

ROBERT MAXWELL BEAVERS

An Evaluation of Cartographic Visualization's Utility in  
the Spatial Analysis of Urban Social Dynamics  
(Under the direction of THOMAS W. HODLER)

The development of computer graphics technology has fostered a new paradigm in cartography. This advancement enabled the emergence of analytical cartography and geographic visualization, wherein map designers now engage in the use of cartographic displays for the analysis of spatial phenomena. Visualization allows for the exploration, analysis, and presentation of data, and is being touted as an important new companion to statistical methods for spatial analysis. This research project evaluated cartographic visualization's utility as a tool for the spatial analysis of urban social dynamics, specifically examining the human capacity for recognizing the strength of relations among urban social data via animated representations of a changing socioeconomic landscape. These representations were presented via a world-wide-web based survey instrument where subject responses were collected using Common Gateway Interface (CGI) scripted forms. Correlations among selected data were used to provide a test value against which test subject estimates were measured. Fifty-five University of Georgia geography students were asked to view a series of ten animated thematic map pairs displaying socioeconomic data in metropolitan Atlanta, Georgia from

years 1960 through 1990 and visually estimate the correlations existing among the data. In addition, these test subjects were asked to provide a qualitative assessment of any spatio-temporal patterns that were observed. The correlation estimates were statistically evaluated both collectively (treating the results as a group) and individually (comparing responses for each test case), and the qualitative assessments were subjectively evaluated. This research provides evidence supporting the usefulness of visualization as a means for the exploration, analysis, and representation of urban population dynamics. Given the nature of the visualization process and the manner in which it is typically employed (by experts familiar with both study area and data), this research presents a strong case for the merits of cartographic visualization as a tool for urban spatial analysis.

INDEX WORDS: Cartography, Cartographic Visualization,  
Geographic Visualization, Map Animation,  
Spatial Analysis, Urban Geography, Atlanta

AN EVALUATION OF CARTOGRAPHIC VISUALIZATION'S UTILITY  
IN THE SPATIAL ANALYSIS OF URBAN SOCIAL DYNAMICS

by

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B.S., Georgia State University, 1984

M.A., Georgia State University, 1993

A Dissertation Submitted to the Graduate Faculty  
of The University of Georgia in Partial Fulfillment  
of the

Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

1999

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## ACKNOWLEDGMENTS

There are many individuals whose support and assistance contributed to the success of this dissertation research. I am exceedingly grateful for their patronage.

First of all, I acknowledge the very important role of my family. To John and Bette Beavers, Margaret Thompson, and especially Gracie Allen Beavers, thank you for steadfastly championing my efforts. To Gene and Linda Odom, thank you for sharing a world of adventure.

Next I would like to recognize those in the Department of Geography at Georgia State University who nurtured my academic development. The encouragement of Dr. Borden Dent, Dr. Truman Hartshorn, and Dr. Zhi-Yong Yin facilitated my professional growth as a geographer and influenced my decision to pursue an academic career.

I would also like to thank the various members of the graduate studies committee here in The University of Georgia's Department of Geography. Their ongoing support provided me with the opportunity to gain valuable experience and develop skills as a university instructor.

To the members of my dissertation committee (Drs. C.P. Lo, James O. Wheeler, E. Lynn Usery, and Kavita Pandit) I express considerable gratitude for their constructive criticisms regarding this project. Additionally, I recognize the valuable advice offered by Dr. Steven R. Holloway during the implementation phase of this project.

I am particularly grateful for Dr. James Wheeler's unwavering assurance regarding my efforts as an academic geographer. It has been an honor to work with one of the discipline's most distinguished scholars.

I express profound appreciation for the support of my major professor, Dr. Thomas W. Hodler. You provided an unbounded commitment to my success that I will endeavor to match as I serve my own students.

Finally, I thank my wife, Mary R. Odom, whose ongoing encouragement was indispensable to my reaching this goal. I am eternally grateful for your wholehearted support. This experience was enhanced by your presence.

## TABLE OF CONTENTS

|                                                  | Page |
|--------------------------------------------------|------|
| ACKNOWLEDGEMENTS .....                           | iii  |
| LIST OF TABLES .....                             | vi   |
| LIST OF FIGURES .....                            | vii  |
| CHAPTER ONE -- INTRODUCTION .....                | 1    |
| 1.1 CARTOGRAPHY'S RECENT EVOLUTION .....         | 1    |
| 1.2 SOCIAL ANALYSIS AND VISUALIZATION .....      | 3    |
| 1.3 VISUALIZATION AND URBAN SOCIAL DYNAMICS .... | 7    |
| 1.4 RESEARCH PURPOSE .....                       | 10   |
| CHAPTER TWO -- LITERATURE REVIEW .....           | 16   |
| 2.1 TWENTIETH CENTURY CARTOGRAPHY .....          | 16   |
| 2.2 EMERGENCE OF VISUALIZATION .....             | 20   |
| 2.3 THE VISUALIZATION PROCESS .....              | 29   |
| 2.4 THE VALUE OF VISUALIZATION .....             | 33   |
| 2.5 TRENDS IN GEOGRAPHIC VISUALIZATION .....     | 41   |
| 2.6 THE CONTEMPORARY CARTOGRAPHIC PARADIGM ....  | 45   |
| 2.7 CARTOGRAPHIC VISUALIZATION RESEARCH TRENDS . | 48   |
| 2.8 VISUALIZATION AND SPATIAL ANALYSIS .....     | 54   |
| 2.9 URBAN SOCIAL PATTERNS .....                  | 57   |
| CHAPTER THREE -- METHODOLOGY .....               | 62   |

|                                                            |     |
|------------------------------------------------------------|-----|
| 3.1 CARTOGRAPHIC GROUNDWORK .....                          | 62  |
| 3.2 REGIONAL ORIENTATION .....                             | 69  |
| 3.3 PREPARING THE ANIMATIONS .....                         | 72  |
| 3.4 ASSESSMENT INSTRUMENT DESIGN .....                     | 75  |
| 3.5 SELECTION OF TEST SUBJECTS .....                       | 78  |
| 3.6 SURVEY AND RESPONSE .....                              | 79  |
| 3.7 STATISTICAL ANALYSIS OF CORRELATION<br>ESTIMATES ..... | 81  |
| 3.8 GRAPHING THE CORRELATION RESULTS .....                 | 82  |
| 3.9 EVALUATING QUALITATIVE ASSESSMENTS .....               | 83  |
| CHAPTER FOUR -- RESULTS .....                              | 85  |
| 4.1 CARTOGRAPHIC ANALYSIS .....                            | 85  |
| 4.2 TEST SUBJECTS .....                                    | 86  |
| 4.3 QUANTITATIVE MEASURES .....                            | 87  |
| 4.4 GRAPHS OF RESPONSES .....                              | 99  |
| 4.5 QUALITATIVE ASSESSMENTS .....                          | 110 |
| CHAPTER FIVE -- CONCLUSIONS .....                          | 142 |
| 5.1 CARTOGRAPHY FOR THE NEW MILLENNIUM .....               | 142 |
| 5.2 ANIMATIONS AND THE SURVEY INSTRUMENT .....             | 145 |
| 5.3 QUANTITATIVE CONSIDERATIONS .....                      | 147 |
| 5.4 GRAPHS AND DATA VISUALIZATION .....                    | 148 |
| 5.5 QUALITATIVE CONSIDERATIONS .....                       | 149 |
| 5.6 RESEARCH ENHANCEMENT AND EXTENSION .....               | 150 |
| 5.7 GOALS AND OBJECTIVES REVISITED .....                   | 152 |
| REFERENCES .....                                           | 155 |

## LIST OF TABLES

| Table                                                                                    | Page |
|------------------------------------------------------------------------------------------|------|
| 4.1 Correlation Coefficients for Test Variables<br>with Percent White Population .....   | 89   |
| 4.2 Single Sample t-test of Correlation Estimates<br>with Mean Actual Correlations ..... | 97   |



## LIST OF FIGURES

| Figure                                                                                                 | Page |
|--------------------------------------------------------------------------------------------------------|------|
| 2.1 A typology of modern mapping displaying<br>the various forms .....                                 | 19   |
| 2.2 Dr. John Snow's map of cholera cases clustered<br>around the Broad Street pump in London, 1954 ... | 23   |
| 2.3 The relationship between visualization and<br>the expanding cartographic paradigm .....            | 25   |
| 2.4 The functions of graphics in the visualization<br>research process .....                           | 31   |
| 2.5 Changes in data resolution invariably affect<br>spatial pattern .....                              | 35   |
| 2.6 Visualization tools enable rapid transformation<br>of map views .....                              | 38   |
| 2.7 Map multiples in temporal sequence displaying<br>spatial patterns .....                            | 40   |
| 2.8 The three dimensions of contemporary cartographic<br>function and utilization .....                | 47   |
| 3.1 Digital files were edited from 1990 data back<br>through the years .....                           | 65   |

|     |                                                                                                            |     |
|-----|------------------------------------------------------------------------------------------------------------|-----|
| 3.2 | Population growth and increasing numbers of<br>census tracts in metropolitan Atlanta .....                 | 68  |
| 3.3 | The five core counties of metropolitan<br>Atlanta, Georgia .....                                           | 70  |
| 3.4 | Population growth in metropolitan<br>Atlanta, Georgia .....                                                | 73  |
| 4.1 | Comparison of mean actual and mean estimated<br>correlation values .....                                   | 95  |
| 4.2 | Correlation estimates for median value housing<br>and percent white population .....                       | 100 |
| 4.3 | Correlation estimates for median gross rent<br>and percent white population .....                          | 102 |
| 4.4 | Correlation estimates for percent housing<br>less than ten years old and percent white<br>population ..... | 103 |
| 4.5 | Correlation estimates for percent owner-occupied<br>housing and percent white population .....             | 105 |
| 4.6 | Correlation estimates for percent renter-occupied<br>housing and percent white population .....            | 106 |
| 4.7 | Correlation estimates for percent without high<br>school diploma and percent white population ....         | 108 |
| 4.8 | Correlation estimates for percent with bachelors<br>degree and percent white population .....              | 109 |
| 4.9 | Temporal map pairs of percent black population<br>and percent white population .....                       | 112 |

|                                                                                                          |     |
|----------------------------------------------------------------------------------------------------------|-----|
| 4.10 Temporal map pairs of median family income and<br>percent white population .....                    | 114 |
| 4.11 Temporal map pairs of population per household<br>and percent white population .....                | 118 |
| 4.12 Temporal map pairs of median value housing and<br>percent white population .....                    | 120 |
| 4.13 Temporal map pairs of median gross rent and<br>percent white population .....                       | 123 |
| 4.14 Temporal map pairs of percent housing less than<br>ten years old and percent white population ..... | 127 |
| 4.15 Temporal map pairs of percent owner-occupied<br>housing and percent white population .....          | 130 |
| 4.16 Temporal map pairs of percent renter-occupied<br>housing and percent white population .....         | 132 |
| 4.17 Temporal map pairs of percent without high school<br>diploma and percent white population .....     | 135 |
| 4.18 Temporal map pairs of percent with bachelors<br>degree and percent white population .....           | 138 |

