8-10-2005

# Comparing Different Levels of Interactivity in the Visualization of Spatio-Temporal Data

Samara Ebinger
*University of New Orleans*

# COMPARING DIFFERENT LEVELS OF INTERACTIVITY IN THE VISUALIZATION OF SPATIO-TEMPORAL DATA

A Thesis

Submitted to the Graduate Faculty of the
University of New Orleans
in partial fulfillment of the
requirements for the degree of

Master of Arts
in
The Department of Geography

by

Samara Ebinger

B.A. George Mason University, 1996

August, 2005

For my parents, John and Angela Ebinger

ACKNOWLEDGMENTS

This thesis would not have been possible without the people mentioned below and I am indebted to them all. I would like to thank the members of my thesis committee for all of their help and support:  Dr. André Skupin, for serving as my major professor and graduate advisor, and for his honest criticism and enthusiasm for the work comprising this thesis; Dr. Ron Hagelman for his encouragement and guidance in my graduate studies, and for also giving me the opportunity to work as his graduate assistant; and Dr. Jane Brooks for her vast insight into the urban landscape of New Orleans and the French Quarter. I thank Walt and Ronda Rose for their friendship and support I was lucky to find during my stay in New Orleans. Finally, many thanks to my parents and sisters for their love and support they have continually given me through the years.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure

LIST OF TABLES

Table

## ABSTRACT

The Internet and other advances in technology have dramatically affected cartography in recent decades and yet these new capabilities have not been adequately evaluated for effectiveness. Are dynamic maps more effective than traditional static paper maps in allowing users to visualize spatio-temporal patterns? How important is a higher level of interactivity in visualizing data? Which format is preferred? To examine these questions, human subject tests were conducted to evaluate different levels of interactivity as represented by 1) a static paper map series; 2) an animated map with 'VCR'-type controls; and 3) a toggle map featuring an interactive temporal legend. Results indicate that while the level of interactivity did not affect accuracy of answers to questions regarding spatio-temporal patterns, the total amount of time in which these questions were answered lessened as the level of interactivity increased. Overall, test subjects were more enthusiastic towards the tools featuring greater interactivity.

# CHAPTER 1

# INTRODUCTION

> The world is complex, dynamic, multidimensional; the paper is static, flat. How are we to represent the rich visual world of experience and measurement on mere flatland? (Tufte 1990, 9)

Edward Tufte's question is one that cartographers have grappled with for hundreds of years. However, the map makers of today are no longer forced to represent our world using just a flat two-dimensional surface. Beginning in earnest in the 1960s, the means of production, the distribution, and the look of maps have dramatically changed due to advances and innovations in computer technology. What has also changed is how cartographers view the purpose of maps and modern mapping tools. The rise of the geographic visualization paradigm (born out of the broader notion of scientific visualization) in the late 1980s shifted this focus. Rather than merely serving as an illustration to accompany 'real science', a map may now instead be seen as a way to explore geographic data sets in order to discover previously unknown spatial and spatio-temporal patterns or anomalies. The emergence of the World Wide Web in the mid-1990s has made the computer an indispensable part of how most of us live our lives; it has made access to previously unimaginable amounts of data much easier; it has also fundamentally changed how we produce, distribute and ultimately interact with spatial data and maps.

Time makes a difference. Yet until quite recently, the depiction of space through time was very much a challenge from a cartographic standpoint. Prior to the middle of the 20$^{th}$ century, the two primary options were either the portrayal of time 'steps' on one map or the use of multiple maps to represent different time periods. The introduction of animation in the late 1950s into geographic and cartographic thought provided a promising new medium to depict spatio-

temporal data. In the 1990s, interactive maps[1] allowing for new ways to show data sets began to appear with increasing frequency mainly due to the growth of computer technology and the widespread use of the Internet.

In 1990, Monmonier argued that the use of computers would provide the means to elevate the concept of time to "its proper place in graphic analysis" using two methods: 1) through the use of interactivity, allowing users to freely manipulate the temporal component of the data, and 2) through animation where "the map becomes a scale model in both space and time" (1990, 40). Today, fifteen years later, both of these methods continue to hold such promise, and yet many questions remain unanswered about their effectiveness and how they can be best utilized in the mapping sciences. How do these new computer tools compare with static paper maps in effectively depicting spatio-temporal data? How important a factor is interactivity in using these tools? Before looking to answer these questions, it is first necessary to provide some background information on several key topics.

## A New Era of Scientific Visualization

MacEachren and Kraak (1997, 3) define scientific visualization as "the use of sophisticated computing technology to create visual displays, the goal of which is to facilitate thinking and problem solving." Proponents of the use of visualization as a scientific tool argue that graphic representations of data (including maps) have previously been viewed simply as communication devices for scientific results, rather than as valid methods for analysis. By

[1] The term 'interactive map' typically refers to a computer-based map that allows a user to change the display by utilizing the computer's mouse or keyboard. The Oxford American Dictionary defines the word 'interact' as "to have an effect upon each other." Using this definition, static paper maps may also be interacted with, in addition to computer-based maps. For the purposes of this thesis, this simple definition will be used. The concept of interactivity is discussed in depth in the following chapter.

relegating graphic elements to such a marginal role, scientists were missing out on powerful research tools.

Today most scientists equate scientific visualization with sophisticated computing technology. In fact, the fundamental ideas at the heart of scientific visualization have been around for some time. Collins distinguishes two major eras in the visual representation of scientific data. The first period of scientific visualization began in the middle of the 17th century and continued into the beginning of the 20th century (Collins 1993). It was during this time that innovative techniques for visual data representation such as the statistical graphic were created and perfected by the leading scientists of Europe, including Descartes, Playfair, and Halley. However, Collins considers the map (which preceded these other techniques by hundreds of years) as one of the primary methods of scientific visualization prior to the computer age.

The second era of scientific visualization began in the 1960s, with the dawn of the computer age. However, it was not until several decades later that this paradigm gained widespread recognition within the scientific community. The early 1980s saw many breakthroughs in the field of computer science. Improved technology allowed for increased computing power and speed while reducing the size of computing devices, eventually leading to the introduction of the desktop computer. In terms of scientific research, such innovations helped to change how and for what purposes computer technology could be used.

In 1987, the National Science Foundation’s Panel on Graphics, Image Processing, and Workstations issued a report titled "Visualization in Scientific Computing." This can be identified as the beginning of the modern trend towards visualization that continues to affect many disciplines today. The NSF report dubbed scientific visualization "the new interactive visual medium" (McCormick, DeFanti and Brown 1987, 6). This phrase conveys an important

principle: the ability of computers to provide an unprecedented level of user control, or interactivity, to new forms of visualization.

## Geovisualization

From the late 1980s onward, scientific visualization served as a new way of looking at data exploration in many disciplines, including cartography and geography. However, these two disciplines already possessed a rich history that espoused the fundamental concepts of visualization. It was soon formally defined as geographic visualization, or geovisualization, as it is now most commonly called.

MacEachren and Kraak (2001, 3) define geovisualization as a concept that "integrates approaches from visualization in scientific computing, cartography, image analysis, information visualization, exploratory data analysis, and geographic information systems to provide theory, methods and tools for visual exploration, analysis, synthesis and presentation of geospatial data." Dibiase et al. (1992, 201) assert that "visual representations of data and concepts are indispensable materials in the construction of scientific knowledge."

MacEachren (1994) characterizes geovisualization in terms of map use, in contrast to the theory of map communication, a paradigm that dominated cartography through the mid-1980s. MacEachren conceptualizes map use within a three-dimensional space, with visualization and communication at opposite ends of a continuum (Figure 1). Based on MacEachren's cartography cube, the following conditions converge to facilitate visualization:

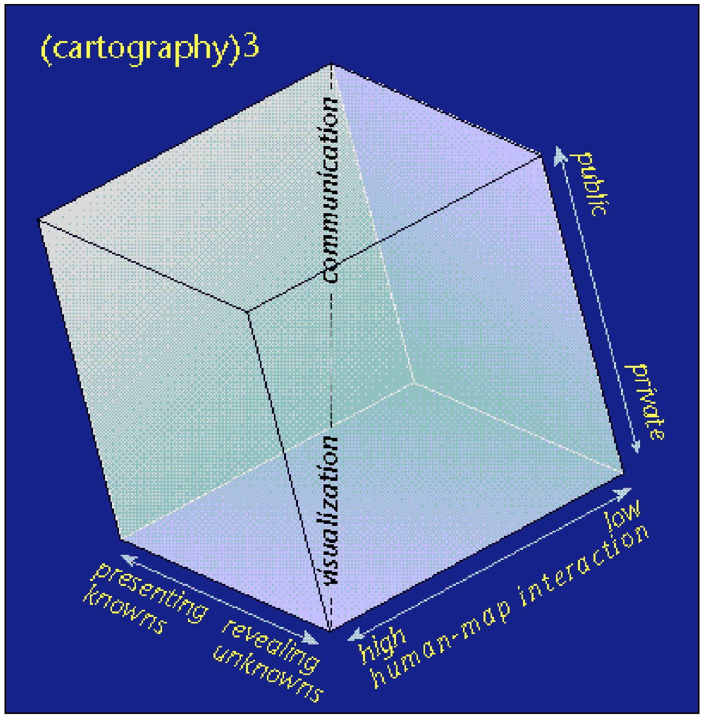



**Figure 1. MacEachren's Cartography Cube**

**Reprinted from Visualization in Modern Cartography by A. M. MacEachren and D. R. Fraser Taylor (Eds.), Oxford: Pergamon, 1994[2].**

1. Map use is intended to reveal unknowns;
2. A map features a high level of interactivity;
3. A map is viewed privately at an individual work station in a research environment.

Geovisualization is seen as a form of 'visual thinking' in which the goal is not to create one ideal map to show a specific data set, but to provide a way to explore the data and to generate ideas about them. MacEachren (1995, 460) once called geovisualization "the most important development in cartography since the thematic mapping 'revolution' of the early 19th century." It has dramatically shifted the focus of cartographic thought in the past decade.

[2] Copyright 1994 (Reprinted with permission from Elsevier).

## Recent Research and Developments in Geovisualization

Since the emergence of geovisualization in the early 1990s, research has primarily focused on the creation of tools that utilize rapidly advancing computer technologies to facilitate spatial data exploration. However, relatively little research has been performed on how these tools can best be utilized for this purpose. It is easy to forget that visualization is first and foremost a mental process; visualization tools are simply aids to this process. Recent studies have expressed a need to shift the focus of research from creating geovisualization tools to studying how they work, how they may best be utilized for specific tasks, and how to make such tools more user-friendly. This is especially important when it comes to the use of animated mapping and interactivity; MacEachren and Kraak (2001, 5) note that when it comes to geovisualization "today's cartographic environments are characterized by two keywords: interaction and dynamics. While visual representation remains a fundamental issue, the focus of both cartographic design and cartographic research now extends to problems in human-computer interaction and in enabling dynamic map and map object behaviors."

It is the purpose of this thesis to evaluate three different geovisualization environments in terms of varying level of interactivity to determine which format allows users to most effectively visualize spatio-temporal patterns and which format users subjectively prefer. These three different interactivity levels/mapping environments include:  1) a static paper map series; 2) an animated map with VCR-type controls; and 3) an interactive toggle map. These three formats will be discussed more in depth in a forthcoming section.

## Depicting Spatio-Temporal Data:  Static Maps

"Conceptualizing the dynamic nature of a phenomenon as it evolves and interacts through space and time is a crucial principle in geographical understanding" (Yattaw 1999, 85). Yet the

representation of spatio-temporal processes in a graphical format is a relatively new phenomenon within cartography. Prior to the computer age, the depiction of such data was restricted to several static mapping solutions. One method included multiple time periods on a single composite map. Another option utilized multiple maps to form a time series. Perhaps because of these limited forms of portrayal, it was not until the middle of the 20$^{th}$ century that spatio-temporal change came to be considered an important topic within cartography and geography (Vasiliev 1997). Contributing to this change undoubtedly were the initial experiments in animated mapping and advances in computer technology that took place at that time.

### The Role of Static Paper Maps in Geovisualization

Static paper maps can be interacted with at a basic level and such activities may include looking over the maps, comparing them to the real environment, and using them for navigation (Crampton 2002). Because of this low level of interactivity, there is debate over whether static paper map displays may even be considered forms of geovisualization by definition. In fact, some definitions of interactivity have purposely excluded static maps, when defining that term in reference to geovisualization (Crampton 2002). While it is arguable that a higher level of interactivity may be appropriate for some mapping tasks, there is little evidence in the body of literature that supports the conclusion that dynamic maps perform conclusively better than static maps in depicting spatio-temporal data in a geovisualization environment.

## Depicting Spatio-Temporal Data: Animation

Cartographic animation in its broadest sense may be defined as the creation of the illusion of movement in relation to space (and in many cases through time)[3]. While the depiction of

[3] A number of disparate definitions of what constitutes cartographic animation exist in the body of literature. This topic will be discussed more in depth in the following chapter.

spatio-temporal data is probably the most common type of cartographic animation produced, non-temporal, attribute-based animations have increasingly become popular as well.

The ability of animation to portray change through time has long been recognized. One of the first animated maps was created by the Disney studios in 1940 to illustrate the Nazi invasion of Poland. However, it was not until almost two decades later that animation was finally perceived as a viable tool within the cartographic research community. In 1959, Thrower advocated the use of animation (at the time, traditional cel- based animation filmed utilizing a movie camera, as used in cartoons) as a way of adding the temporal dimension to cartography.

In the years that followed, cartographers took initial steps to employ animation as a new method for mapmaking. Computer-assisted cartographic animation was first attempted by Cornwall and Robinson (1966), when they used a computer to create individual animation frames. The actual animation was then transferred to film by literally photographing the frames and placing them onto conventional film. Tobler (1970) used a similar approach in his depiction of urban growth in the Detroit region. However, as Harrower (2004, 36) notes, Tobler's study is important because he "used animation to generate new insights into a complex process, rather than to communicate known facts about that process." The promise of animation as a data exploration tool is seen even at this early point in its development and prior even to the formal establishment of geovisualization as a concept.

## Computer Technology, GIS, and Developments in Cartographic Animation

Beginning in the 1980s, revolutionary changes in the computing industry led to the increased power and speed of computers and to the introduction of the desktop computer. Such innovations signaled great changes ahead for cartography and geography (in addition to many other disciplines). One of the most important developments in the geographic and cartographic

sciences has been the growth of *geographic information systems (GIS)*, the computer-based systems that allow for the management, analysis and display of geographic data sets. In the past twenty years, GIS has changed the face of how geographic data is created, managed, and manipulated, and how maps are created. It has also popularized the use of interactivity with regard to maps and made the creation of maps via computer much easier. The growth of GIS, plus the development of computer driven multimedia tools outside of the earth sciences, along with interest generated from the new ideas of geovisualization, reinvigorated interest in cartographic animation in the late 1980s and early 1990s, which, despite its promise, failed to take off as a widespread cartographic tool in the preceding decades.

In 1990, Campbell and Egbert published a comprehensive work on the history and future of cartographic animation, noting that "the relative lack of attention paid to animation is remarkable" (1990, 42). Apparently cartographers took this admonition to heart, as the 1990s saw a dramatic increase in the application of animation. Soon though, additional developments in the computer industry would again dramatically affect cartography and its ever expanding toolbox.

## Cartographic Animation and the Internet

The emergence of the Internet in the mid-1990s fundamentally changed the way digital data of all kinds were distributed. From the viewpoint of animated cartography, the Internet has had several important effects that include:

1) Providing a method of distribution for geographic data and mapping products that allows for unprecedented audiences at a global scale;

2) The underlying interactive nature of the Internet has opened up a wide range of possibilities for how users interact with maps and in general has allowed people to become familiar with interactivity as a concept;

3) Almost any person with a computer can view animated maps at faster speeds and with smaller file sizes using web-ready formats such as Quicktime and Shockwave Flash (Harrower 2004).

### Research Needs in Animated Cartography

Echoing the sentiments of Campbell and Egbert in the early 1990s, MacEachren and Kraak (2001) more recently lamented that the progress made involving cartographic animation over the past ten to fifteen years has been sporadic at best, with many questions remaining unanswered as to the appropriate use of animation in the context of geovisualization. Ogao and Kraak (2002) similarly comment that "when critically assessed, the developments in animation functionality are haphazard and uncoordinated in its efforts."

## Depicting Spatio-Temporal Data: The Use of Higher Levels of Interactivity

In the 1980s, with the emergence of the desktop computer and faster and more powerful computing tools, GIS quickly took off as the primary way to create modern maps. Interactivity is clearly a fundamental component in GIS. The ability to turn on and off and manipulate different data sets and their corresponding symbologies is central to what GIS is and can do. However, such functionality is not typically available to a wide audience:  just to users with the necessary (often very expensive) software. While the GIS analyst may have access to a host of interactive features, frequently the final product she is producing for larger distribution is a static paper or digital map.

It was not until the emergence of the Internet that interactivity became commonplace for most computer users. The ability to choose what we see is what makes the Internet so powerful and popular to users. However, even prior to the Internet, the importance of interactivity to mapmaking was recognized. Campbell and Egbert (1990) identify its importance within the context of cartographic animation, noting that a high level of interactivity is important in making animation as functional as possible. This sentiment was echoed by other researchers in the early 1990s as well (Peterson 1993, Weber and Buttenfield 1993). With the emergence of the geovisualization paradigm and the significance of interactivity within it, its importance only continues to grow.

