Available online at www.sciencedirect.com
SCIENCE DIRECT®
ISPRS Journal of Photogrammetry & Remote Sensing 57 (2003) 390–399
PHOTOGRAMMETRY & REMOTE SENSING
www.elsevier.com/locate/isprsjprs

Geovisualization illustrated

Menno-Jan Kraak*

ITC, International Institute of Geoinformation Sciences and Earth Observation, PO Box 6, 7500 AA Enschede, The Netherlands

Received 13 February 2002; accepted 12 July 2002

Abstract

In recent years, the visualization of geospatial data has undergone dramatic and important developments. Next to static maps, nowadays, immersive and highly interactive virtual environments can be used to explore and present dynamic geospatial data. Additionally, the World Wide Web has developed into a prominent medium to disseminate geospatial data and maps. In visualizing geospatial data, methods and techniques from fields, such as scientific visualization and information visualization, are applied because of the large volumes of data at hand. This has accumulated in what is known as geovisualization—the use of visual geospatial displays to explore data and through that exploration to generate hypotheses, develop problem solutions and construct knowledge. Maps and other linked graphics play a key role in this process. The objective of this paper is to demonstrate the usefulness of geovisualization and, in particular, how alternative graphic representations can stimulate the visual thought process. This is demonstrated by applying geovisualization techniques to Minard's well-known map of Napoleon's 1812 campaign into Russia, the "Carte figurative des pertes successives en hommes de l'Armee Française dans la campagne de Russie 1812–1813" (http://www.itc.nl/personal/kraak/1812/).

Keywords: geovisualization; alternative views; maps; Minard

1. Introduction

Before the 1990s and the era of geographic information systems (GIS), paper maps and statistics were probably the most prominent tools for researchers to study their geospatial data. To work with those paper maps, analytical and map use techniques were developed, which can still be found in the commands of many GIS packages. Via GIS, the same researchers have 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, 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.

The above trend in mapping is strongly influenced by developments in other disciplines. In the 1990s, the field of scientific visualization gave the word "visual-

* Tel.: +31-53-487-4463; fax: +31-53-487-4335.
E-mail address: kraak@itc.nl (M.-J. Kraak).

0924-2716/03/$ - see front matter
doi:10.1016/S0924-2716(02)00167-3

ization'' an enhanced meaning (McCormick et al., 1987). 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 by Hearnshaw and Unwin (1994) and MacEachren and Taylor (1994). 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 (Card et al., 1999).

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 (MacEachren and Kraak, 2001). 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 geocomputing 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 et al. (1992) 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 (1992), who in

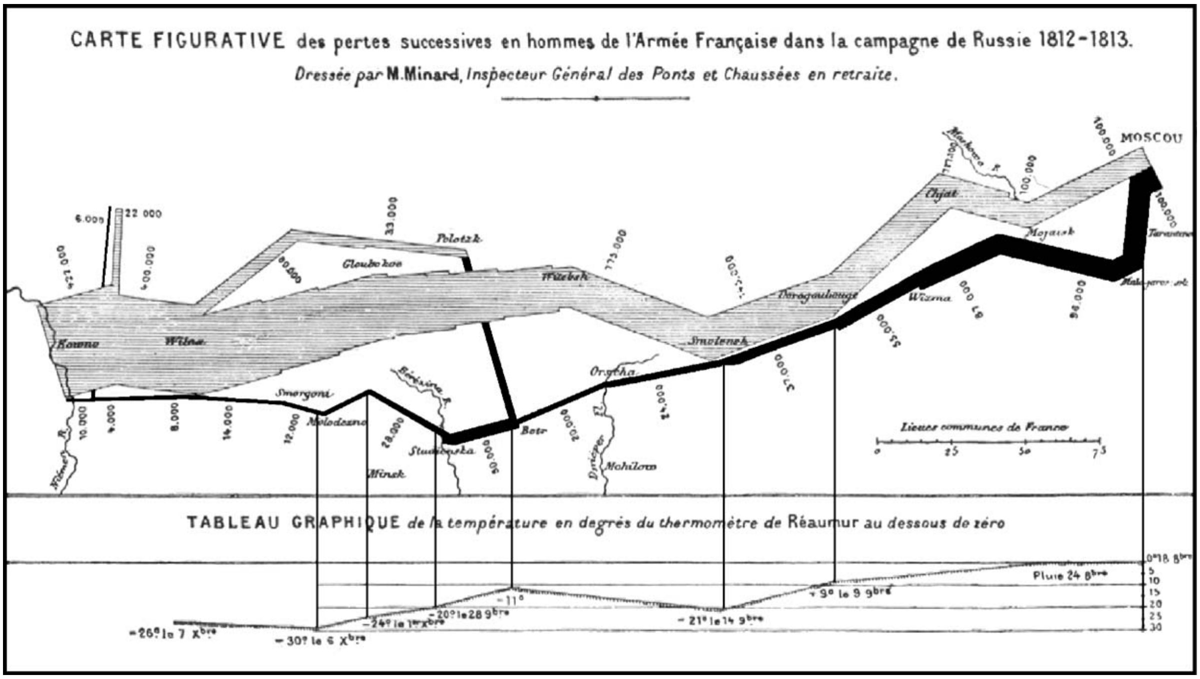


Fig. 1. Charles Minard's map from 1861 ''Carte figurative des pertes successives en hommes de l'Armee Française dans la campagne de Russie 1812–1813'' or Napolean's March on Moscow.

