Revisiting Web Cartography in the United States: the Rise of User-Centered Design

Ming-Hsiang Tsou

Abstract This paper reviews the recent development of web cartography based on Plewe's 2007 short paper in the U.S. National Report to the ICA, titled *Web Cartography in the United States*. By identifying major changes and recent research trends in web cartography, this paper provides an overview about what the web means to cartography, and suggests two major research directions for web cartography in the future: 1) the rise of user-centered design, including design of user interfaces, dynamic map content and mapping functions; 2) the release of the power of map-making to the public and amateur cartographers. I also present web cartography concepts in this paper to challenge the traditional research agenda in cartography.

Keywords: web cartography, user-centered design, neocartographer

Introduction
Redefining Web Cartography

The hybrid or the meeting of two media is a moment of truth and revelation from which new form is born... the moment of the meeting of media is a moment of freedom and release from the ordinary trance and numbness imposed by them on our senses (McLuhan 1964, p. 80). The web is the new medium of maps, changing cartographic representation from paper and desktop GIS to distributed, user-centered, mobile, and real-time geospatial information services. Web cartography is a new frontier in cartographic research transforming the design principles of map-making and the scope of map use.

Following the argument made by Plewe's 2007 paper, the recent development of web cartography research "has not been nearly as dynamic as the commercial sector" (Plewe 2007, p. 135). In the United States, only a few cartographers focus on web mapping research topics, such as web mapping protocols and standards, map application programming interfaces (APIs), mashups, performance and usability, and user-generated map contents. Many cartographers view web mapping as a technical solution rather than an academic research topic. Web cartography plays a less significant role in academics compared to other topics such as visualization, generalization, and thematic map design. For example, the ten major keywords identified by the International Cartographic Association (ICA) for the 2005 ICA brainstorming sessions did not highlight any major web mapping research topics. There is only a tiny paragraph that mentions web mapping in the ICA report (Virrantaus et al. 2009).

Most cartographers would agree that web maps are becoming more and more important in our daily lives and scientific research. The disconnect between the relatively few academic research projects in web cartography and the great popularity of web maps may be explained by the slowness of academia and the rapid changes of web technology. Web cartography has also yet to be defined in the context of "transformative" research, which "involves ideas, discoveries, or tools that radically change our understanding of an important existing scientific or engineering concept or educational practice

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or leads to the creation of a new paradigm or field of science, engineering, or education." (NSF 2007). Here, I propose to elevate and redefine web cartography in order to highlight its potential for transformative research.

Peterson (1997) identified two important categories of web cartography research: Internet map use (such as map types, various users, and the numbers of maps created) and Internet map-making (including web graphic design, file format, printing, map scale, and maps on demand). "The Internet has made possible both new forms of maps and different ways of using them and, perhaps, has created a new category of map user" (Peterson 1997, p.9). Crampton (1999) focused on user defined mapping, and defined online mapping as "the suite of tools, methods, and approaches to using, producing, and analyzing maps via the Internet, especially the World Wide Web, characterized by distributed, private, on demand, and user defined mapping." (p. 292). Both Crampton and Peterson highlighted the important role of map users in web cartography. Peterson's description emphasized the emergence of new web-based users who are quite different from traditional map users. Crampton further described the new characteristics of web map users who are granted more power and control in web mapping.

In the early development of web cartography, many researchers used various terms to describe similar concepts, such as online mapping (Crampton 1999), Internet mapping (Tsou 2003), web mapping (Haklay et al. 2008), and cybercartography (Taylor 2005). Kraak and Brown's edited book Web Cartography (2001) benchmarked web cartography research at that time. Peterson's two books, Maps and the Internet (2003) and International Perspectives on Maps and the Internet (2008) cover key research in web mapping, including user-centered design (Tsou and Curran 2008), web cartographic theories (Monmonier 2008), cartographic education (Giordano and Wisniewski 2008), and map usability and evaluation (Wachowicz et al. 2008).

This article redefines web cartography as *the study of cartographic representation using the web as the medium, with an emphasis on user-centered design (including user interfaces, dynamic map contents, and mapping functions), user-generated content, and ubiquitous access*. This new definition emphasizes two important research directions for web cartography:

1. The rise in importance of user-centered design (UCD), including the designs of user interfaces, dynamic map content and mapping functions.
2. Releasing the power of map-making to the public and amateur cartographers.

