

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

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Interactivity is generally regarded as a fundamental component of modern spatio-temporal visualization solutions. However, too little is known about the exact value provided by interactive tools in general and by specific forms of interactivity. This paper describes a human subject experiment during which three different visualizations of urban land use change were tested: a static map series, an animated map with VCR-type control, and a toggle map controlled through an active legend. Tools providing more control over the spatio-temporal display elicited a larger number of comments and were generally more positively received. Quantitative analysis of the accuracy with which subjects recalled spatio-temporal patterns were inconclusive, but there is some indication that recall speed may be affected by the tool used.

■ **Keywords:** spatio-temporal data, visualization, interactivity, urban land use change

*In der Geovisualisierungsforschung wird Interaktivität als eine wichtige Komponente von raum-zeitlichen Visualisierungstechniken angesehen. Allerdings weiß man derzeit noch zu wenig über die Nutzbarkeit dieser interaktiven Ansätze. Dieser Beitrag beschreibt ein Experiment, in dem drei verschiedene Visualisierungsformen von urbanen Landnutzungsveränderungen getestet wurden: eine gedruckte Kartenserie, eine Kartenanimation mit Videorecorder-basierten Bedienelementen und eine interaktive Karte mit sensibler Legende. Unsere qualitativen Untersuchungen ergaben, dass die Anzahl positiver Anmerkungen mit dem Interaktivitätsgrad der Visualisierungen zunahm. Die quantitative Analyse erlaubte dagegen keine eindeutigen Rückschlüsse hinsichtlich der Genauigkeit, mit der sich die Testpersonen raum-zeitliche Strukturen merken konnten. Die Datenanalyse lieferte allerdings erste Indizien dafür, dass die unterschiedlichen Visualisierungen die Erinnerungsgeschwindigkeit beeinflussen können.*

■ **Schlüsselbegriffe:** Raum- und zeitbezogene Daten, Visualisierung, Interaktivität, urbane Landnutzungsveränderungen

## 1 Introduction

"Assessments of change, dynamics, and cause and effect are at the heart of thinking and explanation. To understand is to know what cause provokes what effect, by what means, at what rate. How then is such knowledge to be represented?" (Tufte, 1997, 9)

While Edward Tufte was not specifically referring just to maps in his intro-

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duction of *Visual Explanations*, these words have a unique resonance within the field of cartography, particularly in relation to the concept of geovisualization. Geovisualization, initially defined in the early 1990s, is 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." (MacEachren and Kraak, 2001, 3) A form of 'visual thinking,' the goal of geovisualization is not to create one ideal map, but to provide a way to explore data and to generate ideas about the phenomena represented.

Much research involving the concept of geovisualization has focused on the creation of different types of geovisualization tools that utilize ever-advancing computer technologies. Studies are now expressing a need to shift the focus of new research from the creation of geovisualization tools to the study of how these tools work, how they may best be utilized for specific tasks, and how to make such tools more user-friendly (MacEachren and Kraak, 2001; Slocum et al., 2001). For example, in the eyes of many scientists, a high degree of interactivity is required for geovisualization, thereby creating a distinction from the traditional static map. However, there has been a lack of consensus as to how the term "interactivity" should be defined within the context of geovisualization (Crampton, 2002). The Oxford American Dictionary defines the word 'interact' as "to have an effect upon each other." Using this definition, even static paper maps may in some sense be considered interactive, with a stable, complex display being seen differently during prolonged viewing. Furthermore, there is still little evidence to support the idea that more interactive geovisualizations hold a distinct advantage over static maps in terms of user performance.

User testing is, of course, nothing new to cartography. However, as cartography has shifted to a primarily computerized format for map production and viewing, researchers now also draw on principles of usability engineering to test such computer-based mapping 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).

The goals of this research project are twofold: to examine how different forms of interactivity affect a user's ability to visualize spatio-temporal patterns and to test this ability using a combination of traditional cartographic user testing practices and elements of computer software usability engineering. This study is intended to provide insight into the following questions: Does the form of interactivity present in a geovisualization influence the user's ability to visualize spatio-temporal patterns? Are computer-animated maps more effective than static maps in this regard? Which format do users prefer?

