

# Charting New Ground: Modeling User Behavior in Interactive Geovisualization

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## ABSTRACT

Geovisualization has traditionally played a critical role in analysis and decision-making, but recent developments have also brought a revolution in widespread online access to geographic data and integration tools, particularly for map-based interfaces. This next generation of geovisualization applications is often characterized by high interactivity and strong end-user participation in both development and use. Building the most effective tools to support user-centered geographic visualization faces a significant challenge, though: very little is known about how people interact with maps. To date, map use research has typically focused on higher order use goals or cognitive interpretations of static map representations. Our research employs Human-Computer Interaction approaches in order to investigate user behaviors that contribute to interactive map use and understanding. This paper describes our approach to studying geovisualization interaction and presents our pilot user studies and initial interaction model. By building a better understanding of how people interact with map interfaces, we will be able to design better user-centered geographic visualizations and learn how to best customize these applications to specific user groups.

## Categories and Subject Descriptors

H.5.2 [Information Interfaces and Presentation]: User Interfaces – *interaction styles, theory and methods, user-centered design.*

## General Terms

Design, Experimentation, Human Factors

## Keywords

Geovisualization, Maps, Interaction

## 1. INTRODUCTION

Building the most effective interaction tools to support user-centered geographic visualization, or geovisualization, faces a significant challenge: “To date, virtually nothing is known about the usability of geospatial technologies” [6]. In laying out the

grand challenges facing geovisualization, MacEachren and Kraak cite the need to “... develop both the theory and practice needed to support universal access and usability for geospatial data and, at the same time, enable greater personalization of geovisualization tools to meet both task and user needs” [5]. This grand challenge gives rise to two complementary research challenges for interactive map visualizations. The *first* is to develop and formalize usability design guidelines for typical end users dealing with different task goals in interactive mapping environments. *Second* is to apply such usability design guidelines in order to personalize interactive mapping environments for better support of particular users dealing with specific tasks.

To help address these challenges, we have developed a user modeling and interaction approach that incorporates Human-Computer Interaction (HCI) methods in behavioral user studies as a foundation to ground and refine map interaction design knowledge. In turn, the design knowledge can serve to ground and refine techniques for personalizing spatial content for users. Here, we focus on the first challenge and present our initial series of behavioral user studies to identify and better understand the basic theoretical foundations of geospatial user interaction.

## 2. INTERACTIVE GEOVISUALIZATION

An important first step in understanding how to design better geovisualization interactions is to understand user tasks and goals. Cartographers traditionally regarded maps as a communication mechanism, where the user’s goal was to understand the message being presented [3]. Geovisualization experts have argued that this view is too simplistic, in light of the shift to more interactive and complex geovisualizations. MacEachren and others [4] have evolved a map use diagram based upon three dimensions of visualization – interaction, data relations, and map audience. These result in four primary map user goals – explore, analyze, synthesize, and present. Our studies focus on the analyze goal.

Other researchers have created lower-level task taxonomies to identify the set of general user tasks in both visualization and geovisualization, including operations such as identify, locate, and correlate [11]. While these taxonomies identify the variety of tasks for a user, they still do not provide significant detail on how users meet those goals within an interactive visualization. Yet, the taxonomies have been useful for structuring studies of user interaction and have been used to improve individual maps and geovisualization techniques [2][9]. More recent studies have also examined usability engineering techniques with screenshot studies [6]. Typically, though, user studies of maps have been used to improve individual maps and geovisualization techniques. Yet, modern geovisualization tools must meet the needs of a wide

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variety of users with a wide variety of data. Perkins, for example, argues for analyses informed by critical cartography [8]. Thus, we need a more general understanding of user interaction in a variety of contexts to provide general-use design guidelines that meet users' needs. Our studies focus on both interactivity and on how underlying user interaction behavior can explain the effectiveness of geovisualization design choices.

### 3. STUDYING INTERACTION BEHAVIOR

We have initially conducted a set of pilot studies in order to understand the issues that would need to be addressed. The pilots were exploratory, observational studies of users performing a variety of map-based tasks, examining their interaction behaviors. Our goal was to understand how users derive meaning and accomplish various analysis goals through interacting with the visualization, and how that behavior varies across user, data, and task contexts. We focused mainly on analysis tasks, which implicitly involve data exploration. Our user studies utilize standard HCI techniques, such as *think-aloud* methodology along with qualitative analysis. Think-aloud studies model cognitive processes by requiring subjects to verbally articulate their thought processes while solving a problem [10]. Since problem solving is a process, not a result, think-aloud methodology gives a more holistic view of how subjects reason to arrive at a given solution.