For this definition, the "web" refers to the connected Internet and its broader network-based applications. The meaning of web in this paper is different from the technical definition of the World Wide Web, which is built upon the Hypertext Transfer Protocol (HTTP). The study of web cartography should not be limited to web browser applications only. For example, Google Earth and NASA World Wind can be used to create cartographic representations in the form of digital globe without web browsers. The following sections will start with an overview of web technology development and then discuss the two research trends in web cartography by highlighting related cartographic research projects in the U.S. and their contributors.

An Evolution in Web Mapping Technology, a Revolution in Web Map Design

Plewe (2007) identified four 'generations' of web mapping technologies. The first was based on HTML and Common Gateway Interfaces (CGI). The second was developed by applets and component-oriented web tools (Peng and Tsou 2003). The third generation included mashups, asynchronous JavaScript and XML (AJAX), and API-enabled mapping applications. The fourth generation came with the invention of Google Earth (and other digital globes, such as NASA World Wind and Microsoft Virtual Earth), which created an immersive mapping environment for users. From a technological progress perspective, these changes in computer science and web technology were an evolutionary process rather than a technology revolution. The evolution of web mapping technology continues today. The fifth generation of web maps is built on cloud computing, rich internet applications (RIA), and crowdsourcing. The following is a short summary of the three key technologies for the new generation of web maps.

Cloud computing: delivers applications, software, and infrastructures as services to many users from distributed data centers over the Internet (Buyya et al. 2009). Users can directly use web-based software (such as Google Docs, Gmails, and ESRI ArcGIS Explorer online), instead of downloading and installing desktop software on their local computers. Programmers and application developers can also use cloud computing to create virtual servers and on-line computing platforms (such as Amazon's EC2 platform and FGDC's Geospatial Platform) for their web applications rather than maintaining expensive local web servers and hardware equipments for their projects .

Rich internet applications: refer to a set of web programming methods for producing interactive asynchronous web applications (Farrell and Nezlek 2007). RIA can provide very user-friendly, high performance, and responsive web applications with powerful user interface gadgets and tools (Kay 2009). Some popular RIA methods include Adobe FLEX, Microsoft Silverlight, and Java Scripts.

Crowdsourcing: is a new approach for generating data or reporting information by amateurs, volunteers, hobbyists, or part-timers (Howe 2006). A large group of people without professional cartographic training can create and share their own maps and geospatial data online. Volunteers can contribute their local knowledge and efforts to collect mapping information by using GPS, mobile sensors, and web mapping tools, such as OpenStreetMap project (Goodchild 2007; Haklay and Weber 2008).

The evolution of web mapping technologies could lead to a revolution of web map designs. In this article, web map designs refer to the integrated design plans for creating effective map user interfaces with dynamic map contents, and mapping functions. Powerful web platforms (RIA and cloud computing) can lead to the creation of innovative map user interfaces. Diversified web user tasks (such as navigation, location-based services, housing and renting, etc.) require unique designs of dynamic map contents (map displays) and mapping functions in order to satisfy different user needs.

Similar to the impacts of Web 2.0 to our society (Batty et al. 2010), web maps have changed the context of cartographic representation; from traditional thematic mapping on paper or desktop computers to user-centered map applications on various mobile devices, virtual globes, and web browsers. Several cartographic studies have highlighted this new design direction with the creation of neologisms, such as maps 2.0 (Crampton 2009), GIS/2 (Miller 2006), neogeography (Turner 2006), and neocartographers (Lui and Palen 2010). These commentaries illustrate the needs for creation of new web map designs to cope with these dynamic changes.

The first wave of the web map design revolution may be observed in 2005, when Google released its two popular mapping services, Google Maps and Google Earth. Miller describes this revolution as new form of GIS, called "GIS/2", enabling the creation of more dynamic and "socially mutable" (changeable and sometime contradictory) geospatial information (Miller 2006), accommodating "an equitable representation of diverse views, preserving contradiction, inconsistencies, and disputes against premature resolution." (p. 196). A related term, "Maps 2.0," was used by Crampton to describe "the explosion of new spatial media on the web, the means of production of knowledge are in the hands of the public rather than accredited and trained professionals" (p. 92). Harris and Hazen (2006) both caution and celebrate that the use of crowdsourced geospatial data by the public in mapmaking may cause counter-mapping and counter-knowledge. One key factor that led to the first wave of web map design revolution was the dramatic improvement in web mapping performance with the adoption of tile-based mapping engines and AJAX technologies (Tsou 2005)., which improve client/server communication response time significantly and generate multi-scale map graphics rapidly. Tile-based mapping engines also improve the performance of web maps by storing a set of pyramidal image layers at different map scales inside web map servers. AJAX and image tiling have existed for a while, but the combination of the two technologies was not seen until 2005. Google maps and Maps.search.ch and are two early examples of web GIS applications using both AJAX and image tiling techniques (Tsou 2005).