### Interactivity and Geovisualization: Research Needs

As stated previously, interactivity is a key part of what defines geovisualization. Yet, little research has been performed that deals with this concept within a geovisualization context. Crampton (2002, 96) states that "interactivity has yet to be formally defined and conceptualized." He continues, noting that there is not "yet a grasp of its limitations compared to static mapping practices." Fairbairn et al. (2001, 16) emphasize the importance of studying user interaction with dynamic representations, specifically how users respond to performing particular tasks and how they understand the representations. The authors express a need to "move well beyond the video-player metaphor for interacting with animations."

## Cognitive and Usability Issues: Geovisualization Tools

In order to create effective geovisualization tools, two separate but related efforts are necessary: 1) cognitive research driven by theory (i.e., understanding "how humans create and utilize mental representations of the Earth's environment" and 2) evaluation of methods

employed in geovisualization in terms of usability (Slocum et al. 2001, 62). This thesis is intended to be more relevant to issues of usability rather than to the specific mental processes employed by the user. However, the results should prove helpful in developing relevant cognitive theory in future analysis.

User testing for map effectiveness is nothing new to cartography. However, as cartography has shifted to a primarily computerized format for map generation and viewing, researchers have begun drawing from principles of usability engineering to test geovisualization tools. Usability engineering may be defined as a multi-step process,
typically used in the evaluation of new computer software, to assess user-friendliness and to test whether the software responds to tasks that users expect of it (Slocum et al. 2003).

### Research Needs: Evaluating Geovisualization Tools

Slocum et al. (2001) express a need to determine how well dynamic representations actually work within the confines of geovisualization. The authors state that "although the notions of animation, exploration, and interactivity have enticed cartographers, we should ask whether dynamic representations truly work. Do animations permit users to interpret spatio-temporal patterns more effectively than static maps and do interactive displays enhance user understanding of spatial patterns?" (Slocum et al. 2001, 64). MacEachren and Kraak (2001) similarly comment on such a need for research in this area.

## Evaluating the Effectiveness of Animated Cartography, Static Maps, and Interactivity: Existing Research

An investigation into the literature reveals a paucity of research dealing with the effectiveness of geovisualization tools. To date, no research study has been performed that compares the effectiveness of static paper maps and animated computer-based maps and that

collectively features three stepped levels of interactivity. However, research has been conducted that involves different combinations of these elements. The results of these studies have been somewhat inconclusive with contradictory findings in some cases. One likely reason is the very diverse nature of the geographic data shown. Because there are so many different types of data available and ways of visualizing them, it is difficult to standardize experiments in order that they may apply to different types of data. To date, experiments involving geovisualization have often included census-based data (Andrienko, Andrienko, and Gatalsky 2000; Dykes 1997; Steiner, MacEachren, and Guo 2002) and also climate and weather-related data (Harrower 2002 [b]; Harrower, MacEachren, and Griffin 2000; Slocum et al. 2003; and Weber and Buttenfield 1993). This thesis instead focuses on the use of the different visualization tools to show spatio-temporal change in land use data types. While urban land use data have previously been included in interactive and animated mapping projects (Hamilton et al. 2001) and in a specifically multi-temporal context (Société de développement de Montréal 2005), such data have not been used to purposely evaluate the effectiveness of geovisualization tools.

## Comparing Animation and Static Maps

From very early on in the development of cartographic animation, its capability as a tool has been questioned (Bertin 1967). Surprisingly little evidence has been generated regarding its effectiveness, and the results are mixed. For example, Patton and Cammack (1996) compared the effectiveness of static and sequenced choropleth maps and concluded that sequenced maps held an advantage in terms of speed and accuracy of response to questions about the data sets shown. Koussoulakou and Kraak (1992) found that animated maps depicting spatio-temporal processes held no advantage in terms of accurately answering data-related questions but that response times were much shorter with the animated maps. Similarly, Johnson and Nelson (1998) found

no significant difference in terms of accuracy when comparing static paper, static computer-based and animated maps, but saw faster response times among those who used the animation. In contrast, Slocum and Egbert (1993) compared sequenced and static choropleth maps and found no significant difference in terms of accuracy or speed, but noted that response times were slightly longer for users of the sequenced maps.

### Interactivity

Regarding heightened levels of interactivity, Krygier et al. (1997) noted that participants that utilized multimedia tools for geographic education enjoyed using interactive tools, once exposed to the concept. Dibiase (1999) also found that in a study involving interactivity and geographic education, students liked the interactive controls. Relatively little empirical evidence has been produced that specifically tests the effectiveness of interactive geovisualization tools, and again these studies show mixed results. Harrower, MacEachren and Griffin's 2000 study dealing with interactive techniques for exploratory data analysis showed minimal positive results for the enhanced interactive tools. On the other hand, MacEachren et al.'s 1998 experiment evaluated similar tools and showed more dramatic positive effects.

## Problem Statement

As stated above, the past several decades have brought great advances in computer technology. These advances have reshaped cartography through the implementation of innovative new ways to visualize spatial and spatio-temporal data. However, research studying the effectiveness of these tools has not kept pace with these developments. Interactivity is considered to be a fundamental aspect of geovisualization. However, very little research has been done to determine how important it actually is in visualizing spatio-temporal data.

The goal of this thesis is to examine how different levels of interactivity affect a user's ability to visualize spatio-temporal patterns. This study is intended to provide insight into the following questions in relation to the above-stated goal: Are dynamic maps more effective in allowing users to visualize spatio-temporal patterns than traditional static paper maps? How important is a higher level of interactivity in effectively visualizing spatio-temporal data? The purpose of this thesis is to examine these questions by conducting human subject experiments that evaluate three different levels of interactivity. These three increasingly complex levels of interactivity are represented by three different visualization tools.

## Methods

The three geovisualization tools tested (in order from least interactive to most interactive) include:

1) a traditional static paper map series;

2) a computer-based animated map with VCR-type controls; and

3) a computer-based interactive map series that allows the user to toggle between different temporal views (or *toggle map*).

These three tools were evaluated using a methodology that combines elements of traditional cartographic user testing and usability engineering principles.

### Study Area

The data set featured in the three geovisualization tools is comprised of commercial and public land use types in a portion of New Orleans' French Quarter over the past century. Specifically the study area consists of four parallel city blocks along both Bourbon and Royal Streets in the French Quarter. This area was chosen because it represents a unique urban

environment where it is known that changes have occurred through time in terms of land use, but the specific nature of the changes are not well known. Only two other known studies have previously recorded detailed information about historical land use in the study area (Marcou, O'Leary and Associates 1968 and University of New Orleans 1992).

## Participants

Participants in this project included college students, specifically undergraduate and graduate students enrolled in Geography and Urban Studies courses at the University of New Orleans, in addition to mapping professionals employed by a private engineering firm in northern Virginia. It was anticipated that recruiting such test subjects would be beneficial for the following reasons:

1) They should already have fairly strong computer skills and a familiarity with the Internet; and

2) The urban geographical subject of the maps might be interesting to the subjects because of their area of study/profession and give them an incentive for learning to use the tool.

## Testing Procedure

Four testing sessions were conducted to evaluate the three tools. The first three sessions were conducted on the campus of the University of New Orleans in New Orleans, Louisiana, and featured 31 test subjects (approximately 10 at a time). The fourth testing session was conducted at the headquarters of Dewberry LLC, a private engineering/mapping firm located in Fairfax, Virginia, and included 10 additional test subjects. Subjects were tested on how well they were able to detect spatio-temporal patterns in the visualizations shown and were also asked more

qualitative questions about their individual likes and dislikes regarding the tools. By using both quantitative and qualitative techniques, it was hoped that the most fitting qualities of usability engineering principles and more standard cartographic user testing principles could be best combined to assess the geovisualization tools displayed.

The questions I plan to answer using the results of these testing sessions are: Does the level of interactivity affect a user's performance in detecting spatio-temporal patterns? Are animated maps more effective in depicting spatio-temporal data than static maps in this regard? Which format do users prefer? It is my hope that the results of this research will aid cartographers in more effectively implementing similar types of geovisualization tools in the future.

# CHAPTER 2

# LITERATURE REVIEW

As discussed in the previous chapter, the goal of this thesis is to compare three different methods of geovisualization that use three varying levels of interactivity to depict spatio-temporal data. Buckley, Gahegan and Clarke (2000, 2) consider geovisualization as "not only the development of theory, tools, and methods for the visualization of spatial data, it also involves understanding how the tools and methods are used for hypothesis formulation, pattern identification, knowledge construction, and the facilitation of decision making." From this angle, it is the objective of this thesis to provide answers to the following questions:

- Does the level of interactivity a geovisualization tool provides affect the user's performance in detecting spatio-temporal patterns?
- Are animated maps more effective in depicting spatio-temporal data than static maps in this regard?
- Which format do users prefer?

This review discusses topics relevant to these research questions, and is divided into the following sections: Interactivity, Geovisualization and Static Maps; Definition of Cartographic Animation; Evaluating the Effectiveness of Geovisualization Tools; and Geovisualization Tools and Usability.

## Interactivity, Geovisualization and Static Maps

An argument can be made that geovisualization is simply the re-hashing of an old idea: that idea being that a map can serve as a way to envision and explore data in new ways to generate new ideas. MacEachren and Kraak (1997) dispute such claims, and argue that the new definition of visualization, within the scientific community outside of cartography, is linked to

different ways of visualizing data through high levels of interactivity, three-dimensional modeling and interface design. Furthermore, the authors state that cartographers have not implemented such tools to their full potential in relation to geographic phenomena.

In the eyes of many scientists, high levels of interactivity have come to define what geovisualization actually is, thereby creating a distinction from the traditional static map. How much of a distinction? According to Wood (1994), "the ability to prompt instantaneous changes in maps results not only in a quantitative difference in the number of things a user can make visible, but a qualitative difference in the way users think and in turn in the way maps function as prompts to thinking and decision making." Clearly, to some, geovisualization is seen as something truly revolutionary to the field of cartography. The increasingly important role of user control and interactivity in cartography has been dubbed the "democratization of cartography" (Morrison 1997). Important as these developments are, there remains little empirical evidence to exclude traditional static maps from geovisualization *based on performance alone*.

In terms of feasibility, it is not practical to create a static map series of very large data sets; in such cases it is only logical to employ computer-based geovisualization tools that may rely on high levels of interactivity. At the same time, it is important to remember that visualization is not a computer program or a paper map or any other method of representation, but rather "an act of cognition, a human ability to develop mental representations that allow us to identify patterns and create or impose order" (MacEachren et al. 1992).

## Defining Interactivity in Relation to Geovisualization

Crampton's work on interactivity within the confines of geovisualization is the most comprehensive piece of literature that specifically tackles the subject. He states that "interactivity has yet to be formally defined and conceptualized" and that "there has to date been little effort to

provide a readily applicable set of concepts that would allow the power of interactivity…to be articulated, nor is there yet a grasp of its limitations compared to static mapping practices" (2002, 96). The goal of his work is to construct a typology of interactivity to aid in filling these gaps in the research.

Crampton (2002, 86) states that "there is a surprising degree of variation in the literature in the usage [of interactivity] and how it is employed." Calling interactivity a "nebulous" term, he notes that authors concur that some forms of interactivity are more complex than others but that what actually constitutes these forms is not agreed upon (2002, 88).

A key goal in Crampton's work is to discount the idea that geovisualization is nothing new to cartography by defining interactivity as something "beyond the capability of the static map environment" (2002, 86). He concedes that traditional static maps involve a basic level of interaction, but advocates retaining a distinct meaning for the term as it relates to most geovisualization environments because the types of interactivity involved are so different. Ultimately, he defines interactivity within the confines of geovisualization as "a system that changes its visual data display in response to user input" (2002, 88). This definition purposely separates static maps from most computer-based geovisualization tools.

Crampton identifies a ranked set of interactive tasks that users engage in when performing geovisualization. These tasks are ordered by the complexity and sophistication of the task, and from lowest to highest level are as follows:

1. Data examination;
2. Data comparison;
3. Re-ordering and/or re-sorting of data;
4. Extraction and/or suppression of data; and
5. Cause and effect analysis.

It is a safe bet to conclude that traditional static maps are not best suited to the three higher level tasks: re-ordering/re-sorting data, extraction/suppression of data and cause and effect analysis. However, clearly they are capable of the first two tasks, as Crampton himself states in his article. He discusses the use of small multiples, as advocated by Tufte, as a valid method of data comparison. Tufte (1990, 67) wrote that "at the heart of quantitative reasoning is a single question: Compared to what?" It stands to reason that if static maps are capable of answering this question so important to scientific investigation, should they not also be considered as possible methods of geovisualization?

Based on the five tasks described above, Crampton constructs a preliminary typology of interactivity that includes:

1. Interaction with data;
2. Interaction with the data representation;
3. Interaction with the temporal dimension; and
4. Contextualizing interaction.

Interaction with the temporal dimension (with which this thesis is primarily concerned) is assigned a medium level of interactivity, because of the many different degrees of interactivity (both high and low) possible within this type. Given the fact that there is an acknowledged

variation in level of interactivity, is it really necessary to exclude traditional static maps from such a typology?

Taking into account Crampton's work, it may be argued that for lower level geovisualization tasks such as data examination and comparison in a spatio-temporal context, it is appropriate to consider static maps as geovisualization tools in certain circumstances, given that there is little empirical evidence to dispute this claim. In the literature, small multiples (as coined by Tufte), or side by side comparisons of data in a map series, have been considered as geovisualization tools, but oftentimes in a computer- based form rather than on paper. For example, Slocum et al. created the MapTime computer program which features a variety of ways of visualizing spatio-temporal data, including the use of small multiples on screen. The authors comment that such a method is useful because of the ease in comparing the maps against one another (2000). In addition, Aerts, Clarke and Keuper (2003) recently used static side by side maps as a method to visualize uncertainty in urban growth data.

Clearly there is some debate over issues relating to the role of interactivity and static maps in geovisualization. Conversely, most research scientists agree that animated maps have an important role in geovisualization. The benefits of animation as a tool for data exploration have long been extolled by proponents of scientific visualization. However, its effectiveness as a visualization tool without satisfactory user controls has been questioned (Peterson 1993; Weber and Buttenfield 1993). Also open to debate is what actually defines animation within the boundaries of cartography and geography.

## Definition of Cartographic Animation

Most people have their own idea of what constitutes animation:  you know it when you see it. The *Oxford Modern Dictionary* defines ‘animation’ as “the technique of filming

successive drawings or positions of puppets or models to create an illusion of movement when the film is shown as a sequence."  However, a suitable definition for cartographic animation has been hard to come by. In the early 1990s, Karl noted that a clear definition of cartographic animation did not exist, and there was no consensus as to what it constituted (1992). Unfortunately, today, there is still no standard definition of the term.

The lack of a comprehensive definition of cartographic animation is in part due to the sporadic use of animation in geographic and cartographic research prior to the 1990s. Technical difficulties and cost in production and distribution were major barriers to its implementation on a large scale. In the early 1990s, Fairbairn and Deeley commented that "it is perhaps only by attempting a project involving animated cartography that one begins to appreciate the ease of construction, ease of use, efficiency, economy and portability of the traditional paper map" (1991, 2). Advances in computer technology and the Internet (as discussed in Chapter 1) have made cost and distribution issues much lesser factors, and have allowed research on animated mapping to progress on a much wider scale.

In defining cartographic animation, Lobben (2003) makes a distinction between cartographic animation and computer slide shows in terms of time scale. In an animation "the viewer cannot detect the point at which one graphic in the series replaces the previous, while in slide shows, the viewer can identify the point at which graphics change. In other words, each individual slideshow graphic frame remains on the screen longer than does each animation graphic frame" (Lobben 2003, 318).

Lobben's definition presents several problems. First, how are we to quantify what constitutes a "longer" amount of time using such a definition? In addition, the ability to recognize change from frame to frame is not only related to speed of the animation but also to

the resolution and nature of the data. It seems unnecessary to define animation in such narrow terms. If a simple presentation created using Microsoft Powerpoint conveys the idea of geographic change through motion, why is it necessary to exclude it by definition? Weber and Buttenfield (1993, 141) define cartographic animations as "cartographic displays having a succession of maps pertaining to the same area whose content changes in relation to the independent variable--time." While this definition seems more appropriate, it does exclude non-temporal forms of animation.

Foley et al. (1990, 1057) define animation as covering "all changes that have a visual effect" including changes in position, shape, color, structure, camera position, and lighting, in addition to other factors. Dorling (1992) notes that a narrower definition than this may be inappropriate based on the wide range of possibilities that animation offers.

Animated maps can come in many different forms. They can be created using different computer software, using disparate types of geographic data, with different purposes in mind, and may show either temporal or attribute change. These many differences and combinations are what makes it so difficult to define and classify cartographic animation. It is also what makes it such a potentially powerful tool. Perhaps more research in discovering actual strengths and weaknesses of its applications is necessary before a consensus may be reached on how it may be appropriately classified or further defined.

## Evaluating the Effectiveness of Geovisualization Tools

Geovisualization tools can encompass a large array of types. Most of the existing literature testing the effectiveness of such tools involves the evaluation of animation or the comparison of animated maps with static maps. Dorling comments that "a single map to show something can be extremely effective, hundreds to look at can be bewildering. Animation often

can solve this dilemma--but it can also compound it. Thus we must decide how and when its use is appropriate. Such decisions can only be made with experience" (Dorling 1992, 216). While studies have been performed evaluating the effectiveness of animation and other geovisualization tools, the results have thus far been inconclusive. Following is a discussion of the existing literature on this topic.