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 (3D) 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.

The objective of this paper is to give an increased awareness and examples of the benefits of the geovisualization approach. It often happens that after explaining what geovisualization stands for people will comment with remarks such as "...interesting..." and move on with their daily activities. This might be partly due to the fact that current (GIS) tools cannot handle the integrated demand for required functions, or because they are not familiar with the potential strengths of geovisualization. To stimulate the understanding of geovisualization, this approach is applied in this instance to Charles Minard's well-known map of Napoleon's 1812 campaign into Russia. The paper will stress the argument that, if one is able to look at the data from different perspectives (for instance, via alternative map views, sometimes in combination with other graphics such as diagrams, graphs or even photographs and videos), the nature of the data at hand will be better appreciated. This argument is supported by the interactive and dynamic graphics on the World Wide Web pages (http://www.itc.nl/personal/kraak/1812/) that accompany this paper.

The map shown in Fig. 1 is rather well known and has been previously described by many authors. Among them, Tufte (1983) claims "it may well be the best statistical graphic ever drawn". He explains that the map is "a narrative graphic of time and space which illustrates how multivariate complexity can be subtly integrated ... so gentle and unobtrusively that viewers are hardly aware that they are looking into a world of four or five dimensions".

2. Minard and his map

The map selected to illustrate the usefulness of geovisualization by presenting alternative visual perspectives of the original map data is entited, "Carte figurative des pertes successives en hommes de l'Armee Franç aise dans la campagne de Russie 1812–1813", or "Napoleon's March on Moscow" by Charles Minard from 1861. This map portrays the dramatic losses of Napoleon's army during his Russian campaign (Fig. 1) and was published alongside a similar map of Hannibal's campaign over the Alps into Italy. The author's purpose of both maps was to stress the senselessness of war.

Minard worked as a civil engineer at the Department "Ponts et Chausées" in France and only later in his life took up cartography. During that period, he produced around 50 published maps, most of which had transport and economic data as a theme, and resulted in flow maps and diagram maps, respectively. The life and work of Charles Joseph Minard (1781–1870) is extensively described by Friendly (2000) and Robinson (1967). An overview of his maps, which influenced the development of thematic cartography, can be found in Palsky (1996) and Robinson (1982). In all of the maps produced by Minard, the general message was much more important than the link between the data and the geography. From this perspective, he paid no attention to map projections and even adapted scales according the need of the theme. This is illustrated in Fig. 1 by the return from Moscow depicted as the black solid band. In reality, the return followed approximately the same route as the march to Moscow, indicated as a thick grey area in Fig. 1. However, Minard has drawn them separately for clarity reasons. The very detailed rivers also do not fit with the all over message of the map. Nevertheless, he tried to portray his thematic data as accurately as possible. In Napoleon's 1812 Russian campaign, this is expressed by generalizing almost all troop movements into a single flow. Minard tended to call his maps, "carte figuratives".

The Minard map shows several "variables". As with any map, there is location. Next to the major paths, some minor paths are distinguished. Linked to the retreat path (the black, solid band) is a diagram indicating temperature. Additionally, the map shows the size of the army by numbers and by the width of the advance and retreat bands. Names indicate major battles and important geographic features. Time is inherently illustrated in the map as a clear distinction between the advance (going east) and retreat path (going west). Only in the temperature diagram, however, are absolute time values provided. Interestingly, there was a long 50-km march between December 6 and 7 under very cold weather conditions, as can be read from the temperature diagram.

In reality, the campaign as mapped by Minard was much more complex (Fig. 2). The main army followed a path via Kovno (June 24), Vilna (June 29), Vitebesk (July 23), Smolensk (August 16), Borodino (September 7) and Moscow (September 15–October 23). The army started with over 500,000 soldiers, but Napoleon arrived at Moscow with less than 100,000. Although some were left at depots and towns on route, and some deserted, most losses were due to poor health conditions resulting in many deaths by illnesses such as dysentery and typhus. The major battle of the whole campaign, the one at Borodino, caused "only" 30,000 deaths. During the retreat, the army fought battles at Maloyaroslavets (October 24), Viazma (November 3), Karsnoi (November 16) and Berezina (November 27). Despite these battles, the winter weather with severe colds was the biggest enemy. Although Napoleon left his army for Paris on December 5, 1812, the crossing of the rear of the army under Marshall Ney on December 14 is seen as the end of the campaign. Extensive descriptions of the campaign can be found in the works of Austin (2000), Clausewitz (1970), Nafziger (1988), Nicholson (1985) and Palmer (1967).

