CASE STUDIES DEMONSTRATING THE UTILITY OF UNCONVENTIONAL DESIGNS FOR GEOGRAPHIC PROBLEM-SOLVING

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Abstract. Visualization as a cognitive process is most successful, particularly in data exploration tasks, when a user is provided means to think creatively about a data set or a phenomenon. Where the 20th century task of the cartographer was to communicate spatial information – and conclusions about that information – to a wide audience, cartographers of the 21st century are additionally asked to provide ways to privately explore and understand large quantities of geographic data for which few hypotheses or conclusions have been made. As such, cartographers and other designers of methods for representing spatial data must work toward facilitating data exploration, encouraging creative and often unconventional thinking about a problem. Designing cartographic representations in non-traditional ways has been used for decades to emphasize particular aspects of a phenomenon, but typically these representations have been created to advance a particular agenda or communicate a specific idea. In this research, we present three experiments that support the hypothesis that such non-traditional representations may be utilized to encourage more open-minded open-ended thinking, as is desired from a visualization application. First, we show through a user interface evaluation that a non-traditional orientation of a timeline in an animated map led to more accurate answers about the animation, possibly a result of increased attention given to the animation because of the unconventional design. Second, we report on the results of a map-reading experiment where a non-traditional orientation of a world map led to more accurate answers and longer attention times. Finally, we present an experiment based on a map designed to enable the use of uncertain geographic information through the manipulation of the base map, challenging the convention of accuracy and veracity by altering the information used to orient the user to the thematic information. While none of these studies evaluated visualization tools directly, the evidence collected in them supports the hypothesis that challenging conventional design in maps leads to increased attention to the phenomenon, encourages reconsideration of existing mental models, and facilitates the sort of creative thinking that is the goal of visualization tools and environments.

Introduction

Visualization of a geographic phenomenon, whether for understanding a communicated idea or exploring a data set for new insights, is inherently a human activity, where the representation and the user are in a dialogue. The map reader is in possession of an *a priori* mental model of the phenomenon, be it ill-formed or precise, which could be based on beliefs, direct experience, or representations (such as text, stories, or other maps) from the reader's past. The map, too, carries conventions, codes, and norms that arise from prior designs and guidelines known to the designer of the map and either reconstituted or revised according to the goal of the representation (MacEachren 1995). As the reader examines the map, his or her mental model of the phenomenon can change, particularly if the map shows something unexpected or challenges preconceptions about the phenomenon or, more importantly, the way the phenomenon is represented. With an adjustment of the mental model, new unexpected insights could be revealed by the map – though the data on the map has not changed, the insight possible from the map may be enhanced because the reader has recognized both the arbitrariness and the malleability of his or her mental models. If a representation presents a challenge to the expectations and norms of the reader, he or she may in fact benefit, as the representation breaks a reader out of a rut of conventional thinking and facilitates a creative approach to solving problems.

This approach in cartography is far from new: as one example, the Strato-Map created by General Drafting Co. in 1944 uses an oblique perspective basemap looking north westward from approximately Ecuador; its overt message is propagandistic, illustrating the relative positions and proximities of various points in the Pacific theater of the World War II, and the threat that is posed by the Japanese in the region. The map is specifically designed to alter mental representations of the vastness of the Pacific Ocean as represented and perpetuated by other projections in common use in media and classrooms of the time. The perspective is purposely jarring and literally head-turning: land masses from "Indochina" to Alaska are "accurately" portrayed but the "unique strato-view" is designed to alter the perceptions of the reader, and likely leads the reader to ponder the map and its contents for a longer time than a more typical projection of the same scene (see also Wood et al., 2006).

In this paper we argue that a similar approach may be taken to enable map use in situations where the end goal of the representation is not the communication of an argument or a conclusion, but the generation of insight, hypotheses, and alternative explanations. Interactivity, a hallmark of visualization environments, facilitates the dialogue between a map user and the representation; it is through the interface – which can include the map itself (an interface to information) and the various buttons, sliders, and interactors (interfaces to the computer system) – that this dialogue most readily occurs. As such, we focus most of our attention here on extant research in interface design, paying particular attention to the use of interface metaphors in human-computer interaction studies. Metaphors, which exploit familiar real-world concepts in order to develop and simplify understanding of complex abstract processes, have obvious utility in geovisualization interface design (Howard and MacEachren 1996; Gabbard, Hix et al. 1999). However, we will echo what some human-computer interaction researchers have argued, that metaphors and interface conventions serve to contrain a user into a proscribed way to think about a problem (Nelson 1990; Preece and Sharp 2003). Based on three user experiments of map reading and understanding, we find that some conventions of cartography used in both map and interface design may serve to hinder the usefulness of geovisualization tools for a diverse set of uses, including exploratory spatial data analysis.