## Animated Maps Involving No Interactivity

Koussoulakou and Kraak (1992) compared the performance of an animated map and a static map series in demonstrating spatio-temporal processes. Test subjects were asked a series of questions specifically relating to the data shown in the maps, with response times to the questions recorded as well. No significant differences were found in the quality of answers (i.e., number of correct answers) between the two types of maps. However, response times for the animated map test group were half those of the static map group. Despite the mixed results, the authors argue that "static maps cannot display the evolution of spatio-temporal phenomena for a long period and in high temporal resolution" (Koussoulakou and Kraak 1992, 106). The authors suggest that interactivity, though not implemented in any way in the study, is essential to improving map usage performance and user-friendliness in animated maps.

Slocum and Egbert (1993) compared static maps with sequenced choropleth maps (animated maps that show one class of data at a time in a particular order) and how the teaching of effective procedures affected knowledge acquisition. Results indicated that in terms of test subjects answering data-related questions, there was no significant difference in accuracy or speed of response between the two types of maps. However, the response times were slightly longer for the test group that used the sequenced maps. Conversely, in a similar study comparing

static and sequenced choropleth maps, Patton and Cammack (1996) found that the sequenced maps held an edge in terms of both speed of response and accuracy.

Johnson and Nelson (1998) evaluated the ability of users to recall spatio-temporal patterns and information, comparing the effectiveness of a paper map series, static computer map series, and an animated map. The authors used flow lines as symbology, arguing that areal representations are not effective in animation because the user must constantly shift their focus back and forth between the legend and the map. While this argument may have some merit, not enough research has been performed to nullify the use of animation with areal symbols (especially given the lack of interactivity as a factor in many studies evaluating effectiveness). In evaluating the tools, tasks to be performed were divided into two categories: 1) the estimation of quantity and 2) pattern recognition. Results indicated that there was no significant difference in terms of accuracy or response time for the quantity evaluation tasks. However, for the pattern recognition tasks, accuracy and response times were improved for the testing group that used animation. In terms of tool preference, the testing group as a whole preferred the paper map series to the other tools. The authors surmise that this was due to the lack of interactivity in the other two tools, which resulted in the subjects having the most control over the paper maps.

Aerts, Clarke and Keuper (2003) compared the use of static maps and an animated map in visualizing uncertainty in urban growth data. The results indicate that subjects using the static maps answered data-related questions more accurately. In addition, the static maps were also preferred in terms of technique over the animated map, which a number of the subjects found annoying, possibly because they had no control over it. The test groups consisted of both novice and expert users, with the experts preferring the animated method, possibly because they were more accustomed to it.

Clearly, the experiments discussed above demonstrate an incomplete picture in comparing the effectiveness of both static and animated maps as geovisualization tools. A recurring problem inherent in these experiments is that despite the knowledge that interactivity could play an important role in the use of animations, it was in some cases deliberately excluded from the testing sessions. Although it is impossible to know how much of a difference interactivity would have made in those studies, the fact that it is mentioned repeatedly by the authors (despite its exclusion from the user testing) indicates its potential importance and a need for further investigation.

## Animations Involving Interactivity

A common way to build interactivity into cartographic animations has been through the use of interactive legends. Such tools can be used for both temporal and non-temporal geographic data. Edsall et al. (1997) assessed different types of temporal legends used in cartographic animation, in terms of ability to communicate information and to facilitate visual thinking. The authors argue that in order for an animated mapping tool to be effective, users must not only be able to perceive the actual spatial data presented, but they must also be able to locate that data in real time and to understand the changes that occur through time to the data.

Legends serve several purposes in animated maps depicting spatio-temporal data. Like traditional maps they must explain the meaning of symbols used in the map. However, they must also provide information about the location in time of what is displayed. Furthermore, in interactive programs, a temporal legend may also function as a tool to manipulate time in different ways; for example, allowing the user to move to a specific point in time or even specifying a particular temporal resolution or period within which to aggregate data (Edsall et al. 1997).

Edsall et al. define three categories of visually separate, temporal legends in animated maps:

1. Text based legends with letters and numbers that continually change with the animation (i.e., a digital clock);
2. Linear bars, that utilize some type of icon to 'fill up' the bar as time progresses;
3. Clock-like depictions that show the progress of time similar to a traditional, analog clock.

The authors' goal was to evaluate these legends in terms of their effectiveness in depicting spatio-temporal data. All three maps/legends depicted the same data set: weather patterns through time. The interactions between the test subjects and the linear bar legends and clock legends were also recorded (the text based legend was not interactive) but the results were not included in the study. The results indicated no significant difference between the three legend types in terms of performance or speed.

MacEachren et al. (1998) developed a geovisualization tool for expert users, designed to assist in the exploration of multivariate health statistics, with the goal of evaluating how such tools may facilitate visual thinking, pattern detection and hypothesis generation. Using qualitative analysis methods, the authors discovered that animation was favored by test participants who also visualized patterns quicker over the second test group that featured the more interactive method of "discrete time stepping" through different points in time in the data.

Peterson (1999, 376) examined the use and design of active legends in animated mapping. An active legend "implements an interactive cartographic animation by making the legend an active element of the display." He notes the problems associated with "passive" viewing of animation, such as the difficulty in viewing the map and the legend simultaneously, thereby affecting the ability of the viewer to understand patterns and relationships from an

animation. He considers non-interactive cartographic animation similar to static maps, in that the viewer is allowed only to view a predefined sequence of maps, as opposed to interactive cartographic animation where the user has some form of control over any such sequence.

Peterson's study implemented a 'mouse-over' legend that allowed users to control the animation and toggle between different variables and classification methods. The goal of the study was to determine the level of functionality of the legend type and how it affected the ability of users to identify patterns in the data. His results indicate that subjects were able to comprehend use of the tools and the patterns in the data set adequately.

Antle (2000) evaluated the effectiveness of several different levels of interactivity in terms of exploring data and data quality concurrently. In her work, she evaluates four tools featuring varied levels of interactivity, including 1) side by side computer-based maps, 2) a sequenced or toggle map, 3) an interactive merger bivariate map and 4) a hybrid of a merger map and a hypermap. Based upon the author's description of the tools, the first two types feature a similar level of interactivity in that a scroll bar is utilized for the side by side (supposedly 'static') maps and the toggle map features just one button to toggle between two different maps. The author also notes that the side by side maps were included in the experiment to serve as a 'baseline,' with the expectation that this tool would not match or exceed the level of effectiveness of the other three tools.

Antle evaluated the tools using level of confidence, accuracy, and preference as variables to signify effectiveness, arguing that response times and accuracy may be inversely related and therefore may not be the best measure of effectiveness of such tools. However, one would think that this conclusion could be discounted if either one of these factors remained constant. It is also possible to have a high level of confidence without accuracy; obviously such a result would not

signify that the tool was effective. In fact, based on Antle's results, the level of confidence decreased as the complexity of a given task increased across all tool groups, indicating that confidence did not play a significant role based on the level of interactivity. Overall, results indicated that an increase in interactivity also resulted in increased accuracy. However, in terms of preference, users did not specifically prefer the more interactive of the tools.

Unfortunately, there are few studies assessing geovisualization tools that adequately take into account the concept of interactivity. The studies discussed above indicate mixed results in assessing the role of interactivity in these tools. This is understandable given the paucity of relevant literature. Clearly more research is necessary before any broad conclusions can be derived from such results.

## Geovisualization Tools and Usability

As mentioned in Chapter 1, there is a history of user testing within the discipline of cartography in terms of evaluating mapping products. The studies discussed above adhere to a standard method of evaluation that focuses on quantitative analysis of factors such as response time and accuracy of response to data-related questions. With the advances in computer technology and the shift in method of production of maps from paper to computer, plus the introduction of new computer tools including animation, researchers have recently begun calling on new ways to evaluate maps and mapping tools based on the principles of usability engineering. Usability engineering consists of a typically qualitative multi-step process that is primarily used to evaluate new types of software in the computer industry in terms of user-friendliness and response to tasks expected of users (Slocum et al. 2003). Usability itself may be defined as "the effective, efficient and satisfying completion of tasks by users" (Lee 1999, 38).

Evaluation on the basis of usability engineering principles involves a number of distinct steps. Slocum et al. recommend Gabbard's (1999) work as being particularly useful in terms of geovisualization applications. Four major steps are called for in Gabbard's approach as summarized by Slocum et al. (2003):

1) An analysis of potential user tasks prior to software development;
2) An evaluation of the software by usability experts;
3) Having actual users work with a broad range of software functions;
4) A comparative evaluation of selected user tasks.

Each of these steps is followed by either the development or refinement of the software, resulting in an eight step process.

Even proponents of the application of usability engineering principles to evaluate geovisualization tools acknowledge that it is not necessarily a perfect fit. Andrienko et al. (2002, 327) state that "not only do the standard principles and methods of usability engineering have limited applicability to the design of geovisualization tools, but so do the existing guidelines for conducting usability tests which require that 'the test tasks should specify precisely what result the user is being asked to produce' (Nielsen and Landauer 1993, 185)." Because the goal of geovisualization tools is to focus on the exploration of data sets, it is difficult to standardize the desired end result. Furthermore, "while a software developer tests a specific program, a geovisualization researcher often wishes to evaluate a certain technique in general, i.e., as a concept, irrespective of a particular implementation" (Andrienko et al. 2002, 327).

Despite these issues, more and more studies are relying on usability engineering as an effective method of evaluation for geovisualization tools. Several of these studies are discussed in depth below.

## Testing Geovisualization Tools Using Usability Principles

Kessler (2000) depended solely on focus groups to evaluate his data exploration system on World War II U-boats. His project combined map animation, interactive database querying, static maps, texts and other elements. The results of his focus group indicated that guidance on how to use the tools was very important as was increasing the level of interactivity in the tools. Kessler notes that "understanding the effect of animation on a viewer's ability to further understand and explain spatial processes is a very important aspect of future research in geovisualization. As yet, this research issue is largely untouched in the literature" (2000, 57). While clearly the results of Kessler's focus groups yielded important findings in people's preferences in using the tools, it seems that a more quantitative approach would probably be necessary to tackle the research issue he describes.

In 2000, Harrower, MacEachren and Griffin developed a geovisualization tool designed to facilitate learning about global weather patterns through time. The Earth Systems Visualizer (ESV) featured two interactive tools and was created with two goals in mind:

1) "to integrate exploratory data analysis methods (focusing and brushing) with animation to produce a dynamic interactive representation that represents time as both linear and cyclic;
2) to implement these tools in a geovisualization system that allows users to explore complex spatial and temporal aspects of multivariate continuously changing phenomena" (2000, 279).

The study was directed toward introductory level college students since, the authors note, much of the research involving geovisualization tools has been focused on expert users already familiar with the subject matter. The major objective of the study was to determine whether the

project tools were comprehended adequately, used to effectively answer questions involving spatio-temporal patterns, and to cultivate new approaches to problem solving and hypothesis generation. The study was conducted in three parts. First, an initial prototype of the system was created, followed by a focus group session to assess and later refine the prototype, and finally a formal user testing session was performed using the final version of ESV.

For the formal user testing, subjects were divided into two groups that used two different versions of the software:  one with the focusing and brushing tools and one without those tools. Multiple-choice questions were asked to determine whether subjects could identify basic facts about the data. In addition, open-ended questions were used to determine how well the tool could be used to generate hypotheses and solve problems. These responses were analyzed based on the consistency, dimensionality and confidence of the answers. In addition, the actual system was evaluated using subjective bi-polar word pairs (e.g., unattractive/attractive; clear/confusing) and a seven point scale allowing test participants to rate their opinion of individual components of the program accordingly.

The results of the study indicated that users of the enhanced version of ESV with the interactive tools did not perform any better than the standard version. The authors attributed this to the test subjects not fully understanding how to use these tools and what tasks they would best be suited for, and as a result, suggest that better instruction screens are crucial in the design of such tools. The authors also note that a major finding in their results was that positive feedback in a focus group session does not necessarily translate to a formal user testing session. The ESV tools were very well received in the focus group, but underutilized and misunderstood in the formal testing session.

Andrienko et al. tested several interactive geovisualization tools in terms of usability (2002). This study also incorporated elements of usability engineering for the method of evaluation, but on a wider scale than the other experiments discussed above. In keeping with usability engineering guidelines, the authors first created a set of prototype tools which were then evaluated by potential users and software usability experts. The authors refined the tools based on received comments and then formally tested the tools. Five interactive techniques were tested from three perspectives derived from usability engineering principles:

1) Learnability (i.e., the ability of users to understand the purposes of the tools and how to use them);
2) Memorability (i.e., the ability to retain these skills for a period of time after not using them);
3) Satisfaction (i.e., whether people develop a liking for the tools and are not afraid of them).

The authors note that their research goal *was not to test how the techniques facilitated data exploration*. Instead, the goal was to initially focus on making the tools usable from a software engineering standpoint, and then later to focus on how well the techniques actually facilitated geovisualization (Andrienko et al. 2002).

Slocum et al. (2003) tested the usability of an interactive tool designed to visualize uncertainties in data pertaining to global water system issues. Focus groups were also used as the primary method of evaluation for the MapTime geovisualization tool (Slocum et al. 2004) and Blok's prototype tool utilizing dynamic visual variables to explore spatial data sets (2005). As in many usability engineering studies, these testing procedures were entirely subjective and often

yielded results that were fundamentally tool-specific; no quantitative data were gathered from the sessions.

In light of the recent trend to involve usability engineering principles in the evaluation of geovisualization tools, it is important to note a few drawbacks to such methods. Undoubtedly, it is important to ensure user-friendliness and optimum performance from the viewpoint of software development for geovisualization tools. However, usability engineering can often result in a very time consuming, laborious process: creating the prototype tool, testing with focus groups, testing with usability and domain experts, and finally formal user testing (not to mention adjusting the prototype tool based on the comments received after each of these steps). In addition, all of this work is prior to any actual testing as to how the tool may facilitate data exploration and geovisualization, the presumed primary goal of the tool in the first place.

As evidenced by Harrower et al.'s 2000 study that demonstrated a fundamental lack of effectiveness of focus groups in determining what users ultimately prefer and how they perform using geovisualization tools, usability engineering methods are clearly not proven to be fail-safe. Is it really necessary to undergo such a laborious process to create a usable tool (from a software development standpoint) when ultimately, that tool may be utterly useless in facilitating data exploration and hypothesis generation? It is possible that an abbreviated process may still provide the benefits of usability engineering, but without spending an excessive amount of time; this would be especially helpful in evaluating less complex types of geovisualization tools.

For this thesis, a method of evaluation was utilized that was informed by usability engineering principles as well as by the more standard approaches of traditional cartographic user testing. The latter is reflected in the recording of test subjects' answers and response times in reaction to data-driven multiple-choice questions regarding spatio-temporal patterns. In

addition, open-ended questions were asked in reference to the observed patterns and, further, more qualitative responses were elicited about the test subjects' likes and dislikes regarding the geovisualization tools. Plus, the actual interaction patterns of users of the two computer-based tools (animated map with VCR-type controls and toggle map) were also recorded. It is hoped that this combination of qualitative and quantitative approaches will give a more complete picture of how geovisualization tools may best be utilized to visualize spatio-temporal data, and result in more informed design decisions in the future regarding such tools.

This literature review has documented a need for further evaluation of geovisualization tools in order to demonstrate their ability to effectively show patterns and relationships in spatio-temporal data. The need to measure the effects of interactivity and to determine whether traditional static maps may serve as useful geovisualization tools are key research topics within cartography and geography that need to be addressed. In the next chapter the specific methods used to implement the goals of this thesis will be discussed.

# CHAPTER 3

# METHODS

In order to determine the importance of interactivity as a factor in detecting spatio-temporal patterns in geographic data, user-testing sessions evaluating three different levels of interactivity were performed. Three different geovisualization tools offering three increasingly complex levels of interactivity were created, and are (from least interactive to most interactive):

1) a traditional static paper map series;

2) a computer-based animated map with VCR type controls; and

3) a computer-based map that relies solely on a user's interaction with the map to determine how the data are displayed (hereinafter referred to as a *toggle map*).

This chapter will discuss the data and methods used to create and evaluate these tools.

## Data

All three geovisualization tools used the same data set. As mentioned previously, the study area consisted of four parallel blocks of Bourbon and Royal Streets in the French Quarter of New Orleans (Figure 2). The data were compiled especially for this thesis and depict commercial and public land use types from 1905 to 2000 in five-year increments, in addition to data for 2003. The study area, along with the rest of the French Quarter, was designated as an historic landmark district in 1937 because of its rich architectural and cultural heritage, and today serves as New Orleans' major tourist hotspot.

The study area and data set were chosen because they represent a unique local example of urban geographic change through time. Also, the specific nature of the occurring changes is not well known. Bourbon Street today is known as a primarily adult entertainment driven commercial area and is zoned specifically for such purposes by the city. On the other hand, the

corresponding blocks of Royal Street, just a block from Bourbon Street, mainly support high-end retail establishments. While subtle changes to Royal Street through time may be expected, the Bourbon Street of today undoubtedly differs dramatically in character and business activity from the beginning of the twentieth century.


