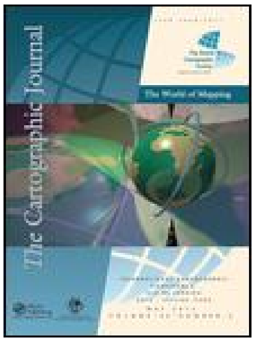

The Cartographic Journal
The World of Mapping

ISSN: 0008-7041 (Print) 1743-2774 (Online) Journal homepage: www.tandfonline.com/journals/ycaj20

Why Maps Matter in GIScience

Menno-Jan Kraak

To cite this article: Menno-Jan Kraak (2006) Why Maps Matter in GIScience, The Cartographic Journal, 43:1, 82-89, DOI: 10.1179/000870406X93526

To link to this article: https://doi.org/10.1179/000870406X93526

Published online: 18 Jul 2013.

The Cartographic journal Vol. 43 No. 1 pp. 82–89 March 2006

OBSERVATION

Why Maps Matter in GIScience

Menno-Jan Kraak

ITC—International Institute of Geo-Information Science and Earth Observation, Department of Geo-Information Processing, PO Box 6, 7500 AA, Enschede, The Netherlands.
Email: kraak@itc.nl

This paper presents some thoughts about the role of maps in GIScience and visualization. In particular, it highlights some developments and trends in the discipline that have revived interest in visualisation and increased the importance of maps in GIScience.

ABOUT MAPS

Maps have the ability to present, synthesize, analyse and explore the real world. Maps do this well because they only present a selection of the complexity of reality and visualize it in an abstract way. The cartographic discipline has developed a whole set of design guidelines to realize the most suitable map that offers insight in spatial patterns and relations. Many textbooks and papers have been written on this topic (Bertin, 1967; MacEachren, 1994; Robinson, *et al.*, 1995; Slocum, 1998; Kraak and Ormeling, 2002). In general, professional geographers don't have to be convinced of the unique qualities of maps to express their ideas, to make a point, to obtain new knowledge and communicate among colleagues, and of course to orientate and navigate. Maps are also appreciated outside our professional community. Ask randomly and the conclusion will be that almost everyone likes them, and has an opinion on their aesthetics and quality, although the last not always based on justifiable arguments.

Despite the above positive remarks the view on maps is often limited to its presentation function. Even the professional geographer might not be fully aware of the possibilities. This view probably partly originates from map descriptions and definitions and partly from unawareness of the developments in the discipline. Definitions go seldom beyond the presentation function of the map. In the current strategic plan of the International Cartographic Association a map is defined as:

> A symbolised representation of a geographical reality, representing selected features and characteristics, resulting from the creative effort of its author's execution of choices, and is designed for use when spatial relationships are of primary relevance. [url 1]

This definition mentions use, but stresses creation. Of course, it is realized that even for exploratory purposes the maps have to be created, but the emphasis is on its use (the exploration). For many other map definitions the website of J.H. Andrews is a good source [url 2]. It lists over 300 definitions. Even though definitions might be limited in scope, maps have been used to solve or highlight problems anyhow. In this respect, many cartographic textbooks, as well as books outside our geo-disciplines (Tufte, 1983, 1997) demonstrate the strength of maps, while some point to the 'danger' of maps (Monmonier, 1991; Wood, 1992; Pickles, 2003). The classical map examples that are revisited frequently are John Snow's map of London depicting a cholera epidemic [url 3] and Minard's map of Napoleon's campaign into Russia [url 4].

The detail of Snow's map is shown in figure 1(a). It displays the individual cholera deaths, as well as the water pumps in the area. Snow linked the cause of cholera to the quality of water and by closing the Broad Street pump, which was located in the vicinity where most victims were found, the epidemic abated. The example can be seen as one of the earliest spatial analysis operations and is referred in both geographical, as well as in medical literature (McLeod, 2000; Frerichs, 2001). Tobler [url 5] used the map to demonstrate how problems can be solved using geographical techniques. He created Thiessen polygons to indicate the area of influence of each pump and executed a point-in-polygon operation to determine around which pump most victims where found. Monmonier used the example to demonstrate how the choice of basic geographical units can influence the outcome of a spatial analysis by selecting different combinations of street blocks as basic units (Monmonier, 1991). Recently, Brody *et al.* (2000) claimed that Snow did not use the map as a means to find a solution, but more as proof that confirmed his approach. Anyhow, the Snow case demonstrates the strength of maps and the different roles they can play. Medical geography and maps go hand-in-hand, and have assisted each other in many other cases. See, for instance, the website of the US National Center of Health Statistics and its Atlas of United States Mortality [url 6] or the Dutch Zorgatlas [url 7].

