User-centered design for digital map navigation tools

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ABSTRACT: Zooming and panning tools are critical for navigation around digital maps, however, there has been little research on how these tools should be implemented to improve user interaction with the maps. As use of digital maps becomes more common, and the use of these maps are not restricted to desktop or laptop computing environments, it becomes more critical to understand the user's perception of the design, functionality, and underlying metaphors that control panning and zooming tools. In this paper, the design and function of zooming and panning tools will be discussed in terms of principles of usability and human-computer interaction (HCI). In addition, the results are presented from a survey of digital map users to examine their perception of how zooming and panning tools *should* function. Through these analyses, we find a conflict in terms of consistent design across digital map systems, between metaphors guiding tool use, and between individuals' perceptions of how these tools should function. These conflicts are enlightening when considering standards and defining logical metaphors for consistent tool design to minimize cognitive load and improve efficiency of digital map navigation.

KEYWORDS: *Digital map; panning; zooming; user interfaces; human-computer interaction*

Introduction

In the last decade, digital maps have become more common as spatial references; in some instances (and for some individuals) they have virtually replaced traditional printed maps. In many ways, digital maps and globes are analogous to the physical references that they replace, however due to constraints of the display devices new methods of interaction have been introduced to allow the map reader to control the displayed information. Two of the most critical of these are the panning and zooming functions, without which the digital references would be effectively useless, or at least no better than carrying around a *very small* paper map. Panning allows for horizontal and vertical re-positioning of a map within the viewing window; zooming is the ability to increase or decrease the map display scale.

Even though these functions are necessary, we still know little about how these tools are best implemented in digital maps. Guidelines for design of panning and zooming tools have been suggested by the European Commission (2004) – the tools should be versatile, intuitive, and allow for repeated use, however these do not address specifics of design nor do they define how an intuitive panning or zooming tool should be implemented. In fact, how panning and zooming tools should be implemented is considered to be one of the important unanswered questions related to improving user interaction with digital maps (Harrower and Sheesley 2005). The importance of the design of user interfaces for digital maps has also been emphasized by Wintges (2003) and is in line with the International Cartographic Association Commission on Maps on the Internet's interests in developing guidelines for the design of web maps (Peterson and Gartner).

To date, there have been relatively few studies focusing on issues of panning and zooming in digital maps. Of these studies, the focus is primarily on challenges for small-screen displays such as PDAs and cell phones (e.g., Jones et al. 2005), or on wayfinding and spatial knowledge acquisition (e.g., Dillemuth 2005; Lloyd and Bunch 2003). These studies have been enlightening in terms of how people use and derive spatial information from digital maps but they do not address mismatches of user expectation and system function or capability, nor do they help us set guidelines for consistency in user interface design. Even though a system is functional, e.g., users can successfully use the navigation tools, it may not be designed in a logical, efficient manner. The work reported here presents an evaluation of existing tools for panning and zooming in digital maps and results of a survey examining individual perceptions of navigation tool functionality. Specifically, this work will address:

- Conflict in metaphors guiding implementation of panning and zooming tools, and how this impacts their implementation in existing online maps
- User perception of how these tools should be implemented
- Consistency, or lack of consistency, of the implementation of panning and zooming tools relative to user perception of function
- Guidelines for establishing consistency for user interface design based on user perception.

Background

Every day millions of people access online digital maps. In 1997, Peterson (1997) estimated that individual sites such as Mapquest see about 800,000 daily requests, or roughly 24 million per month. Now, it is estimated that Mapquest sees almost 140 million visits per month, from over 50 million individual users. Another site, Google Maps, sees over 80 million visits per month, from approximately 40 million users (Quantcast 2008).

Maps are an important means for information dissemination, and with increased internet usage they can be accessed by vast numbers of people with incredibly wide ranges of computer (and spatial) ability and map knowledge. The wide range of user knowledge and experience makes it more important that we concentrate on the design of these digital maps to minimize the cognitive load necessary for operation of the maps. This becomes especially important as we see increased availability of digital maps in mobile locations – for instance in vehicles and on cell phones, we find more individuals actively using them for navigation on the fly. To ensure that a map interface is designed in a manner consistent with the expectations of the user, we can apply principles of human-computer interaction and user-centered design.

Usefulness and usability. One of the key concepts in the human-computer interaction (HCI) field is of *usefulness* of a system – whether or not a system can be used to achieve specific goals (Nielsen 1993). Usefulness of a system is described by its *utility* and *usability*. Utility describes whether a system is capable of doing what is needed; usability describes how well a user can use the system. To further describe the usability concept, Nielsen (1993) has defined it with respect to five components: learnability – how easy to learn, efficiency – allowing a high level of productivity after the system has been learned, memorability – the system should be easy to remember, errors – the error rate should be low, and satisfaction – the system should be pleasant to use. When considering the concept of usability, it is important to recognize that these factors associated with usability are not a simple description of whether or not people can figure out how to use an interface; they are a measure of how well the interface can be used to meet the needs of the individual interacting with a computer application.