## CHAPTER ONE

### INTRODUCTION

#### 1.1 CARTOGRAPHY'S RECENT EVOLUTION

The nature and application of cartography has changed dramatically during the latter third of the twentieth century. The somewhat recent development of computerized mapping and geographic information technology now provides a methodological tool that is useful for spatial analysis, transforming the discipline from its predominantly illustrative historical role. This dawning of an age of analytical cartography has resulted in numerous examples of research within a broad range of subject areas from environmental to cultural demonstrating the viability of utilizing cartographic methods in the analysis of spatially related phenomena. In the last few years such research methods have been increasingly referred to as geographic or cartographic visualization.

Cartographic visualization, involving the use of spatial data display and analysis systems for geographic research, has become a powerful tool for the exploration

and assessment of spatial patterns and processes. Because visualization complements a breadth of mathematically based analytical methods with human visual cognition capabilities, visualization methods are being applied to research problems throughout the geographic discipline (MacEachren and Monmonier, 1992). Visualization offers a number of advantages to geographic researchers. It provides a means for bridging between visual thinking and visual communication. It allows spatial investigators to explore the nature of geographic phenomena and identify patterns and relationships, test hypotheses, synthesize and draw conclusions based on their analyses, and graphically present their results to other interested parties (MacEachren, 1994b; MacEachren *et al.*, 1992). If a picture is worth a thousand words, then visualized geographic data must be worth that much and more.

Visualization enhances geographic research through a variety of means. It can be used to reveal the spatial dimensions of data that might ordinarily be organized in tabular form, allowing researchers to see spatial relations that might not otherwise be apparent. It provides a way to filter data through different scales to seek an appropriate resolution for examination, and it offers the capacity for multidimensional representations

of complex environments. It can help mitigate the temporal limits often associated with the analysis of spatial change over time (MacEachren *et al.*, 1992). The visualization approach is a logical offspring of the marriage between contemporary technological development and the growing collection of spatially referenced data. The technology provides the means for exploring this data, which have already become available in such large volumes that comprehending significant patterns and processes is otherwise unwieldy. Visualization methods offer the prospect of enabling us to see the "data forest" despite the immense volume of "data trees." By its very nature the visualization methodology presents a big picture view of geographic data.

## 1.2 SOCIAL ANALYSIS AND VISUALIZATION

Despite visualization's potential for widespread application, it has not as yet found extensive use in the analysis of urban socioeconomic patterns. Perhaps part of the reason for this is the emergence and growth of critical social theory as a research approach for human geographic analysis. Social theorists might suggest that analysis is best approached from multiple perspectives or points of view, and that traditional mapping involves the production of a limited view of the landscape in question

(Slocum, 1999). For this reason, many who hold this postmodern perspective openly question basic foundations of cartographic theory (Huffman, 1996) and challenge its usefulness in human analysis. Some have argued that essentially all maps, when deconstructed (deconstruction representing a reading between the lines in order to decipher possible underlying agendas), can be interpreted from various perspectives and therefore have hidden or unintended meanings (Slocum, 1999). It is true that maps commonly communicate unintended messages, and that data selected as well as symbolization chosen for mapping can be influenced by the underlying culture associated with the map producer, and many social theorists further argue that the study of racial relations is in itself flawed because race is considered a social construct.

The notion that race is a social construct is simple and straightforward. Race is not a classification based upon biology. Human beings are a single species. Race is socially constructed, therefore, on the basis of generalized physical characteristics such as skin color and physique. This social construct of race is, therefore, cultural rather than biological, and social division among human populations is a common result of these cultural differences.

Issues of race aside, some overlap does exist

between the postmodern and visualization approaches in that both promote the utilization of multiple representations or perspectives in the analysis of a given area. Indeed, when visualization is used for data exploration, the production of multiple views has developed from recognition that a single best representation cannot be developed, and this much at least represents a common thread through these two analytical approaches.

This notion of freeing ourselves from optimal maps in order to fully take advantage of what cartographic abstraction offers dates back nearly four decades, to the origins of contemporary analytical geography (Bunge, 1962). More recently, this idea of exploring spatial data from multiple perspectives has been compared with the artistic approach known as cubism. A foundation of cubism is the ability to overcome constraints of space and time, endowing a freedom to develop composite images that present the environment as if viewed from several perspectives simultaneously. Contemporary cartography is somewhat analogous to this cubist approach, in that we are freed from the static view in order to better explore geographic landscapes with multiple cartographic representations (Muehrcke, 1990). Through this new approach, which is fundamental to visualization, we



enhance our prospects for discovering characteristics about the world around us that might not have been otherwise possible without these methods.

Much of the literature about cartographic visualization speaks of the inherent value associated with an open-minded visual exploration of spatial data sets, in order to tap into the visual thinking skills of individuals engaged in geographic research (Buttenfield and Mackaness, 1991; Jones, 1997; Kraak and Ormeling, 1996; MacEachren, 1995; MacEachren, 1994b; MacEachren *et al.*, 1994; MacEachren *et al.*, 1992; MacEachren and Monmonier, 1992; Peterson, 1994; Taylor, 1994; Turk, 1994; Visvalingam, 1994; Wood and Brodlie, 1994). This involves the utilization of spatial displays of derived information in a more scientific approach to problem solving. Debates, sometimes contentious, continue between spatial analysts and social theorists. Regardless of the esteemed arguments offered by these two camps, more than a kernel of truth about the human landscape has been garnered by both approaches.

Still, there is much that can be learned about urban socioeconomic landscapes via cartographic visualization. A wealth of data from public agencies and private companies are available for analysis and interpretation, and are being utilized by numerous organizations for a

variety of purposes including demography and planning. Exploring these data with the tools of cartographic visualization can aid analysis by displaying results in a form that reveals associated spatial patterns. Public agents such as urban planners can take advantage of visualization tools to model and predict socioeconomic changes in the urban landscape and use the results to enhance their ability to make effective planning decisions. The general public stands to benefit from the utilization of visualization in the work of public agencies.

### 1.3 VISUALIZATION AND URBAN SOCIAL DYNAMICS

One social problem that has been particularly nettlesome for urban planners in the latter twentieth century United States is the issue of race and residential space in metropolitan areas. Throughout the twentieth century, the residential landscapes of many large urban areas have been characterized by spatially well-defined separations of White and African-American populations. The resulting African-American communities are often referred to as ghettos, due to the relative spatial compactness and lack of residential assimilation into the greater urban social fabric (Hartshorn, 1992; Rose, 1971). In the first half of the twentieth century,

this social separation was maintained by the force of policy originating from all levels of government, whether local, state, or federal. Following numerous mid-century judicial rulings abolishing overt practices of racial discrimination in housing, the social forces responsible for the shaping of ghetto space became more subtle in their manifestation (Darden, 1995).

With the Twenty-First Century rapidly approaching it is apparent that there has been little more than modest change in the degree of residential separation between Whites and African-Americans since legal barriers were removed. In this latter half of the century, many U.S. metropolitan areas have experienced a fairly profound urban sprawl, reaching far into the surrounding countryside. Certainly a portion of this exurban growth into newly developed residential communities far-flung from the central city has been fueled by an as yet unrelenting white flight from ghetto space that is likewise spreading into communities surrounding the urban core (Adams *et al.*, 1996; Massey and Hajnal, 1995; Phelan and Schneider, 1996). It may yet be learned that this contemporary urban sprawl has taken a life all its own, fueled by a complex set of factors that includes not only issues of race but also a variety of other considerations that influence the development of a subjective "quality

of life” perspective that makes these outlying areas attractive to more and more residents. Still, within the older core region of urban residential space, there can be no denying the persistence of a socially stratified landscape.

Curiously, as African-American residential populations have increased within the heart of most metropolitan areas, the resulting expansion of ghetto space has not occurred uniformly on all social borders but instead appears as a relatively rapid transformation in some areas while there is little or no concurrent transformation apparent in others. Truman Hartshorn perceives such spatial expansion as highly directional and biased along a primary axis evident within existing ghetto space, and suggests that expansion may be limited by the existence of higher-priced housing and stronger social resistance (Hartshorn, 1992). The idea that there are mitigating factors influencing whether or not a neighborhood or community might experience such social transformation provides an intriguing prospect for the application of visualization tools in the exploration and analysis of this phenomenon.

#### 1.4 RESEARCH PURPOSE

The geographic visualization literature makes a

number of claims, and Christopher Jones sums up these arguments by asserting that visualization helps “identify spatial structures, patterns, and correlations, thus raising the information content of the data” (Jones, 1997). Within the realm of spatial analysis as applied to urban socioeconomic trends and population dynamics, this assertion is as yet largely unsubstantiated within the current body of geographic literature. It is the aim of this research to consider the utility of cartographic visualization as a methodological tool for the exploration and analysis of urban socioeconomic data. In particular, the focus will be on the ability of test subjects to visually estimate correlations that exist among selected urban socioeconomic data (race, income, housing, and education) as represented in animated thematic maps of census data collected in the years 1960, 1970, 1980, and 1990 for the five counties that form the core of the Atlanta, Georgia metropolitan area.