The detail of Minard's map from 1869 is displayed in Figure 1b and shows Napoleon's dramatic losses during his Russian campaign. The objective of the 'Carte figurative des pertes successives en hommes de l'Armee Française dans la

DOI: 10.1179/000870406X93526

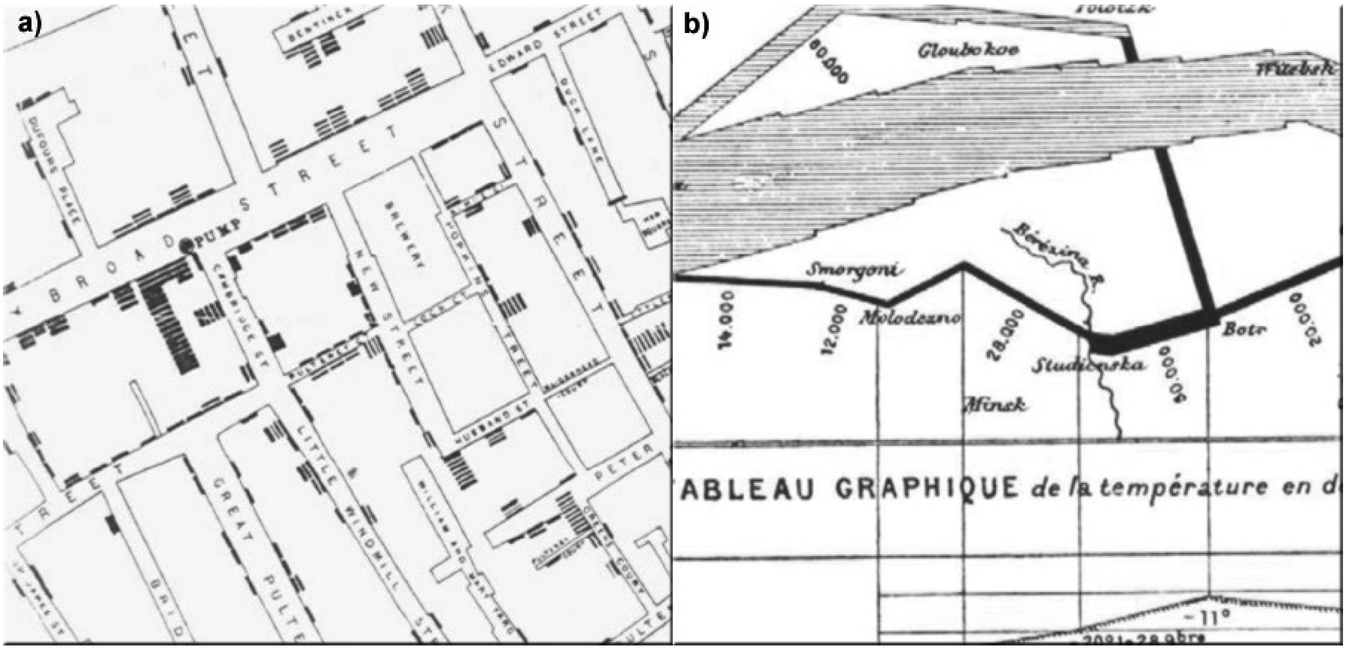

Figure 1. Map classics and their relation to GIScience. (a) John Snow's map of London's 1854 cholera epidemic—one of the first visual spatial analyses. (b) Minard's 1869 map of Napoleon's 1812 campaign into Russia—one of the first multiple view approaches

campagne de Russie 1812–1813', was to stress the senselessness of war. The map shows two distinct paths, the advance to Moscow (in grey) and the retreat (in black). A diagram indicating temperature is linked to the path of retreat, probably making this map one of the first with a linked view. The width of the paths represents the number of troops. The map has been extensively described by several authors and is a good example of a narrative of an event displaying time and space (Robinson, 1967; Friendly, 2000). Recently, the map has been put in the interactive and dynamic context of today's map making and map use (Roth, *et al.*, 1997; Kraak, 2003). These new Minard maps allow the user to interact, query and replay Napoleon's campaign.

The interest in these and other classics maps has certainly been stimulated by Tufte's publications, which are also widely read outside the geo-community, especially in the scientific and information visualization community (Card *et al.*, 1999; Wilkinson, 1999; Spence, 2001; Chen, 2003). Interestingly, these relatively new domains apply cartographic knowledge to realize their objectives and our discipline should be stimulated by the creative graphics created in these domains.

Although the traditional paper map allowed geographers to use it to synthesize, analyse and explore, it is be obvious that the rise of Geographical Information Systems have stimulated these functions. Maps that used to be elaborate to produce can now be created in many alternatives views by the single click of the mouse. Additionally, many more maps are produced and used, a trend multiplied by the development of Internet and especially the WWW (Peterson, 2003). One could argue that these numbers make no difference because of the poor cartographic quality of most of these maps. However, one could also argue if one *needs* properly designed maps under all circumstances. The motto 'fitness for use', as applied when discussing data quality, should also be considered fundamental to cartography.

When taking these developments into account, the ICA definition does not cover all. In the recent book *Exploring Geovisualization* (Dykes *et al.*, 2005) the traditional role of a map to 'present' is recognized, but the map should also be seen as a flexible interface to geospatial data, since they offer interaction with the data behind the visual representation and additionally maps are instruments that encourage exploration. As such they are used to stimulate (visual) thinking about geospatial patterns, relationships and trends, and are increasingly employed throughout the GIScience process. The context where maps like this operate is the world of Geovisualization (Dykes *et al.*, 2005), which can be described as a loosely bounded domain that addresses the visual exploration, analysis, synthesis and presentation of geospatial data by integrating approaches from disciplines including cartography with those from scientific visualization, image analysis, information visualization, exploratory data analysis, visual analytics and GIScience.