**Figure 2. Study Area**
**(Base Map Source: New Orleans Metropolitan Convention and Visitors Bureau)**

The four particular blocks of Bourbon and Royal Streets were chosen for the study area for a number of reasons. First, the four blocks of Bourbon Street are part of the Vieux Carré Entertainment District (VCE) designated by the New Orleans City Council in 1978. This special district allows for more intensive use of this area for nightclubs, and other entertainment venues, and was designated for the specific purpose of attracting more tourist dollars to the area. The VCE includes two additional adjacent blocks of Bourbon Street, not included in the study area

for this thesis. Rather than include these blocks, it was decided to instead incorporate the four corresponding blocks of Royal Street instead; it was anticipated that Royal Street would provide a strong contrast to Bourbon Street because of its dramatically different character as is evidenced today. While, it was expected that in some cases the commercial and public land use types of the past would be radically different from its current land use, the precise nature of this difference was unknown. Therefore, it was anticipated that by depicting the changes that had occurred through the past century, interesting and possibly previously unknown patterns could be visualized.

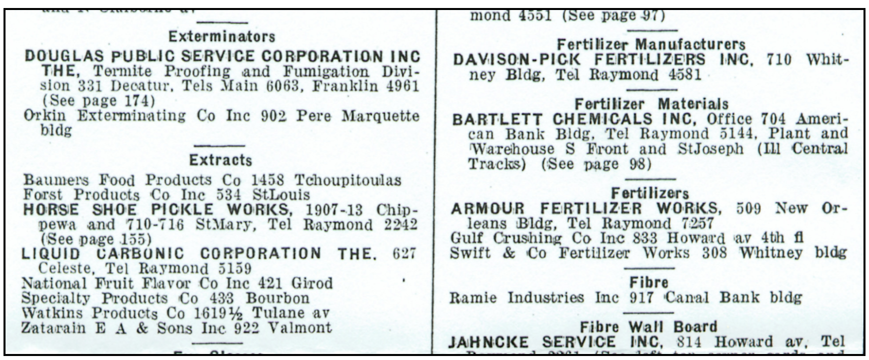
## Compiling the Data

Data were gathered only for commercial and public land use types in the study area. It was decided to omit residential land use from the data set for several reasons. First, business and government addresses and locations were somewhat readily available through the past hundred years. However, in the case of residential buildings, a comprehensive record of such information was not in existence. Although private boarding houses and apartment buildings often appeared in city directories, in the interest of simplicity, it was decided to exclude all forms of residential boarding and housing from the study. In addition, in the earlier half of the twentieth century, most residential boarding in cities occurred on the upper floors of buildings while commercial and other types of uses occurred on the first floor. Because of the added complexity of including three-dimensionality in the geovisualization tools[4], only first floor uses were included in the data set. Since this thesis only deals with first floor uses, using the existing housing data would only have resulted in an incomplete picture of residential housing in the study area.

---

[4] Some complications of using three-dimensionality in this project include: the necessity of adding additional types of interactivity, such as panning/zooming to the two dynamic tools, the inevitable occlusion of some buildings at certain angles, and the difficult task of depicting a 3-D surface on a static paper map.

The raw data were gathered from New Orleans city business directories, published annually beginning in the mid-nineteenth century. For 1905 through 1935, *Soards' New Orleans City Directory* was used to obtain the necessary data. For 1940 through 2003, the *Polk City Directory, New Orleans, Louisiana* was used. To the author's knowledge, these are the only extant directories available for the years considered in this study. These directories contained the business name with street address and business category by year. Because the *Soards'* business directories were organized only by business category (Figure 3), it was necessary to manually scan the entire directory for the necessary addresses located in the study area. In the case of the *Polk* directories, a much easier process ensued, since businesses were instead organized by street block (Figure 4).



Exterminators

DOUGLAS PUBLIC SERVICE CORPORATION INC THE, Termite Proofing and Fumigation Division 331 Decatur, Tels Main 6063, Franklin 4961 (See page 174)
Orkin Exterminating Co Inc 902 Pere Marquette bldg

Extracts

Baumers Food Products Co 1458 Tchoupitoulas
Forst Products Co Inc 534 StLouis
HORSE SHOE PICKLE WORKS, 1907-13 Chippewa and 710-716 StMary, Tel Raymond 2242 (See page 155)
LIQUID CARBONIC CORPORATION THE, 627 Celeste, Tel Raymond 5159
National Fruit Flavor Co Inc 421 Girod
Specialty Products Co 433 Bourbon
Watkins Products Co 1619½ Tulane av
Zatarain E A & Sons Inc 922 Valmont

mond 4551 (See page 97)

Fertilizer Manufacturers

DAVISON-PICK FERTILIZERS INC, 710 Whitney Bldg, Tel Raymond 4581

Fertilizer Materials

BARTLETT CHEMICALS INC, Office 704 American Bank Bldg, Tel Raymond 5144, Plant and Warehouse S Front and StJoseph (Ill Central Tracks) (See page 98)

Fertilizers

ARMOUR FERTILIZER WORKS, 509 New Orleans Bldg, Tel Raymond 7257
Gulf Crushing Co Inc 833 Howard av 4th fl
Swift & Co Fertilizer Works 308 Whitney bldg

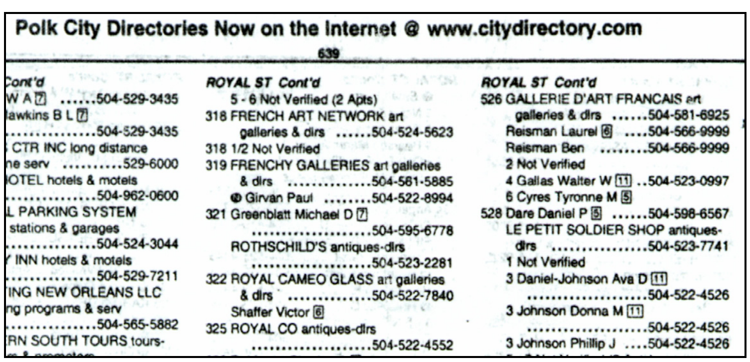
Fibre

Ramie Industries Inc 917 Canal Bank bldg

Fibre Wall Board

JAHNCKE SERVICE INC, 814 Howard av, Tel

**Figure 3. Soards' City Directory entry**



Polk City Directories Now on the Internet @ www.citydirectory.com

639

Cont'd
W A 7 ......504-529-3435
lawkins B L 7
...............504-529-3435
CTR INC long distance
ne serv ..........529-6000
IOTEL hotels & motels
...............504-962-0600
L PARKING SYSTEM
stations & garages
...............504-524-3044
INN hotels & motels
...............504-529-7211
ING NEW ORLEANS LLC
ng programs & serv
...............504-565-5882
RN SOUTH TOURS tours-

ROYAL ST Cont'd
5 - 6 Not Verified (2 Apts)
318 FRENCH ART NETWORK art galleries & dlrs ......504-524-5623
318 1/2 Not Verified
319 FRENCHY GALLERIES art galleries & dlrs ..............504-561-5885
Girvan Paul ........504-522-8994
321 Greenblatt Michael D 7 ....................504-595-6778
ROTHSCHILD'S antiques-dlrs ....................504-523-2281
322 ROYAL CAMEO GLASS art galleries & dlrs ..............504-522-7840
Shaffer Victor 6
325 ROYAL CO antiques-dlrs ....................504-522-4552

ROYAL ST Cont'd
526 GALLERIE D'ART FRANCAIS art galleries & dlrs ......504-581-6925
Reisman Laurel 6 ....504-566-9999
Reisman Ben ........504-566-9999
2 Not Verified
4 Gallas Walter W 11 ..504-523-0997
6 Cyres Tyronne M 5
528 Dare Daniel P 5 ......504-598-6567
LE PETIT SOLDIER SHOP antiques-dlrs ................504-523-7741
1 Not Verified
3 Daniel-Johnson Ava D 11 ....................504-522-4526
3 Johnson Donna M 11 ....................504-522-4526
3 Johnson Phillip J ....504-522-4526

**Figure 4. Polk City Directory entry**

## Organizing the Data

Once a business or government establishment was identified as being located within the study area, it was necessary to classify it into an appropriate business category. This was done by matching the directory category of a particular business (e.g., shoemaker) to the North American Industrial Classification System (NAICS), the coding system established by the U. S. Census Bureau in the late 1990s to categorize modern business establishments. Each business or government entity was assigned a two-digit sector number, corresponding to the broadest level of business classification using the NAICS system (Table 1). Detailed information about the NAICS system and its sectors is available on the U. S. Census Bureau web site at www.census.gov.

All data gathered from the business directories and their corresponding NAICS codes were entered into a database using Microsoft Access so that the data could easily be queried and manipulated. Each individual entry included the following information: name of business, proprietor (if available), street address, business category (as shown in directory), and NAICS sector code.

It was later determined that since the classification of the data by NAICS sector code resulted in at least nine different categories, it would be necessary to further refine the classification and reduce the number of categories in order to make it easier for users to logically comprehend the data and not be overwhelmed by it. Based on the dominant types of uses that showed up in the time frame of the study, the data were reclassified into five categories (Table 2).

**Table 1. NAICS Sector Codes and Descriptions**

| Sector Code | Sector Description |
|---|---|
| 11 | Agriculture, Forestry, Fishing and Hunting |
| 21 | Mining |
| 22 | Utilities |
| 23 | Construction |
| 31-33 | Manufacturing |
| 42 | Wholesale Trade |
| 44-45 | Retail Trade |
| 48-49 | Transportation and Warehousing |
| 51 | Information |
| 52 | Finance and Insurance |
| 53 | Real Estate and Rental and Leasing |
| 54 | Professional, Scientific, and Technical Services |
| 55 | Management of Companies and Enterprises |
| 56 | Administrative and Support and Waste Management Services |
| 61 | Education Services |
| 62 | Health Care and Social Assistance |
| 71 | Arts, Entertainment, and Recreation |
| 72 | Accommodation and Food Services |
| 81 | Other Services (except Public Administration) |
| 92 | Public Administration |

## Adding the Building Footprints

After consulting with city officials, it was determined that a digital file containing footprints of the buildings in the study area was not readily available. Instead, the footprints for the applicable buildings were digitized using two different sources: Sanborn Fire Insurance Maps (of varying years) and the Vieux Carré Commission's web site (www.new-orleans.la.us/home/vcc) which features a map depicting historical significance by building and includes the current building footprints for all extant buildings in the French Quarter.

**Table 2. Reclassified Data Types**

| NAICS Sector and Code | New Category |
|---|---|
| Manufacturing (31-33) | Manufacturing |
| Wholesale Trade (42)<br>Retail Trade (44-45) | Retail and Wholesale Trade |
| Arts, Entertainment, and Recreation (71)<br>Accommodation and Food Services (72) | Arts and Entertainment;<br>Hotel and Food Services |
| Utilities (22)<br>Construction (23)<br>Other Services (81) | Miscellaneous Services |
| Information (51)<br>Finance and Insurance (52)<br>Real Estate and Rental/Leasing (53)<br>Professional, Scientific, Technical Services (54)<br>Education Services (61)<br>Health Care and Social Assistance (62)<br>Public Administration (92) | Professional, Education,<br>and Administrative Services |

(Only NAICS Sectors represented in the study area during the given time period are included in this list.)

Because buildings were razed and new buildings constructed at various points in time, it was necessary to review different sets of maps made throughout the century to make sure all prior buildings were incorporated into the appropriate data set by year. Once the necessary source data were located, the footprints were, if necessary scanned into a digital format, and digitized using AutoCAD digital drafting software. Care was taken to divide buildings with multiple addresses (often buildings housed two or more separate businesses on the lower level) into different segments. By doing this, it allowed for the depiction of multiple land use types within one building. As it happens, this occurred frequently throughout the study area over time.

Symbolizing the Data

Once the classification system was set and the building footprints digitized, a color classification scheme was necessary. Because the different land use types do not represent a quantitative type of classification, but instead are qualitative, reflecting differences in kind, it was determined that a classification system based on varying hues would be most appropriate.

After the legend was finalized for the three geovisualization tools (Figure 5), the individual frames featuring the building footprints by year (previously created in AutoCAD) were imported into Macromedia Freehand illustration software to apply the color scheme to the buildings. The software was chosen for its compatibility with AutoCAD drafting files and for its ease in mixing and applying color to objects.


**Figure 5. Legend: Commercial and Public Land Use Types**

## Creating the Geovisualization Tools

### Static Map Series

To avoid unnecessary confusion to the map users, it was decided to make all three geovisualization tools as simple and straight forward as possible. In addition, all three were made to look as similar to each other as possible. Once the individual 'frames' for each year featured in the study were created, it was relatively easy to create a paper map series out of them. In all, seven map sheets (each sized 7 ¼ inches by 24 inches) were created showing three different maps chronologically arranged (in five year increments, eg., 1905, 1910, and 1915) on it. A title and legend were added to each sheet. A scale and north arrow were not included on the static maps (or any of the three geovisualization tools), as these elements were not considered essential

to the interpretation of the data. A digital representation of the seven map sheets (not to scale) is included in Appendix A.

## Computer-Based Maps

The two computer-based visualizations were created by first importing the previously constructed map frames into Macromedia Director multimedia software. The completed animations were saved as stand-alone Director Projector applications viewable on any Windows-compatible computer. These animations are included in Appendices B and C.

The two mapping environments were kept as similar as possible so that altered design elements would not be a factor in the evaluation of the tools. A simple circular temporal legend was chosen for both tools because of its similarity to a clock face, something commonly associated with time. Also, this design allowed users to easily jump between different time frames using the toggle map (which would have been more difficult using a linear bar type legend). In addition, to reinforce the date shown to the user, the numeric year displays in the middle of the circular legend for both tools (Figure 6).

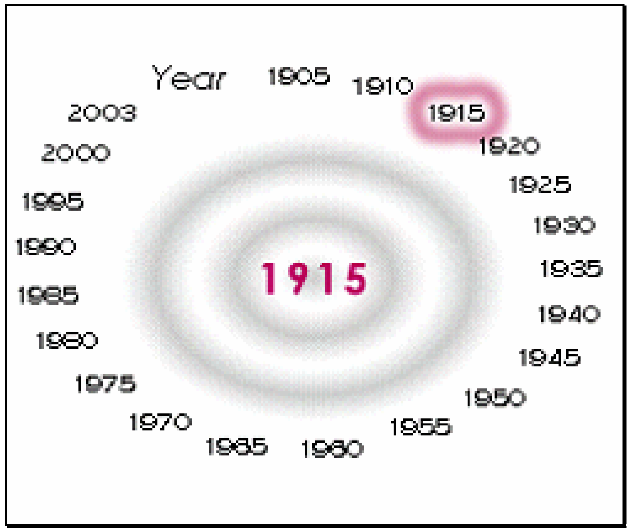



**Figure 6. Temporal Legend for Computer-Based Animated Maps**

### Animated Map with VCR-Type Controls

The map animation was created with a level of interactivity consistent with standard VCR-type controls typical in many animated maps. These included a ‘Play’ button, ‘Stop’ button, 'Pause' button, and ‘Step Forward’ and ‘Step Backward’ controls (Figure 7). The overall speed of the animation was kept purposely slow. This was done because the ‘Step Forward’ and ‘Step Backward’ buttons allow the user to speed up the animation if desired. Initially it was planned to create a tempo control panel that allowed users to interactively control the speed of the animation. It was decided not to add this function because it appeared somewhat redundant in conjunction with the ‘Step Forward’ and ‘Step Backward’ buttons. Also, since this animation tool represents the middle level of interactivity, it was important not to add too much interactivity in order to contrast it appropriately with the toggle map, the most interactive of the three tools.

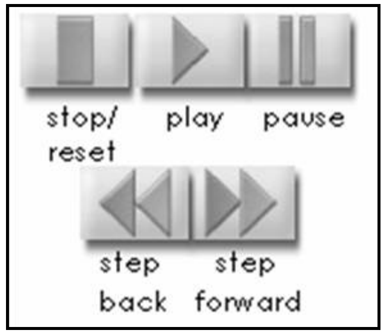



**Figure 7. VCR-Type Control Buttons**

**Toggle Map**

The interactive toggle map features a temporal legend identical to that of the animated map. However, instead of having VCR-type controls, the temporal legend serves as an interface that allows users to 'mouse-over' any one of the twenty one frames of data depicted. When a user places the computer mouse over a certain year, the map appears on the screen, allowing her to toggle between any of the maps available in any desired order.

## Testing the Geovisualization Tools

### *Recruiting Participants*

Test participants were recruited from two different sources. College students, including both undergraduate and graduate students, were recruited from Geography and Urban Studies courses at the University of New Orleans. Participants were randomly assigned to one of three different testing sessions, corresponding to each of the three different geovisualization tools. The testing sessions were held in a computer lab accessible to the Department of Geography in the Liberal Arts building of the University of New Orleans. Additional test participants were recruited from the Geodigital Services and Hazard Mapping divisions of Dewberry LLC, a private engineering firm in Fairfax, Virginia. Participants were randomly assigned one of the

three geovisualization tools to evaluate. The testing session was held in an unused area of the company's headquarters.