Why metropolitan Atlanta? The study area for a project involving the visual estimation of correlations among race and other socioeconomic characteristics requires a city with a sizable and growing African-American population to maximize the proportionate amount of area affected by the phenomenon. It follows that this region would likewise be among the most populated U.S.

metropolitan areas, in order to accommodate such a large sub-segment of the total population. Metropolitan Atlanta fits these parameters. This selection is reinforced by the fair amount of existing literature pertaining to the nature of race and space in the Atlanta area, providing an indication that the region is indeed significant in the minds of more than a few academic researchers.

Perhaps a share of this literature was a natural outcome associated with Atlanta's emergence as a sort of flagship city of the New South. When other southern municipalities were struggling with the federal government over social changes mandated as a by-product of the civil rights movement, political leaders were proclaiming that Atlanta was the "city too busy to hate" (Rutheiser, 1996). Although much of this posturing was not reflected in the reality of daily life in the region, it did represent a positive and pro-business attitude that served well the city's interests at the national level. Much of Atlanta's success as a business center in the latter twentieth century has been related to the maintenance of a loose coalition built between White business leaders and African-American community leaders, a sort of fragile peace for the sake of the economy (Bayor, 1996; Rutheiser, 1996; Stone, 1989). But

underlying social problems have not simply disappeared for the sake of a strong economy, and white flight from an expanding African-American ghetto space has continued throughout the latter twentieth century (Clark, 1988; Rutheiser, 1996; Silver and Moeser, 1995; Wheeler and Davis, 1984).

If the cartographic visualization literature is correct, researchers trained in geographic analysis should be able to estimate relative correlations that exist among urban socioeconomic data based on visual representations. In the case of race and residential space in metropolitan Atlanta, which is evidenced by a clearly defined social separation (Rutheiser, 1996), a visual comparison of such characteristics as income, housing, and education with race provides a suitable test of the methodology.

White populations generally exert economic dominance in most U.S. metropolitan real estate markets, and consequently wield greater influence over the definition of social borders. It is, therefore, reasonable to expect to see the impact of these social forces on resulting residential patterns. Considering the inherent spatiality of this enduring problem, cartographic visualization techniques such as map animation offer much utility for the exploration and analysis of urban social

dynamics.

The goal of this project is to evaluate the utility of cartographic visualization as a tool for the spatial analysis of urban social dynamics. More specifically, this research will examine the human ability to recognize the strength of relations among urban social data via animated representations of a changing socioeconomic landscape. Toward this objective, correlations among the selected data are used to provide a test value against which test subject estimates are measured. It is hoped that the results of this research will provide evidence supporting the usefulness of visualization as a means for the exploration, analysis, and representation of urban population dynamics. Demonstrating the viability of cartographic visualization as a tool for urban socioeconomic research represents an important step in the evolution of both urban spatial analysis and the geographic discipline.

Here are the research design components associated with this project:

1. Develop animated thematic maps of various socioeconomic components of race, housing, education, and income derived from data compiled by the U. S. Census within the designated study area for a series of latter twentieth century



census years.

2. Create a world-wide-web based survey instrument for the presentation of the animated maps in data pairs for test subject visual estimation of data correlation.
3. Use the web based survey instrument to collect quantitative estimates of correlations among the selected data.
4. Use the web based survey instrument to collect qualitative assessments of spatial patterns observed in the map animations.
5. Analyze the correlation estimates using t-test for paired samples to assess whether there are significant differences between the estimated and actual correlations as groups.
6. Analyze the correlation estimates using single sample t-test to assess whether there are significant differences between the estimated and actual correlations individually.
7. Graph the correlation estimates and discuss the resulting distributions.
8. Compile the qualitative assessments and discuss the observations of spatial patterns.

This research endeavor has been designed to explore the viability of cartographic visualization as a

supporting tool for spatial analysis in the examination of urban social problems. Regardless of the attained results, visualization is not proposed herein as a replacement for other means of social analysis. Urban social landscapes are quite complex and are appropriately scrutinized from a broad range of research perspectives.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 TWENTIETH CENTURY CARTOGRAPHY

Throughout the history of cartography, methodological innovations have been associated with technical advances in graphic production. For centuries these changes were limited in scope to such areas as map projection and map production. Thus, in the late nineteenth and early twentieth centuries, academic interest in cartography was generally limited to the consideration of maps as historical documents, the development of projection methods suitable for various modern mapping needs, and the refinement of technical aspects related to the production of modern maps. With a few exceptions, such as Goode at the University of Chicago and Raisz at Harvard, cartographers were widely regarded more as technicians rather than scholars or scientists (McMaster and Thrower, 1991). Following World War II, academic interest in a broader range of cartographic research and theory began to develop with studies related to map communication, cartographic

symbolization, and the delineation of the discipline's philosophical foundations (Tyner, 1992). In recent decades, methodological and technical advances have effected a profound impact on cartography, revolutionizing the discipline. Analytical cartography arose in the 1960s as a by-product of geography's quantitative revolution wherein spatial statistical methods gained widespread application throughout the parent discipline (Tobler, 1976; Tobler, 1970). Subsequent technological innovations in computer systems have enabled the development of software that run sophisticated statistical analysis on tabular data, dynamically display maps showing the distribution patterns resulting from such quantitative manipulations, and also allow for analytical operations performed directly on spatial data via cartographic modeling algorithms in geographic data systems.

Many scholars versed in cartography and GIS believe there is considerable overlap between GIS and analytical cartography in that both fields are built on a unified spatial theory foundation that includes such common components as graphic data structures (raster and vector) and numerous mathematical and analytical methods. Some suggest that the significant difference between analytical cartography and GIS relates to the latter's

predominant focus on practical applications while the former is predominantly focused on developing a base of analytical theory (Moellering, 1991).

The development of computerized mapping systems has truly effected a significant change in the nature of maps. Throughout the vast majority of cartographic history, maps were tangible products static in nature -- hard copy entities that were designed and rendered to serve a fairly specific purpose without offering map readers any means for dynamic interaction. Now, modern computer systems have made it possible to complement such conventional sheet maps with a range of "virtual" maps -- maps that are not limited to a single hard copy landscape view ([Figure 2-1](#)). For some, these virtual maps range from human to technological extremes, with individual cognitive images commonplace to human experience at one extent and computerized data storage and graphic display at another (Kraak and Ormeling, 1996). Others regard the analytical implications of those virtual maps made possible by advances in digital technology as representing a profound advance in mapping science, and further classify virtual maps into the following: 1) maps that are physically viewed but not rendered in permanent form (such as maps shown on a computer screen); 2) maps that are rendered in permanent form but are not being

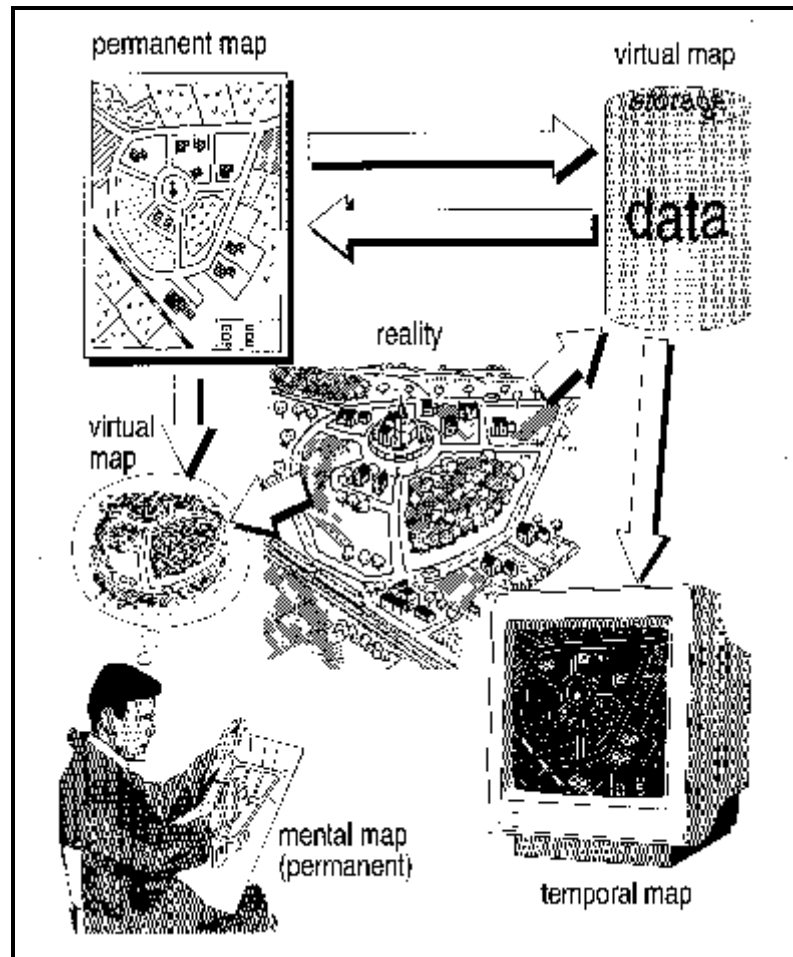


Figure 2-1: A typology of modern mapping displaying the various forms.  
Source: Kraak and Ormeling, 1996.

physically viewed (such as a map stored on a CD-ROM); and 3) maps not being physically viewed and not stored in permanent form (such as a spatial data base stored on magnetic media). Located within this third level of virtual mapping is what is regarded as the deep structure of map information. Deep structure exists in the geographical relationships between spatial objects and their attributes, which are not necessarily capable of being rendered cartographically (Nyerges, 1991; Moellering, 1991). For spatial analysts, these deep structures can be particularly revealing about the underlying nature of the physical and cultural environments in which we live, and this has given rise to the use of computer graphics in the visual analysis of both natural and human phenomena.

## 2.2 EMERGENCE OF VISUALIZATION

Within the past fifteen years, there has been rather substantial growth in the role of visual analysis within the natural and earth sciences, particularly in the exploratory stages of research (MacEachren, 1994b). This growth was invigorated during the mid 1980s, when scientists began utilizing computer systems to graphically display and explore the patterns and processes associated with spatial phenomena in various

fields such as physics and chemistry. The facilitation of this visual analysis through the use of computer graphic technologies came to be known as scientific visualization. This has generated considerable interest in the scientific community at large, as well as a fair amount of fanfare regarding the ability to visually analyze spatial subjects at scales ranging from microscopic to interstellar.

