Mapping, Web

BJ Köbben and Menno-Jan Kraak, Department of Geoinformation Processing, Faculty of Geoinformation Science and Earth Observation, University of Twente, Enschede, The Netherlands

This article is a revision of the previous edition article by M.-J. Kraak, volume 5, pp 562–568, © 2009 Elsevier Ltd.

Glossary

Cartography The art, science, and technology of making and using maps.

Geodata Infrastructure (GDI) Geospatial data infrastructure encompasses the networked geospatial databases and data-handling facilities and the complex of institutional, organizational, technological, human, and economic resources, which interact with one another and underpin the design, implementation, and maintenance of mechanisms, facilitating the sharing, access to, and responsible use of geospatial data at an affordable cost for a specific application domain or enterprise.

Map A symbolized 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.

Web Map A map presented in a Web browser.

The environment in which maps have been produced and used has changed considerably. During the last decades, cartographers, geoscientists, and computer scientists have witnessed highly dynamic and important developments in the fields of acquiring, managing, analyzing, interacting with, and visualizing large amounts of geospatial data. Especially, the field of visualization has undergone a rapid change. Next to static maps, nowadays, immersive and highly interactive virtual environments can be used to explore and present dynamic geospatial data. The World Wide Web is today's prominent medium to disseminate geospatial data and maps. In the past, producing maps was the realm of cartographers. Their skills and laborious activities were a guarantee that authoritative maps were produced. The rise of geographic information systems (GISs) has increased the number of those involved in making maps. Today's revolution in mobile mapping (Cross-reference here) has even further increased the number of people involved in making maps. GIS tools have become more accessible, with open-source alternatives to the traditional commercial software, such as the QGIS desktop software. Making maps via such powerful but complicated tools still is mostly the realm of geoprofessionals; however, making maps via the Web is available to potentially everyone. These new mapmakers have different demands and have forced a change from a traditional supply-driven map production to demand-driven map production. Irrespective of these changes, it is still about maps, which remain the valuable products they used to be.

Web Technology and Maps

The Internet has its origins in the United States Advanced Research Projects Agency Network, a military-funded communication network, which was set up in 1969 to allow the collaboration between distinct computer systems at different locations. Several such networks grew separately over the next decades, until in 1983, most existing networks adopted the then-new communication protocol TCP/IP. This moment can be seen as the birth of the Internet because from then on, all computers in the world can be considered part of one network. The layered structure of TCP/IP allowed other standard protocols like File Transfer Protocol for file transfer, TelNet for terminal services, and SMTP for email to be incorporated. Then in 1993, the hypertext transfer protocol and hypertext markup language (HTML) standards were devised by Tim Berners-Lee at the European Organization for Nuclear Research. The network of linked documents, pictures, videos, and other information sources that these standards enabled is what we call the World Wide Web (nowadays usually just "the Web"). One has to realize that the Web is running on the Internet, and as such is only a part of it, albeit by now the biggest and arguably the most important part.

The so-called *client–server architecture* is the key to how users are able to retrieve information on the Web and therefore also display a map on their screen. Via a Web *client* (the browser), one can send a request to a Web *server*, which will respond by returning the requested item to the browser. In the simplest setup this item is a file that contains the image of a map. Thus, initially, maps presented on the Web were raster-based, static pictures. They had a fixed resolution and would not allow for much interactivity. Common file formats were Graphics Interchange Format, Joint Photographic Experts Group, and somewhat later Portable Network Graphics.

Offering more control over the map to the user makes the client–server structure more complex and leads to so-called *distributed systems*. A distributed approach puts demands on the individual components that have to work together. Technology to be used should allow the interoperability of heterogeneous components. Where the World Wide Web Consortium (W3C) sets interoperability standards for the Web in general, the Open Geospatial Consortium (OGC) has set up a set of specifications to make this work in the geoworld. It should be obvious that such standardization is important, and the OGC has defined specifications for, among others, Web map services (for portrayal of maps), Web coverage services (an interface to raster data), and Web feature service (interface to vector data).