## 2 Interactivity, geovisualization and static maps

A number of research projects have compared different types of interactivity in mapping tools. These studies have yielded mixed results. For instance, in Antle's study (2000) that evaluated the effectiveness of different levels of interactivity in terms of data exploration and data quality, participants using the more interactive tools answered data-related questions more accurately. However, users did not specifically prefer the most interactive tools overall. Harrower et al. (2003) developed a geovisualization tool designed to facilitate learning about weather patterns through time. Two versions of the tool were tested, one featuring an enhanced form of interactivity. Users of the enhanced interactive tool did not perform better in answering data-related questions than users of the standard tool. Overall, there remains little empirical evidence to confirm that interactivity unequivocally enhances the effectiveness of geovisualization tools.

## 3 Testing geovisualization tools

As mentioned, there is a history of user testing within the discipline of cartogra-

phy in terms of evaluating mapping products. In the past, studies that evaluated the effectiveness of traditional static maps have typically focused on quantitative methods of analysis. Such methods have been applied to research involving the comparison of static and animated maps. For example, *Koussoulakou and Kraak (1992)*, *Slocum and Egbert (1993)*, *Johnson and Nelson (1998)* and *Griffin et al. (2006)* all used response times and accuracy of responses to data-related questions to compare the effectiveness of various forms of animated maps with static maps. However, the computer-based tools tested in those research projects featured little or no interactivity – user input and control was minimal, if present at all. With the continued growth in popularity of GIS and the rise of the Internet in the past decade, interactivity has now become a fundamental part of how maps and mapping tools are designed and used. In response to this positive shift in importance of the map user, researchers have recently begun calling on new ways to evaluate maps and mapping tools based on the principles of usability engineering.

### 3.1 Geovisualization tools and usability

Even proponents of the application of usability engineering principles to evaluate geovisualization tools acknowledge that it is not always 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 a geovisualization tool does not necessarily yield a precise end result (e.g., its purpose may involve the exploration of geospatial data sets), it may be difficult to provide such information. However, usability testing can yield important in-

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sights into geovisualization tools that otherwise would not be found using more standardized quantitative methods of analysis. For example, *Kessler (2000)* depended solely on focus groups to evaluate his data exploration system on World War II U-boats. His results indicated that guidance on how to use the tools was especially important to users. Such data on user preferences is crucial as we continue to "shift from a cartographer-centric model of mapping to a user-centric model of mapping" (*Crampton, 2002, 97*).

For this research project, 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. Test participants were asked open-ended questions in reference to observed spatio-temporal patterns. Subjective responses were elicited about the test subjects' likes and dislikes with respect to the geovisualization they had viewed. Quantitative data recorded included test subjects' answers and response times in reaction to multiple-choice questions regarding spatio-temporal patterns. 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.

## 4 Methods

Human subject tests evaluating three different forms of interactivity were performed. Three different geovisualizations of multi-temporal land use data were generated and tested, providing what one might view as different degrees of interactive control:

- 1) a traditional static paper map series,
- 2) a computer-based animated map with VCR-type controls, and
- 3) a computer-based toggle map, in which users choose individual map

frames from an interactive temporal legend.

#### 4.1 Study Area

All three geovisualization tools used the same data set. The study area consisted of four parallel blocks of Bourbon and Royal Streets in the French Quarter of New Orleans, Louisiana, in the United States (Fig. 1). The multitemporal data set contains commercial and public land use types for the period from 1905 to 2000, in five-year increments, plus data for 2003. The study area, along with the rest of New Orleans' French Quarter, was designated as a historic landmark district in 1937 because of its rich architectural and cultural heritage. It continues to function as New Orleans' major tourist attraction, albeit at a more muted level since the devastation caused by Hurricane Katrina in 2005.

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

#### 4.2 Compiling the Land Use Visualization

The raw commercial and public land use data were manually gathered from two sets of annual New Orleans city business directories (*Soards' New Orleans City Directory*, 1905-1935 and the *Polk City Directory*, *New Orleans*, 1940-2003). Once a business or government establishment was identified as being located within the study area, it was necessary

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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 to categorize modern business establishments. Every building thus became associated with a series of land uses over time. Based on the dominant land use types occurring during the 1905-2003 time period, the data were reclassified into five aggregated categories to allow users to more easily comprehend multi-temporal patterns (Tab. 1).

Since land use types represent a qualitative classification, it was determined that a semiotic system based on different hues would be most appropriate. After the legend was finalized for the three geovisualization tools, the individual, year-by-year frames featuring color-coded building footprints were imported into Macromedia Freehand illustration software to apply the chosen color scheme to each individual building for each year of data available.