MAPS AND GISCIENCE

A decade ago the notion of GIScience surfaced. The term was introduced by Goodchild (1992), who described it to deal with the basics of GIS-technology, concentrating on those issues that are an impediment to a successful implementation. In a recent book on GIScience (Duckham *et al.*, 2003) it is worded that GIScience addresses the fundamental research principles on which Geographical Information Systems are based (e.g. research on GIS) or that it refers simply to the use of GIS in scientific applications (e.g. research with GIS). Judging the GIScience research agendas discussed by Mark (2003), it can be concluded that visualization is directly or indirectly seen as an important topic.

Ever since the introduction of the term, GIS-related journals and books changed the 'Systems' part of their titles

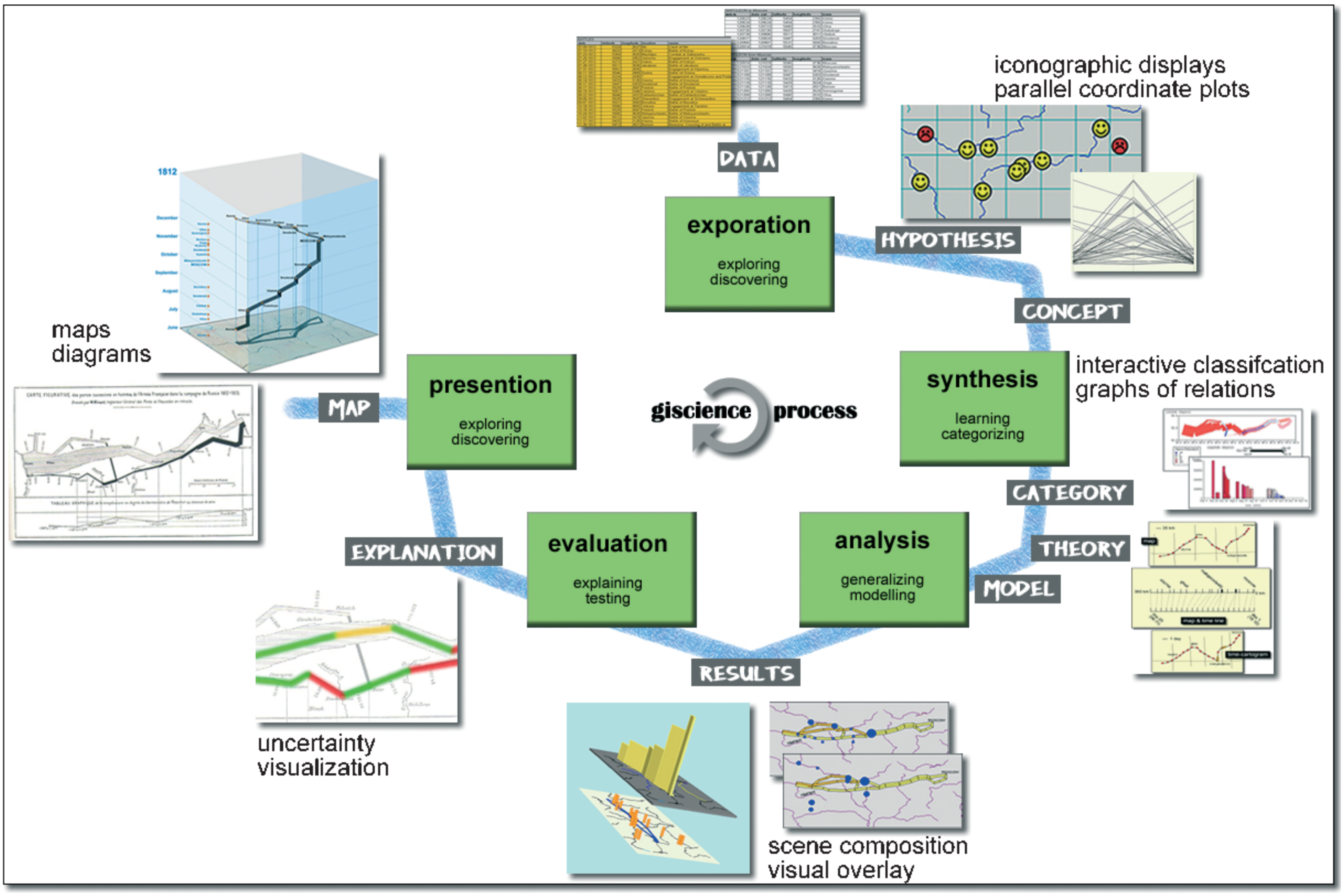

Figure 2. Maps and the GIScience process (based on Gahegan, 2005) and illustrated with Minard's map data. In any of these phases, maps—and other graphics—can play a role to enhance the task at hand

into 'Science'. *The International Journal of Geographical Information Science* used to be *The International Journal of Geographical Information Systems*, and the *American Cartographer* changed from *Cartography and Geographic Information Systems* into *Cartography and Geographic Information Science*. The authors of the two-volume *Geographical Information Systems* (Longley *et al.*, 1999) also adjusted the title when they published a shorter textbook entitled Geographic Information Systems and Science (Longley *et al.*, 2001).