Background

Through the interactive features of a visualization system, the user assumes the traditional role of the cartographer – all of the choices left to a mapmaker can now be placed in the hands of the user (Crampton 2002; Edsall 2003). As such, design of geovisualization systems is now, perhaps more than ever in cartography, reliant on the understanding of how users behave, think, and assimilate information. The "freedom" of highly interactive systems must be tempered by the acknowledgement that the design and selection of tools provided for interaction can be guided by conventions that may serve to perpetuate (mis)perceptions of the users.

Interface Metaphor

Many human-computer interaction (HCI) researchers and practitioners have discussed the merits of metaphors in the design of interfaces as a way of facilitating the understanding of a complex and abstract system (Benyon 1999; Alty, Knott, et al. 2000; Marcus 2002). As users interact with a system through the interface, their knowledge of the system is supported by prior knowledge of both the system and the metaphor (e.g. a "desktop" or "typewriter") to refine their mental models of the system. Thus, metaphors allow the development of improved mental models through the association of familiar real-world concepts to unfamiliar abstract concepts.

Interface metaphors, along with other aspects of a visualization system, including the map and other data displays, facilitate the activation of cognitive schemata, the abstract structures in memory that, when combined, contain the um of our knowledge of the world (Paivio 1974; Winn, Snyder et al. 1996). Schemata can be more effectively activated if the learning material (a map interface, a visualization, etc.) is somehow similar in structure to that of the existing schema (Winn, Snyder et al. 1996). In the context of geographic representation, Peuquet (2002) refers specifically to *anticipatory* schemata, which are patterns in thought that enable a perceiver to expect a certain conclusion. More experienced individuals (for example, good sight-readers of music, or chess masters, or professional tennis players) anticipate a great deal about what is to come, allowing them to assimilate the multi-modal (visual, aural, etc.) stimuli and react appropriately. Metaphors in interfaces can be designed to activate anticipatory schemata and guide a user to an appropriate conclusion.

Such familiar real-world concepts as the desktop, the typewriter, and the book all seem reasonable to utilize as metaphors for computer systems (the Xerox STAR – and the subsequent Macintosh and Windows interface, the word processor, and web "pages," in the examples above) for most humans worldwide. However, in many cases, certain taken-for-granted interface conventions are likely to lead users of diverse backgrounds to hypotheses or conclusions that are incorrect, or worse, unduly influenced by the design of the tools and interface. Interface-relevant cultural mismatches are not uncommon: red is a color of joy in China and of danger in the U.S., the "trash can" icon on a Macintosh interface is frequently misinterpreted in southeast Asia as a wicker basket for storing items, and using an "OK" hand signal from the US might be offensive to some European users. A snowflake might be a confusing icon to use for "cold" in a place that never has received snow, and the "My Computer" name in Windows implies an ownership status that may be confusing to more community than individualistic societies (del Gardo 1990; Yeo 1996; Callahan 2005; Shen et al, 2006). Designers of visualization applications should be cognizant of the implications of designing for an increasingly diverse set of users and applications (Stephanidis 2001, Edsall 2007).

Cartographic conventions and geovisualization

Interface conventions are in many ways similar to the taken-for-granted and well documented cartographic conventions (Slocum et al. 2001). For example, the vast majority of maps, particularly those created in Western societies, are oriented with north at the top of the map. Other conventions include that "higher" corresponds to "more" (as on 3D density maps or 2D bar graphs), that darker colors also correspond to greater quantities (as on choropleth maps), and that temporal progress in an animation is indicated by a rightward movement of a temporal indicator (Edsall and Sidney 2005).

Consider a classic reference map of the physical features of the United States, common to many thousands of school classrooms. The "elevation" color scheme (one of the default schemes of GIS packages), with green at sea level, through olive, yellow, beige, brown, and white with increasing elevation, might lead a user to believe that arid and hot Yuma, Arizona, close to sea level, is lush with vegetation, while the relatively moist and verdant (and high) Appalachian Mountains are barren, dry, and lifeless. This misconception reflects a semiotic mismatch between referent and interpretant; school children or naïve map users may not understand that color on the map symbolizes something other than what is directly visible in the environment (see MacEachren 1995).