#### 4.3 Creating the geovisualizations

All three geovisualization tools were made to look as simple and as similar to each other as possible for ease of use, and to reduce design bias from one tool to another. Once multi-temporal map frames were created, it was relatively easy to create a paper map series out of them (Fig. 2). In all, seven map sheets (each sized 7.25 inches by 24.0 inches) were created, each showing three different frames chronologically arranged in five year increments (i.e., 1905, 1910, and so forth). 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 other geovisualization tools), as these elements were not considered essential to the interpretation of the data.

The two computer-based visualizations were created by first importing the previously constructed map frames into Macromedia Director multimedia soft-

ware. The completed animations were eventually saved as stand-alone Director Projector applications that are executable on any Microsoft Windows-compatible computer. A simple circular temporal legend was chosen for both tools. Circular legends are especially useful when dealing with cyclical phenomena, like those measured in monthly or seasonal intervals (Edsall et al. 1997). In the case of land use types, we are more likely dealing with a linear temporal progression. However, in the context of an interactive legend the circular arrangement of years allows users to more easily toggle between different time frames. Compared to this, a linear temporal legend appears less supportive of this freedom of exploration, because users may feel more pressure to explore frames in their original temporal sequence. In both computer-based tools, the year corresponding to the currently shown frame is numerically displayed in the middle of the circular legend.

The first computer-based visualization (Fig. 3) was equipped with standard VCR-type controls, which most users will be very familiar with. These included a 'Play' button, 'Stop' button, 'Pause' button, and 'Step Forward' and 'Step Backward' controls. The overall speed of the animation was kept purposely slow. This was done because the 'Step Forward' and 'Step Backward' buttons allow for the user to speed up the animation if desired.

The second computer-based map, the toggle map, provided control over the sequence of temporal frames displayed (Fig. 4). Instead of being controlled by a VCR-type interface and the legend merely indicating the current year, the legend itself here serves as an interactive interface element. When a user places the cursor over a certain year (i.e. a "mouse-over" operation) the corresponding temporal frame appears on the screen, allowing rapid toggling between frames in any desired order.

Note: All three geovisualizations are available from the authors upon request

in the form of PDF documents (static map series) or Windows executable applications (two computer-based visualizations).

#### 4.4 Testing the Geovisualizations

Test participants were recruited from two different sources. College students, including both undergraduate and graduate students, were recruited from Geography courses at the University of New Orleans. Additional test participants were recruited from the GIS department of Dewberry LLC, a private engineering firm in Fairfax, Virginia. Each participant was randomly assigned to only one of the three geovisualizations.

A total of 41 test subjects participated in the project. Of these, 31 were students at the University of New Orleans, 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. In some cases, students were given extra course credit for participating in the testing session. Mapping professionals were not compensated for participation.

During the human subject test each participant first saw a brief computer-based introduction, including a synthetic example of the map design and detailed explanation of the categorical data and corresponding legend. Prior to viewing the particular geovisualization, participants were asked to pay attention to how land uses changed through time and space and also what they particularly liked or disliked in the design of the tool itself. Test participants were then given three minutes to freely use the geovisualization tool that had been assigned to them for the session. After those three minutes the paper-based maps were removed and computer-based visualizations automatically stopped. Participants then answered six questions pertaining specifically to the spatio-temporal data they had viewed, including four multiple-

choice questions and two open-ended questions (Fig. 5). All participants, including those who had used the static map series, answered the questions via computer. This allowed automated recording of not only the answers but also of the amount of time taken to answer each question. Participants were informed beforehand that the time taken to answer questions would be documented. For the computer-based maps, mouse movements and clicks initiating interactive control over the animation were also recorded for possible further study. Finally, test participants answered three open-ended questions concerning their overall impression of the geovisualization used.

## 5 Analysis and Results

As stated previously, both quantitative and qualitative methods were utilized in the analysis of data. The four multiple-choice questions asked of participants in relation to the data viewed were used to conduct the quantitative analysis. Short answer questions dealing with both the data viewed and test subjects' attitudes toward the specific tools used were evaluated from a qualitative aspect.

### 5.1 Quantitative Analyses

Overall performance of test participants in utilizing the geovisualization was evaluated based on measures of *accuracy* and *speed*.

*Accuracy* was assessed in two different ways for each test subject: (1) with respect to answering each of the four multiple-choice questions individually (i.e., correct vs. incorrect answer) and (2) in terms of the number of correctly answered questions, out of a total of four multiple-choice questions.

*Speed* was also assessed in two ways: (1) based on response time to each of the four multiple-choice questions individually and (2) as the total response time for all four multiple-choice questions for each test subject. During the test, all response times were recorded and stored in milliseconds.

