distributed.

In Figures 2c and 2d, the relation between time and distance (i.e., geography) is further explored by distorting each individually. This is where the cartogram principle is applied, manipulating the distance line based on time and the timeline based on distance. In Figure 2c, the stops on the distance line are expanded based on the units they occupy on the timeline, such that the connecting lines are vertical. It now clearly shows the different stop durations.

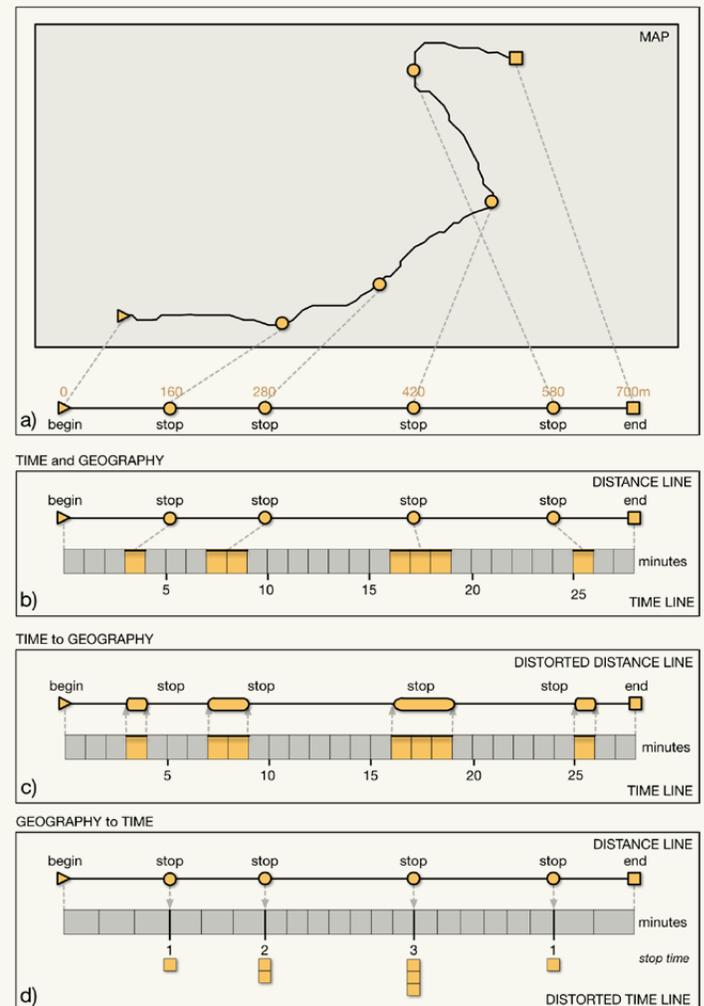


Figure 2: The principles of the integrated time and distance line cartogram include a) the schematization of the movement; b) the direct relation between the geography (distance line) and time (timeline); c) from time to geography—cartogram principles applied on the distance line; and d) from geography to time—cartogram principles applied on the timeline. On the distance line, the location of the stops are represented by the (deformed) orange circles. On the timeline, the orange boxes refer to the moments stopped.

In Figure 2d, the reverse happens. The stops are projected on the timeline and the stop-duration units are removed. The remaining time units are compressed or stretched between the stops. In the figure, this stretching is clearly visible between the last stop and the end. This graph gives an indication of the speed traveled on the separate section between stops. Note that between-stop speed is considered constant, even though this might not always be the case in reality. Wherever the time units are stretched out, the person moved faster, compared to segments with compressed units. To keep a notion of the stop duration, there are indicators below the timeline at the stop location. The example uses stacked squares, but one can imagine that when a stop is considerably long, another design is more appropriate, such as numeral text (see Figure 5c) or proportional symbols.

In Figure 2, only location and time are used. Our proposed solution also allows the integration of quantitative or qualitative attribute information. Figure 3 gives an example of this. Minard's map of Napoleon's Russian Campaign, displaying the path and amount of troops, has

been partly schematized. Since the army moved mostly east to west and back again, the part of the path that returns west from Moskva (Moscow) has been flipped over to get a more or less horizontal distance line. To keep a visual link to Minard's original map, the path has not been fully straightened. The width of the path represents the amount of troops. The timeline has been cartogram-ized, resulting in a very compressed four weeks at the end of September and beginning of October when Napoleon stayed in Moskva (Figure 3a).