This obvious mismatch should lead a cartographer to consider how other less conspicuous conventions could lead users – even experts – to mistaken conclusions. Another, more fundamental, convention, sometimes exploited by less scrupulous cartographers, is the assumption of accuracy that users make when reading a map. We know that many incorrect conclusions and detrimental decisions are made from an unquestioning and uncritical use of maps (Deitrick and Edsall 2007). However, in many circumstances, knowing information about the uncertainty of the mapped information is vital to making appropriate decisions and thinking creatively. Mapping climate model output, for example, with low spatial resolution, or a storm track with low temporal resolution, on a base map that implies high levels of accuracy is a mismatch that may lead viewers to improper decisions and assumptions. Thus, perhaps even base maps should be considered when prompting a map reader to think creatively about a problem.

Usability of visualization

Examination of the usability of visualization systems is challenging because the success of a tool set is highly dependent on the specific application and the mental models of the user of the system (Tobon 2005; Fuhrmann et al. 2005). The tasks in visualization applications are not well-defined (Keim 2001) and thus run counter to experimental designs where the dependent variable is often the successful accomplishment of a specific goal. For example, response time is often used in human-computer interaction studies to test for effective tool design; the shorter the time it takes to accomplish a task, the better. Part of the mission of visualization is the uncovering of new insight, an elusive, qualitative goal that may be indicated by *increases* in time spent with a tool, as a user looks for more information, is inspecting the information closely, or is thinking in ways that expand mental models of a phenomenon (Tobon 2005; Rinner 2007).

Data exploration tasks typical of the use of geographic visualization systems require a different type of cognitive associations than the data communication tasks typical of more traditional cartography and information-oriented graphical design (Slocum et al., 2001). There is a greater requirement for unconventional and creative thinking in applications of visualization, and designing information systems in order to encourage such approaches should be a priority. The mental model development through the use of metaphors as discussed above may run counter to this priority, as metaphors by definition rely on familiar and existing conventions, and may serve to, in fact, "blinker" a user to a proscribed way of thinking about a problem.

This notion of blinkering was mentioned as a criticism of the overuse of interface metaphors by Nelson (1990). An designer who is overly focused on the direct mapping of interface functionality to familiar everyday items (clocks, desktops, etc.) may not only constrain his/her own interface design, he or she may also be constraining the mental models developed (and knowledge constructed) by the user of the system. For example, Preece, Rogers, and Sharp (2002) cite a case that an online documentation system, designed to closely mimic a book, had constrained both the users and the designers, preventing them from organizing the material in a more useful way.

Removing these blinkers may be accomplished by either presenting a challenging but ultimately understandable interface that makes the tools actually less "transparent" and, at least at first, useable, or resetting various aspects of the default views so that they present information to users in unconventional ways (but that could then be readjusted by the user in order to match their individual mental models of the ways things "naturally" work). In one of set of separate experiments, our research group found, at the time, a surprising result that supports this notion that interface conventions may actually serve to suppress creative thinking and careful inductive approaches to visual analysis. Below, we report on this and two other experiments that are designed to determine the influence on alternative map design choices, some partially constructed from conventions, on the use of those maps and geo-representations to generate insight and construct knowledge.

Experiment 1: Interrogating the temporal control of an animated map

The first of the three experiments was not originally designed to test the hypothesis that unconventional interfaces actually improved learning in a geovisualization context. However, one result of the first experiment does, in fact, support that claim. The second and third experiments were designed in part in response to what was anecdotal evidence from the first experiment: that by challenging cartographic interface and representation conventions, insight like that which is considered the "holy grail" of geographic visualization (uncovering unknown things, generating hypotheses, etc.) is encouraged and facilitated.

In the first experiment, we wished to determine if students perform differently on animated map-reading tasks depending on the orientation and direction of motion of the temporal indicator in the graphical user interface of the map. Until this experiment, the choice of the direction that the temporal indicator progressed along an animated linear legend has gone unexamined. Though left-to-right seems to have become a "default" direction for this motion, as is evidenced on weather maps, computer movie interfaces, and VCR/DVD controls, we wished to investigate whether this was, in fact, a guideline that could be codified through empirical tests. For example, in certain situations, it may be necessary for a designer of a dynamic map to orient the temporal legend differently (say, from top-to-bottom). Does such a choice have a significant influence on the ability of users to understand the phenomenon?