Since the first accuracy variable (correct vs. incorrect answers to individual questions) uses a nominal level of measurement, a nonparametric test was used. 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 most appropriate for these variables as well.

Pearson's chi-square test statistic was calculated for the correct/incorrect answers to each of the four questions, cross-tabulated with geovisualization type. Dealing with three different geovisualization types, the data exhibit two degrees of freedom, which corresponds to a critical value of 5.99 at the 0.05 significance level. The results of the chi-square tests indicate that, in terms of geovisualization type, there was *no significant difference* in the accuracy of answers to any of the four questions.

The *Kruskal-Wallis* test was used to analyze the second accuracy variable (total number of correct answers for each test subject with geovisualization type as grouping variable). The mean number of correct answers increases slightly for tools providing more interactive control (Tab. 2). However, at a standard significance level of 0.05, differences among total numbers of correct answers turned out to be *not significant*.

Differences among response times to individual questions did prove *not significant* with respect to geovisualization type (Tab. 3). However, total response times for the two computer-based tools are fairly smaller than the static map (94.37 seconds) and the toggle map has a smaller total response time than the VCR-control animated map (70.26 versus 77.22 seconds). The *Kruskal-Wallis* test determined these differences among total response times to be *significant* ( $0.039 < 0.05$ ).

Preliminary tests analyzing answers to multiple-choice questions based on gender, age, and educational background

were also performed to determine whether these factors played a meaningful role in the results – no significant differences in the results were found based on these variables.

## 5.2 Qualitative Results

Open-ended questions were asked of test participants in order to obtain a more qualitative view of the effectiveness of the three geovisualizations. Two questions referred to the specific nature of the historical land use data. Participants were asked to recall any particular spatio-temporal patterns they had noticed and about any conclusions or hypotheses they were able to formulate. Across the board, it appeared that the geovisualization type did not affect the overall accuracy of responses. Most test participants were able to identify the same basic land use change patterns occurring over time in the study area and to form simple hypotheses about the data. However, in describing patterns in the data, the responses from the participants in the toggle map group tended to feature the most detailed descriptions and were longer on average than responses from either of the other two groups.

Finally, additional open-ended questions were meant to elicit subjects' opinion regarding the geovisualization they had used: What did they like or dislike about it? Which improvements would they suggest? Overall, the response to the geovisualizations was positive and enthusiastic. However, in comparing the responses to the three tools, the number of positive comments about a particular geovisualization tended to increase with the degree of interactive control over the spatio-temporal display. In other words, the toggle map received the most positive comments, followed by the animated map with VCR-type controls, and lastly the static paper map series. As an example, regarding their overall impression of the tools, the static map group elicited the most "blank" answers and more of the comments were negative. Even for variables that remained constant

for the three tools, such as the color scheme, the static maps generated more negative comments than the other tools.

## 6 Conclusions

Based on the quantitative analysis discussed above, this study allows only limited conclusions regarding the effect of degree and type of interactivity on user performance in detecting spatio-temporal patterns. No significant differences were observed in terms of the accuracy with which subjects could answer specific questions about changed land use patterns. While response times for individual questions were likewise statistically inconclusive, the geovisualization type had a statistically significant effect on the total response time for all questions. In further looking at the average total response times, it appears that as the degree of control over the multi-temporal display increases, the total response time decreases. This is most pronounced when comparing the static map series to the two computer-based tools. In other words, higher degree of interactivity – even if this just refers to control over the sequence of displayed temporal frames – may possibly enable users to more quickly answer spatio-temporal questions, even if the quality of their answers is not improved. This may become relevant in time-critical application contexts.

How can these differences be explained? One important dimension is the relative novelty of the computer-based tools, which may have motivated the subjects to become more excited and pay closer attention to the geovisualization tool and the spatio-temporal data depicted. This could explain some of the tool-specific differences in total response time. This argument is also supported by the type and sheer number of open-ended comments made by subjects, especially regarding the toggle map, while the static map series received the least positive feedback. It definitely seems that artifacts featuring more interactive control are preferred.

A different explanation would be that a higher degree of control over the sequence of multi-temporal frames allows subjects to explore the visualization more quickly and deliberately. This should generate more opportunities for getting acquainted with the spatio-temporal patterns inherent in the data, to generate, test, and solidify hypotheses about these patterns. That solidification, based on an almost playful interaction with the tool, may explain why the recall of spatio-temporal patterns has a tendency to happen more quickly for the more interactive tools.