The question is how can we take an alternative look at this map and its data to improve our insight and level of knowledge about the event? Also, can this be done to the degree that Tufte (1983) claims Minard has already done? (Recall Tufte's quote at the end of Section 1.)

3. Alternative visualizations of Minard's map

Geovisualization is more than the creation of alternative visual representation of the data of Fairbairn et al. (2001). It also concerns the geocomputational methods and techniques behind processing the images, the environment in which the images are used (i.e., the interface) and the question "does it work?" (i.e., cognitive aspects). This paper will further concentrate on alternative visual representation. In the discussions, the World Wide Web will be considered the display medium and the examples can be found on the website: http://www.itc.nl/personal/kraak/1812. Information on the different web maps and web map design can be found in Kraak and Brown (2000).

Mapping the time dimension means mapping change in a feature's geometry, its attributes or both. Traditionally, cartographers have three options to display geospatial data with a temporal component. These are a single (static) map, in which specific graphic variables and symbols are used to show change and represent events. Minard's map is a good example of the first category. The second option is a series of (static) maps, sometimes called a small multiple. Fig. 3 gives several examples. The single map represents a snapshot in time and together the series of maps constitutes an event. Change is perceived by the

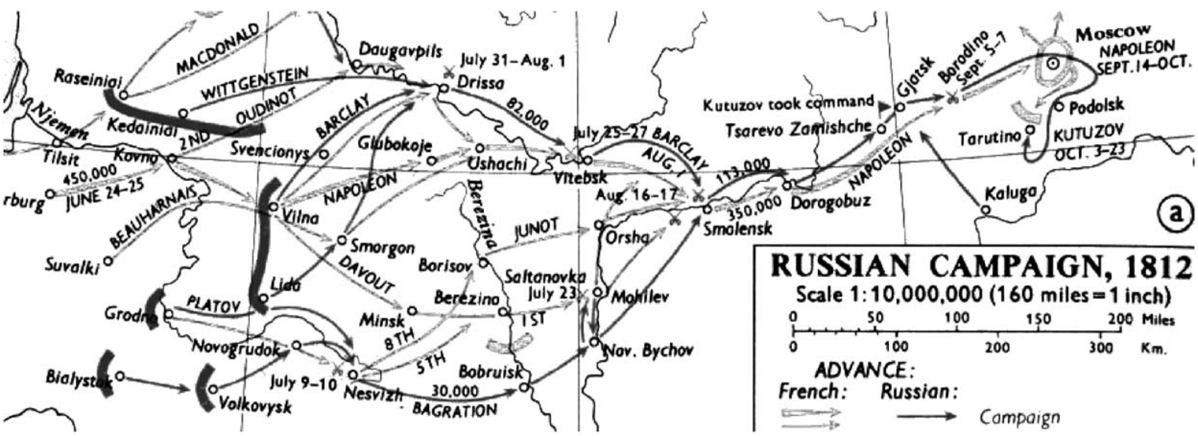


Fig. 2. The complexity of the 1812 campaign illustrated by the advanced maneuvers. Source: Darby and Fullard (1970).