A total of 527 students were subjects in the experiment. The targeted students came from introductory courses known for a significant cultural diversity, with a relatively high percentage of non-American students[1]. Each student was randomly presented an animated map with a temporal indicator / progress bar that moved either left-to-right (as in a conventional Windows Media Player or QuickTime interface), top-to-bottom, or right-to-left. The subjects were asked a series of questions about the animations.

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[1] one of the independent variables we examined was native language reading directionality; see references for paper with details

Further details and illustrations of this experiment are described elsewhere (Edsall and Sidney 2005), but the data revealed a counter-intuitive result. Subjects who saw the right-to-left temporal indicator (considered by all subjects to be the least familiar interface design) answered questions about the animations more accurately than those subjects that saw the left-to-right indicator. In fact, the most conventional (left-to-right) interface style led to the worst performances of the three possible interfaces.

It seems likely that this result occurred because those subjects who were exposed to the non-traditional interface design necessarily attended to the display more than their counterparts. Inversely, those who saw a traditional interface style might have taken the information on the maps for granted, assuming more about the map than they should. In this first experiment, we did not record the time it took for each subject to respond to the questions, but it seems evident that the non-traditional interface design forced individuals to study the maps more carefully and for a longer time, which led to more accurate conclusions about the phenomenon represented on the animations.

Experiment 2: Challenging the north-up convention

To look into the surprising success of the most unconventional design in the experiment above, and to investigate the use of unconventional elements in geographic representation, and its influence on user understanding, the second experiment consisted of a single question requiring map users to make pattern recognition and feature comparison assessments. We wished to determine whether there was an influence on the orientation of a global map – north-up vs. south-up – on successful estimation of area on the maps. Does a non-traditional orientation (south-up) lead users to a different approach in reading and understanding the map, allowing them to use unconventional and more careful thinking?

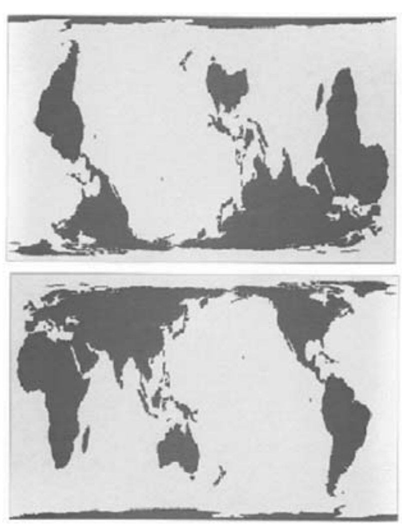

Figure 1. Two cases for north-up experiment: south-up (top); north-up (bottom).

A total of 57 subjects, split between volunteers in front of a student union at an American university and volunteers walking past a public library, were each shown one of two simple maps. Both were cylindrical equal-area projections of the earth in two colors, with land filled with dark gray and water filled with light gray (Figure 1). The maps differed in that one was a traditional north-up map, with the northern hemisphere in the top half of the map, close to the visual center of the page. The other was a south-up map, with the South Pole at the top. We hypothesized that, all else equal, subjects will spend more time answering a question about the south-up map, and will do so more accurately.

We collected three pieces of data for each subject. The first was the subject's estimate of the amount of the area of the earth that is covered by water. We also recorded response time whether or not the subject had an idea about the answer to the water-coverage question before the experiment. Two dependent variables were thus collected for analysis – the estimate of water coverage and the response time of the subjects – with one independent grouping variable – the orientation of the map. The responses of those subjects who claimed to have known the answer previously were removed, and the remaining responses (47 of the 57 subjects) were subjected to Student's t-tests for difference of means (we also ran similar analysis with the 10 subjects retained; results were similar to those described above).

The results indicated that individuals who saw the south-up representation came much closer to the actual water coverage value (about 70%), and that the estimates of water coverage were significantly higher for the south-up respondents (Table 1). This result could be due to one of two factors: first, most of the earth's water is in the southern hemisphere, and a south-up map places the large masses of water in the visual center of the map. This would lead users to tend to overestimate water coverage, at least relative to maps where the large landmasses would be in the visual center (the north-up case). Another explanation, more relevant to the discussion here, is that the south-up representation, being less conventional, would lead map readers to study the map more carefully, looking at it with fewer presuppositions.