In Figure 3b, the distance line has been further schematized, resulting in a straight line. It has also been cartogram-ized, with the locations of the towns (in gray) moved to link with the dates on the timeline that the army actually visited those locations (in black). For instance, compare how far apart Moskva and Malojarslavetz are in Figure 3a versus Figure 3b. In comparing these two figures, the attribute data have been swapped from the distance line to the timeline. The height of each time unit (here a single day) corresponds to the number of troops still participating in the campaign at that particular time. It would

Minard's maps of Napoleon's campaign in Russia

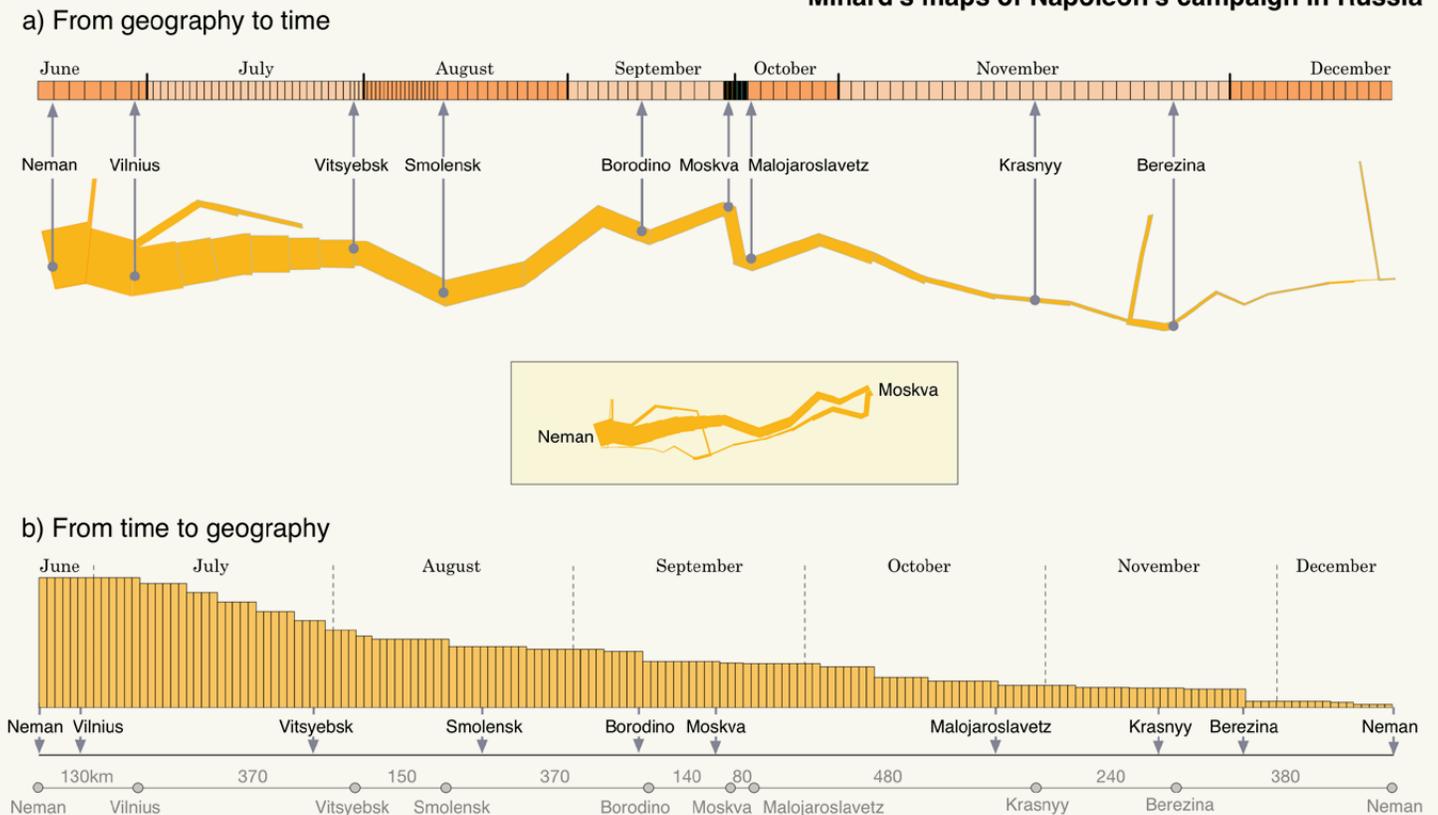


Figure 3: The time and distance lines extended with attribute information, converting a) from geography to time—the distance line is encoded with attribute information; and b) from time to geography—the timeline is encoded with attribute information (based on Kraak 2014).

be possible to add qualitative data too, by segmenting and coloring the bars based on the participating army corps.