While this development is indeed significant, numerous geographic professionals note that cartographers have for many, many years engaged in the production of graphics useful for the exploration and communication of spatial data (Taylor, 1996). Long before the larger community of scientific disciplines began using the term visualization to describe the graphic exploration and analysis of spatial phenomena, cartography was providing such utility to individuals engaged in geographic research. This process has involved taking advantage of innate visual thinking skills to form new cognitive images derived from experience and observation, and producing tangible graphic ideations of these notions in order to develop a greater understanding of explored information (Dent, 1999). Historically, these graphic ideations have been developed as manual sketches created during the visual thinking process to provide a concrete



framework to spatial conceptions.

Most geographers are familiar with the case of Dr. John Snow and his mapping of cholera incidence in a London community. Dr. Snow had suspected that drinking water was the carrier of this deadly disease, and his map showed clustering of individual cases around the now infamous Broad Street pump (Goodchild, 1992). On a fundamental level, his dot map may be viewed as the result of a thematic overlay of three different data layers, with the street grid representing one layer, the dots showing the number of cholera cases another, and the various public water supply locations the third ([Figure 2-2](#)). Based upon this graphic evidence, Snow was able to convince public officials to shut the pump down whereupon new cases of cholera in this area promptly declined (Meade *et al.*, 1988). There are numerous other examples of the utilization of thematic maps as research tools but, prior to the development of computerized mapping, the inability of a researcher to dynamically interact with spatial data hindered such efforts (Wood, 1994a; Wood, 1994b). Given the impact of contemporary technology, that particular handicap is no longer a significant concern for spatial analysts. The advent of computer graphic technologies has, obviously, greatly enhanced the ability of spatial investigators to quickly

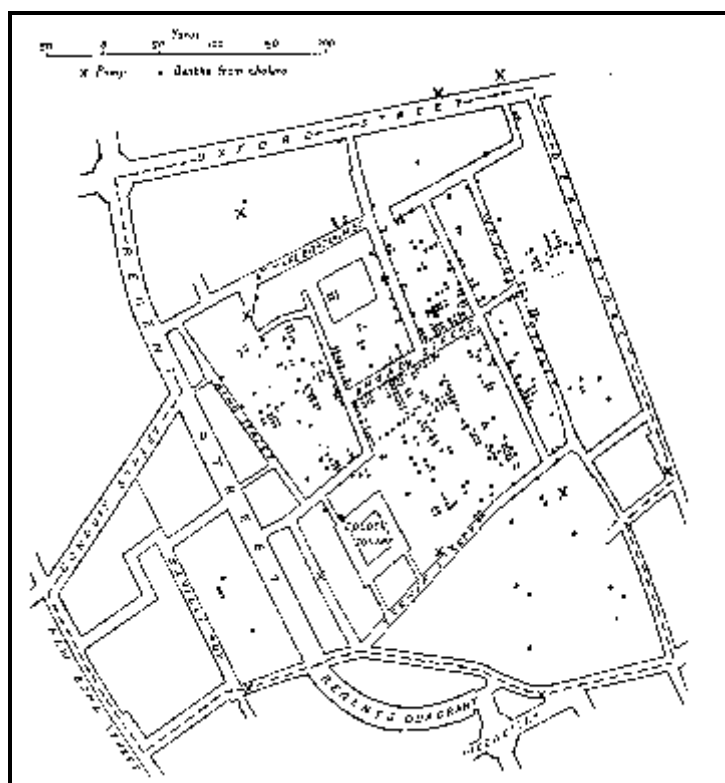


Figure 2-2: Dr. John Snow's map of cholera cases clustered around the Broad Street pump in London, 1854. Source: Gilbert, 1958

construct alternative views of geographic data sets in order to seek out and explore significant spatial patterns.

Even without considering the past two centuries of cartographic innovation in the thematic mapping of quantitative data, it is appropriate to acknowledge that the development of computerized mapping and geographic information systems predated the breakthrough of formalized scientific visualization methods by some two decades (MacEachren *et al.*, 1992; Wood, 1994a; Wood, 1994b). Nevertheless, it cannot be denied that the emergence of scientific visualization has been beneficial for those involved in geographic research and analysis, leading many to regard visualization as a valuable addition to the family of contemporary cartographic methods.

If cartography already boasts a considerable history of spatial data exploration and communication, why then is visualization such an important new enhancement for the field of mapping science? According to Fraser Taylor, visualization is important to cartography because of the impact it has had on the changing role of graphic analysis in scientific investigation ([Figure 2-3](#)). It has introduced a dynamic interactivity for the map user that transforms cartography from a primarily illustrative

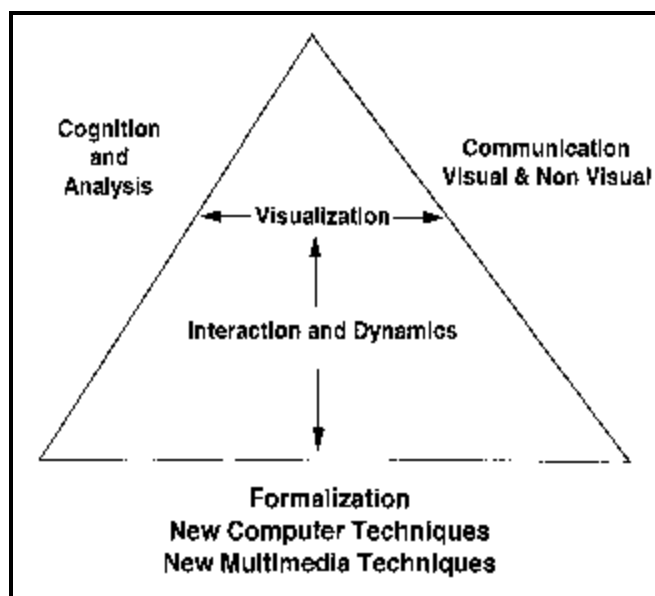


Figure 2-3: The relationship between visualization and the expanding cartographic paradigm. Source: Taylor, 1994.

role to a substantially greater analytical utilization (Taylor, 1994). Because of numerous advances in computer technologies, cartographers now enjoy the ability to employ an expanding number of spatial analysis methods incorporated into analytical manipulations of graphically displayed data sets, enabling a broader flexibility in the search for improved understanding of spatial patterns and processes, as well as an enhanced capacity for the communication of investigation results.

Visualization has much to offer analytical cartographers because it capitalizes on the strength of human perceptual abilities, providing a means for visual analysis to be used in combination with sophisticated statistical methods. The human brain has an impressive capacity for the understanding and assimilation of information that is graphically presented. In the context of scientific methods, visualization involves the use of graphic data analysis and display systems to help researchers explore and acquire deeper insights into the nature of spatially arrayed data. From the cartographic perspective, visualization allows researchers to investigate the structural relationships that exist deep below the more simple surface structures that are readily apparent via the relatively straightforward thematic mapping of unmodeled data. These deeper structures are

found in the geographical relationships that exist among the collected data, and may be revealed through the application of a variety of mathematical models designed for different spatial analysis needs (Nyerges, 1991). Contemporary computer technology provides the ability to quickly manipulate and produce graphic displays of geographic data that endows investigators with the means to thoroughly explore spatial processes and patterns by making repeated adjustments to the data. These adjustments may be as simple as making changes in the way the data are classified or as complex as exploring the mathematical relations between spatial phenomena.

There exists today a plethora of geographically referenced data relating to both environmental and social phenomena, and the quantity of newly compiled data sets is increasing at a dramatic pace. Visualization tools provide the means to filter and explore these rapidly growing quantities of spatial data, perceive patterns that may be apparent at one resolution but may otherwise remain invisible at other resolutions, offer changes in perspective that enable comprehensive views of complex landscapes, consider the relations between multiple data variables, transform the data surface model from two to three dimensions or rapidly alter the projection to suit a particular need, and develop representations of

temporally changing landscapes unlimited by the traditional constraints of a single view map (MacEachren, 1995; MacEachren *et al.*, 1992). The phrase visualization tools is more conceptual than concrete in that it can refer to any computerized method used to graphically render spatial data in any form ranging from highly realistic to highly abstract (MacEachren *et al.*, 1992). For instance, an orthophotomap of barrier islands along the coast of Georgia would provide a highly realistic portrayal of the physical and cultural landscape, while a simplified chart of travel times between coastal cities in that same area reveals meaningful relationships among the data in a much more abstract form. There are, therefore, numerous ways to graphically visualize spatial data sets -- from the utilization of remotely-sensed imagery for environmental analysis to the thematic mapping of statistical information for planning purposes to the construction of graphs describing spatial relations for theoretical generalization -- and collectively they serve as a geographic visualization tool kit.

Computer systems have made interaction with maps readily accessible for contemporary geographic researchers. No longer limited to the static realm of snapshot views of complex landscapes, cartographers are

now able to produce views of the world that can simulate its real-time nature. Alan MacEachren advocates the use of post-processing techniques in the application of visualization methods on large data sets. Post-processing allows for the interactive exploration of cartographic overlay data propagated during the course of spatial model development, along with the animation of time-series maps showing the changing patterns (MacEachren, 1994a). This approach enhances exploratory data analysis by representing dynamic spatial processes in a manner that is instinctively comprehensible.

Cartographic visualization is a methodology now ripe for more widespread application. The already vast amount of information collected for human and environmental research is growing rapidly, and visualization provides an efficient means for analytically processing this data. The utilization of visualization in GIS is beginning to provide spatial analysts with graphic tools to complement statistical methods.

### 2.3 THE VISUALIZATION PROCESS

Geographic visualization specialist David DiBiase has identified four distinct stages in the visualization process that have been identified within two larger domains of visual thinking and visual communication



([Figure 2-4](#)). Within the realm of visual thinking are the initial stages of exploration and confirmation, and within the realm of visual communication are the more advanced conceptual stages synthesis and presentation (DiBiase, 1990).