Table 1. Difference-of-means test for water cover estimates.

	n	Sample mean (%)	s	t	sig.
north up	21	57.1	11.5	2.93	< 0.01 (45 df)
south up	26	66.3	10.1		

To test this possibility, we also recorded response times. The average response times for individuals who saw the south-up map took significantly longer (Table 2). This result is not surprising, but indicates that the unconventional representation required longer attention, which may mean that users considered the answer to the water coverage estimation question more carefully.

Table 2. Difference-of-means test for response times.

	n	sample mean (sec)	s	t	sig.
north up	21	5.85	2.2	2.88	< 0.01 (45 df)
south up	26	8.57	4.2		

Experiment 3: Altering base map detail to encode uncertainty

Elsewhere, we have argued that, in many cases, representing uncertainty has a positive effect for accomplishing the tasks of visualization (Deitrick and Edsall 2007). Providing information about uncertainty is considered by many users to be either irrelevant or detrimental for successful data communication and insight generation. We promote an argument that uncertainty in geographic data should be made *usable*. Toward that end, we propose a method of uncertainty representation that, once again, alters conventions in cartography: we borrow from the displays of some climate modelers who have encoded the low spatial resolution of their

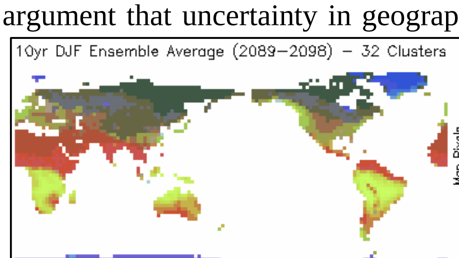

Figure 2. Base map matches spatial resolution of output model

(from www.climatemodeling.org)

output in highly schematic base maps (Figure 2). One way that maps lend authority to data is through an apparently accurate representation of orienting (base map) information. A highly detailed coastline with islands and inlets, or a precisely drawn set of political boundaries, may be mismatched with thematic data of low spatial resolution or high locational uncertainty. Readers may see the detailed and familiar base map and assume that the thematic material is drawn with similar confidence. Conversely, then, one way that uncertainty might be encoded would be an unconventional base map.

In the third of our experiments reported here, we created three choropleth maps of US state-level health data (obesity and a type of cancer). The first was a traditional ("detailed") map showing rates with digitally produced fill patterns on a detailed base map and printed on a color laser printer. The second ("pencil") started with the same base map, printed on a laser printer, but then colored with a colored pencil with the same categories and colors as the first map. Finally, the third ("schematic") map consisted of a highly schematized map of the US (preserving topology relationships; it resembled a population cartogram but the sizes of the states did not encode any variable), filled in using digital color fills, like the first map, and printed on a color laser printer (Figure 3).

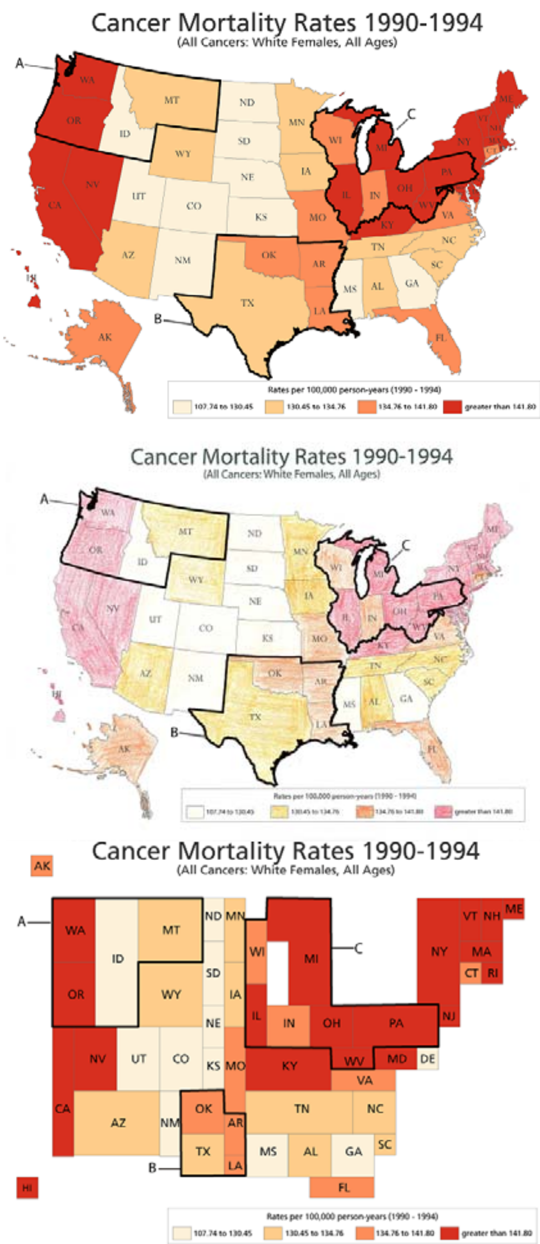

Figure 3. Three types of cancer map, experiment 3: detailed, pencil, generalized.