The second wave of the web map design revolution is the development of mobile mapping on smart phones, tablet PCs, and GPS devices recently. The popularity of smart phones (such as iPhones, Androids, and Blackberrys) and mobile devices (iPads and tablet PCs) is forcing new map user interface designs (using fingers or voice commands as input devices), new mapping functions (tracking friends, navigation, comparing housing values, etc.) and new map content (GPS tracks, messages in social networks, volunteered geographic information, etc.). Apple's iPad devices have several good examples of new web map designs showing innovative web map user interfaces with unique mapping functions and useful map content. The portability, friendly multi-touch screen inputs, and the large screen display, along with its internal locational awareness, make Apple's iPads, and similar tablet devices, a perfect match for innovative web map design. Hundreds of web mapping apps have already been developed for iPads, such as Urbanspoon, GPS HD by MotionX, UpNext 3D Cities, ESRI ArcGIS for iPad, Zilliow.com, etc. This second wave of the web map design revolution was enabled by both portable hardware design and fast software distribution frameworks (such as Apple's App Store and Android's Market Place). Users can easily download and install mapping software directly to mobile phones without worrying about complicated software license settings or installation procedures. Most mobile software development kits (Apple's iOS and Google's Android) are open and free for software developers to download. Open-style software development environments and online application stores have created a great opportunity for small GIS companies and individuals to develop and share innovative web mapping services.

The Rise of User-centered Map Design

Different from traditional cartography, mobile mapping and interactive web maps place more emphasis on the locations of users and user-centered tasks (such as shopping, navigating, and searching), rather than the visualization of spatial phenomena (such as population density, crime rates, and land use) and thematic map design (such as the arrangement of map elements, symbology, and typology). This trend shifts the research focus of web cartography from geovisualization (emphasizing visual analysis functions and thematic maps) to user-centered design (UCD), including the designs of user interfaces, dynamic map contents and mapping functions. UCD in web cartography emphasizes the usefulness and practicality of web and mobile maps, serving the needs of individual users and customers.

Although the concept of user-centered design has been introduced in GIS and cartography before (Medyckyj-Scott and Hearnshaw 1993; Tsou and Buttenfield 1998), most early desktop-based GIS applications did not emphasize UCD. Traditional GIS project users were mostly decision makers and GIS technicians who are familiar with GIS and cartography. On the other hand, web mapping service users are more diverse and most of them do not have any cartographic knowledge or GIS experiences. Therefore, UCD becomes more important and essential for web map users and web mapping applications.

Web cartographers can design effective and intuitive cartographic representation by focusing on the creation of user interfaces, mapping functions, and dynamic map content. Tsou and Curran (2008) introduced a five stage UCD framework (Garrett 2002) for the designs of web mapping services and evaluation processes. The five stages (strategy, scope, structure, skeleton, and surface) can be split into two design tasks: map content design and mapping function design. The adoption of UCD approaches will improve the quality of web mapping services and generate more useful information services.

UCD is essential for many web mapping projects and applications, including the U.S. National Map. The early development of the National Map Viewer was not very successful due to the unfriendly user interfaces, complicated map content, and slow performance. The 2007 report by the U.S. National Research Council (NRC), *A*

Research Agenda for Geographic Information Science at the United States Geological Survey, recommended UCD as a priority research topic within the area of information access and dissemination in the development the National Map web services (NRC 2007). The NRC report facilitated the development of several web mapping tools and technologies in the new National Map 2.0 prototype, such as GeoPDF and ScaleMaster (Usery 2010). These new technologies have improved the user interface of the National Map Viewer significantly. The National Map uses GeoPDF for its online map publication and download format. GeoPDF is an extension of Portable Document Format (PDF) with a highly portable and compact format, and can be easily transferred, downloaded, and printed (USGS 2010). GeoPDF provides a convenient way for the public to download and view topographic maps without installing GIS software locally. ScaleMaster is another major UCD research tool for the improvement of the National Map; it provides support for multi-scale map design and generalization processes with different themes (such as topographic maps, zoning maps, soil maps, and population density maps) and different scales on computer screens based on different user needs (Brewer et al. 2007).