The visualization of the geographic data delivered through said services is no longer limited to static imagery. This is because the Web browser, the software through which we navigate and view the contents of the Web, is no longer just a simple page renderer, it serves as an *application framework*, and is growing into the hub of our computer use—and is pretty good at it! That is made possible because of what W3C has called the *Open Web Platform*: the range of advanced specifications enabling the creation of standards-compliant Web applications (http://www.w3.org/wiki/Open_Web_Platform). In practice, this boils down to a modern standard (*HTML5*) for encoding of Web pages, combined with standards for styling and layout (*CSS3*), and for resolution-independent graphics (the Scalable Vector Graphics [SVG]). SVG is an XML-based language for 2D vector graphics. It allows also for interactivity, such as zoom and pan, for various animated transformations, as well as dynamic change of object attributes. And the last element is a powerful scripting environment (Javascript) that enables interactivity and business logic. Improvements of Javascript in the last decade have been impressive: of the language itself, and especially of its performance and support for features such as local storage, data exchange (through the JSON data grammar), and asynchronous data handling. Modern browsers offer hitherto impossible graphics performance because of adoption of *WebGL*, the JavaScript API for rendering interactive 2D and 3D graphics using the hardware acceleration available in modern computer's Graphics Processing Units.

There are many frameworks and libraries that use the power of the Open Web Platform and simplify the building of interactive maps in modern browsers: from low-level ones for programming data-driven visualizations (e.g., D3.js), through specialized libraries for easy creation of viewers for existing map services (such as OpenLayers), to high-level declarative languages for simple creation of graphs and maps (such as the visualization grammar Vega). Because all the elements mentioned use the same common technology platform, it becomes relatively simple to mix and match available building blocks to build mapping applications. We no longer need to have maps readymade as static pictures; they just become visual output that is created on-the-fly from the underlying databases, their layout and design dependent on the user's preferences or inputs. An example of such a visualization pipeline is shown in Fig. 1.

There are many variations to this kind of visualization pipeline. They basically all follow the same flow of various data inputs (direct from the user and/or from online sources) that get transformed into graphic objects in the browser. It is a very flexible setup that allows customization for each map requested. But as one can imagine, it would not be very efficient for services that get lots of requests for the same or very similar maps. For such services, for example, Google Maps or National Mapping Agency services, usually a visualization pipeline is used that creates map output beforehand. The maps are thus prerendered, usually in a *tiled* setup, that is, a large extent is mapped in small regular subdivisions, at various preset scales, and stored in an indexed data structure, ready to be sent upon request. Nowadays, these map tiles can be in raster format, in vector, and often are a mix of both, to be as versatile as possible.

Web Maps and the Geodata Infrastructure

To realize the availability of maps over the Internet, not only the technology as described in the first section should be available, but the infrastructure to disseminate and access the maps, and their data should be available too. A flexible approach is required because more and more data are available from different sources and ever more users, experts as well as laymen, are using the data; the Web has become the predominant working environment and dissemination channel for geodata. Many commercial and institutional data providers are offering their maps and data via the Web, often through so-called clearinghouses, where users can search for, view maps of, and get access to the data. This access has been facilitated by geodata infrastructures (GDIs). These encompass the networked geospatial databases and data-handling facilities, the complex of institutional, organizational, technological, human, and economic resources, which interact with one another and underpin the design, implementation, and maintenance of mechanisms facilitating the sharing, access to, and responsible use of geospatial data at an affordable cost for a specific application domain or enterprise.

The wide availability of geodata in these open and standardized services, combined with the power of the browser technology described earlier, has made Web mapping accessible to virtually anyone. This started in the early 2000s with tech-savvy people creating so-called "mashups." By creatively combining the then available mapping services (Google Maps predominantly, and a little later OpenStreetMap) with user data, one could, for example, show one's hiking tours captured with a GPS in a Web map for all your friends to see. Fig. 2 shows a sophisticated modern example of what essentially still is a mashup. Inspired by a wind map of the United States, Cameron Beccario built an interactive Web application that lets you spin and project the globe and overlay it with mesmerizing animated patterns of the wind predictions. It uses all the power of modern browser technology mentioned before, combined with data from supercomputer-generated weather and climate predictions that are made available as open data in GDIs.

The creation of such Web maps is technically challenging. But in the years between the first examples popping up and the present, software and service vendors have recognized their potential and have created countless utilities and platforms that facilitate their creation using simple Web interfaces. This is not exclusive to the domain of mapping of course but part of the much larger development of the Web turning into a mass information sharing platform. Cloud services such as Mapbox.com, Carto.com, and Kepler.gl are but a few of the mapping platforms that are active at the time of writing. Such platforms enable you to create fully interactive, data-driven maps with customized styling, simply by point-and-click methods, combining your own data with base map services and other data from GDIs.