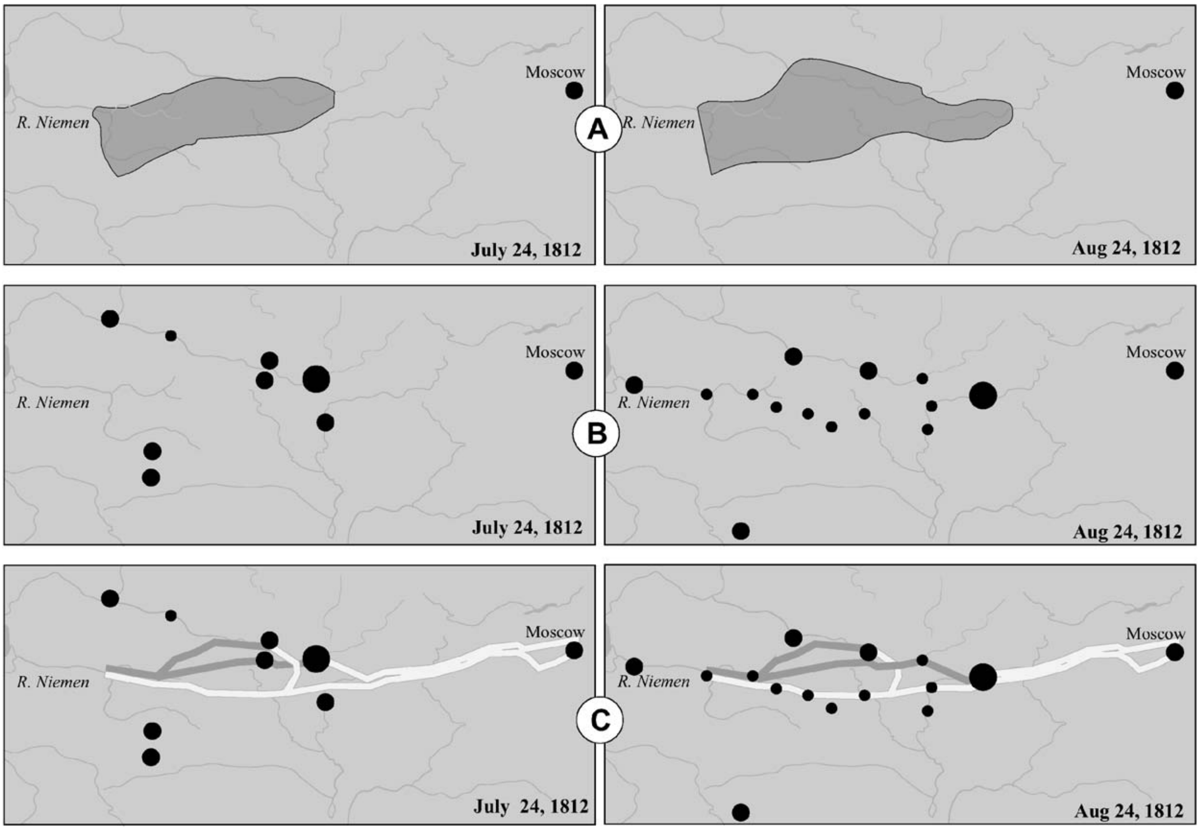


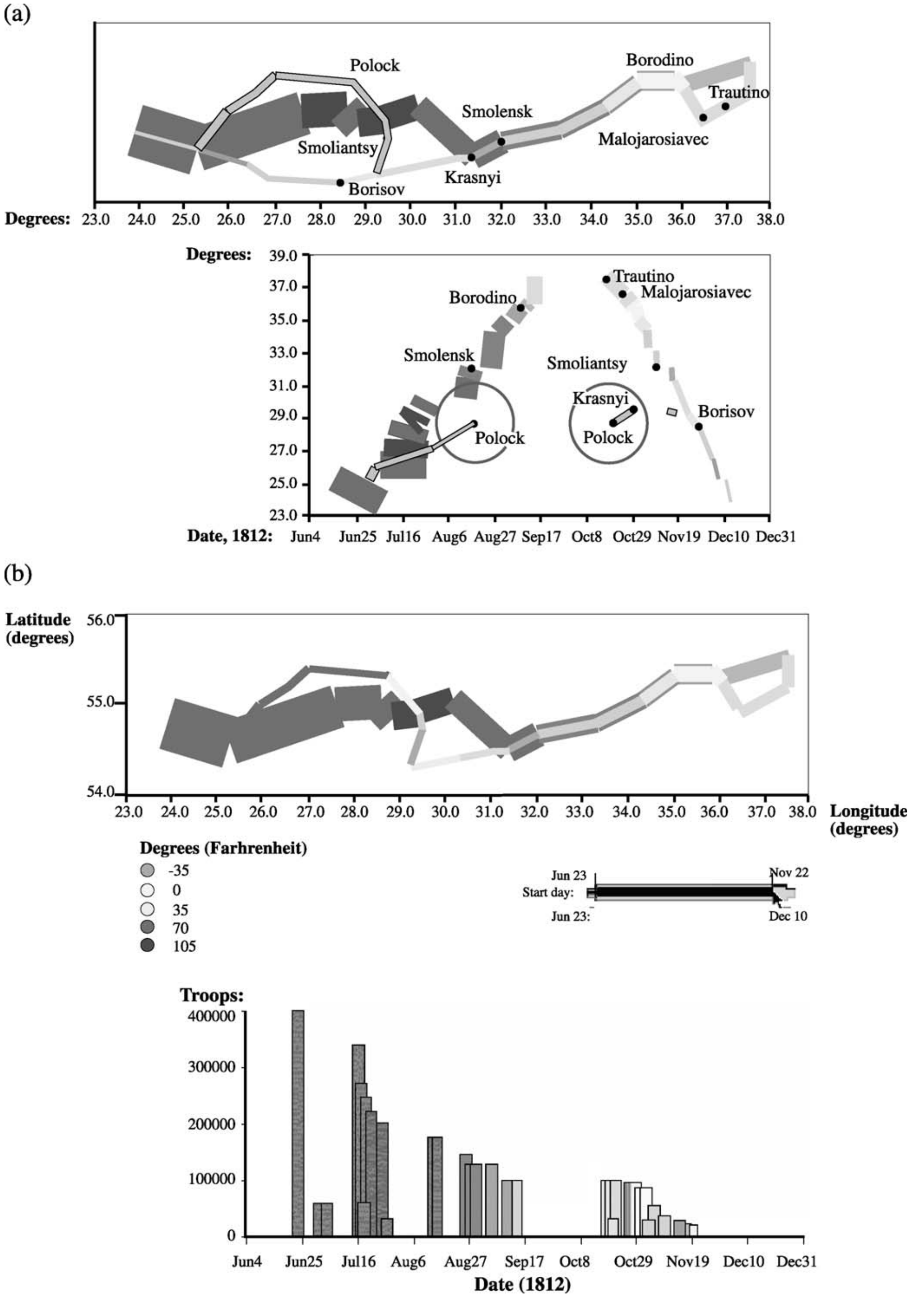
Fig. 3. The campaign in a time series. Here three pairs of two snapshots with the location of the French troops on July 24 and August 24, 1812 are depicted. Each pair shows an alternative cartographic representation of the data (source: ITC-cartography).