In terms of evaluating usability of a system, it is, unfortunately, something that cannot be directly measured (Hornbaek 2006), however, individual aspects of it can be measured to serve as indicators of overall usability. With this in mind, in this work we will focus on aspects of efficiency. Efficiency describes how well the user's navigation tasks are supported by the interface. While it can be assumed that the navigation tools implemented in common digital maps are all usable in the sense that they can be successfully used to perform their intended task, this does not mean that they are designed to optimize the efficiency component of usability. Matching functionality of user interface tools, such as those that control panning and zooming, to user expectation for those tools is critical for an efficient system. For assessing efficiency, we follow Tversky et al.'s (2002) principle of congruence (as modified to describe user interface tools) – we assume that when the design and function of navigation tools correspond to the user perception of how the tools should operate the system will be more efficient.

In the greater scheme of interface design, efficiency requires consistency – within systems and between systems with similar function. Consistency has been recognized almost universally within the HCI literature as critical for a well designed system (e.g., Nielsen 1993; Dix et al. 2004). Ideally, user interfaces should have both consistent design and modes of operation across related systems, and a consistent relationship to the metaphors guiding their design.

Evaluating usability for panning and zooming tools. Specifically in terms of evaluation for panning and zooming tools, Harrower and Sheesley (2005) categorize issues in navigation tools for digital maps based on three questions: what kind of navigation tools are provided, how much control over the map these tools offer, and how the tools should be implemented. User interfaces should be designed so that they aid the user in completing tasks and limit the cognitive load required to complete the task. One way in which this can be done is by designing tools that are consistent with the user's conceptual model of what the tool should do and how it should work. Clues to an object's conceptual model are partly based on the design of the object – how it is used/operated – and the metaphor(s) on which it is based (Norman 1990). Assessing the effectiveness of user interface tools, such as those for panning and zooming in digital maps, can be done by examining the appropriateness of the metaphors guiding operation of these tools. Although digital maps are often have the same general panning and zooming tools available, each map service provider develops its own implementation of the tools.

Metaphors and mappings. Perception of how user interface objects should operate is largely determined based on the user's conceptual model of the object and the metaphors that the user relates to that interface object. A metaphor describes one domain (source domain) in terms of another (target domain). The "mapping" of a metaphor defines the correspondences or connections between the source and target domains. With respect to computer user interfaces, this describes the, presumed, logical connection between the operation of the user interface object and the resulting change to the interface. Natural mappings – those that are based on physical or cultural norms, or are based on common physical activities – are generally the most easily understood. One example of a natural mapping can be seen with in the relationship between moving a slider bar in a computer interface to change the magnitude of a variable and the physical activity of moving the dimmer switch, or potentiometer, on the wall to change the intensity of a light.

Lakoff and Johnson (1980) describe "orientational metaphors" as a special category of metaphor that is based on general concepts of spatial orientation, for instance, up-down, in-out, left-right, North-South. By nature of maps and navigation around digital maps, many of the metaphors guiding the navigation tools are built on these orientational metaphors. One of the relevant orientational metaphors suggested by Lakoff and Johnson is that more is up and less is down (e.g., if you add more liquid to a glass the level goes up). Metaphorical orientations are not arbitrarily assigned; the basis of the metaphors comes from our physical and cultural experiences. As such, in evaluating the metaphors and corresponding mappings in navigation tools for digital maps, we may find differences due to how people conceptualize their space.

Navigation tools: Conceptual models and metaphors

Though there are a seemingly infinite number of digital map products that could be evaluated, this work will focus on seven common online maps, listed in

Table 1. These maps were selected based on their frequent appearance as results in web searches for the terms "digital map", "online map", or other similar terms. Only general purpose, national- or global-scale digital maps were considered for evaluation; special topic interactive maps were excluded from consideration. For reference, Mapquest, Google Maps, Yahoo Maps, and Microsoft Live Maps are considered the top four map websites based on their average number of user visits (Hopkins 2008).

Table 1. Evaluated digital maps

Site Name	URL
Google Maps	http://maps.google.com
Map Machine	http://ngm.nationalgeographic.com/map-machine
Mapblast	http://www.mapblast.com
Mapquest	http://www.mapquest.com
Microsoft Live	http://maps.live.com
Rand McNally Maps	http://www.randmcnally.com/rmc/directions/dirGetMap.jsp
Yahoo Maps	http://maps.yahoo.com

While there are many techniques for implementing panning and zooming in digital environments (e.g., for maps, graphics or word processing software, etc.) there are limited techniques commonly used for digital maps. Panning is typically done with "grab and drag" tools (or "touch and drag" with touch screen devices), navigation tabs / interactive compasses, and/or navigation windows. Zooming is typically done using zoom bars, zoom in/out buttons, and the mouse scroll wheel. Some maps combine panning and zooming functions and include a feature to click to zoom *and* re-center the map. Table 2 itemizes which tools are available in each digital map. These tools and their respective conceptual models and metaphors will be discussed in the next sections.

Table 2. Panning and zooming tools available in the evaluated digital maps. 'x' indicates availability.

	Panning tools				Zooming tools		
Site Name	Direct reposition	Navigation tabs / interactive compass	Navigation window	Click to zoom / re-center	Zoom bar	Zoom buttons	Scroll wheel
Google Maps	x	x	x	x	x	x	x
Map Machine	x	x	x	x	x	x	-
Mapblast	-	x	-	x	x	x	-
Mapquest	x	x	-	-	x	x	-
Microsoft Live	x	x	x	x	-	x	x
Rand McNally Maps	-	x	-	-	x	x	-
Yahoo Maps	x	-	x	x	x	x	x

Zooming tools

There are three tools that are commonly used with digital maps to facilitate the zoom process: slider bars, separate icons specifying zoom in and out, and the mouse scroll wheel bar (Figure 1). Not all of these tools are necessarily present in every digital map, but at least one implementation of these tools will be available in every digital map (see Table 2).