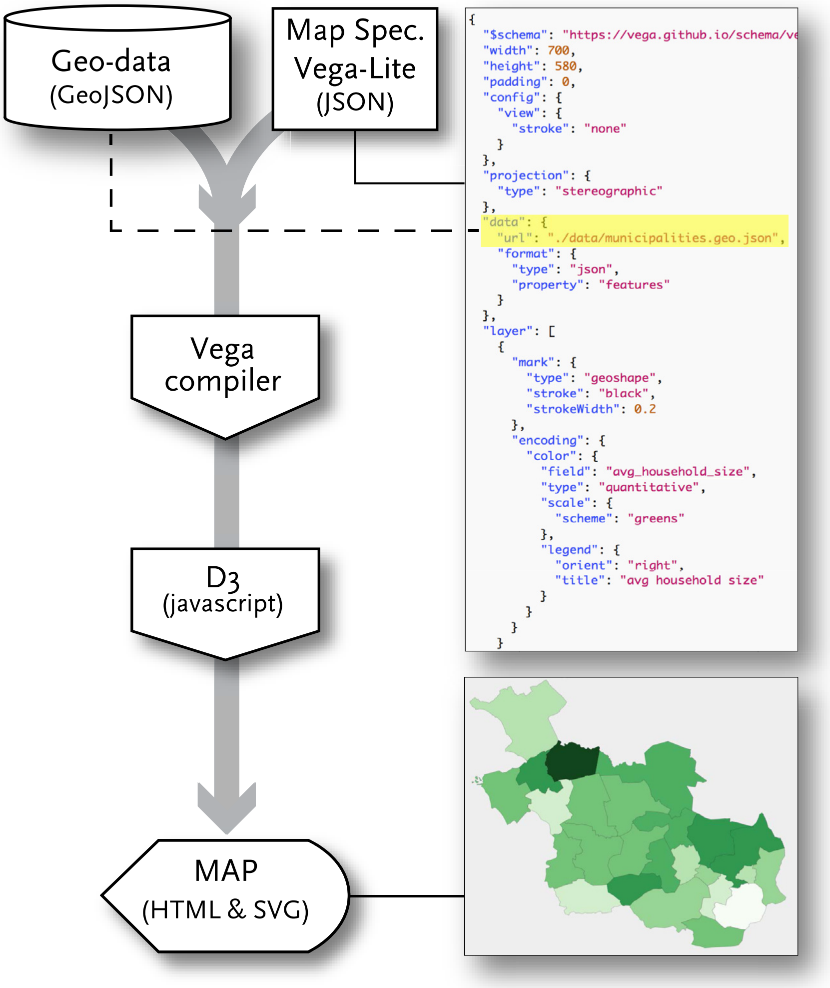

Figure 1 An example of a visualization pipeline for the Web using Vega-Lite specification grammar and GeoJSON data to create a thematic map. A map specification is stored in the declarative grammar called Vega-Lite (see https://vega.github.io/vega-lite). This is a simple text file using JavaScript Object Notation (JSON) syntax to describe the desired outcome by specifying how the data should be encoded graphically using symbols, sizes, colors, and so forth. In this example the data are loaded from an external file from the Web, specified by the URL in the highlighted section. The data are stored as GeoJSON (see https://geojson.org), another standardized JSON syntax, for storing vector geodata using geographic coordinates and attributes. The two datasets are interpreted by the Vega Compiler and transformed into JavaScript code using the D3.js library (see https://d3js.org). This code, in turn, is run by the Web browser, which creates anHTML5 page with SVG graphic objects that is shown as a thematic map in the browser window.

The Role of Web Maps

Maps on the Web can play different roles. Of course, they will still function in their traditional role: They will present a message by showing geospatial patterns and will increase insight into geospatial relations. But in Web-based mapping applications environments, one can store a wealth of data “behind” the map, much more than on a traditional paper map. Linking external elements to the map can enrich them even more, especially on the Web with its unlimited linking options. This allows the use of maps for more than simple communication of data or findings but instead offer a more explorative experience where users can start finding patterns themselves in the available data. Or we can combine several maps with animations, graphs and running text to explain complex interrelated phenomena, in what recently became known as “story maps,” which are, for instance, embedded in online newspapers.