Exploration represents an initial step in the research process. What is the nature of the research problem? What are the issues associated with the investigation? What are the salient questions worthy of consideration? Researchers often develop agendas based upon personal observations or other precipitating experiences, and many have the ability to picture in their mind an initial assessment of the situation. Visualization enhances that ability and takes it a step further, not only enabling a formal view of the original conceptualization but also facilitating the creation of many other views that might provide useful glimpses of patterns that might not have been a part of the initial assessment (MacEachren, 1994b; MacEachren *et al.*, 1992). This is an analytical process that serves well those investigators who proceed with an open mind about their research. New questions can develop while large quantities of data are examined in relatively short order, and new research directions can arise based upon the visual examination of patterns and data relations

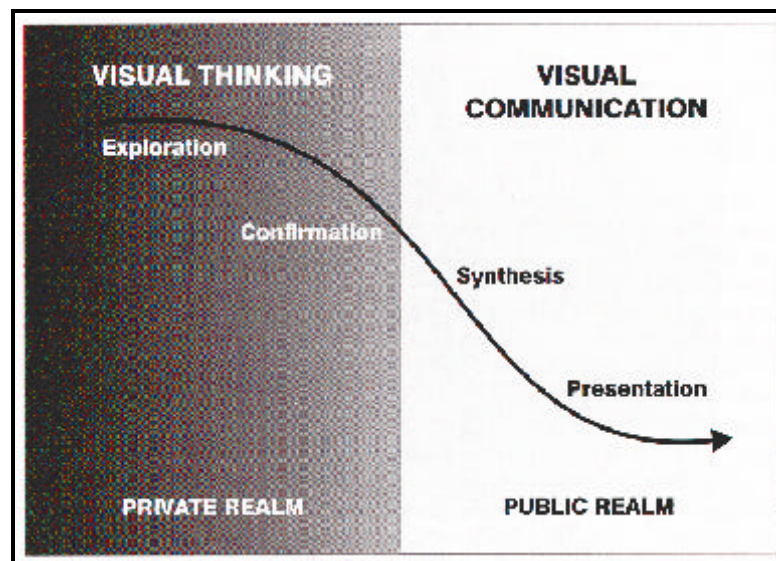


Figure 2-4: The functions of graphics in the visualization research process.  
Source: DiBiase, 1990.

that appear promising.

After initial conclusions are drawn during the exploration stage investigators move on to the next step and pursue a confirmation of the early results. As the research becomes increasingly focused, visualization tools provide the means whereby an investigator can confirm or rule out the validity of the early assumptions. Results from statistical analyses may be graphed and spatial models may be mapped, and these items may be scrutinized in relation to any developing hypotheses (MacEachren, 1994b; MacEachren *et al.*, 1992).

As the inquiry progresses, researchers begin to develop a synthesis of the investigation results. Once it may be confirmed that the research results are on the right track, visualization can be used to synthesize concepts and produce logical generalizations about what to this point may be no more than a loose collection of ideas. This is the time for researchers to frame the results into a broader theoretical context (MacEachren, 1994b; MacEachren *et al.*, 1992).

Now that the research results offer support for investigation hypotheses, it is appropriate to share these results with a wider audience (MacEachren, 1994b; MacEachren *et al.*, 1992). Since the products of visualization analyses are tangible graphics, many regard

them as existing in presentation form, but suitable enhancements to the graphic design should again be considered.

## 2.4 THE VALUE OF VISUALIZATION

An enormous volume of digital data have been generated in the relatively brief amount of time that has passed since the development of computerized spatial analysis technologies, and this obviously represents but a minute fraction of the data yet to come. Visualization methodologies (which, of course, are fairly new and continuing to develop) offer numerous advantages for analytical cartographers, not the least of which is the ability to filter and explore these growing volumes of spatial data. This ability to manage such vast quantities of spatial data enables a comprehensive view of the data, rendering complex landscapes more discernible without eliminating the underlying data structures (Buttenfield and Mackaness, 1991; MacEachren and Monmonier, 1992). The tangible graphic representations that are at the heart of the visualization process stimulate visual thinking and facilitate geographic problem solving.

One issue to consider when working with these large data sets is related to scale. Spatial patterns and

processes exist and are evident at different resolutions. What might be apparent at one scale might remain concealed at another (MacEachren *et al.*, 1992).

Visualization tools allow researchers to account for this characteristic problem by enabling quick looks at graphic displays of data at different resolutions ([Figure 2-5](#)).

With United States Census data, for instance, statistics are collected and aggregated at different levels. It is widely acknowledged that the numbers revealed via the mapping of county level data are not as accurate or informative as the mapping of census tract or block group level data. In this case the higher resolution provides a more meaningful spatial pattern. But there are times when such finer resolution might conceal patterns that may exist at regional rather than local scales, and a coarser resolution would be more suitable (MacEachren *et al.*, 1992). It is essential, therefore, that spatial data be filtered in a manner appropriate for the given research task.

The increasing complexity of spatial data sets is another significant concern for analytical cartographers. A considerable volume of data is being collected and compiled in multidimensional form (MacEachren *et al.*, 1992). Remote sensing, for instance, routinely provides a wealth of data about the earth's surface that supplies

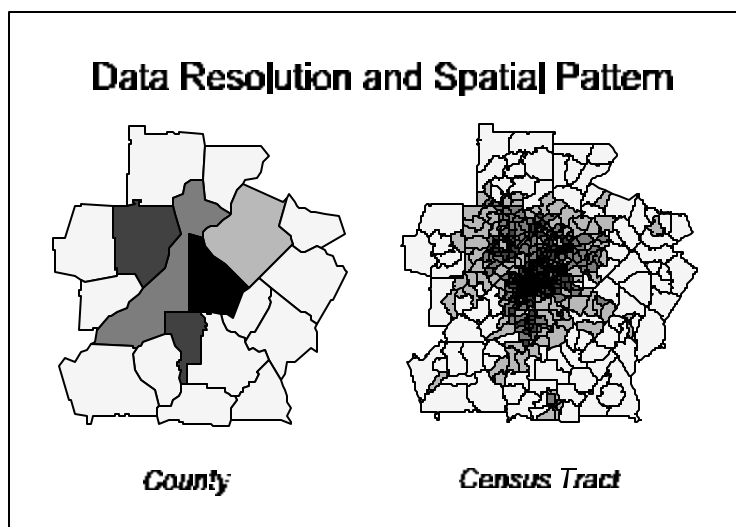


Figure 2-5: Changes in data resolution invariably affect spatial pattern.  
Source: author, 1997.

spatial analysts with valuable information related to land cover and land use in rich detail. Many of these data are collected as electromagnetic spectrum reflectance values by multispectral scanners, and are recorded on several different bands. Investigators can take these multidimensional data and organize the results into spectral signatures that may be used to provide in-depth examinations of landscape patterns.

Obviously, the transformation of spatial data from one form to another represents an important component of the visualization process. These transformations can involve not only the changes in resolution and dimension already indicated but can also involve numerous other changes, including the way a terrain or statistical surface is depicted. Visualization methods enable the rendering of surface views that simulate three dimensions, despite being limited to such two dimensional output options as hard copy and computer screen forms. Many years ago cartographers began devising technical methods for the depiction of three dimensional surfaces, and the emergence of computer mapping technologies has facilitated the development of new techniques that not only render surface views but also provide analytical capabilities useful for civil engineering and environmental analysis (MacEachren *et al.*, 1992).

Topographic maps historically presented landscape views that depict undulating surfaces through the use of elevation contours. Often, these surface representations were further enhanced by such techniques as hill shading, which provide the map reader with more realistic and somewhat more easy to visualize scenes. Contemporary computerized tools have automated and enhanced the process of transforming surface depictions from strictly two-dimensional views associated with contour maps to simulated three-dimensional perspective views that are readily generated by many mapping systems ([Figure 2-6](#)). Remotely-sensed imagery is often draped over digital elevation models in order to provide realistic visualizations of environmental landscapes. The hill shading technique has likewise been adapted for use in computer mapping systems and, when used in conjunction with digital elevation models, may be particularly effective when representing actual topographic landscapes. Attribute information such as vegetation cover or soil types may be draped over the view to provide a dramatic rendering of the relationship between such categorical features and variations in the terrain. Statistical information such as population density can also be presented as a surface view, often with the ability to rotate the perspective and adjust the “eye”



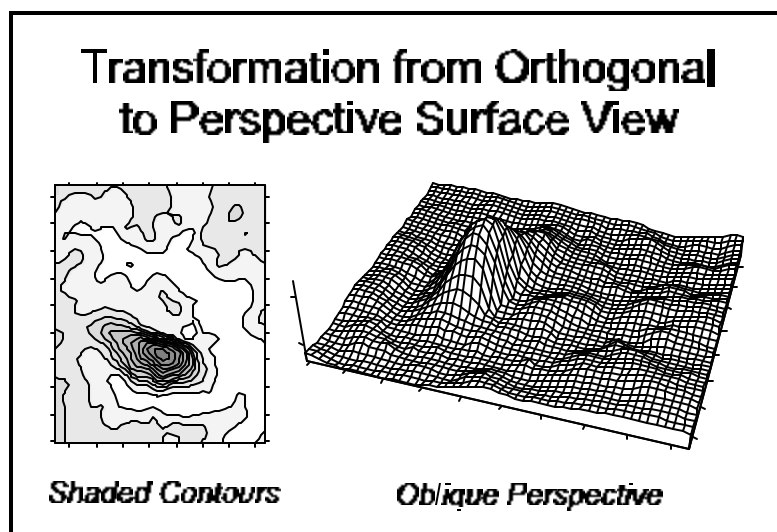


Figure 2-6: Visualization tools enable rapid transformation of map views.  
Source: author, 1997.

position in terms of vertical height and proximity to the mapped features. A further transformation that is quite useful for researchers who engage in the spatial analysis of population data involves the conversion of data from vector to raster form. Spatial data that exists in raster form can often be more readily explored and analyzed than when it exists in vector form.

Mathematical operations that are performed on maps rendered in raster form may be processed more quickly than operations performed on the vector equivalent. Since analysis is a key element of the visualization process, this flexibility may be an enormously valuable asset.