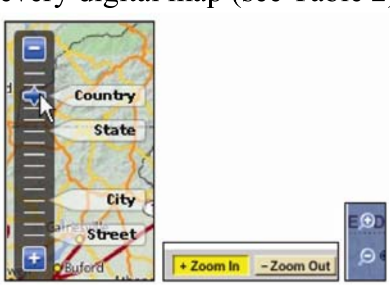

Figure 1. Zoom tools – slider bars, and two types of zoom button. (Sources, from left: Yahoo, National Atlas, Microsoft Live)

Zoom slider bars. As implemented in digital maps, slider bars are controls that enable the user to adjust zoom values in a finite range along either a horizontal or vertical axis. Vertical axis slider bars are more common for digital maps. On slider bars, one end of the bar represents the maximum scale and the other end represents the minimum scale permitted for the map. A movable slider in the middle represents the current scale of the map. Theoretically, infinite scales are possible and the viewer could see the map scale continuously as the slider bar is moved, however, digital maps typically restrict the user to several pre-defined, discrete levels of zoom. The actual scale value at each end of the zoom slider is not provided; occasionally relative scale detail such as "street," "city," or "country" is given to indicate the range of potential values. The location of the slider along the bar indicates the current level of zoom of the map. Zoom bars on some digital maps do not provide for "sliding" the bar to control the level of zoom. Instead, they simply provide a series of buttons indicating discrete levels of zoom and the user clicks on the button of choice rather than sliding a bar along the zoom bar (Figure 2). For this study they are considered to be equivalent.

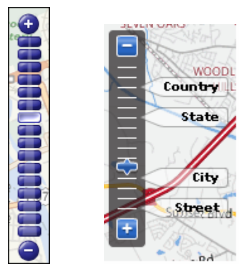

Figure 2. Two versions of zoom bars - individual buttons to allow the user to select discrete levels of zoom (left, from Mapquest) and a slider bar to select the desired level of zoom (right, Yahoo Maps)

As a whole, slider bars in user interfaces are typically guided by the principle of Lakoff and Johnson's (1980) orientational metaphor that "more is up." To match with real world equivalents, this translates to the function of linear potentiometers, as we are used to seeing them used for functions such as controlling volume on stereo equipment or light switch dimmers. For slider bars, there are two issues that arise when considering orientational metaphors to explain the function of the tool: what is considered to be more, and whether more really is up.

First, with respect to a "more is up" metaphor to control the function of slider bars, what is considered to be more when zooming in and out? When defining the concept of more, we encounter an issue in the opposing definitions of cartographic and geographic scale. Large cartographic scale implies a representative fraction closer to one – more equals a larger representative fraction and more detail in the map; large geographic scale provides an opposite meaning – more equals larger geographic area. While both of these interpretations are possible, the underlying metaphor of more equals a larger cartographic scale seems to have more support from the general design of the zoom slider bar. Slider bars tend to offer graphical cues to indicate "zoom in" (+) and "zoom out" (–). In all instances of the digital maps we examined in this work, the function of zoom in and out always refers to cartographic scale; zooming in increases the value of the representative fraction and zooming out decreases the value of the representative fraction. However, inclusion of + and – does not mean that the design is consistent with the way in which a user interprets the functionality of the slider bar.

Second, we with respect to design of the slider bar as a user interface object, is more really up? Matching the non-computer equivalents to user interface objects, an earlier study has indicated that people typically believe that "more" is found at the top of vertical slider bars and to the right on horizontal slider bars (Langston and Kuban 2002). If we translate the graphical cues indicating zoom in (+) and zoom out (–) to numeric values, it is assumed that the + would always be on the top of the slider (positive numbers are always greater than negative numbers). However, is this assignment true when we consider the opposing (and both logical) definitions of scale, rather than the more straightforward increase and decrease of volume? In terms of implementation, there is little consistency in design of the slider bars to provide a definite answer for what metaphor guides the design. Of the seven digital maps surveyed, four follow a pattern of zoom in on the top of the slider, two have zoom out at the top of the slider (Mapblast and Yahoo Maps), and one does not use a slider bar for zooming (Microsoft Live).

Zoom icons. Zoom icons are related to the zoom slider bar; instead of the series of discrete steps for zooming in and out provided on zoom slider bars, each press of one of the zoom icon buttons zooms in or out by a predefined amount. Often these icons take the form of + or – signs to indicate zoom in or zoom out, respectively, sometimes the + or – signs occur within magnifying glass icons. Occasionally, zoom icons are text based and simply list "zoom in" and "zoom out." A logical design for these buttons is to follow the same more is up metaphor of the zoom slider bars. Of course, this means that we must clarify our definition of "more" with respect to scale.