## The Testing Process

A total of 41 test subjects participated in the project. Of the 41, 31 were students at the University of New Orleans (13 graduate students and 18 undergraduate students), and 10 were mapping professionals employed by Dewberry LLC. Divided by gender, there were 14 female participants and 27 male participants. Divided by area of study, 22 had an educational background in geography with the remaining 19 in various other disciplines.

After first signing a consent form (required by the university for all tests using human subjects-see Appendix D) participants were asked to fill out a brief questionnaire providing background information about themselves, including education level, coursework completed in geography, urban studies, and/or GIS, familiarity with the study area and the Internet (Appendix E).

Test participants then completed a brief computer-based tutorial, explaining the nature of the study, the tasks expected of them, and a short demonstration version of the geovisualization tool they were to use. In the case of the static paper maps, for purposes of consistency, participants also undertook an abbreviated version of this computer-based tutorial. It was assumed that subjects would be familiar with the paper map format.

Test participants were allotted three minutes to view the map assigned to them for the session. Participants then answered four multiple-choice and two open-ended questions that dealt specifically with the spatio-temporal data they viewed (Appendix F). All participants, including those who viewed the static map series, answered the questions via computer in order to record

the amount of time required to answer the questions. For the computer-based maps, mouse movement in conjunction with the maps was also recorded for further study.

Finally, test participants answered three open-ended questions concerning their overall impression of the geovisualization tool used (Appendix G).

## Choosing Which Questions to Ask

In order to determine how well the different levels of interactivity/geo-visualization tools performed in depicting spatio-temporal change, it was crucial to develop a set of relevant questions for test participants to answer. While the open-ended questions were left purposely vague to allow the participants to respond as they saw fit, it was important to quantify the level of difficulty a particular change-recognition task represented in reference to the four multiple-choice questions.

Harrower proposed the notion of the Change Task Cube, which he defines as "a conceptual framework for systematically characterizing 1) the kinds of visual change-recognition tasks associated with animated maps, and 2) the relative difficulty of those tasks" (2002 [a], 189). Based on this framework, Harrower states that three factors need to be considered in differentiating change-recognition tasks:

1) the number of entities involved (e.g., one region, multiple regions, all regions);

2) what type of information is needed regarding the entities (e.g., qualitative vs. quantitative types of information); and

3) the spatio-temporal extent involved (e.g., 1 year vs. 10 years).

Harrower concludes as a general rule, that as the total amount of information on the map increases, it becomes more difficult for viewers to track those changes.

Four multiple-choice questions were formulated that vary in complexity based on the

number of entities (i.e., tracking patterns for one of the two streets vs. both streets) and the spatio-temporal extent (i.e., tracking patterns for a smaller period of time vs. the entire time frame (Appendix F). Since the information (land use type) does not change in type and is qualitative, this factor was not considered in formulating the questions. The four multiple-choice questions are discussed below in order of complexity of task.

The first question below features a large spatio-temporal extent (i.e., the entire duration of the study time period) and also requires the test subject to differentiate between the two streets featured in the data set (number of entities). Therefore this question is the most complex of the four in terms of change recognition task:

***For the duration of the time period shown, Royal Street has always been dominated by which land use type?***

*a) Arts and Entertainment*
*b) Professional, Education and Administrative Services*
*c) Retail & Wholesale Trade*
*d) Miscellaneous Services*
*e) Manufacturing*
*f) Don't know*

The next question also requires the test subject to differentiate between the two streets within the data set, rather than looking at the entire data set holistically. The spatio-temporal extent is reduced, in that only the data prior to 1960 are required to answer the question:

***Prior to 1960, Bourbon Street:***

*a) was dominated by Retail/Wholesale Trade.*
*b) was dominated by Manufacturing.*
*c) had a mixture of diverse land use types.*
*d) was dominated by Arts & Entertainment; Hotel & Food Services.*
*e) was dominated by Miscellaneous Services.*
*f) was dominated by Professional, Education and Administrative Services.*
*g) Don't know.*

The next question does not require the test subject to differentiate between the two streets in the data set resulting in a less complex task. However the spatio-temporal extent covers the entire duration of the study time period:

***In general, commercial and public land use types became more diverse through time in the study area.***

*a) True (Very Certain)*
*b) True (Somewhat Certain)*
*c) Don't Know*
*d) False (Somewhat Certain)*
*e) False (Very Certain)*

The last question represents the least complex change recognition task since it does not require the test subject to differentiate between the two different streets and also does not deal with the full spatio-temporal extent of the data:

***Which two land use types became dominant in the study area from 1950 up to present day?***

*a) Manufacturing and Retail & Wholesale Trade*
*b) Arts & Entertainment;Accommodation & Food Services and Retail & Wholesale Trade*
*c) Professional, Education and Administrative Services and Miscellaneous Services*
*d) Don't know*

This chapter has discussed the methods used to create the spatio-temporal data set of commercial and public land use in the study area and the three geovisualization tools representing three different levels of interactivity. Also outlined were the procedures used to implement the user testing sessions organized to evaluate the tools. In the following chapter, the results of these testing sessions will be analyzed and discussed in detail.

# CHAPTER 4

# ANALYSIS AND RESULTS

As discussed in the preceding chapter, three different geovisualization tools offering three increasingly complex levels of interactivity were created, and are (from least interactive to most interactive):

1) a traditional static paper map series;

2) a computer-based animated map with VCR-type controls; and

3) a computer-based map that relies solely on a user's interaction with the map to determine how the data are displayed (or *toggle map*).

The following questions will be addressed using the results of the user testing sessions featuring the three tools:

- Does the level of interactivity affect a user's performance in detecting spatio-temporal patterns?
- Are animated maps more effective in depicting spatio-temporal data than static maps in this regard?
- Which format do users prefer?

Once the testing sessions discussed in the previous chapter were completed, the results were analyzed using two different methods. As stated previously, one goal of this thesis was to employ both quantitative and qualitative methods (taking cues from traditional cartographic user testing and also from usability principles often used in designing and evaluating computer software). Four multiple-choice questions asked of all participants in relation to the data viewed

were used to conduct the quantitative analysis[5]. For the qualitative analysis, short answer questions dealing with both the data and the specific tools used were asked. This chapter will discuss the quantitative and qualitative analysis results using the data gathered from the testing sessions in two separate sections.

## Quantitative Analyses

### Research Hypotheses

In order to address the research questions discussed above (using quantitative analysis methods), the overall level of performance of test subjects by tool type was assessed. For the purposes of this project, overall performance was measured using two separate variables: accuracy and speed. In terms of analysis, two hypotheses were tested using inferential statistics. These hypotheses are as follows:

*1. Higher levels of interactivity do* ***not*** *affect* ***accuracy*** *in the recall of spatio-temporal patterns based on multi-temporal geovisualization.*

*2. Higher levels of interactivity do* ***not*** *affect* ***speed*** *in the recall of spatio-temporal patterns based on multi-temporal geovisualization.*

### Computing the Variables

The independent variable in this research project is the geovisualization tool type (i.e., the three levels of interactivity as represented by the static paper map series, the animated map with VCR-type controls, and the toggle map). For this project, overall level of performance was measured in terms of two separate dependent variables: accuracy and speed. These two variables

[5] One of the multiple-choice questions (See Appendix F) featured a true/false format with Likert Scale answer options in terms of certainty of answer (e.g. Very Certain, Somewhat Certain, etc.) After considering the type of analysis to be performed on the data, it was decided to reclassify the answers for this question as either incorrect or correct (regardless of certainty of the test subject).

were derived from data collected from the four multiple-choice questions asked of all participants at the end of their respective testing sessions.

**Accuracy**

Accuracy as a measure of overall performance in utilizing the three different geovisualization tools was measured in two separate ways: 1) as the individual answer to each of the four multiple choice questions (i.e., correct vs. incorrect answer) and 2) in terms of the number of correctly answered questions, out of the four total multiple choice questions. In the former case, since answers were classified as either correct or incorrect, this data variable is a nominal level of measurement (i.e., no ranking is possible). In the latter case, the number of correct answers is a ratio level of measurement (i.e., the intervals between data points are known and there is an absolute 0 established). The four multiple choice questions with correct answers noted are available in Appendix F.

**Speed**

Speed, as a measure of overall performance in evaluating the three different geovisualization tools, was also measured in two separate ways: 1) as the individual response times to each of the four multiple-choice questions and 2) as the total response time to all four multiple-choice questions for each test subject. All response times were recorded in milliseconds using a tracking file on each computer used in the testing sessions. These two speed variables have a ratio level of measurement (i.e., the intervals between data points are known and there is an absolute 0 established).

## Choosing a Method of Statistical Analysis

In reviewing the relevant literature in which similar user testing experiments were performed, the more common methods of inferential statistical analyses (the choice of which of course relies heavily on the nature of the data sets used) include the parametric analysis of variance test (ANOVA) (Edsall et al. 1997; Patton and Cammack 1996; and Johnson and Nelson 1998) and the t-test (Koussoulakou and Kraak 1992), in addition to the nonparametric chi-square test (Aerts, Clarke and Keuper 2003) and the Kruskal-Wallis test (Edsall et al. 1997 and Harrower 2002 [a]). The first step in my analyses was to determine the most appropriate type of statistical test for the data sets gathered.

The most frequently used and preferred type of inferential statistics are parametric tests (e.g., *t*-test, ANOVA). However, a number of assumptions about a data set must be made when using parametric tests. These include that:

- the data must have an interval or ratio level of measurement;
- random sampling must have occurred;
- frequency distributions must be normal; and
- population variances must be equal.

In cases where these assumptions are not met, other (nonparametric) tests are more appropriate.

Since the first accuracy variable (correct vs. incorrect answers to individual questions) in this project is a nominal level of measurement, a nonparametric test was determined to be the most appropriate choice. Furthermore, while the two speed variables and the remaining accuracy variable (total number of correct answers) feature a ratio level of measurement, they do not have

normal frequency distributions. Hence, nonparametric testing was also deemed most appropriate for these variables.

## Nonparametric Statistical Tests

### Testing Using the Accuracy Variables

The chi-square test was used to analyze the first accuracy variable (i.e., correct answers for each of the four multiple-choice questions depending on the geovisualization tool type). The chi-square test is nonparametric and is used in evaluating nominal or categorical data in cases where there are three or more different groups. Specifically it compares observed and expected frequencies to determine if there are any statistically significant differences between the two.

First, the raw data sets were converted into a Microsoft Excel spreadsheet containing test subject identification number, geovisualization tool type tested, and correct/incorrect answers for each question (Appendix H). Next, the Excel file was imported into the SPSS 10.0 statistical software program. The Pearson's chi-square test statistic was calculated for the correct/incorrect answers to each of the four questions and cross tabulated with geovisualization tool type. A standard significance level of 0.05 was considered valid for the analysis. Two degrees of freedom were used in the analysis which resulted in a critical value of 5.99 at the 0.05 significance level.

The results of the chi-square test indicate that there was no significant difference in the accuracy of the answers to any of the four questions in terms of geovisualization tool type. Printouts generated from the chi-square test results are attached as Appendix I.

The Kruskal-Wallis test was used to analyze the second accuracy variable (i.e., total sum of correct answers to the four multiple-choice questions for each test subject). The Kruskal-Wallis test is a nonparametric independent group comparison test and a generalization of the

Mann-Whitney procedure. It is used to explore for significant differences between three or more groups and serves as an alternative to the independent group ANOVA test when the assumption of a normal distribution cannot be met. The ranks of data rather than raw values are used in calculating the statistic. This test requires that the data must be interval, ratio or ordinal level data.

Again, raw data sets were converted into a Microsoft Excel spreadsheet (Appendix H), which was then imported into the SPSS 10.0 statistical software program. The Kruskal-Wallis test was applied for the total number of correct answers for each test subject with the geovisualization tool type as the grouping variable. A standard significance level of 0.05 was considered valid in this analysis.

While the results of the Kruskal-Wallis test indicate that there was no significant difference in terms of total number of questions answered correctly when grouped by geovisualization tool type, the mean number of correct answers does increase slightly as the level of interactivity increases (Table 3). Printouts generated from the Kruskal-Wallis test results are attached as Appendix J.

**Table 3. Mean Number of Questions Answered Correctly**

| Geovisualization Tool Type | Static Paper Map Series | Animated Map with VCR-Type Controls | Toggle Map |
|---|---|---|---|
| Mean Number of Correct Answers | 2.38 | 2.62 | 2.87 |

Based on the results of the statistical analyses discussed above, the following research hypothesis cannot be rejected:

*Higher levels of interactivity do* ***not*** *affect* ***accuracy*** *in the recall of spatio-temporal patterns based on multi-temporal geovisualization.*

**Testing Using the Speed Variables**

Basic descriptive statistics were calculated for the speed variables and are summarized in Table 4. From looking at the mean response times, it is evident that they decrease as the level of interactivity increases. Furthermore, the total response times of the two computer-based tools (77,221 and 70,259 for the animated map with VCR-type controls and the toggle map, respectively) are much closer to each other than those of the static paper map series group (94,374). However, in order to determine if these differences were statistically significant, it was necessary to perform further statistical analyses of the data sets.

**Table 4. Mean Response Times (in milliseconds)**

| | Static Paper Map Series | Animated Map with VCR-Type Controls | Toggle Map |
|---|---|---|---|
| Question #3 | 22,490 | 23,076 | 18,298 |
| Question #4 | 24,164 | 17,951 | 18,590 |
| Question #5 | 21,388 | 17,884 | 16,352 |
| Question #6 | 26,332 | 18,310 | 17,019 |
| Total Response Time | 94,374 | 77,221 | 70,259 |

As with the second accuracy variable, the Kruskal-Wallis test was used to analyze the two speed variables (i.e., response times for each multiple choice question and total response time for each test subject). The raw data sets were converted into a Microsoft Excel spreadsheet containing the test subject's identification code, geovisualization tool type tested, response time for each question and total response time (Appendix H). The spreadsheet was imported into the SPSS 10.0 statistical software program where the Kruskal-Wallis test was applied to the response times for each of the four questions and for the total response time for each test subject. A standard significance level of 0.05 was considered valid in this analysis.

The results of the analysis indicate that there was no significant difference in terms of response times and geovisualization tool type for any of the four individual questions. However,

for the total response time there was a significant difference in terms of geovisualization tool type (0.039 < 0.05). Printouts generated from the Krukal-Wallis test performed in SPSS are available in Appendix K.

Based on the results of the Kruskal-Wallis test discussed above, it appears that the following hypothesis may be *rejected*, when considering the total response time of test participants:

*Higher levels of interactivity do **not** affect **speed** in the recall of spatio-temporal patterns based on multi-temporal geovisualization.*

## Qualitative Results

As stated previously, a number of open-ended questions were asked of test participants in order to obtain a more qualitative view of the effectiveness of the three geovisualization tools. The responses to these open-ended questions are discussed below.

### Questions about the Data

Two of the questions asked dealt with the specific nature of the historical land use data (See Appendix F). Specifically, participants were asked about particular patterns they saw in the data through time and about any conclusions or hypotheses they were able to formulate from viewing the data. Across the board, it appears that specific geovisualization tool type did not affect the responses. Most test participants were able to identify basic land use change patterns (e.g., the change from a diverse mixture of land use types to land use dominated primarily by retail and entertainment uses today).

Questions about the GeovisualizationTools

Three questions about the actual geovisualization tools viewed by the test subjects were also asked. In some cases, these questions yielded substantially different results depending on the tool type.

Overall, the response to the geovisualization tools was positive and enthusiastic.[6] However, in comparing the responses to all three of the tools, it appears that the number of positive comments about a geovisualization tool tended to increase with the level of interactivity. In other words, the toggle map, representing the highest level of interactivity received the most positive comments, followed by the animated map with VCR-type controls, and lastly the static paper map series. In general, the two computer- based tools generated more comments in general, positive or negative, while the static maps on average generated considerably shorter answers.

**Feedback on Specific Geovisualization Tools**

As noted above, the static map series tended to generate the least amount of comments from test subjects. One participant specifically mentioned that she did not like having to flip through the seven map sheets. The remainder of the comments on the static map series primarily dealt with specific elements of the maps (similar observations were made in reference to the other two tool types as well). Color choices for the legend and placement of specific map elements were common topics of discussion.

For the two dynamic geovisualization tools, the responses were primarily enthusiastic and very positive. However, several people suggested adding more interactivity into the tools—for instance, allowing users to click on the building footprints to obtain detailed historical

information about the buildings and land use through time. In reference to the toggle map, several participants suggested making the legend linear rather than circular to allow for easier manipulation of the data. Other participants specifically noted that they liked the circular legend.

**General Comments about the Geovisualization Tools**

The colors used in the legend clearly had an impact, positive or negative on the test subjects regardless of which tool they were evaluating. Approximately an equal amount of subjects liked and disliked the color choices. Some recommended using patterns or symbols to better differentiate the land use types.

In monitoring the testing sessions and talking with people afterward, I found that the two dynamic maps generated a lot of enthusiasm—people wanted to talk about the tools and explain what they liked about them. In contrast, the static map series (while participants at times commented favorably on them) generated considerably fewer of these discourses.

[6] "Positive" feedback ranged anywhere from "I thought it was great" to "Maps were easy to read" and "Liked the general map layout."

# CHAPTER 5

# CONCLUSIONS

As discussed in previous chapters, the primary goal of this thesis was to produce answers to the following questions:

- Does the level of interactivity affect a user's performance in detecting spatio-temporal patterns?
- Are animated maps more effective in depicting spatio-temporal data than static maps in this regard?
- Which format do users prefer?