Releasing the Power of Map-making to the Public and Neocartographers

Creating traditional maps (paper maps or GIS maps) is very expensive, involving costly printing equipment and GIS software. Web mapping tools have reduced the cost of map-making significantly. Both professional and amateur mapmakers can easily use or combine free online mapping services and access high quality online base maps (road maps, aerial photos, or topographic maps). The power of map-making is no longer controlled by professional cartographers or GIS experts. With the development of free and open source software (FOSS) (Tsou and Smith 2011) and free web mapping APIs, "FOSS cartography" and mashup maps have become important componenents in web cartography (Crampton 2009). Mashups are web applications that merge distributed data sources and separated application programming interfaces (APIs) into one integrated client-side interface (Benslimane et al. 2008). Two exemplar free and open source cartographic research projects in the U.S. are:

- web-based epidemiological atlases that utilize PostGIS (a database engine) and GeoServer (a web map engine) (MacEachren et al. 2008),
- demonstrations of interoperability and high visual quality with various web GIS datasets using MapServer (a web map engine), PostgreSQL (database tools), PostGIS extension (database links), and the libxslt XSLT processor (a document parser) (Yao and Zou 2008).

The freedom of web map-making enables amateur cartographers to create their own maps and easily distribute them. They embrace new web mapping tools and free mapping APIs to publish and share their do-it-yourself maps with the whole world. Lui and Palen (2010) used several mashup examples in disaster responses to demonstrate the powerful impacts made by "neocartographers", a new term describing amateur cartographers without formal map design training. Neocartographers are able to create various mashup maps, with "frequently updated data from multiple sources, allow[ing] us to see microbehavior" – in this case, user responses to social network messages by micro-blogging services – "spatio-temporally"(Lui and Palen 2010, p. 70). The emergence of amateur cartographers and free web mapping tools facilitates many do-it-yourself web maps with user-generated contents. One major challenge is how to improve the credibility and how to reduce the uncertainty in these user-generated contents and maps. Cartographers need to develop intelligent information-ranking algorithms and strategies for processing user-generated contents and to filter out inaccurate geospatial data in web mapping services.

The ubiquitous display of maps on various mobile devices is another key factor enabling the freedom of map-making. Developers no longer limit themselves using traditional desktop computer screens or printout maps for map outputs and display. Mobile devices provide flexible and portable map display/output options for web mapping services. It is important to understand the advantages and disadvantages of mobile display in different web mapping services and associated visual design principles. Dillemuth et al. (2007) examined design principles for various map scales and map extents on mobile devices for navigation systems. Gartner et al. (2007) suggested a few research topics in ubiquitous cartography, including 4D (space-time) representation, adaptive representation, real-time navigation, and locational privacy concerns (Gartner et al. 2007). Gartner further described how mobile map users can become part of the map as an avatar positioned in real time using GPS (or RFID, Wi-Fi), and how the mobile map can be dynamically changed or mirror the real geographic place in which the user is situated.

Discussion

Re-inventing the Design Principles of Web Maps for the Renaissance of Cartography

In the last decade, major advancements in web mapping technologies have been advanced by the information technology (IT) industry, rather than by cartographers or other associated academic researchers (Plewe 2007; Haklay et al. 2008). Today, the new medium (the web), the new tools (mobile devices), and the new participants (new map makers and new map users) provide a great opportunity for academic researchers to re-invent the design principles of web maps, including user interface design, dynamic web content, and new mapping functions. These new design principles and strategies will transform the study of cartography into an important scientific and technological discipline with the emphasis of information representation, map communication, and computing functions. Some preliminary ideas for the re-invented design principles of web maps are suggested in the following:

User interface design: voice-activated zoom-in, zoom-out mapping commands, video-interpreting gesture mapping commands, and motion-sensor-based mapping input.

Dynamic map content: augmented reality for web maps, dynamic linkages between movies, pictures, and texts with user generated contents, and time-sensitive map display.

New mapping functions: In-door shopping and navigation tasks, location-based social networking, and presenting the credibility of volunteered geography information.

To enable this renaissance in cartography, this article suggests that the transformative research agenda of web cartography should focus more on user-centered design, user generated content, and ubiquitous access from mobile devices. The ultimate goals of developing innovative web mapping applications and research are to improve our quality of life, resolve human conflicts, and facilitate sustainable development of our society. Ideally, cartographers should be a part of these projects, partnering with computer scientists, sociologists, activists, psychologists, and IT engineers, who will all be transformed to “spatial information designers” or “geospatial information architects” to create innovative web map applications. These innovations in cartography will help us to create a more collaborative, humanistic, and sustainable society.

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