When zoom icons are included in the interface to supplement a zoom slider bar, their orientation is in line with the slider bar; when the zoom icons are included as a stand alone navigation tool their orientation varies. Microsoft Live is the only digital map examined for this work that contained stand alone zoom icons; in this interface the zoom in icon was located above the zoom out icon ("zoom in is up").

Scroll wheel. The scroll wheel was introduced to computing in 1996 with the Microsoft IntelliMouse – a standard two-button mouse with a wheel located between the two buttons. While the device was initially conceived for zooming within Excel, the original implementation was more broadly focused to support scrolling in various Office 97 products (Microsoft 1996; Michelman 2008). In the digital map context it is used to control zooming. In all of the digital maps that included scroll wheel functionality, the map would zoom out when the mouse wheel was rolled towards the user. The four maps that did not include scroll wheel functionality were Mapquest, Mapblast, Map Machine, and Rand McNally Maps.

As a navigation tool, the scroll wheel is the least transparent implementation of zooming functionality. The novice computer user may not know that it is an option as it is an "invisible" zooming function. For advanced computer users that are new to the digital map domain, the function of the scroll wheel for zooming is different from its use in other common software (i.e., scrolling up or down a page, which is more of a panning function).

The basic conceptual model behind the scroll wheel is that rolling the wheel moves *something*, but what that something is and how it moves will vary. For scrolling up and down web pages or text documents the mouse wheel serves as a device to move a scroll bar on the side of the screen – we can push the scroll bar up or pull the scroll bar down. It is a little less clear how this translates to zooming in and out on a digital map. For zooming we need to think in terms of three dimensions, the scroll wheel is moving something backwards or forwards to enlarge or reduce the scale of the map. We can take either an egocentric or exocentric viewpoint. An egocentric view assumes that the scroll wheel controls the virtual location of the individual; rolling the mouse wheel away moves the individual forward towards the map providing a close up view (zooming in). An exocentric view assumes that the scroll wheel controls the virtual location of the map; rolling the mouse wheel away pushes the map or globe away from the user providing a view of a larger geographic area (zooms out). On all of the digital maps examined in this work, rolling the mouse wheel away zooms in.

Panning tools

Panning is the ability to horizontally re-position a map within the viewing window. Panning in online digital maps is typically done with direct repositioning tools, navigation tabs / interactive compasses, through pointing and clicking, and/or using navigation windows.

Direct repositioning. Direct repositioning allows for continuous panning around a map. By moving the mouse with the mouse button depressed the user can directly reposition the map. Often when this tool is available the user is presented with a "hand" cursor that changes to a “grab” cursor when the mouse button is clicked. Direct repositioning allows operates on a “grab and drag” metaphor that reflects the real-life activity of picking up an object and moving it. This is one of the more straightforward metaphors for map navigation tools.

Navigation tabs or interactive compass. Navigator tabs or interactive compass buttons provide for constrained panning, with the map moving a set amount in the direction of the arrow on the navigator tab. Navigation tabs are located around the outside of the map frame; interactive compasses present all of the navigation buttons in a single location. When navigation tabs or interactive compass buttons are pressed, the map moves to show the geographic area located in the direction of the arrow; if the arrow pointing East is clicked the map moves to show the area located to the East of the current map center. Often there are only four options presented to the map user: North, East, South, West, however four additional options may be presented for diagonal navigation: Northeast, Southeast, etc. Navigation tabs are presented on the outside of the map frame (e.g., the North arrow is located on the top, center of the mapped area and the South arrow is located on the bottom, center of the mapped area), while interactive compasses are grouped together in one location (Figure 3). While it seems that use of navigator tabs was more common in earlier digital maps, the current map design tends more towards interactive compasses for panning. Navigation tabs or interactive compasses are included on all of the digital maps evaluated in this paper, with the exception of Yahoo Maps.

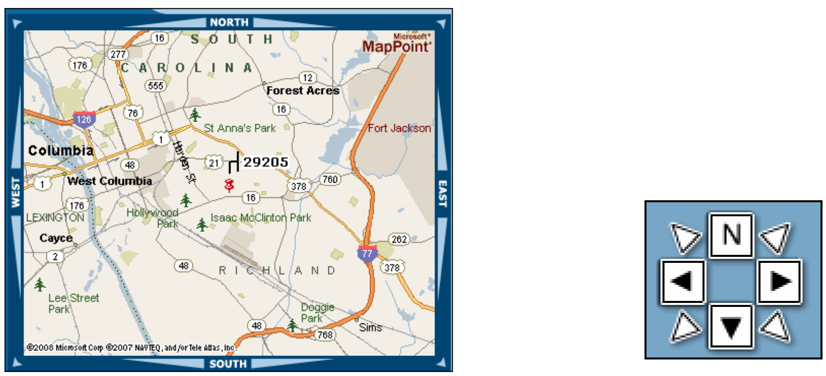

Figure 3. Two styles of navigation tabs - around the map frame (left, from Mapblast) and navigation tabs grouped separately (right, from Map Machine).

In terms of conceptual model and metaphor, the buttons making up navigation tabs and interactive compasses serve as direct manipulators for the mapped data. The potential conflict in the metaphor is what the buttons control – is the indicated direction related to what the user *wants* to see or what direction the map should move? Essentially this translates to whether or buttons are linked to the map or to the map frame. A button linked to the map would logically move the map in the direction of the arrow (i.e., clicking on the East pointing button would move the map towards the East); a button linked to the map frame would perform an operation equivalent to moving the map frame over a new (not currently visible) portion of the map though location of the users frame of view would not change (i.e., clicking on the East pointing button would “move” the frame to the East, effectively moving the viewed area to the West). The results from using these two conflicting models are illustrated in Figure 4.