Our world is a very dynamic place, and spatial patterns and processes typically occur within a temporal context. Historically, the mapping of change over time has been achieved in two ways: through a single map that strives to capture the essence of the temporal change (either movement from place to place or attribute evolution through time), and through multiple maps viewed together in series to provide a visual comparison of a temporally changing attributes for a given area ([Figure 2-7](#)). The depiction of temporally changing landscapes is an exciting new trend in cartographic visualization, particularly with the development of technology that has

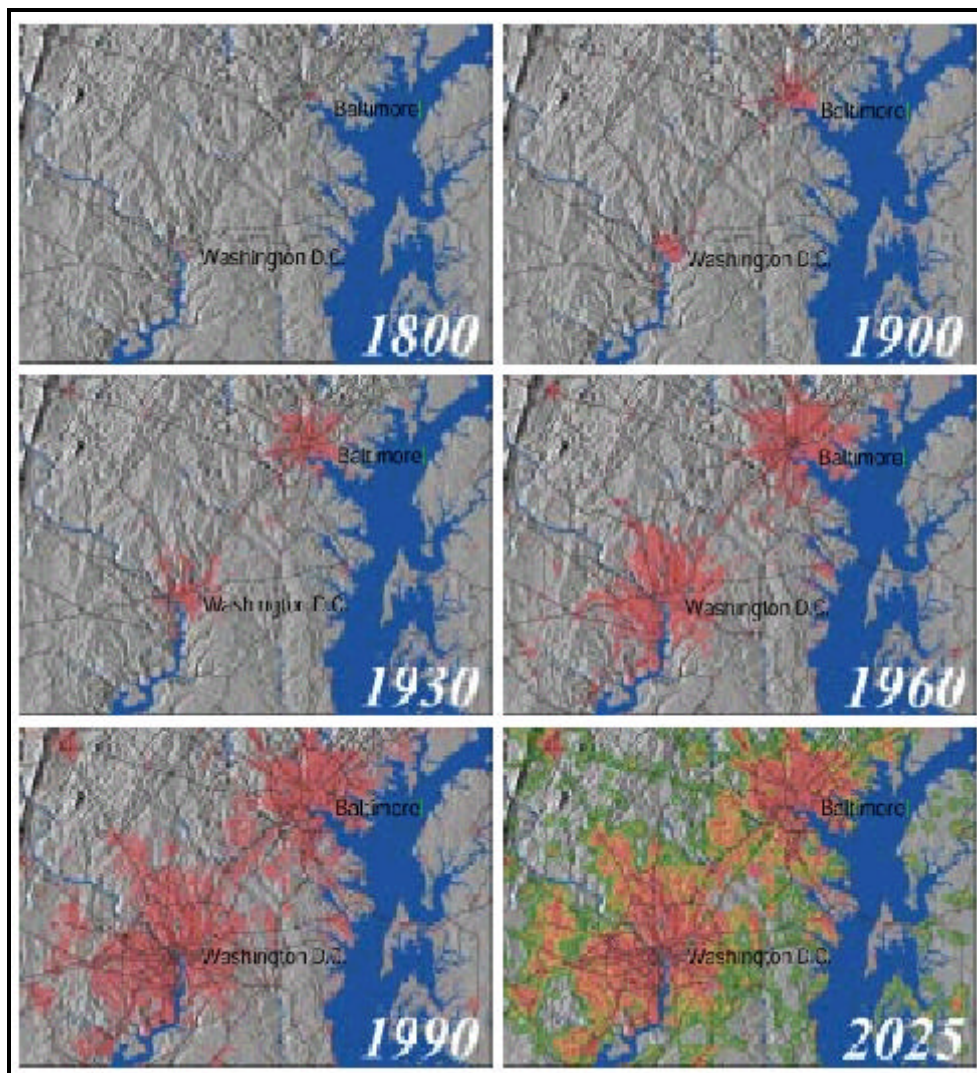


Figure 2-7: Map multiples in temporal sequence displaying spatial patterns.  
Source: USGS Fact Sheet FS-000-99, 1999.

made animation a more accessible option (Blok *et al.*, 1999; DiBiase *et al.*, 1992; MacEachren, 1994b).

Furthermore, the ever growing body of spatial data makes the growth of time sequence mapping a logical and inevitable outcome. The sheer volume of chronologically collected remotely-sensed data has resulted in a considerable amount of time series analysis of environmental change, research that has undeniable value given the rapid changes in global environment and land use that continue to occur through the present century and beyond. As other data sources continue to add to the digital historical record, it appears that the utility of temporal change mapping will continue to grow.

## 2.5 TRENDS IN GEOGRAPHIC VISUALIZATION

There are some key trends in the ongoing development of visualization, including the growth of map animation applications, the further evolution of spatial analysis techniques, the increasing interactivity associated with map system/map user interfaces, and the expanding sophistication of electronic atlas systems.

The development of map animation techniques has allowed cartographers to incorporate the temporal context directly into their visualizations. There are presently several common forms of map animations (Gershmehl, 1990).

Within the context of spatial analysis the primary form involves using the flip-book approach showing a series of maps in chronological sequence where the animation is used as a metaphor for the passage of time (albeit somewhat accelerated). There are also examples where the data are reordered within some sub-field of time to emphasize patterns that may be dependent on some other temporal context (such as time of day), and there are other examples that are based on some variable other than time (such as a map showing relationships between a cause and effect). Flip-book animations of space-time processes may be produced for a vast array of topics ranging from the depiction of changing environmental conditions to changing population patterns and offer a growing utility for cartographers interested in exploring spatio-temporal dynamics. Other common map animation techniques utilized in cartographic visualization include metamorphosis (also known as polymorphic tweening) which is sometimes used to represent time-sequenced events such as shifting weather patterns, and a virtual reality approach that creates a sense of flying through a three-dimensionally rendered scene. Polymorphic tweening should be utilized with some caution because it implies a level of detail within the transformation stage of the animation as it changes from one map view to another that

is in reality derived from the algorithm associated with the computer software and the metamorphosis control points selected by the animator rather than from actual observation values associated with the data set. The software enhances the metamorphosis by generating numerous images representing intervening steps in a process between the initial view and the end view. These intervening steps provide an implication of spatio-temporal change for the map viewer that may in fact misrepresent reality. Virtual reality animations that provide simulated flying tours of three-dimensionally rendered landscapes may be useful for visualizing environmental phenomena, such as interactions between weather and transportation features.

Utilizing map animations within visualization provides researchers with an inductive reasoning tool that renders temporal dynamics more accessible for spatial analysis (Openshaw *et al.*, 1994). The ability to view patterns and processes via map animation enhances the results offered by traditional mathematical modelling methods by visually revealing the spatial dynamics.

These spatial dynamics represent an important component of contemporary spatial analysis. It has long been a goal of spatial analysts to develop insights into the spatial patterns and processes of human and

environmental interactions in the world around us. Within the context of space-time processes, there has been an historical disadvantage in the strictly mathematical approach, in that the standard means for dealing with rich spatio-temporal data sets have been to aggregate data both spatially and temporally, into smaller numbers of areal units and time periods. This results in a less-detailed data series which reduces the quality of the data and ultimately lessens the resulting accuracy. The move towards interactive visualization methods furnishes opportunities for broader insights into the rich and complex data sets that have become a common component of spatial analysis.

As the technology of visualization continues to grow, the degree of interactivity is also expected to increase. Researchers who have the perceptual and cognitive expertise necessary for the evaluation of the patterns and processes associated with spatial phenomena require considerable freedom and flexibility in the pursuit of their investigations. Much of how this interactivity develops will be based on fundamental awareness of the underlying spatial dynamics. An effective interface will be one that minimizes the impediments between human and machine (Buttenfield and Mackaness, 1990; Davies and Medyckyj-Scott, 1994;

Lindholm and Sarjakoski, 1994).

This interactivity will also play an important role in the increasing sophistication of electronic atlases. Future electronic atlases will undoubtedly incorporate much of the visualization tool kit, moving beyond relatively simple geographic data storage and retrieval to an increasing exploratory and analytical capability. Atlas users will have the ability to interactively navigate through flexible combinations of maps, diagrams, text, and audio to explore landscapes from around the world (and beyond!) while not only maintaining control over direction and pace, but also possessing the power to select and perform an array of spatial analysis tasks (Mersey, 1996).

## 2.6 THE CONTEMPORARY CARTOGRAPHIC PARADIGM

Cartographic research has discussed and demonstrated the differences between exploratory and presentation graphics, which require different design strategies for the different stages in the visualization process. The design of exploratory graphics is focused on the ability to look at data in many different ways while the design of presentation graphics is focused on presenting an optimal view (Krygier, 1996). The recent emphasis on visualization as a tool for exploratory data analysis has



drawn attention to the graphic quality of GIS output (Mersey, 1996).

Despite arguments from GIS proponents that GIS maps are intended only as quick intermediate views of data rather than final polished maps, the value of any GIS as a visualization tool is greatly compromised if these quick views fail, for design reasons, to communicate the true nature of the spatial information they represent (Mersey, 1996). In this context, some have suggested that map design plays a pivotal role in the effectiveness of exploratory data analysis (Mackaness, 1996). It is, therefore, incumbent upon contemporary cartographers to develop the design tools that facilitate data exploration.

Those who believe that cartography's communication paradigm is but a thing of the past are mistaken (Patton and Cammack, 1996). MacEachren (1994) views the current cartographic paradigm in three dimensions, with visualization and communication related by degrees across a central transect ([Figure 2-8](#)). The cube illustrates the range of application and use now employed within contemporary cartography. Along one axis is found the range between public and private use, with public use primarily involving communication and private use involving visualization for exploration and analysis.

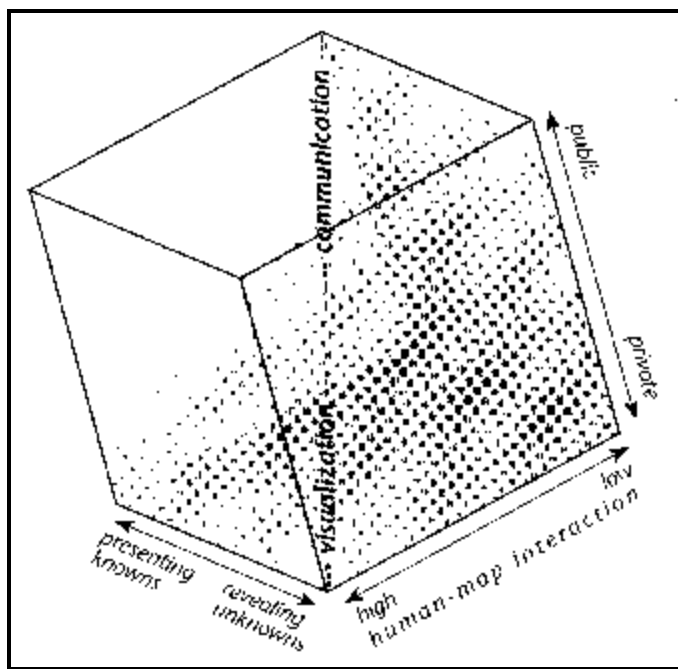


Figure 2-8: The three dimensions of contemporary cartographic function and utilization.  
Source: MacEachren, 1994.