These developments have also influenced the International Cartographic Association. In their recent strategic plan they express the ambition '… that the International Cartographic Association should be qualified with the sub-title *The International Society for Cartography and Geographic Information Science*' [url 1]. During the 2005 general assembly this idea did not get enough votes. In their plan, GIScience is defined as:

> The scientific context of spatial information processing and management, including associated technology as well as commercial, social and environmental implications. Information processing and management include data analysis and transformations, data management and information visualisation. Associated methodology includes both hardware and software. Commercial, social and environmental implications refer to the wide scope of applications of GI and GISystems as well as the analysis of their implications locally and globally. [url 1]

Since geovisualization studies promotes all kinds of (map) graphics that stimulate visual thinking, the approach to GIScience as research on GIS would fit best. One tries to develop the visual methods and techniques (tools) to present, analyse, synthesize and explore geospatial data, but one is also interested it their effect on problem-solving (efficiency, effectiveness). In his book chapter, entitled 'Beyond tools: visual support for the entire process of GIScience', Gahegan (2005) addresses this particular problem. He described the GIScience process, and projected possible maps and graphics, as well as computational methods on each of the process steps. He writes: "To better support the entire science process, we must provide mechanisms that can visualize the connections between the various stages of analysis, and show how concepts relate to data, how models relate to concepts, and so forth" (Gahegan, 2005, p. 85).

Figure 2, based on Gahegan's ideas, is a simplified version of the process illustrated with the data behind Minard's map. The process contains the steps exploration, synthesis, analysis, evaluation and presentation, but not necessarily in a sequential order. Let's look at Napoleon's campaign and follow the process. In this example, the objective is to understand what happened during the campaign. The data available consist of statistics and maps

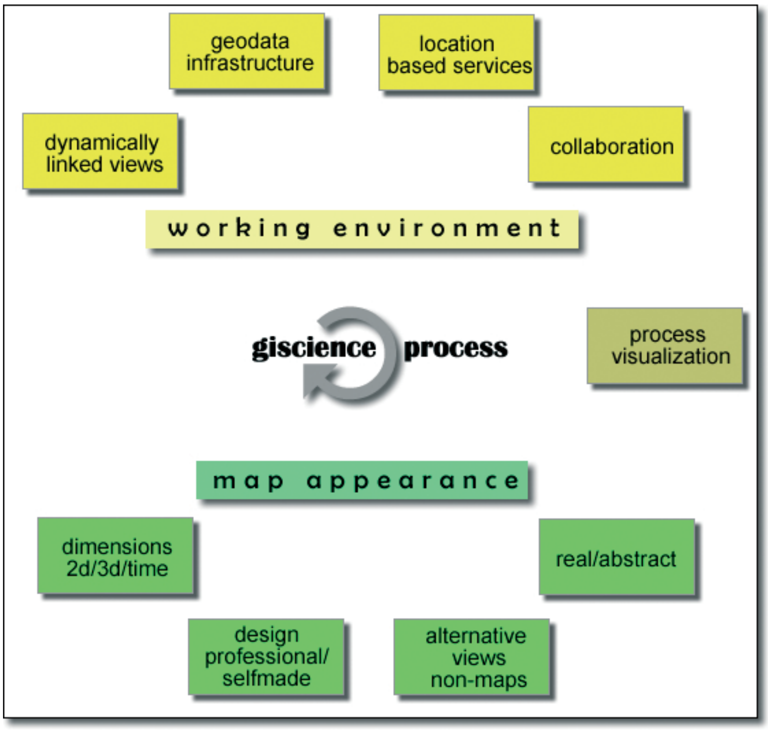

Figure 3. Maps, the GIscience process, and some developments and trends related to the environment maps are in use, as well as those related to the map appearance. In the diagram process visualization is given a separate position, which refers to the use of maps and graphics to illustrate the GIScience process and not the geodata themselves

derived from all kind of sources such as official French army documents, diaries of individuals, Russian reports and other references (Austin, 2000). In Figure 2, this is summarized by a few tables. To get insight into these data one has to explore the data, for instance via a parallel co-ordinate plot in which all variables, such as number of troops, temperature, battles, deaths and wounded are given. The geographical locations for which these facts are known are represented by ‘horizontal’ lines. At such a stage, one might formulate a hypothesis like: ‘Since Napoleon lost the campaign he probably lost most battles’. This could be checked via an iconic display, with for instance Chernoff faces to show who won the battles. Additional variables like number of troops involved, wounded, death, etc., could be expressed in the faces as well. Since he won most battles one will wonder why he lost the campaign and might be interested to view the relation between the loss of troops and factors such as weather and geography over time. Interactive visualization tools, such as SAGE (Roth *et al.*, 1994) could reveal interesting patterns. Alternatively, one could create time-cartograms to better understand the influence of geography on time. As a result of the analysis one can create time series to compare individual events or create a visual overlay of the data available. A three-dimensional model with different layers of information can display the relations between the different thematic layers. Before the final maps are drawn, one should evaluate the result via uncertainty visualization. This graphic could indicate the accuracy of both the location of the campaign path, as well as of the numbers of troops. In a last phase the findings are put in well-designed maps and diagrams. Minard’s map could be an example, but it could equally be an interactive space time cube.