Point and click. With point and click panning, the user simply clicks on a point of interest and the map will re-center to that location. Occasionally this includes a zooming component so that a click on the map will re-center the map on that location and zoom in by a predefined amount. While other techniques for panning include a visual cue as to how the tool is used (e.g., a hand icon or visible navigation button), the point and click panning tool is not explicitly described for the interface – a user must either know that it is available or find it through experimentation. In terms of a conceptual metaphor, this tool is strictly based on the concept of pointing and clicking to serve as a cue to “go to this particular location.”

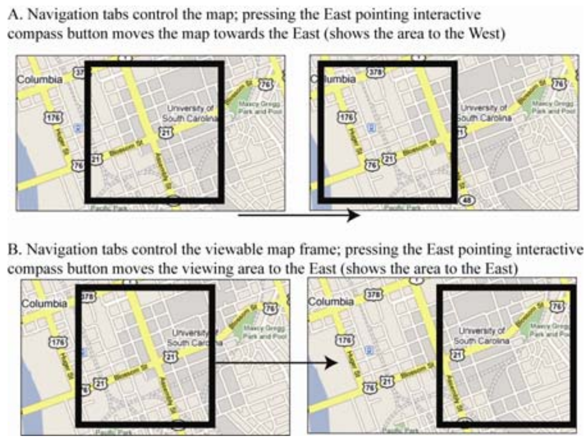

Figure 4. Conflicting models describing function of navigation tabs / interactive compasses. (a) assumes that the navigation tabs control the map; (b) assumes that the navigation tabs control the viewing frame. For each of the maps, the area that would be visible to the map reader is shown in the black frame.

Navigation windows. Navigation windows are a second, smaller map browser contained within the main digital map (Figure 5). The navigation window contains a smaller-scale overview map, which includes a box drawn to indicate the geographic area being shown in the main map. When the user pans or zooms in the main map, the location of the box in the navigation window updates to show the location of the area shown in the main map relative to its location on the global map. Additionally, the user can manipulate the location of the box in the navigation window to pan across larger distances. In terms of function, navigation windows have a distinct advantage over navigation tabs or interactive compasses – the user has a visual cue to indicate exactly what part of the map will be visible after panning.

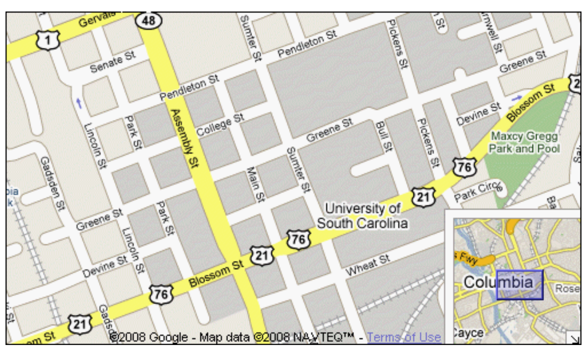

Figure 5. An example of a navigation window, as provided in the Google Map interface. The navigation window is shown in the lower right corner of the image. Navigation windows provide a smaller-scale overview map with a box to indicate the area shown in the main map.

User perception of navigation tool functionality

In the previous section, we highlighted number of conflicts in the implementation of and conceptual models behind panning and zooming tools for digital maps. What do these conflicts mean in terms of user perception of how the tools *should* function? In this section, the conflicts will be examined in light of results from a survey of perception of navigation tool functionality.

Participants

A total of 124 students (69 male, 53 female, and 2 that did not state their gender) participated in the study to assess user perception of how panning and zooming tools should operate. Seventy-two of these participants were included in a follow-up study adding an additional survey question. All participants were recruited from undergraduate classes (geography and non-geography classes). The students in these classes participated voluntarily and did not receive any course credit for their participation. An effort was made to ensure that there were participants with a variety of levels of experience with digital maps, from novice or infrequent users, to those with extensive experience with them.

The average age of all participants was 21.5 years (*SD* = 5.1); participants ranged from 18 to 55 years. All participants had experience with digital maps, though their level of experience varied; eighteen indicated that they rarely use digital maps, forty-seven use them roughly once a month, forty-five use them on a weekly basis, and eleven use them daily. One hundred of the participants were primarily PC users; twenty-one were Mac users.

Materials

Survey. Participants were given a three page packet containing a set of questions on the function of several panning and zooming tools. The panning and zooming questions presented in the study focused on the three tools with apparent conflicts of implementation or conceptual metaphor: zoom slider bars, the mouse scroll wheel, and navigation tabs / interactive compasses. The navigation tools for which the functionality was clearly defined and consistently implemented across digital maps were not evaluated. Additionally, participants were surveyed on their preference between navigation tools when there were multiple tools available for the same function. For general background, participants were also surveyed regarding the online maps they tended to use most frequently. All questions provided graphical and written descriptions of terms (e.g., zoom in and zoom out), as well as graphical depictions of the navigation tools (e.g., zoom slider bars) to avoid any potential confusion or misunderstanding.