Why is the Web an interesting medium to present and disseminate maps and/or the data behind those maps? The answer is that information on the Web is virtually platform independent. Also, many users can be reached at minimal costs, and it is easy to update the maps frequently. And because the Web has become a collaborative environment, the users can share data as well as visualizations among themselves, and they have become what some have called “prosumers,” a combination of map producers and consumers. An excellent example of this is the OpenStreetMap Project, based at https://openstreetmap.org. This worldwide mapping effort passed the1 million contributors mark in 2018. It is an initiative to create and provide free geographic data to

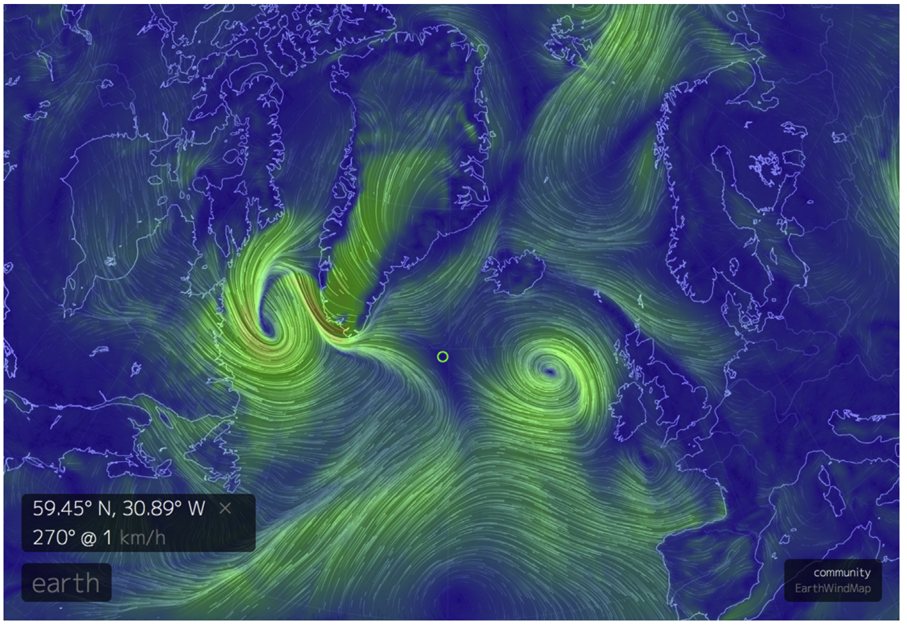

Figure 2 Detail from a global wind pattern map created using Cameron Beccario's Web application (available at https://earth.nullschool.net). The wind speed at the location of the yellow circle in the center of the map is shown at the lower left. The user can zoom and manipulate the globe and map a plethora of other open weather and climate data.

anyone, by anyone: you can download the actual vector and attribute data of OSM and use it for your own projects free of charge, and you can also create and edit the data directly and in this way contribute to the building of OSM itself. It is the foundation under many online mapping applications and a major open-source alternative to commercial services such as Bing and Google Maps.

Design of Maps for the Web

What makes Web maps different? Designing maps for the Web is in essence no different from traditional map design. That is, while producing the map, one will apply the cartographic design guidelines considering the nature of the data to be represented, as well as the message the map should tell. Normally, one would include audience in the previous sentence as well; however, for maps presented on the Web, the audience is very much unknown. Even though one might aim at a particular user community, one will never be sure of who is looking at the maps. In some cases, the geospatial data provider will not even be sure on how their maps look at all, which might be partly due to the user's Web browser environment but can also be due to interaction and symbolization options given to the user. The map's information density should, in general, be low because a typical user surfing the Web has a relatively short span of attention.

All this may look disadvantageous, but the Web technology offers plenty of possibilities to still produce well-designed maps. One can put all kinds of additional information "behind" the map image and click objects can make this (additional) information accessible. These techniques can also be used for map text. Whereas presenting large amounts of place-names in an on-screen map is rather problematic in terms of visibility and legibility, this can be solved by, for example, showing the name of a town only when the user moves the pointer over it.

Mouse-over techniques can also be used to highlight geographic objects based on user interaction. The basic map could be viewed in pastel tints while moving the mouse around will present the object under the pointer in bright colors. Design techniques in relation to clarity (crispness of the symbol's appearance) and transparency can be applied. In summary, all these "special effects" can not only just be used to make the maps attractive but also to provide additional information or help in navigating the Web map and can function even as a map legend.