Visualizing a single path, as in Figures 2 and 3, can be revealing, but in many situations the option to compare multiple paths will be more informative. As Figure 4 demonstrates, several combinations are possible. In the first four situations shown, the paths are all the same, but the location or order of the stops are different. Trains that stop everywhere, or buses that stop on request only, are typical examples. In the last four situations, the paths are not equal, and also the locations or order of the stops are different. Figures 5 and 6 provide more detailed examples of some of these situations.

Figure 5 explains the basic options when comparing two movements along the same path. In the example, a bus line in Minneapolis-St. Paul, USA is used. As the map shows, the line starts at Apple Valley and, via three potential stops, it ends at the Mall of America. Figure 5b has a timeline and two distorted distance lines of the green and red bus. The green bus leaves at 06:55 and makes a pair of two-minute stops, arriving at the Mall at 07:24. The red bus leaves Apple Valley at 07:02, makes three stops, two of two minutes and one of a single minute, and arrives at its destination at 7:35. In the lower diagram shown in Figure 5b, the timeline information has been normalized, with all trips starting at 00:00. This allows a better comparison of the red and green bus

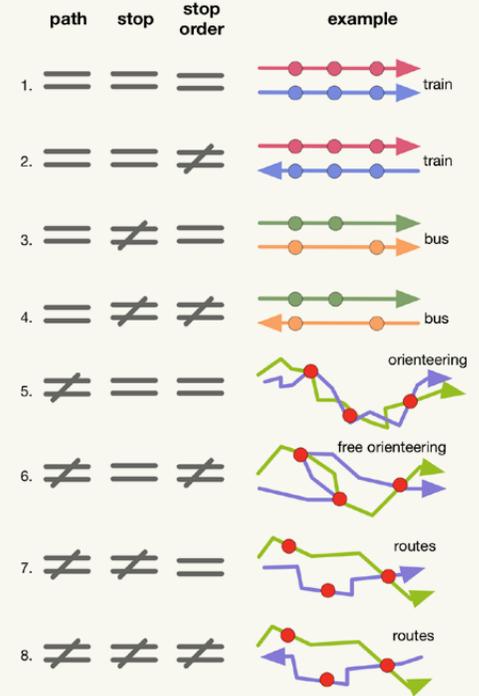


Figure 4: Comparing movements in time and space. Examples of eight different situations where path, stops, and stop order are varied.