Procedure. Participants were asked questions about their personal use of digital maps (e.g., Mapquest, Google maps, etc.) They were also asked several questions about how they feel that panning and zooming tools *should* function. It was stated repeatedly throughout the instructions for each question that the questions were related to the participants' thoughts on how the tools should function, not how they think that tools are implemented in specific digital maps.

Results

Digital map use. Table 3 presents a summary of the digital map use patterns of all of the participants. Of the digital maps used by participants, Google Maps and Mapquest were the most common. One hundred and ten of the participants used one or both of the Google or Mapquest maps most frequently, four participants indicated that they only used Yahoo Maps, and one did not answer. Of the Google Maps and Mapquest users, twenty-two indicated that they also use another digital map program regularly; most of the participants with frequent use of multiple maps used both Google Maps and Mapquest. Participants were also given an option of writing in the name of other digital maps that they used. Five participants wrote in additional digital maps that they use, and all were for special purpose digital maps (e.g., directions to business locations, campus maps, etc.) and were used infrequently.

The Hitwise assessment of market share for online maps show Mapquest with a 50% market share of internet map traffic, followed by Google Maps with 22%, Yahoo Maps with 13%, and Microsoft Live with almost 4% (Hopkins 2008). While the results here, showing Google Maps and Mapquest with roughly equivalent usage, are a bit off from the Hitwise estimate of map use, we assume that this is a reflection of the incredible increases in popularity of Google Maps within the last year or so. Traffic to Mapquest has decreased in the past year, while Google Maps' traffic has increased 135% in the same time. (Hopkins 2008).

Table 3. A summary of the digital maps most frequently used by participants. When participants indicated roughly equal (and high frequency) levels of use of more than one digital map they are counted more than once, so the total users listed will be greater than the number of participants.

Site Name	Number of frequent users
Google Maps	63
Mapquest	72
Microsoft Live	2
Yahoo Maps	8

Zoom tools. Zoom slider bars and the scroll wheel are the tools with the greatest complexity in terms of finding a consistent metaphor to guide their functionality. To gauge perception of how the zoom slider bars should function, participants were presented two graphics of slider bars (one horizontal and one vertical) and asked to fill in a "+" sign on the end of the slider that would zoom in, and to fill in a "-" sign on the zoom out end of the slider bar. Written and graphic descriptions of zooming in and out were given to eliminate possible confusion. For the vertical zoom slider, ninety-eight participants indicated that moving the slider towards the top of the slider bar should zoom in and thirteen indicated that this should zoom out. For the horizontal zoom slider, ninety-one participants believe that moving the slider to the right of the slider bar should zoom in, and twenty believe it should zoom out. These are both as would be expected if participants were following an orientational metaphor. In comparison to actual implementation, Yahoo Maps and Mapblast both use vertical zoom slider bars with zoom out at the top. The five other maps examined in this paper place zoom in at the top. To test for potential influence of map use, we examined for independence of preferred map and perception of zoom slider functionality. Participants' preferred maps and their perception of zoom slider operation were independent for both vertical and horizontal slider bars, $\chi^2(2, N=100)=2.28$ $p>.05$; $\chi^2(2, N=90)=0.7962$ $p>.05$, respectively.

To gauge user perceptions of how the scroll wheel should be used for zooming in and out on a digital map, participants were asked to indicate what they feel should happen if they roll the mouse wheel away from their person. A graphic was included in the question to clarify what was meant by "roll away." Written and graphical descriptions of zoom in and out were also provided for clarification of all relevant terminology. Results were mixed, with sixty-two participants indicating that rolling the mouse wheel away should cause the map to zoom in and forty-four participants indicating that it should cause the map to zoom out. This reflects the conflict in identifying a single metaphor to describe perception of the tool's function. In comparison to actual implementation in the maps surveyed here all of the maps that included scroll wheel functionality zoom in when the mouse wheel is rolled away. Since one of the most frequently used digital maps, Mapquest, does not provide scroll wheel functionality it is worth testing for whether Mapquest users show more agreement or disagreement in their perception of how the tool should function. As it turns out, perception of scroll wheel function was independent from the participants' preferred maps, $\chi^2(2, N=90)=1.74$ $p>.05$, and Mapquest users were just as conflicted in their perception of how the scroll wheel should function for zooming.

In addition to perception of how the scroll wheel should function for zooming in and out, participants were queried regarding their preference for the location that was zoomed in or out on, the center of the map or the location of the mouse when the scroll wheel was used. Forty-five participants indicated that the map should zoom in on the map center, and seventy-seven participants indicated that the map should zoom in on the mouse location. Of the maps surveyed, three use the scroll wheel for zooming – Google Maps and Microsoft Live zoom in and out on the mouse location, Yahoo Maps zooms on the center of the map regardless of mouse location. Stated preference of location where the map zooms in when using the scroll wheel is also independent of map preference, $\chi^2(2, N=97)=1.05$ $p>.05$.