Likewise, the axes representing interactivity and presenting/revealing information also show the relative order of use and application between communication and visualization. Ultimately, the development of effective data exploration tools can only be aided by an understanding of human perception and cognition, and cognitive research into effective map design will continue to play an important role in the evaluation and development of effective visualization tools (Patton and Cammack, 1996).

## 2.7 CARTOGRAPHIC VISUALIZATION RESEARCH TRENDS

To date, research in cartographic visualization has focused primarily on such concerns as the development of environmental applications, the visualization of data quality, the development of interactive interfaces, the effects of dynamic cartography of issues of design and symbolization, and the use of map animation to represent temporal change. Here is a brief summary of contemporary research in cartographic visualization.

The development of environmental applications in visualization is not surprising, given the vast quantities of spatial data that have become available in recent years. The physical sciences in general have considerable resources at the ready for collecting and

compiling spatially referenced information, whether in the form of remotely sensed data or as collected at the surface by a host of public agencies, private organizations, and individual research projects. The problem of urban air pollution was examined through a visualization application by Koussoulakou (1994). He utilized a variety of data related to industrial and automotive emissions, meteorological conditions, air quality, topography, and urban setting characteristics to visualize the changing conditions over and around Athens, Greece. The challenges of visualizing multivariate paleoclimatic data were addressed by DiBiase *et al.* (1994) in order to accommodate the needs of the University's Earth System Science Center, an interdisciplinary unit which studies the earth's history and human impacts on the earth system. This application simulates three to five climatic phenomena for nine to twelve atmospheric levels. Environmental modeling activities were enhanced using the visualization approach by Thorpe and Karimi (1997) of the MCNC-North Carolina Supercomputing Center. They developed views of ground-level ozone concentrations as predicted by the MCNC MAOSIP model, rush-hour nitrogen oxide emissions that were used as input into the Urban Airshed Model, surface evaporation during January as predicted by a global

climate model, and carbon monoxide concentrations as predicted by the MCNC MAQSIP model.

Research activity in the visualization of data quality has offered a number of important ideas. Scholars have been particularly interested in finding ways to reveal the relative accuracy and reliability of geographic representations. Battenfield and Beard (1994) suggest that the goals of this research should involve the incorporation of geographical realism and graphical logic into data quality visualizations. By decomposing data quality into components of accuracy, resolution, and consistency, producers of data will be able to isolate areas of concern and track them separately. They recommend the development of visual tools to monitor error propagation during GIS modeling. Van der Wel *et al.* (1994) developed a framework for visualizing information on data quality. They propose the use of a variety of graphical symbolizations for alerting map users to the problem of uncertainty in map data, such as a blurring or fuzzy resolution of objects whose values are less reliable and blinking objects to bring attention to problem areas. Fisher (1996) has explored the use of animation as a tool for visualizing the relative reliability of spatial data. It provides a method for examining reliability and in surface data using dot maps

and digital elevation models.

The development of interactive interfaces offers greater control for the map user in managing the visualization process. A number of projects have been developed to improve this component of graphical analysis. Howard and MacEachren (1996) have recognized the increasing usage of digital mapping in scientific research, and note the likewise increasing need for users to manipulate map parameters effectively and efficiently. They propose a hierarchical approach to interface design with conceptual, operational, and implementational levels. They describe a prototype geographic visualization system that addresses each of these levels and culminates in the production of a system with six different types of interface "widgets" that allow the user to control the map base, drawing tools, pop-up menus for selecting actions, text, map manipulation, and pointing. Lindholm and Sarjakoski (1994) suggest that cartographers will more and more become user interface designers, because the task of presentation has to be adapted to individual users rather than the traditional creation of static maps. They offer some ideas on the design of these new interactive map interfaces, with a guiding principle that the user should be allowed to think only of the data and forget all about the.

Medyckyj-Scott (1994) points out what may seem obvious: that the components of interaction influence effective interaction. He agrees with others in the call for further research into the nature of human interaction with these systems in order to design more effective interfaces.

Effective and appropriate design is a core consideration among scholars in cartography, and the development of new representation using modern computing technologies has renewed the dialogue in cartographic design. Monmonier (1996) has expressed the view that these new rapidly paced animated maps created to represent a sequence of spatial change over time can, in some instances, be visually disorienting due to shifts and flickering of symbols and patterns. He suggests a number of approaches to help map authors avoid deceptive movement, including dissolves or fades to diminish such effects that occur in transition from frame to frame. Vailiev (1996) reviewed and discussed fundamental issues in the mapping of time. There are moments (events that occur at a given time in a given place), there is duration (how long?), there is structured time (how time is organized), there is time as a distance (measured time), and there is space as a clock (spatial relations as a measure of time). Each of these issues requires

different symbolization. Taylor (1996) has summarized the evolution of cartography, with the admonition that multimedia and telecommunications developments are dramatically changing the role of cartographers as geographic information scientists, and Muehrcke (1996) relishes the prospect of incorporating more design dimensions (sound, animation, and interactivity) into cartographic products. He welcomes the notion that the map itself no longer needs to be designed to serve as the primary storage medium for geographical information, because electronic maps are themselves backed up by vast georeferenced data holdings. The new cartographic design paradigm now focuses on the role of maps as graphical interfaces to these spatial databases.

Finally, map animation is becoming an increasingly important component of the visualization tool-kit. It is particularly attractive for geographic analysts working with large spatio-temporal data sets. Dynamic variables may be used to emphasize the location of a phenomenon, emphasize its attributes, or visualize change in its spatial, temporal and attribute dimensions (DiBiase *et al.*, 1992). Some have explored how time series data correspond through the use of synchronization. Synchronization is used to identify patterns where, if peaks and troughs in data relations match they are in



phase, and if they do not match they are out of phase. This synchronization of relationships may be used for the visual exploration and analysis of causal relationships, such as exists with rainfall and vegetation (Blok *et al.*, 1999). Others have explored the relative merits of static versus animated maps in the visualization of spatio-temporal data. The advantages of animation over the traditional static map form include the ability to show the dynamics of the data using a single map rather than map multiples. In a recent study Johnson and Nelson (1998) found that test subjects were able to learn and remember trend patterns in the data more effectively from the map animations than from the static maps.

A considerable volume of the research published in geographic visualization has been somewhat philosophical or theoretical in nature. The development of applications and interfaces figured prominently as well, although to a perhaps somewhat lesser extent, and issues of symbolization and design likewise represent a significant concern among cartographers.

## 2.8 VISUALIZATION AND SPATIAL ANALYSIS

Historically, the geographic analysis of spatio-temporal data sets has involved the aggregation of non-uniform boundary units into larger nested enumeration

areas. Unfortunately, this approach sacrifices an often significant level of detail by virtue of the aggregation, with a coincident loss of conveyed information. The use of map animation as a spatial analysis tool, on the other hand, provides the ability to accelerate time without effect on data structure in the process of searching for space-time patterns. Map animations provide visual representations that illuminate the process and enhance inductive reasoning. The animation of spatial characteristics is a strong companion tool for spatial analysis because it combines the communication power of maps with an element of temporal dynamism. Some argue that the use of video media to explore geographic data provides the means to better observe spatial patterns and processes than possible when simply modeling data mathematically (Openshaw *et al.*, 1994). Others have shown that the utilization of cartographic statistical surface models in the spatial analysis of data collected during consecutive census periods provides an effective means to mitigate the problems associated with differing areal units. Bracken and Martin (1995) describe such cartographic modeling as “computationally elegant” and consistent with the theoretical assumptions of geographic information science. At the very least, as part of a growing body of automated geographic research methods,

map animation can provide valuable supporting evidence in the analysis of spatio-temporal processes.

Considerable support exists for the employment of such automated geographic investigative techniques offered through geographic information systems. Often, map animations are used to describe processes of spatial diffusion, with a goal of understanding spatio-temporal structure in order to predict future trends. Gould (1993) suggests that because the human brain is quite adept at discerning such visualized spatiotemporal information, these geographic visualizations are appropriate exploratory foundations for quantifiable analyses. Fotheringham (1993) believes that spatial analysis will derive considerable benefit from the interactivity offered by GIS based analyses, and also expects a refocusing of attention on such fundamental issues as the modifiable areal unit problem. Sui (1994) foresees a growing role for GIS in spatial analysis and suggests the possibility that GIS and social theory can become more positively interrelated in scholarly urban research. Clark (1993) views the emergence of GIS as a powerful tool for "small area analysis" as a means for extending spatial forecasting, enumeration, and analysis. Openshaw (1994) puts forward the notion that the utilization of GIS in spatial analysis makes data

exploration a more creative activity and stimulates researchers' intuitive capabilities. Dorling (1995) asserts that the social patterns revealed by visualization reflect a broader reality associated with spatially changing social structures. These views represent a growing consensus among empiricist researchers regarding the considerable research value associated with the evolving relationship between geographic information science and spatial analysis.

## 2.9 URBAN SOCIAL PATTERNS

There exists a large body of research in the social sciences related to the study of changing urban social patterns. Investigators have explored a breadth of perspectives related to the socioeconomic stratification of urban landscapes. In major U.S. cities throughout the twentieth century, race has been a primary characteristic associated with this stratification.