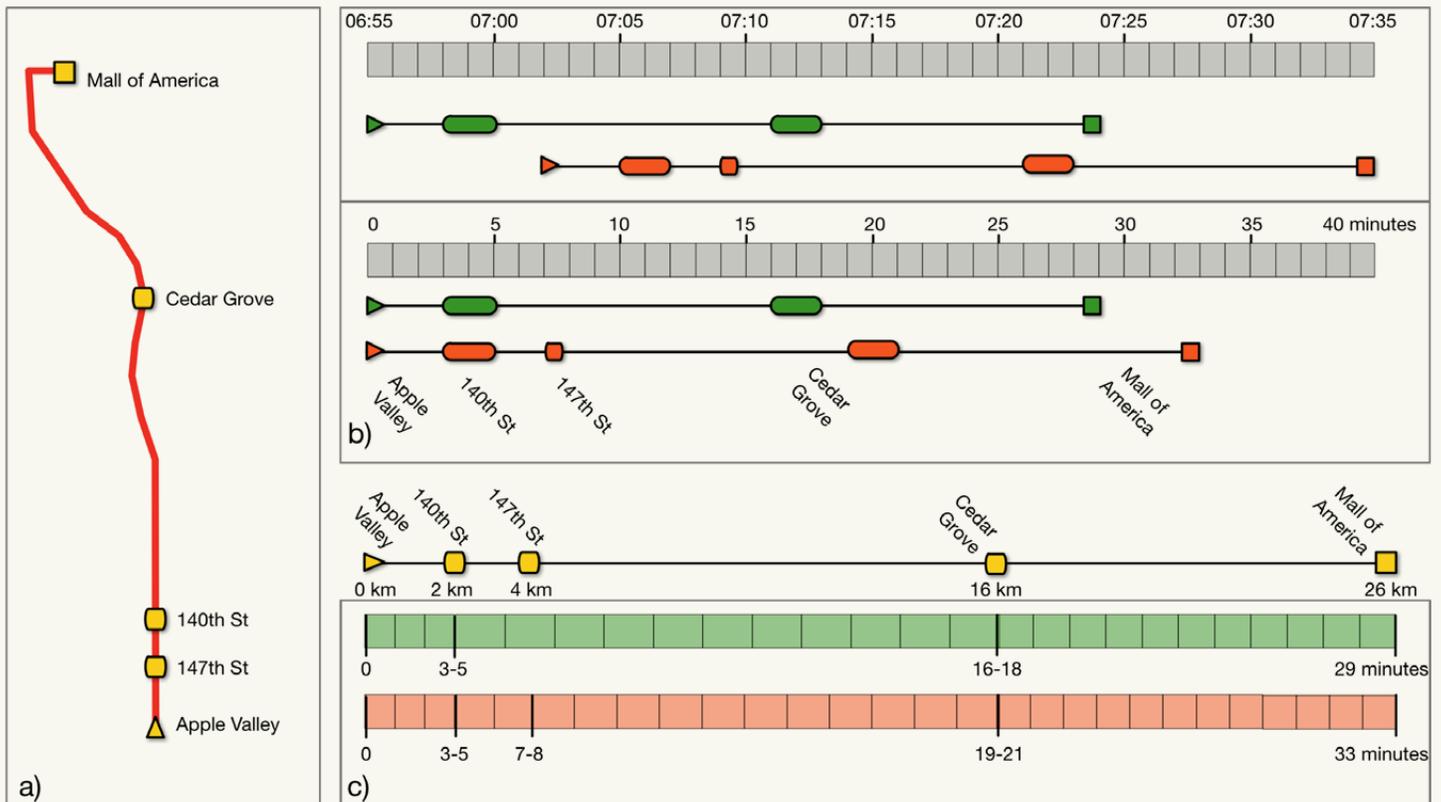


Figure 5: Comparing two bus trips, according to a) the route; b) the timeline and distorted distance lines as default and normalized; and c) the distance line and normalized distorted timelines.

when interested in the total trip length. The extra stop of one minute results in a longer trip duration. Other reasons could be involved, such as the bus encountering more traffic because it started later. For this kind of reasoning, the upper diagram is needed as well. In Figure 5c, the same information is displayed via a distance line and two distorted timelines. In the timelines, the time units (minutes) are distorted between the stops. The stops are indicated by vertical lines, and a text label indicates the stop times relative to the start of the trip. Compare this with the visualization of stops by stacked squares in Figure 2d. An online, interactive version of this kind of visualization compares three bus lines in the city of Dublin (see kartoweb.itc.nl/kobben/D3tests/tracksViewer/busses.html).

Figure 6 shows a snapshot of an interactive web application using integrated time and distance line cartograms. Background information on its development and implementation is given below. This example represents the fifth situation from Figure 4. The map shows part of the city of Dresden, Germany, with the paths of two runners who participated in the International Cartographic Conference 2013 Orienteering Race. Runners had to follow given control points in a fixed order, but due the different accuracies

and settings of runners' GPS devices, it looks as if the control points are not always on the exact same positions.

The blue runner (Laszlo) is an experienced runner, but the red runner (Menno-Jan) was only competing in his third orienteering race ever. The map shows that the paths and strategies employed to reach the control points differ. The lines in the “time to geography” box present a timeline and two distorted distance lines. The third stop of the red runner is selected because it looks like a relatively long stop, and the pop-up menu in the map reveals it took just over a minute before the runner located the control point. It also gives the distance covered so far. The selected control point on the map is simultaneously highlighted on the line diagrams (by increasing the size of the symbols). The diagram also shows that, despite the delays, the red runner was faster. In contrast to Figure 5c, the “geography to time” box has been split into two diagrams. The distorted timelines show only a minimal distortion (compare the time units between the start and control point 2). The stop length is not shown below the timelines. Comparing these two diagrams shows that the red runner covers quite a bit more (unnecessary) distance. The blue runner was more efficient. The red runner also missed a control point (6) and therefore was disqualified.