In order to investigate these questions, three geovisualization tools featuring a commercial and public land use data set spanning the past century and covering an eight block segment of New Orleans' historic French Quarter were created to represent three different levels of interactivity. They included: 1) a static paper map series consisting of seven separate map sheets, representing the lowest level of interactivity; 2) a computer-based animated map with VCR-type controls, representing a moderate level of interactivity; and 3) an interactive toggle map representing the highest level of interactivity. In order to evaluate the three tools, user testing sessions were held, in which test participants viewed one of the tools and then answered multiple-choice and open-ended questions about what they saw. The results of these testing sessions and how they relate to the aforementioned research questions are discussed below.

- *Does the level of interactivity affect a user's performance in detecting spatio-temporal patterns?*

Based on the quantitative analyses discussed in Chapter 4, it appears that the level of interactivity does in certain ways affect user performance in detecting spatio-temporal patterns.

While there was no significant difference in terms of accuracy (whether questions were answered correctly), or in terms of response time to individual questions, the total response time of test participants was significantly different when comparing the three geovisualization tool types.

Furthermore, in terms of accuracy, while no significant difference was found in analyzing the total number of correct answers to the four questions, the mean scores reveal that the numbers did increase slightly with the level of interactivity. More research may be needed to confirm that accuracy truly is not affected by the level of interactivity in a given geovisualization tool.

- *Are animated maps more effective in depicting spatio-temporal data than static maps in this regard?*

In looking at the average total response times, it is evident that as the level of interactivity increased, the total response time decreased. There is also a noticeable difference between the average total response time of the two computer-based dynamic tools and the static paper map series. While the toggle map had the lowest average total response time, the animated map with VCR-type controls had a similar (if slightly higher average) unlike the static map series results. This indicates that to some degree, animated maps do appear to be more effective than a static paper map series in terms of speed in answering spatio-temporal data-related questions.

How can these differences be explained? It is possible that because the two animated tools represented something novel and new, test subjects were more motivated to pay closer attention to the geovisualization tool and data shown. This possibly could have resulted in the ability of test subjects to answer the questions quicker (and slightly more accurately based on the mean number of correct answers to the multiple-choice questions) than their counterparts in the static map group. However, it is also possible that providing test subjects with the ability to

quickly move through data sets (using the toggle map) allowed for more time to become better acquainted with the data and any resulting spatio-temporal patterns, thus allowing participants to answer the questions more quickly. More research is needed to determine the role novelty and other factors ultimately play in the faster response times for the more interactive tools.

- *Which format do users prefer?*

Judging from the answers to the open-ended questions asked about the geovisualization tools themselves, clearly test subjects issued the most positive feedback regarding the toggle map, the most interactive of the three tools. The static paper map series received the least positive feedback. Thus, it may be concluded that the tools featuring higher levels of interactivity are preferred.

## Combining Qualitative and Quantitative Methods of Analysis

Another important objective of this thesis was to evaluate the geovisualization tools using both standard cartographic user testing and usability engineering principles. By using both techniques, a clearer picture of what level of interactivity the participants preferred versus what level of interactivity was most effective from a quantitative standpoint appeared. For the purposes of this research project, it appears that a higher level of interactivity is preferable in both cases.

## Future Research Directions

This thesis has demonstrated that interactivity appears to have a positive effect on users' ability to visualize spatio-temporal data. However, more research is clearly necessary on this topic. As noted in Chapter 2, surpisingly little research has been performed that deals specifically with quantifying performance in terms of interactivity from the viewpoint of geovisualization.

Furthermore, the existing research on interactivity and animation has yielded mixed results concerning its effectiveness. In evaluating the results of this thesis, a number of tasks for additional related research have emerged:

1. As evidenced by the comments of some of the test subjects, additional levels of interactivity are desirable. The tools featured in this thesis were relatively simple and did not include multiple types of interactivity (such as panning and zooming). The effectiveness of more complex types/combinations of interactivity should be evaluated in comparison with less interactive tools.
2. More research featuring a larger number of test subjects is needed to further validate these results. Since it can be difficult to recruit volunteers, an option may be to post future tools online and to utilize an Internet-based survey. This could greatly increase the potential number of volunteers available for testing.
3. There is a need to determine how the attributes of a given data set may affect user performance, specifically:
    - How does a change in temporal resolution of the data (e.g., using a one year interval versus a five year interval, etc.) affect performance?
    - How do different types of data (e.g. 3-dimensional or non-temporal data) compare with the data set used for this thesis in terms of performance?
4. More research needs to be done concerning user preference. Surveys and focus groups are good tools to determine which formats people prefer. The results of this thesis indicate that more research is needed for interface design, specifically legends:
    - What are the benefits of slide bars versus clock faces?
    - Which color schemes work best in an interactive environment?

Since interactivity is considered one of the most important concepts to geovisualization, clearly additional research into these above-mentioned issues would be beneficial, in order to get a better grasp on how it may be optimally utilized.

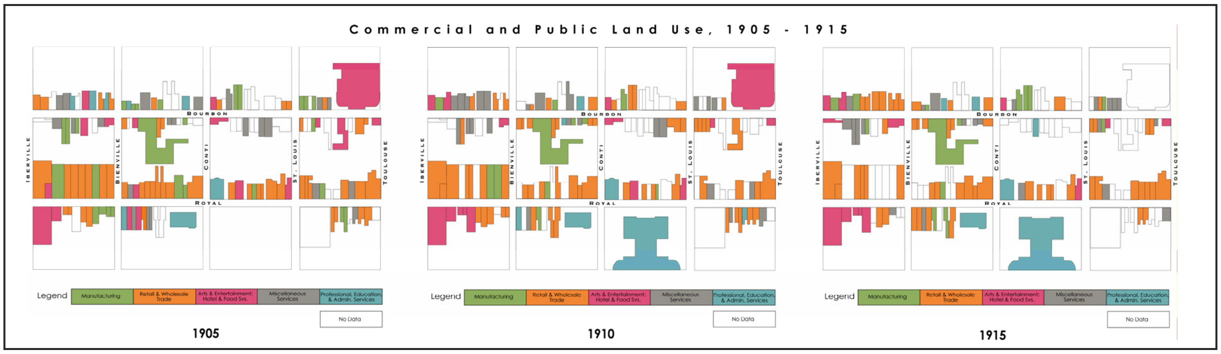
## Final Thoughts

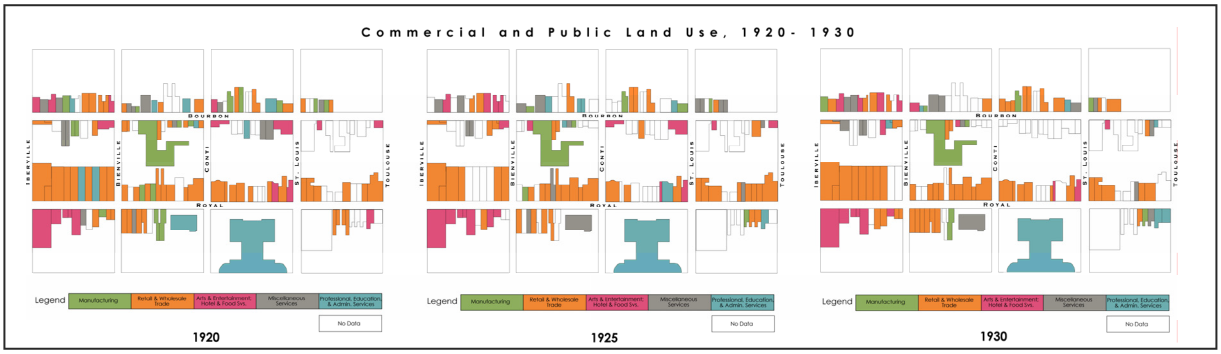
Interactivity (in various forms) has been present in cartography and geography for close to half a century now. Despite this fact, the need to *quantify* the importance of interactivity within geographic thought remains. For what purposes is it most useful? For what purposes is it not useful, or actually a hindrance to the goals of geovisualization? There are a myriad of interactive maps floating on the Internet—but these questions remain unanswered. Clearly there is room to improve how we design, create and use these tools now available at the finger tips of millions of people. Thrower once noted that "animated maps are not a substitute for conventional, static cartography, but for certain purposes they have possibilities which have not yet been adequately exploited by cartographers (1961, 22)." While this statement was made over forty years ago, there is still truth in it today.

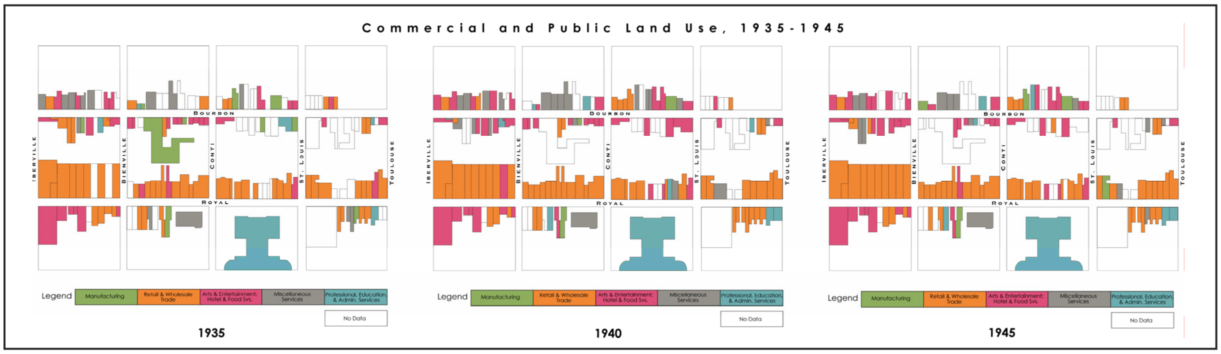
# APPENDIX A

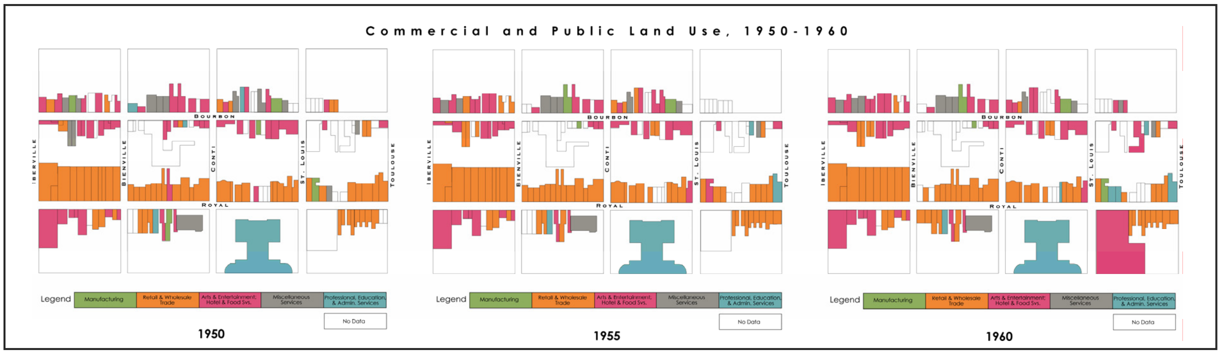
## Static Map Sheet Layouts

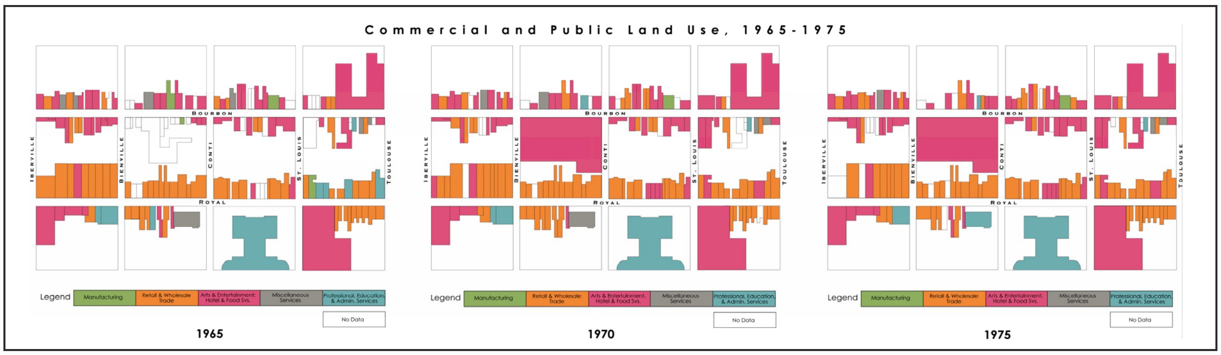
Below are the layouts of the seven static paper maps used for the project (not to scale). To view the tutorial viewed by the test subjects who used these maps, click on the link below:

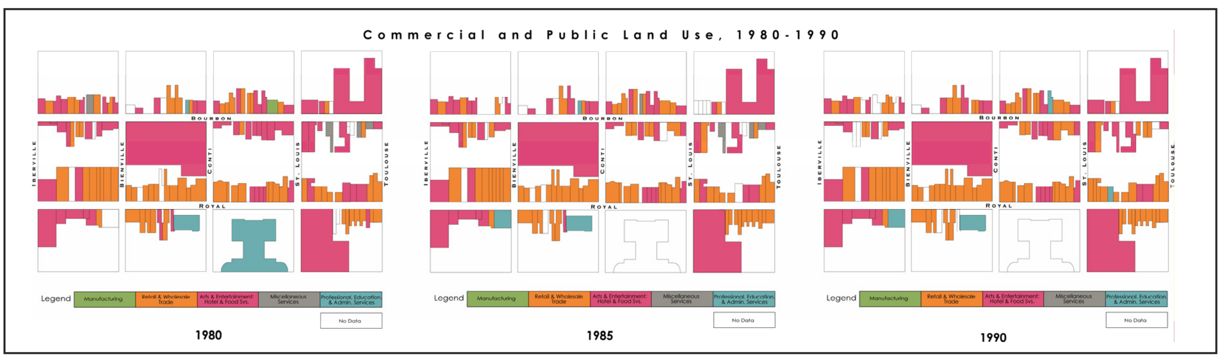


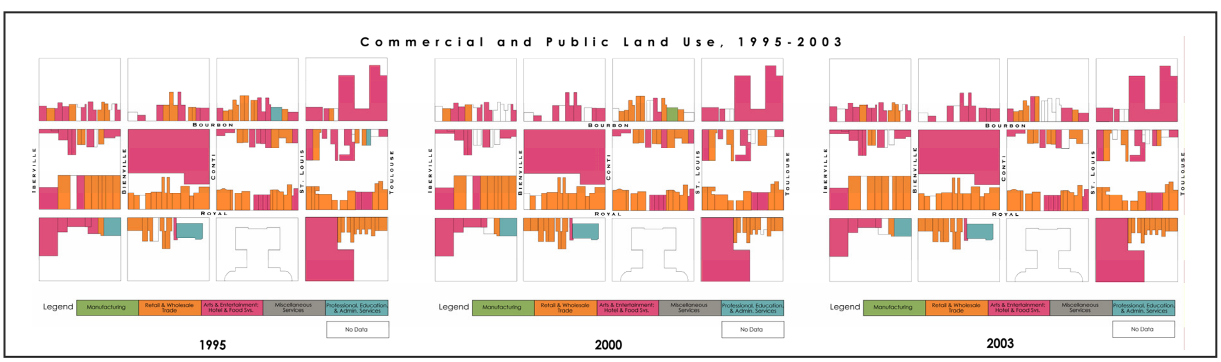




Commercial and Public Land Use, 1950-1960
Bourbon
Iberville
Bienville
Conti
St. Louis
Toulouse
Royal
Legend
Manufacturing
Retail & Wholesale Trade
Arts & Entertainment; Hotel & Food Svs.
Miscellaneous Services
Professional, Education & Admin. Services
No Data
1950
1955
1960


Commercial and Public Land Use, 1965-1975
Bourbon
Iberville
Bienville
Conti
St. Louis
Toulouse
Royal
1965
1970
1975


Commercial and Public Land Use, 1980-1990
Bourbon
Iberville
Bienville
Conti
St. Louis
Toulouse
Royal
1980
1985
1990


Commercial and Public Land Use, 1995-2003
Bourbon
Iberville
Bienville
Conti
St. Louis
Toulouse
Royal
1995
2000
2003

# APPENDIX B

## Animated map with VCR-type controls

To view the animated map with VCR-type controls, click on the link below:

APPENDIX C

Toggle map

To view the toggle map, click on the link below:

APPENDIX D

*University Committee for the Protection of Human Subjects in Research University of New Orleans*

**Form Number:** **01sept03**

*(please refer to this number in all future correspondence concerning this protocol)*

**Principal Investigator** Samara Ebinger **Title:** Graduate Student

**Faculty Supervisor:** Dr. Andre Skupin ***(if PI is a student)***

**Department:** Geography **College:** Liberal Arts

**Project Title:** Comparing the effectiveness of different levels of interactivity in the visualization of spatio-temporal data: An experiment using static maps, cartographic animation, and interactive toggle maps

**Date Reviewed:** 8/17/04

**Dates of Proposed Project Period** From 9/1/04 to 8/30/05

****approval is for one year from approval date only and may be renewed yearly.***

**Note: Consent forms and related materials are to be kept by the PI for a period of three years following the completion of the study.**

| **Approval Status** | **Date** |
|---|---|
| ☐ **Full Committee Approval** | |
| ☒ **Expedited Approval** | **8/17/04** |
| ☐ **Continuation** | |
| ☐ **Rejected** | |

☐ **The protocol will be approved following receipt of satisfactory response(s) to the following question(s) within 15 days:**

**Committee Signatures:**

Laura Scaramella, Ph.D. (Chair)
Pamela Jenkins, Ph.D.
Anthony Kontos, Ph.D.
Betty Lo, M.D.
Richard B. Speaker, Ph.D.
Gary Talarchek, Ph.D.
L. Allen Witt, Ph.D.