succession of the individual maps depicting the events in successive snapshots. It could be said that the temporal sequence is represented by spatial sequence, which the user has to follow, in order to perceive temporal variation. Finally, one can create an animated map. Here change is perceived to happen in a single image by displaying several snapshots one after the other. The difference with the animation from the static series of maps is that the variations introduced to represent an event are not deduced from a spatial sequence, but from real movement on the map itself.

Most other maps found of Napoleon's campaign into Russia fit the first category of single, static maps. These maps originated from school atlases or specialized military atlases and follow a rather traditional design pattern. For example, arrows in different colours are often used to display movements of French and Russian troops, and symbols indicate battles while some text might give explanations. The map in Fig. 2 is an example of this.

Although Minard's map definitely includes a temporal component, if one were to ask what is the sit-

Fig. 4. The campaign data in multiple-linked views. The two snapshots created after SAGE (Roth et al., 1997) each show a map and a diagram. The maps show the path of the campaign in segments. The widths of segments correspond to the number of troops. These segments are also represented in both diagrams. On top, the diagram has time along the horizontal axis and longitude along the vertical axis. At the bottom figure, the situation on November 22 is shown (see position slide bar), and the diagram has time along the horizontal axis and the number of troops along the vertical axis. The grey values in the figure represent temperature. Clicking a segment in a diagram would highlight the corresponding segment in the map.


(a)
Polock
Borodino
Trautino
Smolensk
Malojarosiavec
Smoliantsy
Krasnyi
Borisov
Degrees: 23.0 24.0 25.0 26.0 27.0 28.0 29.0 30.0 31.0 32.0 33.0 34.0 35.0 36.0 37.0 38.0
Degrees: 39.0 37.0 35.0 33.0 31.0 29.0 27.0 25.0 23.0
Date, 1812: Jun4 Jun25 Jul16 Aug6 Aug27 Sep17 Oct8 Oct29 Nov19 Dec10 Dec31
(b)
Latitude (degrees) 56.0 55.0 54.0
23.0 24.0 25.0 26.0 27.0 28.0 29.0 30.0 31.0 32.0 33.0 34.0 35.0 36.0 37.0 38.0 Longitude (degrees)
Degrees (Farhrenheit)
-35
0
35
70
105
Jun 23
Nov 22
Start day:
Jun 23:
Dec 10
Troops:
400000 300000 200000 100000 0
Jun4 Jun25 Jul16 Aug6 Aug27 Sep17 Oct8 Oct29 Nov19 Dec10 Dec31
Date (1812)

uation on August 24, the answer is not obvious. Even if one could locate that moment in time, all other campaign details remain visible and may cause confusion. Alternatively, adding a slider to the map would more explicitly introduce time and would allow the user to define the progress of the campaign. However, in this process, there is no link between world time and display time. Moving the slider with regular intervals also would not result in a regular passing of time because Napoleon remained at certain places for a longer period. For instance, in Moscow, he paused for more than a month, information that cannot be derived from the original static map. Some of the animations available on the website have similar problems because frames only exist for moment in time that the change is registered.

The use of a series of maps, each representing a particular moment in time, could offer an alternative display of changes over time. In Fig. 3, three options are given, each showing a different (traditional) cartographic solution. The upper maps (A) show the progress of the campaign by a zone assumed occupied by the French. The maps in the middle (B) depict the position of individual French troops on July 24 and August 24. The viewer is not distracted by previous or future moments in time. The lower set of maps (C) follows a similar approach as (B), but additionally provides (just as the original map) an overview of the whole campaign. The path of the campaign passed up to the particular date has been highlighted.