Specifically, we had subjects complete various tasks using different mapping interfaces (Google Earth and ArcMap) while they were asked to think aloud. Usability software was used to visually and audibly record the participant while completing the study, as well as storing a complete screen capture of the user's session. All data were transcribed and qualitatively coded by multiple researchers to ensure validity and reliability. For the initial pilots, coding was first performed through template coding based on an initial categorization that was developed from previous literature. However, this categorization was insufficient, so we then employed *grounded theory* to create an interaction model based on our user's behavior patterns. Grounded theory is a qualitative analysis technique for identifying themes and their relationships as they emerge from the data [1].

#### 3.1 Pilot 1: Geocaching

We initially sought to study a broad range of participants performing several map-based tasks. Our goal was to choose a tool and set of tasks that were accessible to general, everyday map users in order to observe them doing more traditional navigation tasks as well as analysis tasks with maps. Participants in our first pilot study were asked to use Google Earth to perform geocaching tasks. Geocaching is similar to a treasure hunt where participants use geographic information to locate a geocached target. Specifically, participants were asked to create a plan for walking from a given starting position to a geocaching site on our university campus, then on another unfamiliar campus. The goal was for participants to perform a familiar navigation task but also look beyond roads to sidewalks and other walkways that are abundant on college campuses. Participants were then given a specification of good qualities of a geocaching site, and were asked to analyze each campus for good areas of potential new geocaching locations. Finally, we asked them to choose one location on each campus as a new site. Users were asked to think-aloud as they interacted with the map.

The study involved seven participants, both students and staff at our university. All participants were very detailed in performing

the navigation tasks. They spent much time zooming in and out of the map, carefully choosing and talking through a walking route on both the familiar and unfamiliar locations. A typical user first zoomed out far enough to put both the start and end location on one screen. She then zoomed in to see more details of the roads and sidewalks, and panned small amounts as she chose and talked through a particular path. Occasionally, she zoomed back out to re-locate the end location, and zoomed back in to continue. While most users could have easily chosen a walking path on our own campus using their memory and minimal interaction with the map, most users seemed to want to zoom in and pan through their path in small increments.

Despite the time spent navigating, our larger goal was to observe users during analysis. However, our participants spent very little time on this aspect of the task. They generally scanned the campus very quickly, found a relatively unoccupied area close to their current location, and chose a point, all without much detailed thought. After this pilot, we realized that this kind of geographic-based decision-making was not a very natural and common task for these users. Thus, we decided to completely redesign the study and focus on more complex, data-driven understanding and analysis tasks that are typical in GIS and related disciplines. Still, this study did provide some insights into map interaction.

One interesting finding concerns the role of interface interactivity. With Google Earth, users could zoom in and out either by double clicking on the map, or with the mouse wheel. Double-clicking on a location slowly zooms in by a predetermined amount. With the mouse wheel, users more quickly and easily control the zoom level. This meant that users who utilized the mouse wheel zoomed in and out much more frequently. However, this did not lead them to complete their tasks any faster. Instead, these users explored more of the map at more levels of abstraction. They would zoom in and out even while talking about their navigation path choice, and sometimes just while thinking about their next steps. Thus, greater control and interactivity appeared to lead to a deeper exploration of the map for our participants.

#### 3.2 Pilot 2: Crime data

For the second pilot, visualizations were created with crime data and several quality of life statistics (birth rates, income change, dropout rates, etc.) from our county. ArcMap from ESRI was selected to create a map with a number of layers for the datasets, as well as roads and satellite images.

Participants were asked to look for various patterns of relationships in the datasets. For example:

- Bradley Park is a low crime neighborhood surrounded by high crime neighborhoods. Identify the possible reasons for this using the map and quality of life variables.

For this study, GIS undergraduate and graduate students who were already familiar with map-based analysis and with ArcMap were recruited. Thus, users did not need to be trained in the map program or how to do map analysis. This allowed them to spend more time actually interacting with the datasets.