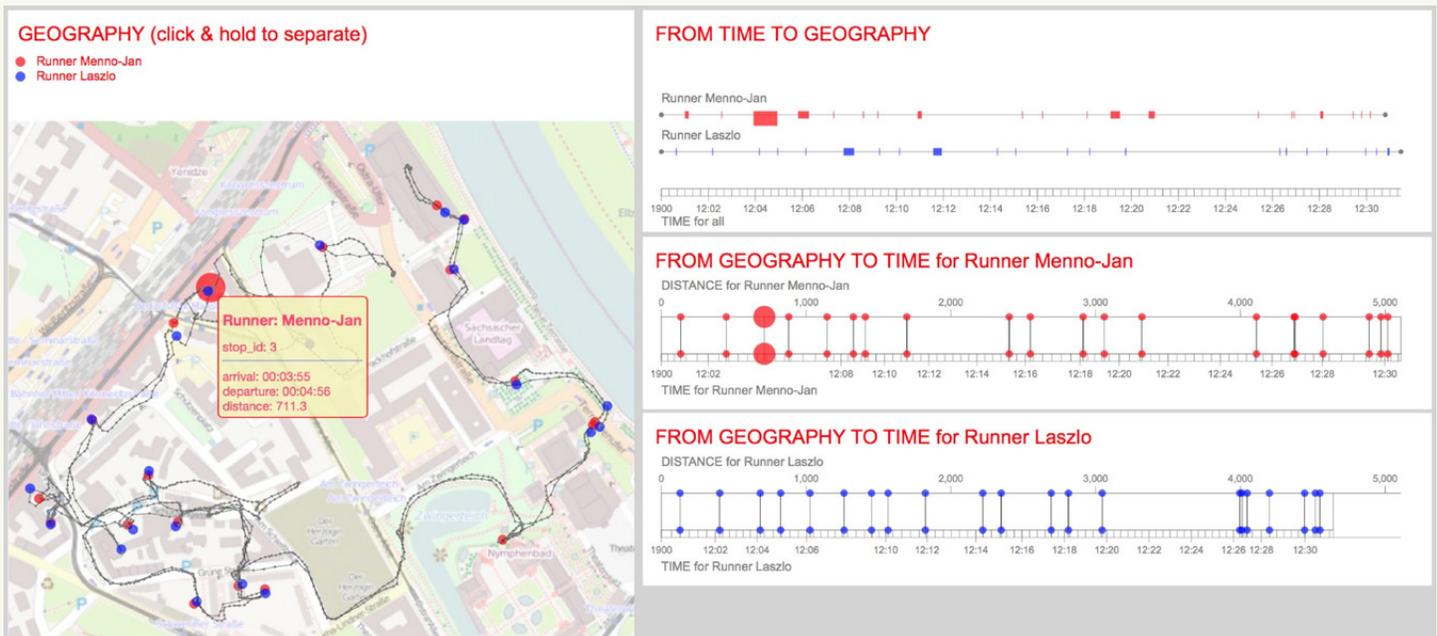


Figure 6: The web based implementation of the integrated timeline and distance line cartogram. The example shows the comparison of two paths in an orienteering race.

IMPLEMENTATION

TO IMPLEMENT THE VISUALIZATION functionality of the integrated time and distance line cartogram described above, we looked for a solution that would offer an easy implementation of high-quality graphics in an interactive web environment. The selection was guided by the need to have viewer components based on the modern Open Web Platform, the range of advanced, open Web standards enabling the creation of standards-compliant web applications (www.w3.org/wiki/Open_Web_Platform). In practice, this boils down to an updated standard (HTML5) for encoding web pages, combined with standards for styling and layout (CSS3), and for vector graphics (SVG), as well as a scripting environment (JavaScript) to enable interactivity and business logic.

There are several JavaScript frameworks and libraries that support the Open Web Platform, and simplify the building of interactive web graphics using HTML5 in modern browsers. The D3 library (Bostock et al. 2011; d3js.org) was chosen because of earlier favorable experiences in using it in experiments with a client for thematic mapping of service-based data (Köbben 2013).

D3.js is a JavaScript library for manipulating web pages programmatically through their Document Object Model (DOM). It allows one to bind arbitrary data to the DOM and then apply data-driven transformations to it, using the full capabilities of modern web standards. D3 was found to be fast and efficient, even when using large datasets. Its code structure, based on the popular JavaScript framework jQuery, allows for dynamic behaviors of the objects, thus enabling maps with interaction and animation.