## Consent Form for Human Subjects

**1. Title of Research Project**

Comparing the Effectiveness of Different Levels of Interactivity
in the Visualization of Spatio-Temporal Data

**2. Project Director**
Samara Ebinger, (Graduate Student, Department of Geography, UNO)
Phone: (504) 512-1219
e-mail: samara_ebinger@hotmail.com

**Faculty Supervisor**: Dr. André Skupin, Associate Professor, Department of Geography, UNO
Phone: (504) 280-7157

**3. Introduction**

The purpose of this project is to evaluate how patterns in geographic data are visualized through space and time using both paper and computer-based maps. It is hoped that the results of this project will assist cartographers in making better design choices regarding computer and Internet based maps. The geographic data used in this project deal with some of New Orleans' unique urban characteristics and how they have changed over the past century.

**4. General Experimental Procedure**

As a participant, you will be evaluating one of the three different types of map display tools discussed above. It is anticipated that each testing session will last approximately 25 minutes, but this may vary slightly depending on each participant. The session will consist of the following steps:

1) You will first answer a brief questionnaire providing general information about yourself. This information will be collected solely to analyze the results of this project and will not be disclosed at any time. (Anticipated time used: 5 minutes)
2) You will then be asked to read a computer-based introduction to the experiment, which includes general information about the project, the study area, and what tasks you will be asked to perform. This will be followed by a brief demonstration of the mapping tool you will be using. (Anticipated time used: 7 minutes)

3) You will then view a map series or computer-based mapping tool. If you are assigned one of the computerized tools, your interactions with the mapping tool will be automatically recorded by the computer for later analysis. Keep in mind that you will be allotted only 3 minutes to view the maps/mapping tool, so please try to be attentive to what is being shown. (Anticipated time used: 3 minutes)
4) You will then be asked to answer a set of questions regarding the visualization seen in step 3 above. These questions will be answered and recorded using a computer. Keep in mind that the amount of time taken to answer this first set of questions will be automatically recorded, so please try to answer each question as soon as you are able (but use as much time as you need). You also will be asked several open-ended questions about what you particularly liked and disliked about the maps or mapping tool used. (Anticipated time used: 10 minutes)

**5. Potential risks of discomfort**

There are no risks associated with this project, apart from possible slight mental frustration or fatigue. If you have any particular concerns, please consult with the Project Director listed above.

**6. Potential benefits to you or others**

By participating in this project, you will be helping to determine how geographic information can best be depicted using computers and the tools of the Internet. This is important because web-based maps have the ability to reach countless viewers. The results may assist cartographers in making better design choices regarding these types of maps in the future.

**7. Alternative Procedures**

Your participation in this project is completely voluntary and you may withdraw your consent and terminate your participation at any point during the testing session.

8**. Protection of Confidentiality**

The names of all subjects participating in the testing session will be kept confidential at all times. Individual testing results with names of participants will be available only to the principal

investigator and the faculty supervisor. No information will be made public that would allow the identity of any participant to be compromised.

**9. Signatures**

I have been fully informed of the above-described procedure with its possible benefits and risks and I give my permission to participate in this study.

| | | |
|---|---|---|
| ______________________________ | ______________________________ | ____ |
| Signature of Subject | Name of Subject (Print) | Date |
| ______________________________ | ______________________________ | ____ |
| Signature of Person Obtaining Consent | Name of Person Obtaining Consent (Print) | Date |

## APPENDIX E

### Introductory Questionnaire

*Please answer the following questions to the best of your knowledge. All answers will be kept confidential and will be seen only by the project director and faculty supervisor.*
*Thanks for participating!*

1. ***Name______________________________***
2. ***Gender:*** *___ male ___female*
3. ***Age______***
4. ***I am an:*** *___undergraduate student*

   *___graduate student*

   *___professional*
5. ***My major area of study is in ___________________.***
6. ***I have taken college-level courses in Geography*** *(circle one) Yes No*

   ***If yes, a) How many? ____***

   ***b) Did any of these courses deal specifically with GIS***

   ***(Geographic Information Systems)?*** *Yes No*
7. ***I have taken college-level courses in Urban Studies*** *Yes No*

   ***If yes, a) How many?____***

   ***b) Did any of these courses deal specifically with GIS (Geographic Information Systems)?*** *Yes No*

   ***c) Did any of these courses deal with New Orleans' French Quarter specifically?***

   *Yes No*
8. ***How would you describe your familiarity with the Internet?***

   *a) Very familiar*

   *b) Familiar*

   *c) Sort of familiar*

   *d) Not at all familiar*
9. ***As far as you know, is your color vision impaired in any way?*** *Yes No*

   ***If yes, what type of impairment is it that you have?_______________________________***

*10.* ***How familiar are you with the French Quarter of New Orleans?***

*a) Very*

*b) Somewhat*

*c) Not really*

*d) Never been there*

11. ***Is English your native language****? Yes   No*

APPENDIX F

Data-related test questions

1) Describe any particular patterns or trends that you noticed as you viewed the data on the map:

2) Did viewing the map allow you to come to any specific conclusions or hypotheses about commercial/public land use in the study area? If yes, discuss below.

3) What two land use types became dominant in the study area from 1950 up to present day?

a) Manufacturing and Retail & Wholesale Trade
b) Arts & Entertainment;Accommodation & Food Services and [CORRECT ANSWER]
 Retail & Wholesale Trade
c) Professional, Education and Administrative Services and Miscellaneous Services
d) Don't know

4) In general commercial and public land use types became more diverse through time in the study area.

a) True (Very Certain)
b) True (Somewhat Certain)
c) Don’t Know
d) False (Somewhat Certain) [CORRECT ANSWER]
e) False (Very Certain) [CORRECT ANSWER]

5) For the duration of the time period shown, Royal Street has always been dominated by which land use type?

a) Arts and Entertainment
b) Professional, Education and Administrative Services
c) Retail & Wholesale Trade [CORRECT ANSWER]
d) Miscellaneous Services
e) Manufacturing
f) Don't know

6) Prior to 1960, Bourbon Street:

a) was dominated by Retail/Wholesale Trade.
b) was dominated by Manufacturing.
c) had a mixture of diverse land use types. [CORRECT ANSWER]
d) was dominated by Arts & Entertainment; Hotel & Food Services.
e) was dominated by Miscellaneous Services.
f) was dominated by Professional, Education and Administrative Services.
g) Don't know.

APPENDIX G

Open-ended evaluation questions

1) Describe your overall impression of the map. Was there anything you found particularly helpful or difficult? Liked or Disliked? If so, describe below:

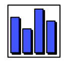
2) Were the instructions on how to use the map and describing the data clear enough? If necessary, please explain.

3) Is there anything you would recommend changing about the map to make it easier to understand or more helpful?

APPENDIX H

Initial spreadsheet of quantitative data collected

To access this file, click on the link below:



APPENDIX I

Chi-square test results

Results for Question #3 (See Appendix F):

Testgroup:
1.00 = Toggle Map
2.00 = Animated Map with VCR-Type Controls
3.00 = Static Paper Map Series

Question 3:
1.00 = Correct Answer
2.00 = Incorrect Answer

Crosstabs

**Case Processing Summary**

| | Cases | | | | | |
|---|---|---|---|---|---|---|
| | Valid | | Missing | | Total | |
| | N | Percent | N | Percent | N | Percent |
| **testgroup * q3ansnew** | 41 | 100.0% | 0 | .0% | 41 | 100.0% |

**testgroup * q3ansnew Crosstabulation**

| | | | q3ansnew | | Total |
|---|---|---|---|---|---|
| | | | 1.00 | 2.00 | |
| testgroup | 1.00 | Count | 13 | 2 | 15 |
| | | Expected Count | 12.4 | 2.6 | 15.0 |
| | 2.00 | Count | 11 | 2 | 13 |
| | | Expected Count | 10.8 | 2.2 | 13.0 |
| | 3.00 | Count | 10 | 3 | 13 |
| | | Expected Count | 10.8 | 2.2 | 13.0 |
| Total | | Count | 34 | 7 | 41 |
| | | Expected Count | 34.0 | 7.0 | 41.0 |

| Chi-Square Tests | | | |
|---|---|---|---|
| | **Value** | **df** | **Asymp. Sig. (2-sided)** |
| **Pearson Chi-Square** | .505(a) | 2 | .777 |
| **Likelihood Ratio** | .490 | 2 | .783 |
| **Linear-by-Linear Association** | .444 | 1 | .505 |
| **N of Valid Cases** | 41 | | |

a 3 cells (50.0%) have expected count less than 5. The minimum expected count is 2.22.

Results for Question #4 (See Appendix F):

Testgroup:
1.00 = Toggle Map
2.00 = Animated Map with VCR-Type Controls
3.00 = Static Paper Map Series

Question 4:
1.00 = Correct Answer
2.00 = Incorrect Answer

Crosstabs

**Case Processing Summary**

| | Cases | | | | | |
|---|---|---|---|---|---|---|
| | Valid | | Missing | | Total | |
| | N | Percent | N | Percent | N | Percent |
| **testgroup * q4ansnew** | 41 | 100.0% | 0 | .0% | 41 | 100.0% |

**testgroup * q4ansnew Crosstabulation**

| | | | q4ansnew | | Total |
|---|---|---|---|---|---|
| | | | 1.00 | 2.00 | |
| **testgroup** | **1.00** | **Count** | 13 | 2 | 15 |
| | | **Expected Count** | 10.2 | 4.8 | 15.0 |
| | **2.00** | **Count** | 6 | 7 | 13 |
| | | **Expected Count** | 8.9 | 4.1 | 13.0 |
| | **3.00** | **Count** | 9 | 4 | 13 |
| | | **Expected Count** | 8.9 | 4.1 | 13.0 |
| **Total** | | **Count** | 28 | 13 | 41 |
| | | **Expected Count** | 28.0 | 13.0 | 41.0 |

| Chi-Square Tests | | | |
|---|---|---|---|
| | **Value** | **df** | **Asymp. Sig. (2-sided)** |
| **Pearson Chi-Square** | 5.286(a) | 2 | .071 |
| **Likelihood Ratio** | 5.447 | 2 | .066 |
| **Linear-by-Linear Association** | 1.120 | 1 | .290 |
| **N of Valid Cases** | 41 | | |
| a 3 cells (50.0%) have expected count less than 5. The minimum expected count is 4.12. | | | |

Results for Question #5 (See Appendix F):

Testgroup:
1.00 = Toggle Map
2.00 = Animated Map with VCR-Type Controls
3.00 = Static Paper Map Series

Question 5:
1.00 = Correct Answer
2.00 = Incorrect Answer

Crosstabs

**Case Processing Summary**

| | Cases | | | | | |
|---|---|---|---|---|---|---|
| | Valid | | Missing | | Total | |
| | N | Percent | N | Percent | N | Percent |
| testgroup * q5ansnew | 41 | 100.0% | 0 | .0% | 41 | 100.0% |

**testgroup * q5ansnew Crosstabulation**

| | | | q5ansnew | | Total |
|---|---|---|---|---|---|
| | | | 1.00 | 2.00 | |
| testgroup | 1.00 | Count | 9 | 6 | 15 |
| | | Expected Count | 9.9 | 5.1 | 15.0 |
| | 2.00 | Count | 9 | 4 | 13 |
| | | Expected Count | 8.6 | 4.4 | 13.0 |
| | 3.00 | Count | 9 | 4 | 13 |
| | | Expected Count | 8.6 | 4.4 | 13.0 |
| Total | | Count | 27 | 14 | 41 |
| | | Expected Count | 27.0 | 14.0 | 41.0 |

**Chi-Square Tests**

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| **Pearson Chi-Square** | .360(a) | 2 | .835 |
| **Likelihood Ratio** | .357 | 2 | .836 |
| **Linear-by-Linear Association** | .270 | 1 | .604 |
| **N of Valid Cases** | 41 | | |

a 2 cells (33.3%) have expected count less than 5. The minimum expected count is 4.44.

Results for Question #6 (See Appendix F):

Testgroup:
1.00 = Toggle Map
2.00 = Animated Map with VCR-Type Controls
3.00 = Static Paper Map Series

Question 6:
1.00 = Correct Answer
2.00 = Incorrect Answer

Crosstabs

**Case Processing Summary**

| | Cases | | | | | |
|---|---|---|---|---|---|---|
| | Valid | | Missing | | Total | |
| | N | Percent | N | Percent | N | Percent |
| **testgroup * q6ansnew** | 41 | 100.0% | 0 | .0% | 41 | 100.0% |

**testgroup * q6ansnew Crosstabulation**

| | | | q6ansnew | | Total |
|---|---|---|---|---|---|
| | | | 1.00 | 2.00 | |
| testgroup | 1.00 | Count | 8 | 7 | 15 |
| | | Expected Count | 7.0 | 8.0 | 15.0 |
| | 2.00 | Count | 8 | 5 | 13 |
| | | Expected Count | 6.0 | 7.0 | 13.0 |
| | 3.00 | Count | 3 | 10 | 13 |
| | | Expected Count | 6.0 | 7.0 | 13.0 |
| Total | | Count | 19 | 22 | 41 |
| | | Expected Count | 19.0 | 22.0 | 41.0 |

| Chi-Square Tests | | | |
|---|---|---|---|
| | **Value** | **df** | **Asymp. Sig. (2-sided)** |
| **Pearson Chi-Square** | 4.332(a) | 2 | .115 |
| **Likelihood Ratio** | 4.522 | 2 | .104 |
| **Linear-by-Linear Association** | 2.333 | 1 | .127 |
| **N of Valid Cases** | 41 | | |
| a 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.02. | | | |

APPENDIX J

Kruskal-Wallis test results
(Accuracy: total number of multiple-choice questions answered correctly)

Testgroup:
1.00 = Toggle Map
2.00 = Animated Map with VCR-Type Controls
3.00 = Static Paper Map Series

NPar Tests

**Descriptive Statistics**

| | N | Mean | Std. Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| **qcorrect** | 41 | 2.6341 | 1.0899 | .00 | 4.00 |
| **testgroup** | 41 | 1.9512 | .8352 | 1.00 | 3.00 |

Kruskal-Wallis Test

**Ranks**

| | testgroup | N | Mean Rank |
|---|---|---|---|
| **qcorrect** | **1.00** | 15 | 23.40 |
| | **2.00** | 13 | 20.77 |
| | **3.00** | 13 | 18.46 |
| | **Total** | 41 | |

**Test Statistics(a,b)**

| | Qcorrect |
|---|---|
| **Chi-Square** | 1.283 |
| **Df** | 2 |
| **Asymp. Sig.** | .527 |

a Kruskal Wallis Test

b Grouping Variable: testgroup

APPENDIX K

Kruskal-Wallis test results (Speed)

Results for Test Question #3

Testgroup:
1.00 = Toggle Map
2.00 = Animated Map with VCR-Type Controls
3.00 = Static Paper Map Series

NPar Tests

**Descriptive Statistics**

| | N | Mean | Std. Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| **Q3TIME** | 41 | 21142.44 | 10083.29 | 7454 | 51886 |
| **testgroup** | 41 | 1.9512 | .8352 | 1.00 | 3.00 |

Kruskal-Wallis Test

**Ranks**

| | testgroup | N | Mean Rank |
|---|---|---|---|
| **Q3TIME** | **1.00** | 15 | 17.20 |
| | **2.00** | 13 | 22.77 |
| | **3.00** | 13 | 23.62 |
| | **Total** | 41 | |

**Test Statistics(a,b)**

| | Q3TIME |
|---|---|
| **Chi-Square** | 2.413 |
| **Df** | 2 |
| **Asymp. Sig.** | .299 |

a Kruskal Wallis Test

b Grouping Variable: testgroup

Results for Test Question #4

Testgroup:
1.00 = Toggle Map
2.00 = Animated Map with VCR-Type Controls
3.00 = Static Paper Map Series

NPar Tests

**Descriptive Statistics**

| | N | Mean | Std. Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| **Q4TIME** | 41 | 20154.73 | 8650.36 | 7820 | 56987 |
| **testgroup** | 41 | 1.9512 | .8352 | 1.00 | 3.00 |

Kruskal-Wallis Test

**Ranks**

| | testgroup | N | Mean Rank |
|---|---|---|---|
| **Q4TIME** | **1.00** | 15 | 19.40 |
| | **2.00** | 13 | 17.69 |
| | **3.00** | 13 | 26.15 |
| | **Total** | 41 | |

**Test Statistics(a,b)**

| | Q4TIME |
|---|---|
| **Chi-Square** | 3.665 |
| **Df** | 2 |
| **Asymp. Sig.** | .160 |

a Kruskal Wallis Test

b Grouping Variable: testgroup

Results for Test Question #5

Testgroup:
1.00 = Toggle Map
2.00 = Animated Map with VCR-Type Controls
3.00 = Static Paper Map Series