Interesting alternative visualizations have been produced by Roth et al. (1997) and Wilkinson (1999). They used Minard's map to demonstrate the capabilities of a scientific and information visualization software. Their products are examples of visualizations not influenced by traditional cartographic rules. Fig. 4a provides two snapshots of the visualization produced by Roth and his team with their tool called SAGE. Their website gives a dynamic demonstration of this product (http://www.cs.cmu.edu/Web/Groups/sage/sample.html). In the snapshots, the map is linked to diagrams, a principle Minard also followed in 1861.

The maps in both snapshots if Fig. 4b are oriented north, with the degrees of longitude indicated along the horizontal axis. In both diagrams, the horizontal axis represents time. In the upper snapshot, the vertical axis of the diagram represents longitude and, in the lower snapshot, it represents the number of troops. These combinations reveal some interesting facts when compared with the original map in Fig. 1. The diagram in the upper snapshot reveals two battles took place at Pollock (located at the northern path in the map and circled in the diagram) instead of one. The gap in the diagrams in both snapshot shows that Napoleon stayed for a month in Moscow before returning west, information not found in the original map. These examples show that alternative views can be revealing and clarifying. In addition, environments in which such graphics are presented should be interactive as the SAGE software demonstrates.

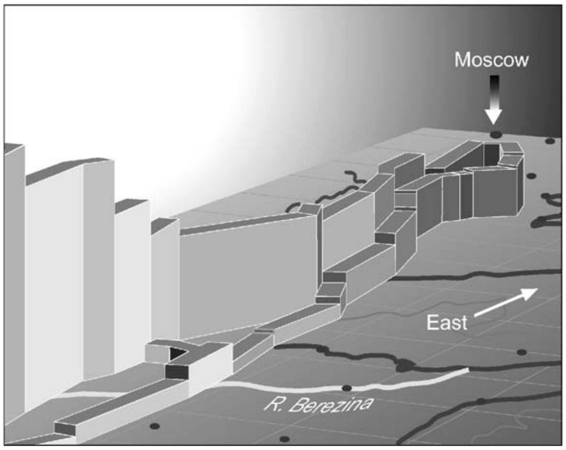


Fig. 5. Three-dimensional view of the size of Napoleon's troops during his Russian campaign in 1812. The crossing of the River Berezina is highlighted (source: ITC-cartography—see http://www.itc.nl/personal/kraak/1812 to interact with the 3D VRML model).

What if we add another dimensional component to the map? Fig. 5 presents a 3D view in which the height of the columns of the path-segments represents the number of troops. The crossing of the River Berezina is highlighted. Napoleon lost half of his remaining troops during this crossing. This information is also found in the original map, but the 3D display is more dramatic. Other variables such as temperature can be represented in 3D view as well. The columns can be coloured depending on the temperature—applying colour schemes with blue for cold and red for warm.

Links with diagrams such as shown in Fig. 4 also are possible, including the interaction options presented. The ability to manipulate the 3D scene in space to change the perspective view is a prerequisite, since many interesting facts might be hidden behind objects. If one would have looked at the River Berezina crossing from the north, it would have been hidden by the troop-columns representing the advance. Additional layers with other information can be stacked below or even above the campaign information.

Based on terrain heights, a fly through can be generated demonstrating the impact of the terrain on the campaign. In this particular case, it does not result in a spectacular view since the landscape passed by Napoleon is relatively flat. Land use data derived from satellite imagery also can be draped over the terrain to enhance the animation realizing, of course, that land use patterns will have changed considerably in some