How to design or produce the Web map will depend on the provider's aims. The possibilities offered by the Web have extended the traditional cartographic variables. Web design software enables the application of new variables, like blur, focus, and transparency, while shadow and shading play a prominent role as well. Blur gives symbols a fuzzy appearance and can, for instance, be applied to visualize uncertainty, while focus can introduce blinking symbols to attract attention. Both transparency and shading/shadow can be used to simulate a 3D look. Transparency can be used as a kind of fogginess, by which part of map content is obscured or faded in favor of other information. For example, it can be applied to subdue the background in a map to enhance the main theme in the foreground (for instance, a drape of geology over terrain features). In a 3D "landscape" environment it can also be used as a depth cue. The use of shadow and shading increase the sense of depth. Shading is commonly used to increase the contrast between "figure" and "ground" or, for instance, in relief maps to create a 3D terrain impression. Shadow, also known as cast or drop shadow, can be applied to give symbols a 3D look. In Web maps, this 3D feel of the symbols invites users to click on

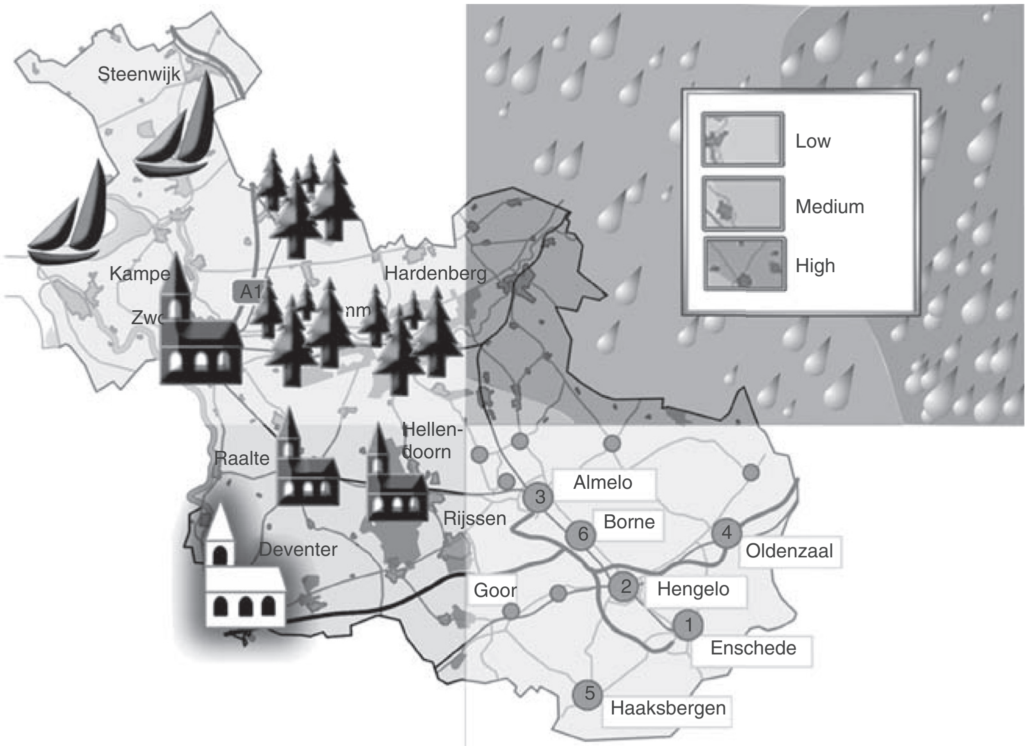

Figure 3 New graphic variables: shadow/shading (A); blur (B); transparency (C); and blinking/focus (D). From Kraak, M. and Ormeling, (F*) (2010). Cartography: visualization of geospatial data. Pearson Education, Harlow, third edition, ISBN: 978-0-273-72279-3.*

them to activate hyperlinks or mouse-over effects. The visual effect of shadow is casting a shadow of the symbol on to the background. On overview is given in Fig. 3.

The new variables have been fully accepted in cartography; however, further research effectively remains to be done because as with all technological progress, it remains important to carefully check if and how such new representations and interfaces work.

Conclusion

An important advantage of the Web is that the geospatial data and maps can be easily reused for different purposes. Somehow, the same data are offered by different Web map services to both professional and public user groups, resulting, for instance, in road datasets created by national mapping agencies being enriched by commercial vendors who offer the data to the public via online route planners, and tapping into drives mobile phones allows for real-time traffic integrating in the car navigation systems. Today's picture shows a complete merger of both professional and public mapping worlds. External (technological) influences will keep dictating the future appearance of the map, as has been the case in the past.

See Also: Map Interactivity.

Further Reading

Kraak, M.-J., Ormeling, F.J., 2010. Cartography: Visualization of Geospatial Data, third ed. Pearson Education, Harlow, ISBN 978-0-273-72279-3.
Muehlenhaus, I., 2013. Web Cartography: Map Design for Interactive and Mobile Devices. CRC Press, Boca Raton.
Peterson, M.M., 2014. Mapping in the Cloud. The Guilford Press, New York.

Relevant Websites

https://openstreetmap.org OpenStreetMap.
www.opengeospatial.org Open Geospatial Consortium.