For each of the individual steps particular visualization tools exist, often created with a specific domain dependent task in mind. However, there is no single software environment that can handle all. In a fully-fledged geo-visualization environment easy access to all required functionality should be available. Research in that direction is ongoing (MacEachren and Kraak, 2001). The approach described based on Figure 2 is just one possible view on the GIScience process and as Gahegan (2005) writes:

> The more we understand about how the researcher is trying to think and what they are attempting to produce, the better we can design suitable visualization tools that support their tasks. (Gahegan, 2005, p. 91)

It should also be clear by now that the notion of what a map is should be taken very liberally. As location is involved when solving geo-problems in a GIScience context, maps are indispensable, but the non-map view might be just as revealing or helpful. Sometimes maps will not be involved at all. If one, for instance, considers driving from A to B (a geo-problem) some solutions (particular car navigation systems) work without a maps and instruct the driver by voice where to go left or right. Personally, I cannot imagine that geographers would not need an additional map to put the trip in the geographical context. It is the strength of the combined graphics that support finding a (potential) solution.

In the next section some trends are sketched out that have a tremendous impact on the cartographic discipline. Figure 3 distinguishes between developments that are mainly related to the working environment and those that influence map appearance. Work environment-related developments include the on-screen multiple dynamically linked view, the geodata infrastructure and data portals (clearing houses), the possibility for visual collaboration and location-based services. Map appearance-related developments include the dimensionality of the map content, the design approach, the alternative views and the realistic maps views (virtual and augmented reality).

MAP APPEARANCE: DEVELOPMENTS AND TRENDS

Design and Content: Professional/Self-made

Paper maps and especially topographic maps, are designed and made by professionals. They are very useful under many different circumstances. In the future, maps like these will still be produced, but the demand from the user community is forcing traditional cartographic organizations to change their approach to the market. Users want digital geodata, to be able to process with it their own GIS software. One of the consequences is that to be able to offer the right services, national mapping agencies not only have to provide up-to-date digital data, they also have to step away from their century-long map sheet production thinking. This has a tremendous influence on how mapping organizations have to arrange their work processes, since today revisions are often linked to map sheet numbers and not to themes such as infrastructure, even though that type of data is in high demand for car navigation systems. For the GIScientist it is important that required data is available on demand, preferably via web mapping services. Based on the problem at hand scientists can use the data in their own software environment or can compile maps via the web services offered. In this process, content (map layers on or off), layout (colour and style of symbols) and the area of interest can be defined by the user. A potential disadvantage might be that there is no guarantee that the final map design adheres to cartographic rules because of the many options available. In the professional GIScience, environment this might be less problematic then in the consumer environment.

Dimensionality

In the past, restrictions in data collection, modelling and display techniques prevented the representation of the three-dimensional world around us as truly three-dimensional. This resulted in maps with a two-dimensional view of reality, which in most situations is sufficient. However, sometimes the availability of a three-dimensional world that can be queried, analysed and viewed would improve insight and is likely to result in better decisions. Examples are the multi-use of space in urban areas where complex planning problems have to be solved to avoid conflicts of interest. Three-dimensional displays require an interactive viewing environment that allows one to view the objects from any direction to avoid obstruction and allow query of all objects in the representation. In GIScience the analysis of terrain characteristics, the surface and subsurface features, etc., requires a true three-dimensional approach and many different viewing options (Döllner and Kersting, 2000). In other situations, a three-dimensional view of multiple attribute space can provide clarification as well (Lucieer and Kraak, 2004), but might not be enough since data collection with, for instance, hyperspectral sensors, may result in large multivariate datasets. These require even more advanced visualization techniques than, for instance, those applied in scientific visualization or information visualization. The inclusion of a temporal component will complicate the visualizations even further. Animations seem to be a good solution as long as the user has the ability to interact with this type of map representation (Acevedo and Masuoka, 1997).

Alternative Views

In understanding spatial patterns and relationships, the GIScientist has many different map types available to them, but despite that these are based on proven concepts it can be refreshing to view data from a different perspective. However, some of the interesting alternatives require complex computation and data handling, and are not available in off-the-self software. Examples of these maps are cartograms, schematic networks and three-dimensional models (Avelar, 2002; Keim, *et al.*, 2003; Krisp and Ahonen-Rainio, 2003). To be successful, these alternatives should be used in conjunction to the familiar map view. It should be remembered that the conceptual ideas behind many of these representations have often been developed during the fifties and sixties of the last century, but only today have they become operational in our GI-environment. With the tremendous increase in available data the use of maps alone is often no longer sufficient. Graphic techniques to reduce the dimensionality of the data, as they are common in information visualization are needed (Keim *et al.*, 2003, 2005). These graphics, such as parallel co-ordinate plots, scatter plots or even self-organizing maps should also be linked to the map view. The self-organizing map was originally designed as spatialization of non-geographical data, but can also be used as a view on attribute space in our GIScience environment (Skupin and Fabrikant, 2003).