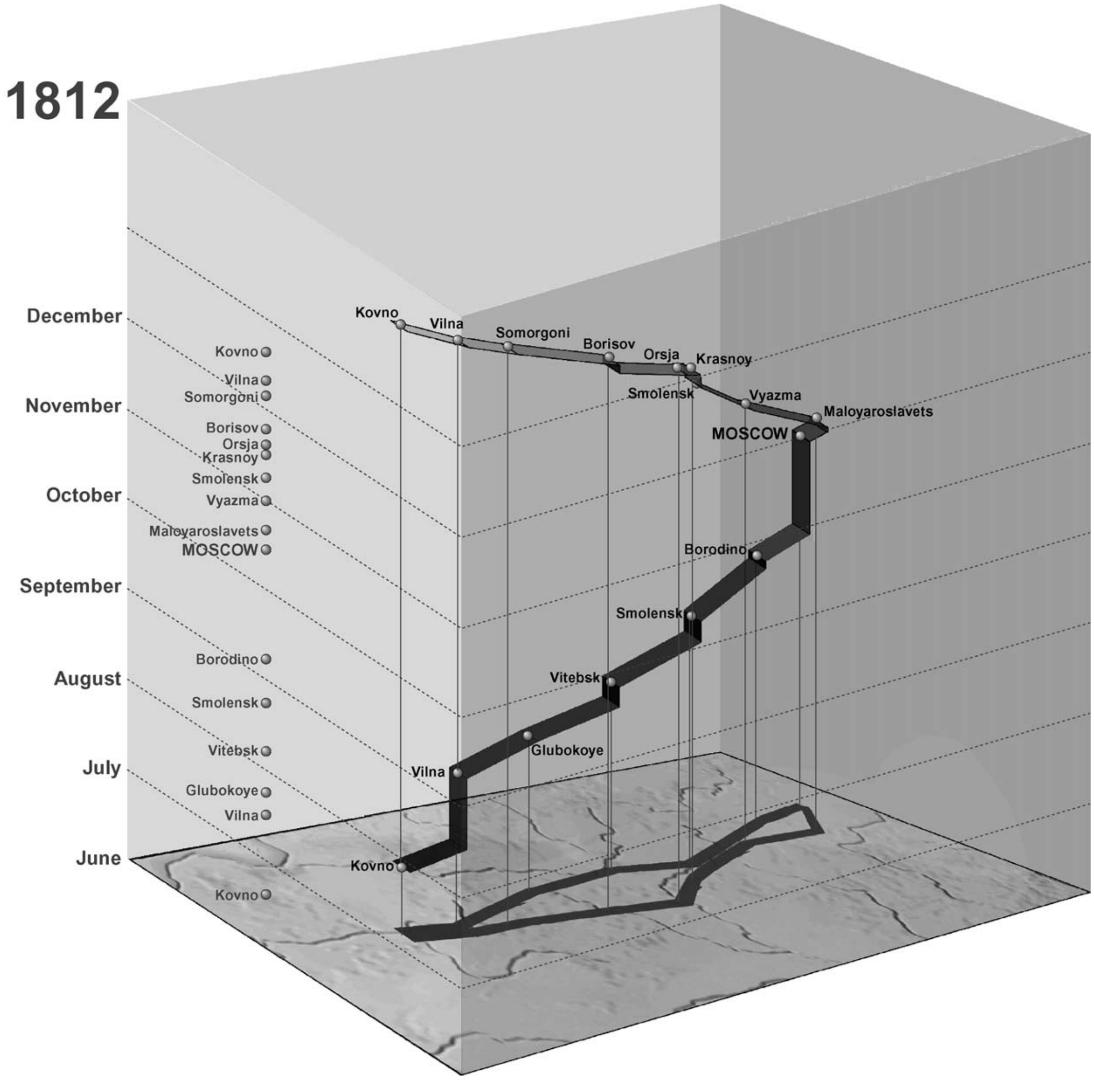


Fig. 6. A space–time cube of Napoleon's march in Russia (source: ITC-cartography).

places over the last 200 years. Alternatively, software exists which allows the landscape to be "dressed randomly and light conditions applied based on the season and time of the day. Even a snow cover can be simulated. Applications can be found in virtual reality environments. For example, in a two-dimensional animation, one can change the background of the landscape depending on the temperature from blue in winter to green in summer.

The third dimension can be applied from a completely different perspective. Fig. 6 presents a so-called space–time cube in which the x- and y-axes represent the geography and the z-axis represents time. Originally, this idea was promoted by Hägerstrand (1967) and is recently revisited by work of Kwan (2000). Again, this solution would benefit greatly from interactive options to manipulate the viewer's perspective of the cube. An additional option could be slider planes along each of the cube's axes. The user can then move the sliders through the cube and, as such, can highlight a time period or location. One could of course also change the type of data represented along the axes and, for instance, create temperature versus troops versus time.

4. Discussion and conclusions

In summary, geovisualization implies the use of visual geospatial displays to explore data and through that exploration to generate hypotheses, develop problem solutions and construct knowledge. It is obvious that this is facilitated by an interactive and dynamic environment, where the user has access to the data via graphic representations. In this paper, it was argued that the use of alternative, if not unusual, graphics representations stimulate the visual thinking. These graphics can reveal patterns that are not necessarily visible when traditional map display methods are applied. In an ideal environment, the user is able to select the graphic representations at will and can query and compare the different approaches via multiple dynamically linked views.

The example of Minard's map was selected because it is seen as one of the best drawn historical graphics, includes multiple variables and has been examined by various other authors. The aim of the different graphic representations presented here was not necessarily to try to reveal new patterns in the Minard data, but to demonstrate that alternative representations each give a different perspective and new insights to the data.

The value of adding multimedia elements to the data could, in the particular case of the Minard data, give the user an impression of the historical situation. For instance, links to images of the dramatic paintings of the retreating army crossing the River Berezina will make the user understand how it could happen that during the crossing half of the troops did not survive.