### 6.1 Future Research Directions

This study produced limited evidence for a higher degree of interactive control to have a positive effect on users' ability to detect patterns within spatio-temporal geovisualizations and that users generally like to be given interactive control over multi-temporal visualizations. However, more research is clearly necessary to quantify performance differences when dealing with various interactive visualization tools. Furthermore, the existing body of work on interactivity and animation has yielded mixed results concerning its effectiveness. A number of tasks for additional related research emerge from our project:

1. More research featuring a larger number of test subjects is needed to further validate these results, for example to see how consistent the differences in recall speed are. Since it is notoriously difficult to recruit volunteers, an option may be to utilize an Internet-based survey.
2. While comments made by some of our test subjects indicate a preference for higher levels of interactivity, the actual effectiveness of more complex types/combinations of interactivity should be evaluated in comparison to simpler and less interactive tools.
3. The quantitative evaluation of subject performance presented here was based solely on recall tasks, i.e., questions were asked *after* undirected

exploration by the subjects (except that they had been instructed to watch for spatio-temporal land use patterns in general terms). It would be interesting to observe speed and accuracy in the use of tools in response to a given task or question.

4. There is a need to determine how certain attributes of a given data set affect user performance. This includes a possible dependence of performance on temporal resolution (e.g., one-year interval versus a five-year interval) and on the data type (e.g., three-dimensional or non-temporal data). Also, there is a continued need to determine how geovisualization tools may be improved for use with very large data sets (MacEachren and Kraak, 2001).
5. Finally, given that total response time yielded the only statistically significant result among the quantitative measures, future studies may want to further elaborate on this effect in a time-critical application context, such as an emergency response scenario.

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Table 1: Reclassified land use types

Table 2:  
Mean number of  
questions answered  
correctly

Table 3:  
Mean response  
times (in milli-  
seconds)

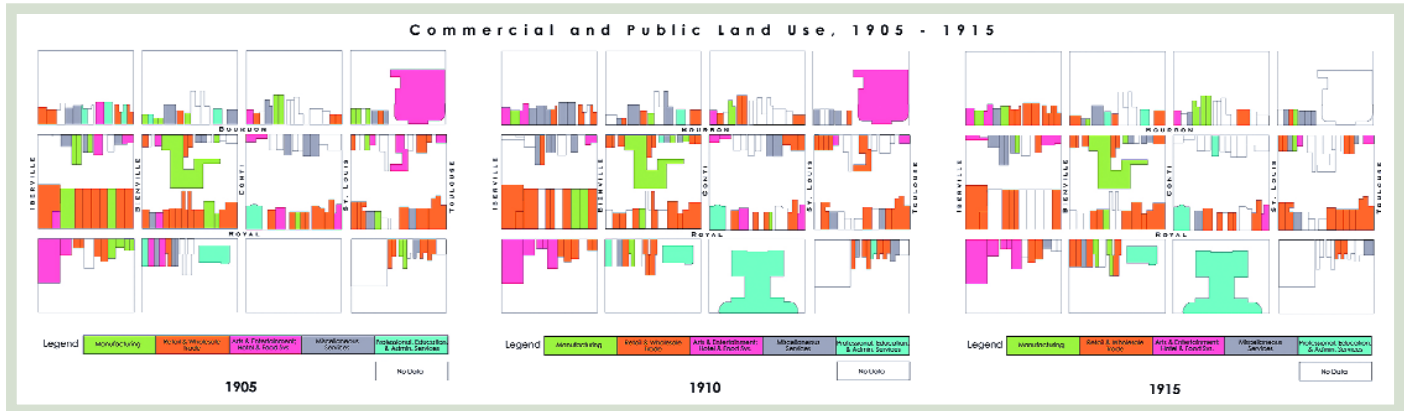
Fig. 1: Study area (Base Map Source: New Orleans Metropolitan Convention and Visitors Bureau)