Abstract or Real

An important characteristic of maps is the fact that they represent selections from reality in an abstract way. Especially for presentation purposes, maps that look 'empty' might even work better than maps with an overloaded view. In an exploratory mode, an overloaded map could be very representative for the topic being studied, and via interactive selection and filtering techniques the user can 'drill-down' to the information thought relevant (Shneiderman, 1998). The 'selection/abstraction' characteristic is not only challenged by exploration, but also by new viewing environments such as virtual and augmented reality (VR and AR) (Dykes *et al.*, 1999a; Unwin and Fisher, 2001; Sherman and Craig, 2002). These allow a different view on reality and, in addition, one can become completely absorbed in this 'reality'. VR and AR require realism in the imagery used, which can be obtained via state of the art data collection techniques, such as laser scanning and close range photogrammetry. Again, a combination of both the map world and the VR/AR world seem to be the best solution with the option to emphasize one of the two depending on the task at hand (Verbree *et al.*, 1999). For a navigation task, the map view might be more helpful, and to judge if a newly-designed building fits the building style of an old city centre, a realistic view will give a better impression.

WORKING ENVIRONMENT: DEVELOPMENTS AND TRENDS

Dynamically Multiple Linked Views

The argument that different alternative views of data will spark the mind and stimulate visual thinking (Peuquet and Kraak, 2002) should be supported by a suitable working environment. This leads to an environment of multiple views with different maps, diagrams, tables, etc., of the same and/or related data that are linked to each other. The strength of this combination of maps and other graphics is that user action in any of the views will result in highlighting the relevant objects in all the other views. Several of these more or less experimental exploratory environments exist. With roots in statistics (Haslett *et al.*, 1991), map-based examples also exist like CommonGIS (Andrienko and Andrienko, 1999) and Cartographic Data Visualizer (Dykes, 1997). Recently, a conference series with contributions of different perspectives has been established [url 8].

Geodata Infrastrucuture

Where to get all the data? The answer is the Internet and, for supply, the GIScientist can access a web portal or clearinghouse of a geospatial data infrastructure (GDI). Such portals are often a collection of metadata describing the geodata available based on which the user will decide the data's fitness for use. Metadata can be visualized in maps, diagrams or by browsing graphics to give the user additional information on content and quality (Ahonen-Rainio and Kraak, 2004). A GDI offers a set of institutional, technical and economical arrangements to enhance the availability (access and use) for correct, up-to-date, fit-for-purpose and integrated geo-information and geo-services, timely and at an affordable price to support decision making processes (Groot and McLaughlin, 2000). Maps will also play a role as part of the search mechanisms in portals. Not only can they be used to indicate the area of interest, but their role can be extended by linking the atlas concept to the portal use in a structured approach to create easy access (Aditya and Kraak, 2004). GDI developments also introduce new technology stimulated by the Open Geospatial Consortium. The introduction of concepts-related web mapping, the XML-based GML (Geographic Markup Language) and SVG (Scalable Vector Graphics), their style sheets, etc., result in a standardized approach to (web) mapping and geodata exchange.

Location-based Services

Human mobility has increased the demand for (geo)services (Gartner and Uhrliz, 2002). Although the paper map can be considered mobile, its content is not. The technology push of tablet PCs, PDAs, mobile phones and wireless networks has stimulated the demand. It is the opportunity to get fresh and up-to-date information anywhere at anytime that introduced the world of the so-called location-based services, using the web services of geospatial infrastructures and web portals. Examples could be information to get to the nearest bookshop or museum. A GIScientist is likely to by more interested in downloading data from the office while in the field to compare findings with the information already in the database (Dykes *et al.*, 1999b).

Collaboration

The magnitude of geo-problems to be solved, like in disaster management, as well as the large amount of data available, requires a multi- and interdisciplinary approach. This obviously means collaboration of one kind or the other. Via the Internet and wireless networks, it is possible to work on the same project with colleagues who are based on different continents. Experiments are conducted to realize this type of work (Wood *et al.*, 1997; MacEachren, 2000, 2005).

CONCLUSIONS

During the GIScience process, different maps and graphics have their role to play to assist the researcher in understanding the data and to support problem solving. In this process maps retain their traditional roles in enhancing insight in spatial patterns and relationships by symbolizing an abstraction of reality via a cartographic design process. Maps are flexible interfaces to geospatial data and offer interaction with the data behind the representation. Maps are instruments that encourage exploration, because they are there to stimulate thinking, to show the unexpected, to point to the outliers and to demonstrate trends.

Maps and graphics cannot do this alone. Different algorithms, models, and other methods and techniques are behind the images, for each of the phases in the GIScience process. In this paper, the impact of some developments and trends have been discussed without pretending to be complete. For instance, the whole field of (visual) data mining has not been discussed, but is an important component of the GIScience process. Maps do much more then just present geographical data. Maps cover the range from presentation all the way to exploration in a connected, dynamic and interactive environment. The keen interest in GIScience goes parallel with a revived interest in visualization in general and maps in particular. Maps do matter.