Of course, it should be noted that the function of individual zoom tools are not isolated from one another; there should be logical connection between the methods for operating tools that complete the same function. To look at this relationship, we compared results from perceived operation of the zoom slider bar and the scroll wheel. A logical relationship between these two tools would be for the zoom function assigned to rolling the scroll wheel away would correspond with the function assigned to the top of the zoom slider. This would correspond with the standard use of the mouse scroll wheel to scroll up and down through a document. This relationship is true for the three maps that provide scroll wheel functionality, but does not hold true for perceived function of digital maps. Fifty-one of the one-hundred participants who answered both questions believe that the zoom function at the top of the zoom slider bar is opposite that that occurs when rolling the scroll wheel away. Most of these participants, forty-four, indicated that the slider should zoom in at the top of the slider bar and the scroll wheel should zoom out when rolled away.

Panning tools

To evaluate perception of how navigation tabs or interactive compasses control digital maps, participants in the survey answered one of two questions regarding which button would be pressed to move a point of interest into the center of the map (Figure 6). Since navigation tabs and interactive compasses are two distinct designs, participants only saw a question regarding one of the two designs; no participant saw both questions. Seventy-two of the participants took part in this portion of the study.

Figure 6. A question to identify user perception of how navigation tabs control map panning.

Using the interactive compass, twenty-nine of thirty-eight participants correctly identified the button that would move the point of interest (the X in Figure 6) into the center of the map. With the navigation tabs, thirty-one of thirty-six participants correctly identified the tab that they would press. There was no difference of accuracy between participants in these two groups, $\chi^2(1, N=74)=1.16$ $p > .05$; navigation tabs and interactive compasses were equally effective for this task.

In addition to assessing perceived function of the interactive compass tool, participants were asked about their preference of tools that permit panning around a map – interactive compass versus the grab-and-drag tool. All of the preferred digital maps used by participants in this study offer grab-and-drag functionality, and we assume that all participants have used it to some extent in their map browsing. Eighty-four participants indicated preference for grab-and-drag tools, twenty-five indicated preference for the interactive compass, and one selected both. Twenty-one of the twenty-five participants that prefer the interactive compass are Mapquest users, which may be a reflection of the (relatively) recent introduction of this function in Mapquest (Mapquest 2007), and the extremely positive reaction that Google Maps has received for the function.

Discussion

In terms of correspondence with existing implementation of panning and zooming tools, are the methods of implementing common tools for panning and zooming consistent with user perception of their functionality? Yes and no. In some instances, even with apparently conflicting metaphors that could describe a tool's functionality, there was clearly a single dominant model. For instance, this is true with zoom slider bars, where we found more consistency in user perception that the tool should operate in line with the "more is up" orientational metaphor and that "more" describes the level of detail on the map not the geographic area shown. Even with this general agreement between participants in the study, there is not agreement between digital map designers on how zoom slider bars should be implemented and we find opposing designs in commonly available digital maps. There also appears to be a single dominant model for how navigation tabs and interactive compasses should function, and there is consistent implementation of these tools in the common digital maps.

In other instances, there was no clear agreement between participants on which metaphor guided the operation of the navigation tool and, thus, we found greater variation in user perception. For instance, participants were conflicted on how the mouse scroll wheel should function for zooming in and out on the map. However, there was no conflict in design and the mouse scroll wheel functions the same in all digital maps examined. Unfortunately, since the mouse scroll wheel is used for zooming functions in many other software tools, the conflict in perception may be due to unaccounted for outside factors. Use of the mouse scroll wheel for zooming may be one of the most inconsistent tools for implementation – even with software produced by the same company. For example, in several Adobe products (e.g., Photoshop, Illustrator, and InDesign) the scroll wheel functions differently in each program.

Conclusion

Returning to Harrower and Sheesley's three questions underlying development of interactive mapping systems, we should concern ourselves with the following: what kind of navigation tools are provided, how much control over the map these tools offer, and how the tools should be implemented. We know that we need basic tools for panning and zooming in digital map to counter the effects of screen size being too small relative to the overall digital map area. We also know that there are a limited number of techniques that are commonly used in today's digital maps, and we can easily assess the function of these tools and the amount of control that they offer over the maps. This leaves us with the issue of how the tools *should* be implemented.

In this paper we have presented a summary of the panning and zooming methods that are currently found in online digital maps, as well as results from a survey of user perception of how these tools function. Through this work we identified conflicts in implementation between digital map interfaces, conflicts between user perception of how panning and zooming tools function and their actual function, and some user preferences for modes of interaction with digital maps.

Suggestions for intuitive design.

Even though we have identified conflicts in how these tools are implemented across systems, we feel that all of the *individual* digital maps have acceptable, functional designs. Taken as a whole, however, they do not have consistent design – and as they are intended for the same general purpose, we feel this is unacceptable and reduces a user's ability to transfer their knowledge to other digital map systems. As we start to see an explosion in use of digital maps, and increased used of these maps in mobile situations (e.g., PDA, cell phone, or in-vehicle), it is becoming more important to ensure that the tools for interacting with the map interface are designed to be as intuitive to use as possible. Part of the increase in use of digital maps is due to the relative ease of creating and serving them on the internet. While it is relatively easy to create these digital maps, it is also easy to ignore some principles of usability in the design process.