Participants were given a description of each of the layers in the map, along with 4 task questions. They were not asked to write down or perform any numerical analysis, but instead to think-aloud as they interacted with the map and make verbal conclusions. Four participants were studied in this pilot. Two

| User Goal  | Operation |            |           | User Type      | Action | Data Type | Active Data Result |
|------------|-----------|------------|-----------|----------------|--------|-----------|--------------------|
| Explore    | Select    | Trace      | Measure   | Mapping Expert | Zoom   | Region    | Layers             |
| Analyze    | Identify  | Compare    | Quantify  | Mapping Novice | Pan    | Point     | Features           |
| Synthesize | Locate    | Correlate  | Adjust    | Domain Expert  | Select | Line      | Scale              |
| Present    | Search    | Categorize | Highlight | Domain Novice  | Alter  |           |                    |
|            | Recognize | Position   |           |                |        |           |                    |

Table 1. Potential dimensions for map interaction framework.

were experts with years of GIS experience, and two were relative novices who had each taken several courses in GIS. All of these participants spent significant amounts of time interacting with the map to understand and analyze the data and answer our questions. Thus, this pilot study did allow us to observe detailed analysis behaviors. We used a grounded theory approach to analyze the recordings of each participant. We created a textual timeline of each participant's behavior, writing detailed descriptions of what they were doing and what they were saying as they worked on the tasks. Then, each of their lower-level tasks and goals were labeled to create an overall model of these behaviors, as described in the following section.

In this pilot, we noticed a very distinct difference between the two experts and the two novices. The two experts were familiar with more advanced features of ArcMap and utilized more functionality. They quickly came up with clear strategies for performing our tasks, and followed through those strategies to reach a conclusion. The two experts moved more strategically around the map visualization, delving into the underlying data tables at times for specific values represented on the map. The two novices instead took different strategies: one displayed one data layer at a time, the other turned on most of them all at once, even unnecessary ones. They often arrived at a decision more quickly, based more on visual patterns and expected or pre-conceived data relationships. The experts were more methodical, and explored a greater amount of the data and relationships in our visualization.

### 3.3 Discussion

These two pilots uncovered the range of behaviors, strategies, and expertise of users which geovisualization designers must support. For example, we observed clear differences between expert and novice behaviors. The expert strategy in both studies involved focusing on the data needed, then subsequently moving from higher levels of abstraction to lower, and back again. In Pilot 1, users first found the start and end points to get a general feel for their route. They then zoomed in on the start point, moved a little at a time, sometimes zooming out to see the larger picture and back in again. While a full route could have been chosen at a high zoom level without panning the map, users preferred to choose their route while zoomed in. In Pilot 2, the expert strategies involved first focusing the visualization on the relevant pieces of data, turning on or hiding different layers and selecting a particular neighborhood or datasets as needed. They then used the map as a starting point for gathering more data, opening up smaller data tables to see specific values using an information tool. The numbers gave them a feel of the meaning behind the map symbols, and allowed them to better compare, relate, and correlate various datasets. They frequently returned back to the map to choose the next object of focus or to look at the higher level patterns with their detailed understanding in mind.

Our results suggest that novice users may not be inclined to do deep analysis. In Pilot 1, our everyday users spent almost no time attempting to do any analysis and jumped to a very quick conclusion. In Pilot 2, the more novice users did examine the

datasets, but not as thoroughly or methodically as the experts. This helped us determine that we do need to seek out a broad range of expertise, with both tools and with domain expertise, to ensure we understand the broad patterns of interaction behavior that users may exhibit. We also need to ensure that we choose tasks that experts will relate to, but that novices can still perform. Another interesting observation was that easier exploration of the visualization, either because of greater interactivity in the interface or greater expertise of the user, led to longer task times due to a more thorough examination of the visualization. Thus our goals in improving geovisualization interfaces may not be to make the process more efficient, but instead encourage greater and more in-depth investigation of the data.

## 4. MAP INTERACTION FRAMEWORK

Our Map Interaction Framework identifies a set of task-oriented behaviors that are supported, or impeded, by the various interactive features of the map visualization. The task context of the user is related to the map visualization features through the user's interaction behavior. The finalized framework will serve as a foundational reference for prescriptive interaction design guidelines within interactive mapping environments.