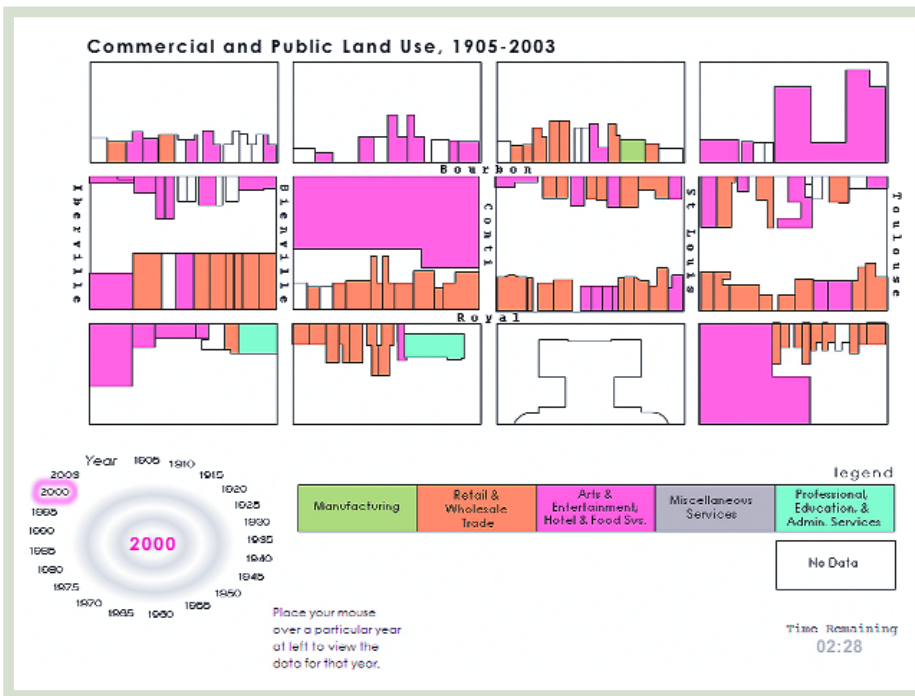
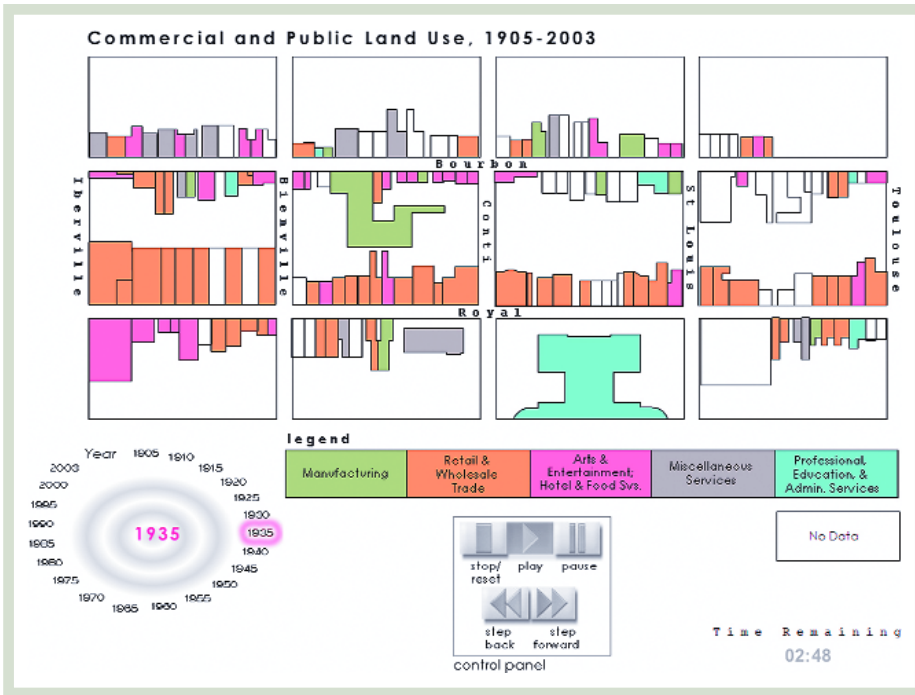
Fig. 2: Static map series

Fig. 3: Animated map with VCR-type controls

Fig. 4: Toggle map

Fig. 5: Questions asked of participants





**Data-related 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) 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 [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) Dont 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

**Open-ended evaluation questions**

- 1) Describe your overall impression of the map. Was there anything that 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?

NAICS Sector and Code	New Category
Manufacturing (31-33)	Manufacturing
Wholesale Trade (42)	Retail and Wholesale Trade
Retail Trade (44 – 45)	
Arts, Entertainment, and Recreation (71)	Arts and Entertainment;
Accommodation and Food Services (72)	Hotel and Food Services
Utilities (22)	Miscellaneous Services
Construction (23)	
Other Services (81)	
Information (51)	Professional, Education,
Finance and Insurance (52)	and Administrative Services
Real Estate and Rental/Leasing (53)	
Professional, Scientific, Technical Services (54)	
Education Services (61)	
Health Care and Social Assistance (62)	
Public Administration (92)	
<i>(Only NAICS Sectors represented in the study area during the given time period are included in this list.)</i>	

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

	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