Harrower and Sheesley (2005) have stated that there is no single best implementation for panning and zooming tools as there will always be individual differences in knowledge, experience, and needs. We agree with this statement, and feel that we can meet the needs of most individuals through offering a variety of methods for panning and zooming and ensuring consistent implementation of each of these methods would be beneficial. In line with our interests in a consistent interface, we make some suggestions for increasing the intuitiveness of navigation tool design based on current implementation, user preference, and user perception of how navigation tools should function – with the understanding that the metaphors behind panning and zooming tools are constant and users' natural perception of these metaphors will not change. We realize that these digital map systems do not operate using the same client / server systems and some functions are difficult, to effectively implement in different systems. However, we do not limit our suggestions based on the technology.

Zooming tools. It was almost universally accepted by participants that zoom in is "up" on the zoom slider bar, indicating that this is the most intuitive design for the slider bar. Of the seven digital maps surveyed in this work only two, Yahoo Maps and Mapblast, presented zoom out at the top of the slider bar. To maintain congruence with user perception – which is consistent with Lakoff and Johnson's orientational metaphors and with common implementation of slider bars in every day life (e.g., higher light intensity is "up" on the light switch dimmer) – zoom sliders should be standardized with zoom in on the top of the slider bar. While there were no instances of horizontal zoom slider bars found in the maps surveyed here, the same metaphor corresponds to zoom up being located to the right on the zoom slider. To maintain consistency, the placement of + and – or text-based buttons to control zoom functions should follow the same guideline – zoom in is always to the right or top, zoom out is always to the left or bottom.

In terms of a perceived best design for the mouse scroll wheel, we found conflict between perception of zoom slider and scroll wheel functionality. Logically, it makes sense that the function of the scroll wheel should be consistent with the design of the zoom slider bar; the map zooms in when the user rolls the mouse wheel away and the map zooms out when the user rolls the mouse wheel towards her person. This action would be consistent with the function of the scroll wheel in document navigation (e.g., scroll away to move towards the top of the document). If this logic is carried through, it would mean that the scroll wheel should always zoom in when the mouse is rolled away. Unfortunately results from this work make it difficult to say with conviction that this is the dominant model; many participants see the function of the scroll wheel from an opposing point of view – the scroll wheel controls the location of the map. Regardless, consistency and agreement between interface items is more important in this case and we suggest that the scroll wheel operate to align with the recommended zoom slider function; rolling the scroll wheel away should zoom in. With respect to tool availability, when scroll wheel function is included we feel that a zoom slider bar should also be included as the scroll wheel is an "invisible" function and may not be recognized by some users.

Panning tools. Panning tools were the most easily understood by the participants in this study. There were relatively few problems and limited confusion with perception of navigation tabs and interactive compasses. Other panning tools, such as direct repositioning with the "grab and drag" tool and navigation windows are straightforward in their operation and provide graphic cues to their function. In terms of implementation, as these appear so consistent in current implementation and user understanding, we present no substantive suggestions to establishing consistent implementation other than to provide multiple modes of interaction. Since most users prefer the grab and drag function, this should be considered whenever it is possible to implement it (recognizing that some client/server systems do not make this easy). In choosing between navigation tabs and interactive compasses, the option does not seem to hinder a user's ability to successfully use a system – though they may affect the time necessary to complete tasks, something which was not tested here. For navigation windows, when implemented there should be an option to use them or not, as many systems have implemented now – the window can easily be added or removed from the corner of the map.

Future work and broader implications. There is still a large amount of work that needs to be done to examine the design and function of navigation tools in order to improve user satisfaction and efficiency. This is true for the digital maps that we access on our desktop and laptop computers as well as on small-screen navigation devices. It is also true outside of the digital map arena – navigation is an important part of working with most any document in a digital domain, yet we have little agreement on how navigation tools should be implemented for examining spatial data (e.g., in online maps, AutoCAD, GIS, GPS units, etc.) or other types of digital files (e.g., Photoshop, Illustrator, Excel, etc.).

Specifically with respect to online maps, we need further examination of how navigation tools are used in context. One philosophical approach to studying cognition is that cognition is "embodied," or that our experiences and physical actions play a role in shaping our thinking in certain situations (e.g., Lakoff and Johnson 1999). With respect to the work reported here, theories of embodied cognition suggest that how individuals perceive navigation tools to function may differ when the individual is simply thinking about the tool (i.e., in the written survey) and when they are physically applying the tool in a digital map situation. This is likely reflected in the fact that all but one of the Yahoo Map users identified that the zoom slider bar should be laid out in the opposite fashion to the way that it is implemented in Yahoo Map. While perception of tool functionality is important to understanding the basic logic that individuals apply when working with digital map interfaces (or other interfaces requiring similar tools for panning and zooming), it does not provide the whole picture of how individuals physically interact with an interface – or how they expect the interface to act in a particular situation. Further work needs to be done in this area to test perceptions in digital map use situations.

In terms of other questions that need to be addressed – there are many design issues specific to individual tools that should be examined in order to assess their impact on users' productivity, efficiency, and satisfaction. For instance, the effect of tool placement, level of interaction, increased cues for how tools change the viewed area – by how much does the map pan or zoom, and where the zoom centered. Additionally, we need to examine how different strategies for panning and zooming tools work with small, mobile displays and how touch-enabled screens change interactions with the map. There are many questions to answer as we work towards efficient, productive, and consistent user interfaces for digital maps, and virtually all of these questions require conscious inclusion of map users, and attention to the range of digital map products and uses in order to create meaningful suggestions for interface design.

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