A total of 35 subjects took part in a study examining and interpreting these three maps. Each subject was asked the same set of questions but saw the maps in random order to eliminate learning effects. Multiple choice questions such as, "which region has the highest rate of cancer?" referred to highlighted regions on the maps. Additionally, we asked three 5-level Likert-scale questions about the subjects' confidence in their decision, their perception of the certainty of the data, and their perception of the reliability of the map, respectively.

Because the data on each of the three maps was identical, as was the classification and color scheme, we interpret any systematic difference in performance, confidence, and perceptions to be a consequence of the different symbolization schemes. Table 3 shows that none of the three maps outperformed another in paired comparisons of accuracy of responses. However, other response variables did show dependence on map type. Decisions about rate estimation were made with less confidence using the pencil map vs. the detailed map. The schematic map was judged to be less “reliable” than the detailed map, and, most importantly for the perception of uncertainty, the data on the schematic map, despite being identical to those on the other maps, was deemed less certain on the schematic map compared to both the pencil and the detailed map.

Table 3. Comparisons for significant differences between pairs (D = detailed, P = pencil, G = generalized).

significant ($p<0.05$)?	**Identification of Region with Highest Rate**	**Confidence in Decision**	**Reliability of Map**	**Certainty of Data**
D v. P	no	yes ($p = 0.024$): D > P	no	no
P v. G	no	no	no	yes ($p = 0.027$) P > G
D v. G	no	no	yes ($p = 0.009$): D > G	yes ($p = 0.003$): D > G

We consider this an important finding, as this reveals that the generalized base map implied to users that the thematic information on that map was less certain than on maps with detailed base maps. However, this appearance of uncertainty did not also lead to loss of confidence in decisions made with the map. This indicates that the unconventional representation of a “rough” base map, which doesn’t correspond to users’ mental models of the shapes of enumeration units or perhaps to their presumptions about the accuracy of maps in general, could be utilized to imply uncertainty without making the data any less useful to the readers.

Discussion

The three experiments described above suggest that unconventional design may aid the understanding of complex geographical problems. In each case, the success of representations that challenge fundamental conventions of geographic representations testifies to their potential usefulness outside of controlled experimental settings. We note that in the first experiment, “conventionality” was not used (in an explicit sense) as an independent variable to measure success, but that the results of that experiment led us to consider the latter two experiments where varying conventions was used as a condition. We also note that the dependent variables used to measure “success” of the representation were not typically associated with “creative” thinking and insight generation, the hallmarks of geovisualization. However, in all three experiments the attention given to the unconventional designs was greater and led to decisions and conclusions that illustrate a reshaping of existing mental models. In the first case, spatiotemporal trends are highlighted and more sharply perceived because of a reorientation of a conventional interface element. In the second case, simple area judgments were completed more accurately after an unconventional map orientation allowed analysis that was less complicated by existing bias and (mis)perceptions about the world. And finally in the third experiment, while the generalized (topologically correct) base map of the United States did not underperform in regional value assessment tasks relative to other map types, it challenged a convention of authority in maps that can be considered a hindrance to decision making under uncertainty.

Conclusion

Cartography has manipulated conventions in the past to create persuasive arguments, but similar strategies in geographic visualization could be implemented to take analysts out of their "comfort zones." The experiments herein have provided support for the idea that unconventional design may serve to alter existing mental models – and the misperceptions that accompany them – in ways that would be beneficial to analysts using maps to explore data and to more general readers using maps to obtain information. By no means are we calling for all conventions of map design to be overthrown for the sake of insight generation; we do not wish to prevent the adoption of tools by users who are discouraged by interfaces and representations that are difficult to understand, uncomfortable, or just plain strange. Our goal is to illustrate to users the subtle ways that even highly interactive systems can perpetuate misconceptions and enforce proscribed ways of thinking that could inhibit the freedom visualization designers hope to provide.

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