We first identified the expected primary contextual dimensions of the framework, based on previously proposed taxonomies of user goals, operations, and interface actions in interactive and geographic visualizations. Table 1 summarizes these framework dimensions along with representative context values. When complete, the framework will be used to describe all the behavioral patterns we observe in our studies for each task, including the variations and context. For example, consider the *search* task described in Table 2.

| User Task | User Type      | Data Type         | Interaction  |
|-----------|----------------|-------------------|--|
| Search    | Mapping Novice | Geographic Region | <ul style="list-style-type: none"> <li>• Zoom until labels readable;</li> <li>• Pan map;</li> <li>• Click and drag to zoom in; or use zoom in tool multiple times</li> </ul>   |
| Search    | Mapping Expert | Geographic Region | <ul style="list-style-type: none"> <li>• Open attribute table for regions;</li> <li>• Sort name, ascending/descending;</li> <li>• Scroll to locate region name;</li> <li>• Highlight region name row;</li> <li>• Close or hide attribute table;</li> <li>• Right click on layer label;</li> <li>• Click on "Zoom to Selected Boundary";</li> </ul> |

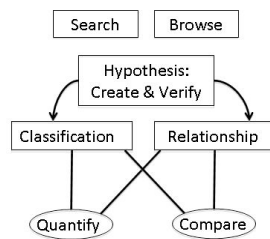
Table 2. Map interaction framework description for example 'search' task.

The four participants in Pilot 2 needed to locate a specific neighborhood as part of one of the tasks. Thus, they were searching for a geographical region on the map. The two novices zoomed in on the map until the neighborhood labels were readable, then visibly scanned the map until the desired area was found. In contrast, the experts both opened up the attribute table

of neighborhoods, located the neighborhood name in the table, and selected the neighborhood. They then right clicked on the neighborhood layer title to open up a menu and selected “Zoom to Selected Boundary”, which zoomed the map into the outlined neighborhood. Both strategies were successful in our study, but on a larger and more complicated map, the expert strategy would be a better option. Thus, an interface should make such a technique easily available for searches. And, if a user performs such a technique, he is indicating strong interest in particular region that the visualization could adapt to.

In analyzing the behaviors in our second pilot study, we began by attempting to label behaviors based on a list compiled from previous research and the first pilot, some of which are listed as the Operations in Table 1. However, we discovered that these categories were not sufficiently distinct to categorize what the participants were attempting to accomplish. Thus, we started over and used a grounded theory approach to determine the list of operations and their relationships based on the behaviors that we observed. This has formed an initial model of interaction behaviors, which will populate the operation column of the Map Interaction Framework.

In Figure 1, we present our initial interaction model based on our pilot studies. As our focus is analysis, the overall goal of users is *hypothesis formation* or *hypothesis verification*. After this step, we found an interaction of four related user goals. To explore hypotheses, users sought to either *classify* data or determine *relationships* between data. In order to do either of these activities, users would *quantify* a particular data item represented in the visualization, or *compare* data items in the visualization. Supporting all of these activities were both *search* and *browse*. A detailed example of searching for a neighborhood is shown in Table 2. We found that participants searched for information at different abstractions. Sometimes their goal was to find a specific object, like an elementary school, and sometimes it was to find objects in general, like all schools in the region.



**Figure 1. Initial interaction model.**

Similar to search, we also found many occurrences of browsing, where participants may have had a goal of exploring a data layer or layers, but not a particular object or set of objects in mind. Instead, we found that sometimes they were trying to familiarize themselves with the map, and at other times, they were trying to plan their next objective. Participants also performed many of the same interaction sequences as search, such as panning the map and turning layers off and on.

We have observed a number of other behaviors, or variations of behaviors, that we have not been able to incorporate into this initial model. For example, users often focused their attention on particular data items through turning on or off data layers, or zooming on the map. They also did a variety of data comparisons looking for different kinds of relationships. We now need to move

beyond our small sample of pilot participants to explore a greater number and variety of people to expand, refine, and validate this model.

## 5. CONCLUSION

Our pilot behavioral user studies have helped to identify, ground and better understand the basic theoretical foundations of geospatial user interaction. Based on this understanding, we have developed an initial Map Interaction Framework to improve end user interactions through better interaction design. We have completed data collection for a larger-scale study of 17 users on a more complex geovisualization and task set in order to verify and validate both the framework and insights on behavioral study design for analysis task goals. We are currently transcribing user sessions for detailed coding and analysis. Through this study, and a planned follow-on, we will refine and expand our interaction model, and identify the patterns of interaction sequences that accomplish and support these user operations. User-centered interactive geovisualizations are increasingly popular, yet they represent largely uncharted ground in terms of fundamental interaction behavior analysis. By exploring how individuals interact with map interfaces, we will be better able to navigate end-user design practices for mapping applications so that both users and the tasks they need to perform are best supported.

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