The resulting *TracksViewer* experiments are available online at kartoweb.itc.nl/kobben/D3tests/tracksViewer. Here, you can find the orienteering race example from Figure 6 as well as a version of the buses experiment from Figure 5, both of which show multiple events. Apart from these, versions with single events are also included; these show the possible timeline and distance line cartogram variations that were identified in Figure 2. To enable a better understanding of the relation between the various

cartograms and the map, all the views in each of the visualizations are interlinked: whenever one moves the mouse over a stop event in any of the diagrams, the corresponding stop event is highlighted (by a change of the symbol size) in the other diagrams, and some key attributes of the data instance are shown.

All these visualizations use the same D3 code base (made available on the GitHub open source code-sharing platform: github.com/kobben/D3tests/tree/master/tracks-Viewer; also available at cartographicperspectives.org/index.php/journal/issue/view/cp77). The individual versions are created from a set-up file in which one defines the types of cartograms and maps to be shown, and the data attributes to use for the interlinking of the views and in the info panel. It also sets the map scale and center, as well as the time and distance scales for the line cartograms. These can vary substantially, as one can observe by the difference between the GPS walk visualization, covering 1500m in some 25 minutes, and that of Napoleon's Russian Campaign, which spans almost all of Europe's width over the period of half a year.

The data for the visualizations are stored as a GeoJSON, the spatially enabled version of the JavaScript Object Notation format. In principle, any GeoJSON file that stores a sequence of positions can be used. In the experiments, the data were originally GPS tracks, except the Napoleon data. The only pre-processing needed is to either identify the existing stops, or alternatively calculate or derive them from the tracks, as explained earlier.

We observed that in the examples with multiple events, the distinction between the individual tracks in the map could become quite difficult, most obviously in the buses visualization. Therefore we added the possibility to briefly separate the tracks when clicking and holding down the mouse button. Functionality for adding a background map was added, too, shown in the example in Figure 6. For now, one can only use a local raster file. But as the D3 library has full map projection capabilities, we plan to add the possibility of using Web Map Services.

PRELIMINARY EVALUATION

TO GET AN IDEA of the usability of the integrated time and distance line cartograms, we conducted a small and preliminary test. Further testing is required, but some

interesting insights were retrieved from this first evaluation. Table 1 shows the questions we formulated, related to time, distance, and space (map). The objective of the

evaluation was to get an indication of the typical questions for which the proposed solution is suitable. The line cartograms were also compared with another visual solution able to show paths and stops, the space-time cube.

For the evaluation, two groups of eight Geoinformatics MSc students (n=16) were recruited. The first group had to answer the questions listed in Table 1 using the space-time cube, and the second group worked with the line cartograms to answer the same questions. A pilot test was conducted before the actual evaluation to improve the test set-up. The participants were first introduced to the purpose of the test, and given time to familiarize themselves with the testing environment. During the test, measures on effectiveness and efficiency were collected, by having participants fill out answer sheets, and think aloud. An eye-tracker registered their eye-movements. The test ended with an interview to measure the participant's satisfaction and to gather other comments.

The answers of the participants dealing with the space-time cube differed little from those dealing with the line cartograms. However, with the space-time cube, participants took on average more than twice as long to answer. This can be explained if one realizes that the space-time cube only shows the "raw" tracks while the line cartograms show interpreted data.

The objective of using the eye-tracker was only to get an impression of which views would attract attention depending on the type of questions asked. Because of this, the gaze data have not been analyzed further, as suggested by

Questions to be answered during evaluation	
1. Did the two competitors follow the same path from target 1 to target 2? [M]	
2. Which competitor ran the longest distance during the event? [D]	
3. Which competitor took most time for the event? [T]	
4. Who was the first to reach target 2? When did he arrive and depart again? [T]	
5. Who ran a longer distance between target 3 to target 4? [D]	
6. Who spent more time between target 2 to target 3? [T]	
7. Who was faster when running from the start to target 1? [T]	
8. Who spent more time while staying at target 3? [T]	
9. Did the two competitors visit all the targets? [M]	
[M] map oriented; [D] distance oriented; [T] time oriented	

Table 1: User tasks.

Coltekin et al. (2013). The questions were map, distance, or time oriented. If a question was time-oriented such as Question 8 in Table 1, one would expect many fixations on timelines. In Figure 7, three sample gaze plots, one for each question type, have been selected. Each displays the order and length of the participant's eye fixations.