REFERENCES

Weblinks

url 1: map definitions http://www.usm.maine.edu/~maps/essays/andrews.htm

url 2: ICA maps http://www.icaci.org/en/strategic.html

url 3: John Snow Cholera Map of London http://www.ph.ucla.edu/epi/snow.html

url 4: Minard's Map of Napoleon in Russia http://www.itc.nl/personal/kraak/1812
url 5: Thiessen Polygon and Snow's Map http://www.ncgia.ucsb.edu/pubs/snow/snow.html
url 6: US Mortality Atlas http://www.cdc.gov/nchs/products/pubs/pubd/other/atlas/atlas.htm
url 7: Zorgatlas the Netherlands http://www.rivm.nl/vtv/data/site_atlas/
url 8: Coordinated & Multiple Views in Exploratory Visualization http://www.cvev.org/

Bibliography

Acevedo, W. and Masuoka, P. (1997). 'Time-series animation techniques for visualizing urban growth', **Computers & Geosciences**, 4, 423–436.

Aditya, T. and Kraak, M. J. (2004). **A National Atlas Metaphor in the Access to the GDI**, in GSDI7. Bangalore, India, p. 83.

Ahonen-Rainio, P. and Kraak, M. J. (2004). 'Towards multivariate visualization of metadata describing geographic information', in **Exploring Geovisualization**, ed. by Dykes, J., MacEachren, A. M. and Kraak, M. J., pp. 611–626, Elsevier, Amsterdam.

Andrienko, G. L. and Andrienko, N. V. (1999). 'Interactive Maps for Visual Data Exploration', **International Journal of Geographic Information Science**, 4, 355–374.

Austin, P. B. (2000). **1812**, Greenhill, London.

Avelar, S. (2002). Schematic Maps on Demand—Design, Modeling and Visualization, Diss. ETH no. 14700, ETH, Zuerich.

Bertin, J. (1967). **Semiology Graphique**, Mouton, Den Haag.

Brody, H., Rip, M. R., Vinten-Johansen, P., Paneth, N. and Rachman, R. (2000). 'Map-making and myth-making in Broad Street: the London cholera epidemic, 1854', **Lancet**, 356, 64–68.

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

Chen, C. (2003). Mapping Scientific Frontiers—the Quest for Knowledge Visualization, Springer Verlag, London.

Döllner, J. and Kersting, O. (2000). 'Dynamic 3D maps as interfaces to spatio-temporal data', **Proceedings of ACM GIS 2000**, pp. 115–120.

Duckham, M., Goodchild, M. and Worboys, M. (2003). **Foundations of Geographic Information Science**, Taylor & Francis, London.

Dykes, J., MacEachren, A. M. and Kraak, M. J. (2005). **Exploring geovisualization**, Elsevier, Amsterdam.

Dykes, J., Moore, K. and Fairbairn, D. (1999a). 'From Chernhoff to Imhof and beyond: VRML and cartography', in **VRML '99, Proceedings of the Fourth ACM SIGGRAPH Symposium on the Virtual Reality Modeling Language**, pp. 99–104, Paderborn, Germany.

Dykes, J. A. (1997). 'Exploring spatial data representation with dynamic graphics', **Computers & Geosciences**, 4, pp. 345–370.

Dykes, J. A., Moore, K. E. and Wood, J. D. (1999b). 'Virtual environments for student fieldwork using networked components', **International Journal of Geographical Information Science**, 4, pp. 397–416.

Frerichs, R. R. (2001). 'History, maps and the Internet: UCLA's John Snow site', **SoC Bulletin**, 2, 3–7.

Friendly, M. (2000). 'Re-visions of Minard', **Statistical Computing and Graphics Newsletter, 1**.

Gahegan, M. (2005). 'Beyond tools: visual support fot the entire process of GIScience', in **Exploring Geovisualization**, ed. by Dykes, J., MacEachren, A. M. and Kraak, M. J., pp. 83–99, Elsevier, Amsterdam.

Gartner, G. and Uhrliz, S. (2002). 'Maps, multimedia and the mobile Internet', **Geowissenschaftliche Mitteilungen (Technische Universitat Wien)**, 143–150.

Goodchild, M. (1992). 'Geographical Information Science', **International Journal of Geographic Information Systems**, 1, 31–45.

Groot, D. and McLaughlin, J. (2000). 'Geospatial data infrastructure—concepts, cases, and good practice', **Spatial Information Systems**, Oxford University Press, Oxford.

Haslett, J., Bradley, R., Craig, P., Unwin, A. and Wills, G. (1991). 'Dynamic graphics for exploring spatial data with application to locating global and local anomalies', **American Statistician**, 3, 234–242.

Keim, D. A., North, S. C., Panse, C. and Schneidewind, J. (2003). 'Visualizing geographic information—visual points vs. cartodraw', **Information Visualization**, 2, 58–67.

Keim, D. A., Panse, C. and Sips, M. (2005). 'Information visualization: scope, techniques and opportunities for geovisualization', in **Exploring Geovisualization**, ed. by Dykes, J., MacEachren, A. M. and Kraak, M. J., pp. 23–52, Elsevier, Amsterdam.