NPar Tests

**Descriptive Statistics**

| | N | Mean | Std. Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| **Q5TIME** | 41 | 18434.51 | 11554.35 | 5260 | 48969 |
| **testgroup** | 41 | 1.9512 | .8352 | 1.00 | 3.00 |

Kruskal-Wallis Test

**Ranks**

| | testgroup | N | Mean Rank |
|---|---|---|---|
| **Q5TIME** | **1.00** | 15 | 17.53 |
| | **2.00** | 13 | 19.77 |
| | **3.00** | 13 | 26.23 |
| | **Total** | 41 | |

**Test Statistics(a,b)**

| | Q5TIME |
|---|---|
| **Chi-Square** | 3.872 |
| **Df** | 2 |
| **Asymp. Sig.** | .144 |

a Kruskal Wallis Test

b Grouping Variable: testgroup

Results for Test Question #6

Testgroup:
1.00 = Toggle Map
2.00 = Animated Map with VCR-Type Controls
3.00 = Static Paper Map Series

NPar Tests

**Descriptive Statistics**

| | N | Mean | Std. Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| **Q6TIME** | 41 | 20381.34 | 11340.33 | 4522 | 55754 |
| **testgroup** | 41 | 1.9512 | .8352 | 1.00 | 3.00 |

Kruskal-Wallis Test

**Ranks**

| | testgroup | N | Mean Rank |
|---|---|---|---|
| **Q6TIME** | **1.00** | 15 | 18.60 |
| | **2.00** | 13 | 19.00 |
| | **3.00** | 13 | 25.77 |
| | **Total** | 41 | |

**Test Statistics(b,c)**

| | Q6TIME |
|---|---|
| **Chi-Square(a)** | 3.025 |
| **Df** | 2 |
| **Asymp. Sig.** | .220 |

a Based on availability of special working memory.
b Kruskal Wallis Test
c Grouping Variable: testgroup

Results for Total Response Time (Sum of Response Times for Questions 3, 4, 5, and 6)

Testgroup:
1.00 = Toggle Map
2.00 = Animated Map with VCR-Type Controls
3.00 = Static Paper Map Series

NPar Tests

**Descriptive Statistics**

| | N | Mean | Std. Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| **QTIMETOT** | 41 | 80113.0244 | 27381.9401 | 28850.00 | 134520.0 |
| **testgroup** | 41 | 1.9512 | .8352 | 1.00 | 3.00 |

Kruskal-Wallis Test

**Ranks**

| | testgroup | N | Mean Rank |
|---|---|---|---|
| **QTIMETOT** | **1.00** | 15 | 16.33 |
| | **2.00** | 13 | 19.92 |
| | **3.00** | 13 | 27.46 |
| | **Total** | 41 | |

**Test Statistics(a)**

| | QTIMETOT |
|---|---|
| **Chi-Square** | 6.164 |
| **Df** | 2 |
| **Asymp. Sig.** | .046 |

A Kruskal Wallis Test

APPENDIX L

ELSEVIER

425·125

YEARS OF PUBLISHING

TRADITION | EXCELLENCE

We commemorate the founding of the House of Elzevir in 1580 and celebrate the establishment of the Elsevier company in 1880.

27 July 2005 Our ref: HG/smc/July 2005.bk375

Dr Samara Ebinger

Samara_ebinger@hotmail.com

Dear Dr Ebinger

VISUALIZATION IN MODERN CARTOGRAPHY, 1994, Page 6, ISBN 0-08-042415-5, MacEachren & Fraser (Eds), 1 Figure only

As per your letter dated 12 July 2005, we hereby grant you permission to reprint the aforementioned material at no charge **in your thesis** subject to the following conditions:

1. If any part of the material to be used (for example, figures) has appeared in our publication with credit or acknowledgement to another source, permission must also be sought from that source. If such permission is not obtained then that material may not be included in your publication/copies.

2. Suitable acknowledgment to the source must be made, either as a footnote or in a reference list at the end of your publication, as follows:

   "Reprinted from Publication title, Vol number, Author(s), Title of article, Pages No., Copyright (Year), with permission from Elsevier".

3. Reproduction of this material is confined to the purpose for which permission is hereby given.

4. This permission is granted for non-exclusive world **English** rights only. For other languages please reapply separately for each one required. Permission excludes use in an electronic form. Should you have a specific electronic project in mind please reapply for permission.

5. This includes permission for UMI to supply single copies, on demand, of the complete thesis. Should your thesis be published commercially, please reapply for permission.

Yours sincerely

Helen Gainford

***Rights Manager***

**Your future requests will be handled more quickly if you complete the online form at** www.elsevier.com/locate/permissions

References


Aerts, J. C. J. H., K. C. Clarke, and A. D. Keuper. "Testing Popular Visualization Techniques for Representing Model Uncertainty." *Cartography and Geographic Information Science* 30, no. 3 (2003): 249-261.

Andrienko, N. V., G. L. Andrienko, and P. Gatalsky. "Visualization of Spatio-Temporal Information in the Internet." In *Proceedings of DEXA'2000 Workshop on Web-Based Information Visualization, Greenwich, England, September 4-8, 2000*, 577-585. Los Alamitos, California: IEEE Computer Society Press, 2000.

Andrienko, N. V., G. L. Andrienko, H. Voss, F. Bernardo, J. Hipolito, and U. Kretchmer. "Testing the Usability of Interactive Maps in CommonGIS." *Cartography and Geographic Information Science* 29, no. 4 (2002): 325-342.

Antle, A. A. "Interactive Visualization Tools for Spatial Data and Metadata." Ph.D. diss., University of British Columbia, 2000.

Bertin, J. *Semiologie Graphique*. Paris: Gauthier-Villars, 1967.

Blok, C. "Dynamic Visualization Variables in Animation to Support Monitoring of Spatial Phenomena." Ph.D. diss., Utrecht University, 2005.

Buckley, A. R., M. Gahegan, and K. Clarke. "Geographic Visualization." *UCGIS White Paper,* 2000.

Campbell, C. S. and S. L. Egbert. "Animated Cartography: Thirty Years of Scratching the Surface." *Cartographica* 27, no. 2 (1990): 24-46.

Collins, B. M. "Data Visualization - Has it All Been Seen Before?" In *Animation and Scientific Visualization: Tools and Applications*, ed. R. A. Earnshaw and D. Watson, 3-28. London: Academic Press, 1993.

Cornwall, B. and A. Robinson. "Possibilities for Computer Animated Films in Cartography." *Cartographic Journal* 3, no. 2 (1966): 79-82.

Crampton, J. W. "Interactivity Types in Geographic Visualization." *Cartography and Geographic Information Science* 29, no. 2 (2002): 85-98.

Dibiase, D. "Evoking the Visualization Experience in Computer-Assisted Geographic Education." In *Spatial Multimedia and Virtual Reality*, ed. A. S. Camara and J. Raper, 89-101. London: Taylor and Francis, 1999.

Dibiase, D., A. M. MacEachren, J. B. Krygier, and C. Reeves. "Animation and the Role of Map Design in Scientific Visualization." *Cartography and Geographic Information Systems* 19, no. 4 (1992): 201-214, 265-266.

Dorling, D. "Stretching Space and Splicing Time: From Cartographic Animation to Interactive Visualization." *Cartography and Geographic Information Systems* 19, no. 4 (1992): 215-227, 267-270.

Dykes, J. "Exploring Spatial Data Representation with Dynamic Graphics." *Computers and Geosciences* 23, no. 4 (1997): 345-370.

Edsall, R. M., M.-J. Kraak, A. M. MacEachren, and D. J. Peuquet. "Assessing the Effectiveness of Temporal Legends in Environmental Visualization." *In Proceedings of GIS/LIS '97 in Cincinnati, Ohio, October 28-30, 1997*, 677-685.

Fairbairn, D. and N. Deeley. "Animation in the Cartographic Drawing Office." *Bulletin of the Society of University Cartographers* 25, no. 1 (1991): 1-7.

Fairbairn, D., G. Andrienko, N. Andrienko, G. Buziek, and J. Dykes. "Representation and its Relationship with Cartographic Visualization." *Cartography and Geographic Information Science* 28, no. 1 (2001): 13-28.

Foley, J. D., A. Van Dam, S. K. Feiner, and J. F. Hughes. *Computer Graphics: Principles and Practice*. Reading, Massachusetts: Addison-Wesley, 1990.

Gabbard, J. L., D. Hix, and J. E. I. Swan. "User-Centered Design and Evaluation of Virtual Environments*." IEEE Computer Graphics and Applications* 19, no. 6 (1999): 51-59.

Hamilton, A., N. Trodd, X. Zhang, T. Fernando, and K. Watson. "Learning Through Visual Systems to Enhance the Urban Planning Process." *Environment and Planning B: Planning and Design* 28 (2001): 833-845.

Harrower, M. "A Look at the History and Future of Animated Maps." *Cartographica* 39, no. 2 (2004): 33-42.

Harrower, M. "Visual Benchmarks: Representing Geographic Change with Map Animations." Ph.D. diss., Pennsylvania State University, 2002. [a]

Harrower, M. "Visualizing Change: Using Cartographic Animation to Explore Remotely Sensed Data." *Cartographic Perspectives* 39 (2002): 30-42. [b]

Harrower, M., A. M. MacEachren, and A. L. Griffin. "Developing a Geographic Visualization Tool to Support Earth Science Learning." *Cartography and Geographic Information Science* 27, no. 4 (2000): 279-293.

Johnson, H. and E. S. Nelson. "Using Flow Maps to Visualize Time-Series Data: Comparing the Effectiveness of a Paper Map Series, a Computer Map Series, and Animation." *Cartographic Perspectives* 30 (1998): 47-64.

Karl, D. "Cartographic Animation: Potential and Research Issues." *Cartographic Perspectives* 13 (1992): 3-9.

Kessler, F. C. "Focus Groups as a Means of Qualitatively Assessing the U-Boat Narrative." *Cartographica* 37, no. 4 (2000): 33-59.

Koussoulakou, A. and M.-J. Kraak. "Spatio-Temporal Maps and Cartographic Communication." *Cartographic Journal* 29, no. 2 (1992): 101-108.

Krygier, J. B., C. Reeves, D. Dibiase, and J. Cupp. "Design, Implementation and Evaluation of Multimedia Resources for Geography and Earth Science Education." *Journal of Geography in Higher Education* 21, no. 1 (1997): 17-39.

Lee, A. T. "Web Usability: A Review of the Research." *The SIGCHI Bulletin* 31, no. 1 (1999): 38-40.

Lobben, A. "Classification and Application of Cartographic Animation." *The Professional Geographer* 55, no. 3 (2003): 318-328.

MacEachren, A. M. *How Maps Work*. New York: Guilford Press, 1995.

MacEachren, A. M. "Visualization in Modern Cartography: Setting the Agenda." In *Visualization in Modern Cartography*, ed. A. M. MacEachren and D. R. Fraser Taylor, 1-12. Oxford: Pergamon, 1994.

MacEachren, A. M., B. P. Buttenfield, J. B. Campbell, D. W. Dibiase, and M. Monmonier. "Visualization." In *Geography's Inner Worlds*, ed. R. F. Abler, M. G. Marcus, and J. M. Olson, 99-137. New Brunswick, New Jersey: Rutgers University Press, 1992.

MacEachren, A. M., F. P. Boscoe, D. Haug, and L. W. Pickle. "Geographic Visualization: Designing Manipulable Maps for Exploring Temporally Varying Georeferenced Statistics." In *Proceedings, IEEE Symposium on Information Visualization Held in Research Triangle Park, North Carolina, October 19-20, 1998*, edited by G. Wills and J. Dill, 87-94, 156. Los Alamitos, California: IEEE Computer Society, 1998.

MacEachren, A. M. and M.-J. Kraak. "Exploratory Cartographic Visualization: Advancing the Agenda." *Computers and Geosciences* 23, no. 4 (1997): 335-343.

MacEachren, A. M. and M.-J. Kraak. "Research Challenges in Geovisualization." *Cartography and Geographic Information Science* 28, no. 1 (2001): 3-12.

Marcou, O'Leary and Associates. *Plan and Program for the Preservation of the Vieux Carre; Historic District Demonstration Study*. New Orleans: Bureau of Governmental Research, City of New Orleans, Louisiana, 1968.

McCormick, B. H., T. A. DeFanti, and M. D. Brown, ed. "Visualization in Scientific Computing." *Computer Graphics* 21, no. 6 (1987): [entire issue].

Monmonier, M. "Strategies for the Visualization of Geographic Time-Series Data." *Cartographica* 27, no. 1 (1990): 30-45.

Morrison, J. L. "Topographic Mapping for the Twenty First Century." In *Framework of the World*, ed. D. Rhind, 22-46. Cambridge: Geoinformation International, 1997.

Nielsen, J. and T. K. Landauer. "A Mathematical Model of the Finding of Usability Problems." In *Proceedings of ACM INTERCHI '93 Conference*, Amsterdam, The Netherlands, 24-29 April, 206-213, 1993.

Ogao, P. J. and M.-J. Kraak. "Defining Visualization Operations for Temporal Cartographic Animation Design." *International Journal of Applied Earth Observation and Geoinformation* 4 (2002): 23-31.

*Oxford American Dictionary*. New York: Oxford University Press, 1982.

*Oxford Modern Dictionary*. New York: Oxford University Press, 1992.

Patton, D. K. and R. G. Cammack. "An Examination of the Effects of Task Type and Map Complexity on Sequenced and Static Choropleth Maps." In *Cartographic Design: Theoretical and Practical Perspectives*, ed. C. H. Wood and C. P. Keller, 237-252. Chichester, England: John Wiley and Sons, Inc., 1996.

Peterson, M. P. "Active Legends for Interactive Cartographic Animation." *International Journal of Geographical Information Science* 13, no. 4 (1999): 375-383.

________. "Interactive Cartographic Animation." *Cartography and Geographic Information Systems* 20, no. 1 (1993): 40-44.

Slocum, T. A., C. Blok, B. Jiang, A. Koussoulakou, D. R. Montello, S. Fuhrmann, and N. R. Hedley. "Cognitive and Usability Issues in Geovisualization."*Cartography and Geographic Information Science* 28, no. 1 (2001): 61-75.

Slocum, T. A., D. C. Cliburn, J. J. Feddema, and J. R. Miller. "Evaluating the Usability of a Tool for Visualizing the Uncertainty of the Future Global Water Balance." *Cartography and Geographic Information Science* 30, no. 4 (2003): 299-317.

Slocum, T. A., R. S. Sluter, Jr., F. C. Kessler, and S. C. Yoder. "A Qualitative Evaluation of MapTime, A Program for Exploring Spatiotemporal Point Data." *Cartographica* 39, no. 3 (2004): 43-68.

Slocum, T. A., S. C. Yoder, F. C. Kessler, and R. S. Sluter. "MapTime: Software for Exploring Spatiotemporal Data Associated with Point Locations." *Cartographica* 37, no. 1 (2000): 15-30.

Slocum, T. A. and S. L. Egbert. "Knowledge Acquisition from Choropleth Maps." *Cartography and Geographic Information Systems* 20, no. 2 (1993): 83-95.

Société de développement de Montréal. "Le Patrimoine du Vieux-Montréal en Détail." [available through the Internet from http://www.vieux.montreal.qc.ca/inventaire/hall_fla.htm]; last accessed July 17, 2005.

Steiner, E. B., A. M. MacEachren, and D. Guo. "Developing and Assessing Light-Weight Data-Driven Exploratory Geovisualization Tools for the Web." Presented at *Lecture Notes in Computer Science, Spatial Data Handling,* Ottawa, Canada, 2002.

Thrower, N. J. W. "Animated Cartography." *Professional Geographer* 11, no. 6 (1959): 9-12.

Thrower, N. J. W. "Animated Cartography in the United States." *International Yearbook of Cartography* (1961): 20-30.

Tobler, W. R. "A Computer Movie Simulating Urban Growth in the Detroit Region." *Economic Geography* 46 (1970): 234-240.

Tufte, E. R. *Envisioning Information*. Cheshire, Connecticut: Graphics Press, 1990.

University of New Orleans, College of Urban and Public Affairs. *Changing Land Use in the Vieux Carre: Managing Growth to Preserve a National Landmark District.* New Orleans: University of New Orleans, 1992.

Vasiliev, I. R. "Mapping Time." *Cartographica* 32, no. 2 (1997): 1-51.

Weber, C. R. and B. P. Buttenfield. "A Cartographic Animation of Average Yearly Surface Temperatures for the 48 Contiguous United States: 1897-1986." *Cartography and Geographic Information Systems* 20, no. 3 (1993): 141-150.

Wood, M. "Visualization in Historical Context." In *Visualization in Modern Cartography*, ed. A. M. MacEachren and D. R. F. Taylor, 13-26. Oxford: Pergamon, 1994.

Yattaw, N. J. "Conceptualizing Space and Time: A Classification of Geographic Movement." *Cartography and Geographic Information Science* 26, no. 2 (1999): 85-98.

# VITA

Samara Ebinger was born in Fairbanks, Alaska in 1973. Growing up, she lived in many disparate locales with her family, including Texas, California, Alabama, Virginia and Japan. She received her Bachelor of Arts degree in Geography from George Mason University in Fairfax, Virginia in 1996. Currently, she resides in Alexandria, Virginia and works as a cartographer in support of the U.S. Department of Homeland Security.