Figure 7a shows a typical gaze plot that belongs to Question 2, a distance-oriented question. While thinking aloud, several participants remarked that they would only require the geography-to-time view to answer the question. In Figure 7b, a gaze plot from the map-oriented Question 9 is shown. The question could be answered by all views, but the strategy of most participants indeed was to look at the map and check all the control points. This particular participant found that one of the runners missed control point 6, which is revealed by the high concentration of long fixations in the south west of the map and the

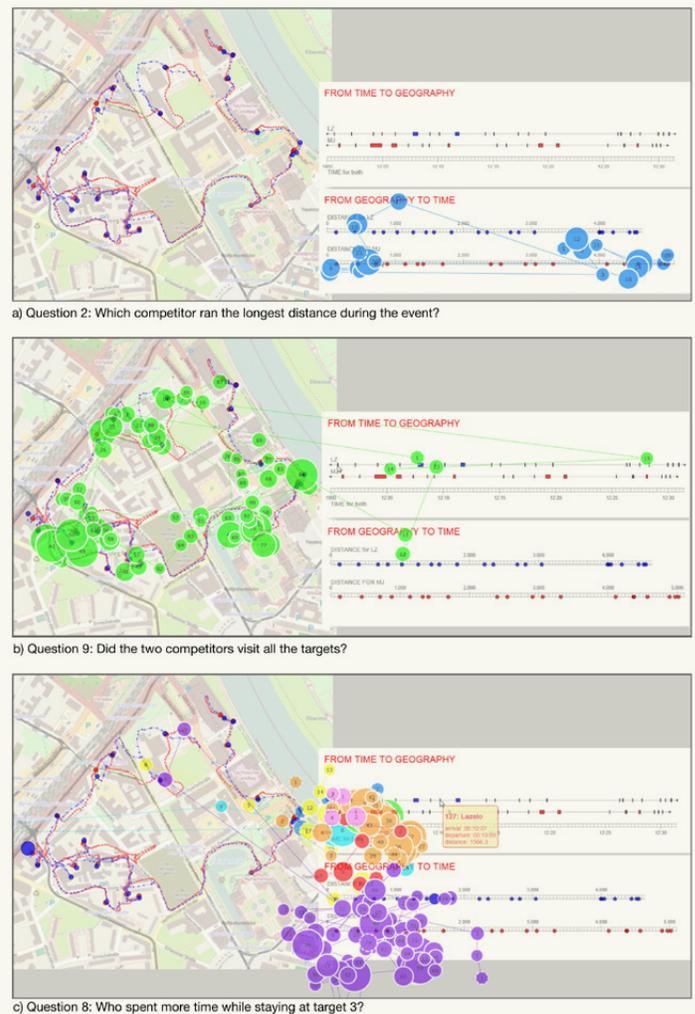


Figure 7: Gaze plots of a) Question 2 related to distances, b) Question 9 related to location, and c) Question 8 related to time.

fixations on both distance and timelines near control point 6 as well. The participant probably used these to confirm his findings in the map. In Figure 7c, the gaze plots of all eight participants for the time-oriented Question 8 are shown. All but one participant used the time-to-geography view to answer the question. This participant

mentioned in the think-aloud session that he did not understand the line diagram very well. In all gaze plots of this participant, the gaze paths are extensive and mostly not in the relevant view. Of all participants, this one spent the most time looking at the screen before answering all of the questions.

CONCLUSION

THIS PAPER INTRODUCED an alternative for looking at movement data from different perspectives. The movements are schematized into lines and distorted based on time or distance in order to answer specific location- or time-based questions. We implemented our alternative in a web environment using D3, with different linked views that allow a user to explore the nature of the movements. Its strength is the ability to compare multiple movements. A simple preliminary evaluation of the product showed it does perform as expected, and that it is able to answer time and space related questions.

The method is expected to lose its advantage with high visual complexity. This is not necessarily due to the fact that

there are many movement trajectories to represent and/or many stops involved. Rather, the spatial and temporal distribution of both the trajectories and/or stops will ultimately decide on the complexity. However, some interaction technique to visually unclutter the trajectories while exploring the data, as used in the online bus example, can be helpful.

Dealing with both qualitative and quantitative attribute data on the time and distance lines (the integration of the flow map) will be one of the first follow-up steps in this project, as well as experimenting with many more tracks, which will require specific “comparison” functionality.

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