Kraak, M. J. (2003). 'Geovisualization illustrated', **ISPRS Journal of Photogrammetry and Remote Sensing**, 1, pp. 1–10.

Kraak, M. J. and Ormeling, F. J. (2002). **Cartography, Visualization of Geospatial Data**, 2nd edn, Prentice Hall, London.

Krisp, J. M. and Ahonen-Rainio, P. (2003). 'Combining real and virtual components for visualizing ecological barriers', in **Proceedings 21st International Cartographic Conference**, Durban South Africa.

Longley, P., Goodchild, M., Maguire, D. M. and Rhind, D. (1999). **Geographical Information Systems: Principles, Techniques, Management, and Applications**, J. Wiley and Sons, New York.

Longley, P. A., Goodchild, M. F., Maguire, D. J. and Rhind, D. W. (2001). **Geographic Information Systems and Science**, Wiley, Chichester.

Lucieer, A. and Kraak, M. J. (2004). 'Alpha-shapes for visualizing irregular shaped class clusters in 3d feature space for classification of remotely sensed imagery', in **Proceedings of SPIE-IS&T Electronic Imaging, SPIE and IS&T. Conference: Visualization and Data Analysis 2004**, 5295, pp. 201–211, San Jose, USA.

MacEachren, A. M. (1994). **Some Truth with Maps: a Primer on Design and Symbolization**, Association of American Geographers, Washington DC.

MacEachren, A. M. (2000). 'Cartography and GIS: facilitating collaboration', **Progress in Human Geography**, 3, 445–456.

MacEachren, A. M. (2005). 'Moving geovisualization toward support for group work', in **Exploring Geovisualization**, 445–462, Elsevier, Amsterdam.

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

Mark, D. M. (2003). 'Geographic Information Science: defining the field', in **Foundations of Geographic Information Science**, ed. by Duckham, M., Goodchild, M. and Worboys, M., pp. 3–18, Taylor & Francis, London.

McLeod, K. S. (2000). 'Our sense of Snow: the myth of John Snow in medical geography', **Social Science & Medicine**, 7–8, 923–935.

Monmonier, M. (1991). **How to Lie with Maps**, Chicago University Press, Chicago.

Peterson, M. P. (2003). **Maps and the Internet**, Elsevier, Amsterdam.

Peuquet, D. J. and Kraak, M. J. (2002). 'Geobrowsing: creative thinking and knowledge discovery using geographic visualization', **Information Visualization**, 1, 80–91.

Pickles, J. (2003). **A History of Spaces: Cartographic Reason, Mapping, and the Geo-Coded World (Frontiers of Human Geography)**, Routledge, London.

Robinson, A. H. (1967). 'The thematic maps of Charles Joseph Minard', **Imago Mundi**, 95–108.

Robinson, A. H., Morrison, J. L., Muehrcke, P. C. , Kimerling, A. J. and Guptill, S. C. (1995). **Elements of Cartography**, J. Wiley and Sons, New York.

Roth, S. F., Chuah, M. C., Kerpedjiev, S., Kolojejchick, J. A. and Lucas, P. (1997). 'Towards an Information Visualization Workspace: Combining Multiple Means of Expression', **Human-Computer Interaction Journal**, 1–2, 131–185.

Roth, S. F., Kolojejchick, J., Mattis, J. and Goldstein, J. (1994). 'Interactive graphic design using automatic presentation knowledge', in **Proceedings of the Conference on Human Factors in Computing Systems (SIGCHI '94)**, Boston, MA, pp. 112–117.

Sherman, W. B. and Craig, A. B. (2002). **Understanding Virtual Reality—Interface, Application, and Design**, Morgan Kaufmann Publishers, San Francisco.

Shneiderman, B. (1998). **Designing the User Interface—Strategies for Effective Human–Computer Interaction**, Addison-Wesley Publishing Company, Reading.

Skupin, A. and Fabrikant, S. I. (2003). 'Spatialization methods: a cartographic research agenda for non-geographic information visualization', **Cartography and Geographic Information Science**, 2, 95–119.

Slocum, T. A. (1998). **Thematic Cartography and Visualization**, Prentice Hall, Englewood Cliffs, NJ.
Spence, R. (2001). **Information Visualization**, Addison Wesley/ ACM Press Books, Harlow.
Tufte, E. R. (1983). **The Visual Display of Quantitative Information**, Graphics Press, Cheshire, Conn.
Tufte, E. R. (1997). **Visual Explanations**, Graphics Press, Cheshire, Conn.
Unwin, D. and Fisher, P. F. (2001). **Virtual Reality in Geography**, Taylor & Francis, London.
Verbree, E, Maren, G. van, Gems, R., Jansen, F., and Kraak, M. J. (1999). 'Interaction in virtual world views—linking 3D GIS with VR', **International Journal of Geographical Information Science**, 4, 385–396.
Wilkinson, L. (1999). **The Grammar of Graphics**, Springer, New York.
Wood, D. (1992). **The Power of Maps**, Routledge, London.
Wood, J.D., Wright, H. and Brodlie, K. W. (1997). 'Collaborative visualization, in **IEEE Visualization 97 Conference**, pp. 253–259.