Animation further allows the dynamic addition of the temporal component of the data. In the discussions, the importance of the link between display time and world time was stressed to insure a correct impression of the temporality of the event. Neglecting this would not reveal that Napoleon's progress was not constant and he stopped at several locations for a longer period. Interaction with an animation is also seen as a requirement in order to allow the user to query specific moments or periods in time. Animation also can be used to display non-temporal aspects of the data. Next to flight over the terrain, one could, for instance, use a variable such as temperature to order the events during the campaign and relate those to the number of casualties.

The third dimension allows for an additional variable to be displayed in a single view and, as such, gives the user a direct insight to the relationship between these variables. Traditionally, the terrain heights are used, but one could also depict other variables as Fig. 5 demonstrates. In such environments, even more data layers can be displayed or time can be used as the third dimension, resulting in the space–time cube shown in Fig. 6. The traditional Cartesian geometry also could be changed based on the progress of the troops each day, resulting in a linear cartogram. All these graphics should be linked together and should allow the user to brush to each of the views while seeing corresponding effects in the other views.

The example in this paper and, more importantly, the examples on the website, demonstrate that much more information on Napoleon's campaign can be revealed using geovisualization and alternative map views. In addition, although Minard's data already have been exploited and discussed, they sufficiently demonstrate the potential options of alternative visual geospatial displays. Imagine what can be accomplished using other, even more extensive and complex, data sets.

References

Austin, P.B., 2000. 1812: Napoleon's Invasion of Russia. Greenhill, London.

Card, S.K., MacKinlay, J.D., Shneiderman, B., 1999. Readings in Information Visualization: Using Vision to Think. Morgan Kaufmann, San Francisco.

Clausewitz, C.V., 1970. The Campaign of 1812 in Russia. Academic International Press, London. In: Darby, H.C., Fullard, H. (Eds.), The New Cambridge Modern History Atlas. Cambridge Univ. Press, Cambridge.

Darby, H.C., Fullard, H. (Eds.), 1970. The New Cambridge Modern History Atlas. Cambridge University Press, Cambridge.

Fairbairn, D., Andrienko, G.L., Andrienko, N.V., Buziek, G., Dykes, J., 2001. Representation and its relationship with cartographic visualization: a research agenda. Cartography and Geographic Information Systems 28 (1), 13–28.

Finke, R.A., Ward, T.B., Smith, S.M., 1992. Creative Cognition: Theory, Research, and Applications. MIT Press, Cambridge, MA.

Friendly, M., 2000. Re-visions of Minard. Statistical Computing and Graphics Newsletter 11(1), 1 and 13–19. Available at http://www.math.yorku.ca/SCS/Gallery/minard/minard.pdf (accessed 22 November 2002).

Hägerstrand, T., 1967. Innovation Diffusion as a Spatial Process. University of Chicago Press, Chicago.

Hearnshaw, H.M., Unwin, D.J. (Eds.), 1994. Visualization in Geographical Information System. Wiley, London.

Keller, P.R., Keller, M.M., 1992. Visual Cues, Practical Data Visualization. IEEE Press, Piscataway.

Kraak, M.J., Brown, A. (Eds.), 2000. Web Cartography—Developments and Prospects. Taylor and Francis, London.

Kwan, M.P., 2000. Interactive geovisualization of activity travel patterns using three-dimensional geographical information systems: a methodological exploration with a large data set. Transportation Research C-EMER 8 (1–6), 185–203.

MacEachren, A.M., Kraak, M.J., 2001. Research challenges in geovisualization. Cartography and Geographic Information Systems 28 (1), 3–12.

MacEachren, A.M., Taylor, D.R.F. (Eds.), 1994. Visualization in Modern Cartography. Pergamon, London.

McCormick, B., DeFanti, T.A., Brown, M.D. (Eds.), 1987. Visualization in scientific computing. Computer Graphics 21 (6).

Nafziger, G., 1988. Napoleon's Invasion of Russia. Presidio Press, Novato.

Nicholson, N., 1985. Napoleon 1812. Harper and Row, London.

Palmer, A., 1967. Napoleon in Russia. Constable, London.

Palsky, G., 1996. Des Chiffres et des Cartes: Naissance et développement de la Cartographie Quantitative Francais au XIXe siècle. Editions de CTHS, Paris.

Robinson, A.H., 1967. The thematic maps of Charles Joseph Minard. Imago Mundi 21, 95–108.

Robinson, A.H., 1982. Early Thematic Mapping in the History of Cartography. University of Chicago Press, Chicago.

Roth, S.F., Chuah, M.C., Kerpedjiev, S., Kolojejchick, J.A., Lucas, P., 1997. Towards an information visualization workspace: combining multiple means of expression. Human–Computer Interaction Journal 12 (1–2), 131–185.

Tufte, E.R., 1983. The Visual Display of Quantitative Information. Graphics Press, Cheshire, CT.

Wilkinson, L., 1999. The Grammar of Graphics. Springer, New York.