A portion of this research is theoretically oriented. The following examples represent a sampling of the many studies documenting the considerable extent of racial separation that exists between African-Americans and Whites. Recent quantitative measures have indicated that for several of the largest urban areas, the extent of the social isolation related to this separation is

more extreme than previously recognized (Massey and Denton, 1989). Other research suggests that despite the profoundness of the social separation there is evidence suggesting that, when the majority of U.S. metropolitan areas are included in the analysis, a modest overall decline in the amount of residential separation is found (Farley and Frey, 1994). Community change from census to census has been explored from a diffusion perspective, in an examination of the role depopulation plays in the growth of extreme poverty areas (Greene, 1991). The expansion of predominately African-American residential space into suburban regions has been examined for underlying social factors, uncovering evidence that neighborhood demographic transition remains an ongoing process (Clark, 1988) and that social isolation between African-Americans and Whites likewise continues largely unabated (Massey and Hajnal, 1995; Phelan and Schneider, 1996).

Other examples of research related to race and residential behavior are offered as evidence to encourage or support governmental action. The investigation of residential migration patterns has provided insights useful for the development of urban policy related to the political management of metropolitan areas (Adams *et al.*, 1996). The status of minority suburbanization has been

reviewed to determine general population characteristics, in order to evaluate relations between government influence and quality of life (Phelan and Schneider, 1996). The desegregation of residential space has been found least likely to occur in metropolitan areas that are home to a relatively high proportion of African-American underclass, and most likely to occur in metropolitan areas where the proportion is so low that desegregation would be possible without threatening theoretically established white preference levels for limited social contact with African-Americans (Massey and Gross, 1991).

Numerous researchers have pointed out that white flight commonly occurs in response to African-American residential entry into neighborhoods that previously had a very high proportion white, when those neighborhoods are adjacent to areas that are already predominantly African-American (Davies and Herbert, 1993; Ley, 1983 ; Hartshorn, 1992; Rose, 1971). Concepts such as invasion-succession, filtering, tipping-point mechanism, and gentrification are routinely employed by geographers engaged in the study of race and residential behavior (Davies and Herbert, 1993; Hartshorn, 1992). Rose (1971) has indicated that despite such recognition of these principal dimensions of expected human behavior, the role

of race is but one among many variables that promote a difficult-to-predict social response. He includes housing age, characteristics of tenancy, quality of schools, economic and social status, life cycle stages, housing accessibility, and the general condition of the local real estate market as important factors influencing whether or not a neighborhood experiences a dramatic change in racial composition. One factor that has been explored relates to the influence social preferences play in residential choice. Empirical testing associated with this research confirms apparent behavior: that White populations prefer living among high proportionate populations of their own racial group, and are largely unwilling to remain in or move into majority African-American neighborhoods (Clark, 1991; Clark, 1989). Some research focuses on African-American community growth and portrays ghetto expansion as a diffusion process much like the spatial adoption of a new innovation, with growth spreading away from an established core. In the mid-1960's, Morrill (1965) developed a diffusion model to simulate the expansion of African-American ghetto space in Seattle. He characterized African-Americans as "active" agents and Whites as "passive" agents of resistance or inertia, and he recognized that ghetto expansion did not progress uniformly along all borders

(Morrill, 1965). In the metropolitan Atlanta area, this territorial growth has occurred first to the west and southwest and then, more recently, to the southeast and east.

Race and residential space has been a subject of longstanding concern among social scientists. Finding the means to enhance understanding of the social relations that play a role in population dynamics is a worthy goal, and the tools of geographic visualization may yet prove valuable in this regard.



## CHAPTER THREE

### METHODOLOGY

#### 3.1 CARTOGRAPHIC GROUNDWORK

This research provides an assessment of cartographic visualization via map animation as a tool for urban spatial analysis. The focus is on the five innermost counties of the metropolitan Atlanta area (Fulton, DeKalb, Cobb, Clayton, and Gwinnett), which were selected due to a combination of factors including the clearly defined social separation existing between African-American and White populations and the dramatic population growth experienced in the region during the latter decades of the twentieth century. Before thematic maps and subsequent animations could be developed, however, a bit of data editing and management was required.

Data collected and compiled by the United States Bureau of the Census during decennial census years 1960, 1970, 1980, and 1990 for census tracts in the five selected counties of the metropolitan Atlanta area were utilized. The mapping of selected data begins with the

1960 census year because that was the first period when the Bureau of the Census published census tract data for all five counties (the 1950 census included census tract data for little more than the area bounded by Atlanta's city limits). Data for the project were selected as benchmarks of socioeconomic status for population, education, income, and housing characteristics, and were somewhat restricted or limited to those data which appeared consistently on each of the decennial census reports. The selected data include total population, total white population, total black population, total households, persons in household, total population twenty-five years or older, total without high school diploma, total with bachelors degree, median family income, total housing units, total owner-occupied housing units, total renter-occupied housing units, total units less than ten years old, median value owner-occupied housing, and median gross rent (a combined value of rent and utilities).

Most of the test variables were derived from the discrete totals listed above into proportionate (percentage) values such as percent white population, percent black population, percent housing less than ten years old, percent owner-occupied housing, percent renter-occupied housing, percent without high school

diploma, and percent without bachelors degree. Median family income, median value housing, and median gross rent required no derivation.

Before these data could be mapped in digital form for the development of thematic map animations, there had to exist digital versions of census tracts for each of the selected decennial years. Digital data for the 1990 census tracts were readily available in the form of the Bureau of the Census' Topologically Integrated Geographic Encoding and Referencing (TIGER) files. TIGER was developed for the 1990 census as a refinement of the Bureau of the Census' previous attempt at developing a digital infrastructure for mapping census data known as Dual Independent Map Encoding (DIME). TIGER overcame some of the limitations of the DIME system by enhancing the geocoding of spatial features, improving the topological model, and by incorporating a greater variety of cartographic objects including hydrography and a greater number of cultural features (Clarke, 1995; DeMers, 1997).

In order to provide digital base maps for census tracts from the decennial census years 1960, 1970, and 1980, the 1990 digital census tracts were decomposed, so to speak, backwards through time ([Figure 3-1](#)). For most instances, this required a joining together or merging of

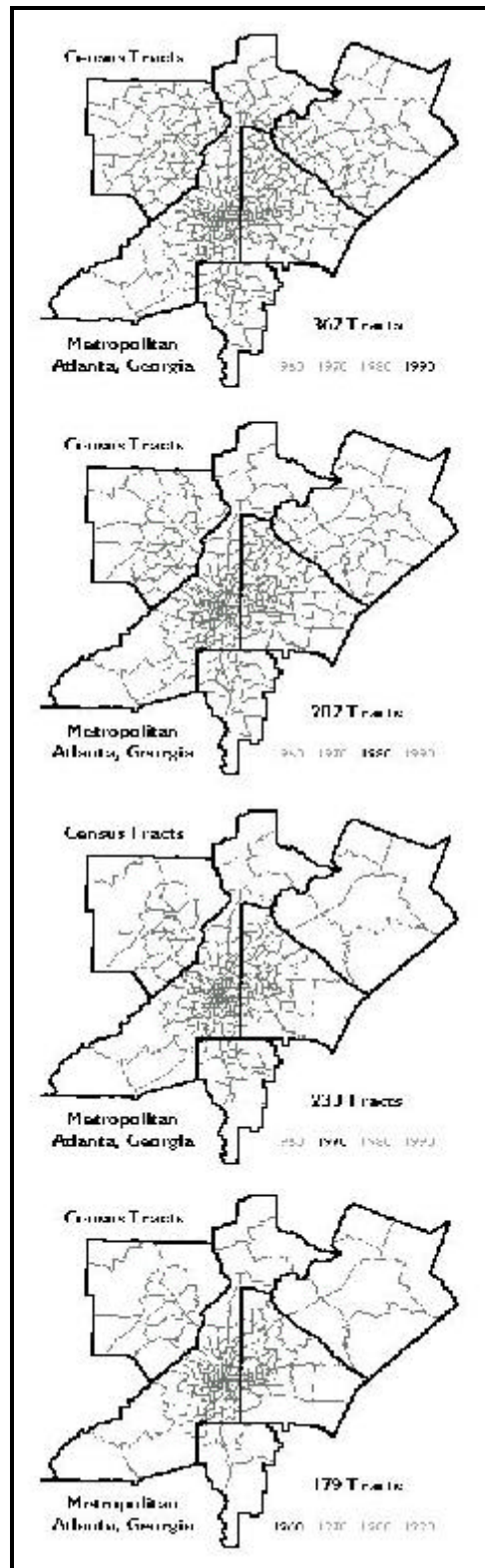


Figure 3-1: Digital files were edited from 1990 data back through the years.

existing tracts to form the previous unit. The most common practice in the changing of census tracts from one decennial census year to a subsequent decennial census year involves splitting a larger tract into two or more smaller tracts when population increases beyond a given threshold. The goal is to maintain census tract populations that are somewhat equivalent in population, in order to gain meaningful information about socioeconomic characteristics of urban landscapes.

At this point the issue of the modifiable areal unit problem (MAUP) should be considered. Census data are collected for things such as people and households and are reported for arbitrarily defined and modifiable enumeration districts with no intrinsic geographic meaning. The problem arises in that analytical results are somewhat dependent upon how and where these enumeration districts are defined. It is the arbitrary and modifiable nature of these districts that can affect the reliability of the results in varying degrees (Openshaw, 1984).

There are occasions when census tract boundaries change in response to factors other than simple population growth. In these instances the boundaries may be adjusted to reflect significant changes in the physical environment as well as other less readily

identifiable factors, and historic tract numbers have sometimes been eliminated when their geographic areas were absorbed into surrounding tracts. In the case of metropolitan Atlanta, these changes have most frequently occurred in the area surrounding Hartsfield Atlanta International Airport, although they are found in other locations as well.

The Bureau of the Census provides information with each decennial reporting about census tracts that were split due to population increases between decennial census years and other factors. This information includes the previous and current census tract identification numbers. The Bureau of the Census also produces maps delineating census tract boundaries for each of the decennial census years. These two sources were used in the decomposition of the 1990 digital census tract map backward through time to produce digital versions of first the 1980, then the 1970, and finally the 1960 census tract boundary maps.

For each of the decennial census years considered in this project, there was strong population growth in the region, with a corresponding increase in census tracts ([Figure 3-2](#)). Over the course of the thirty years explored by this study there was a 214 percent increase in population in the five inner counties, and a

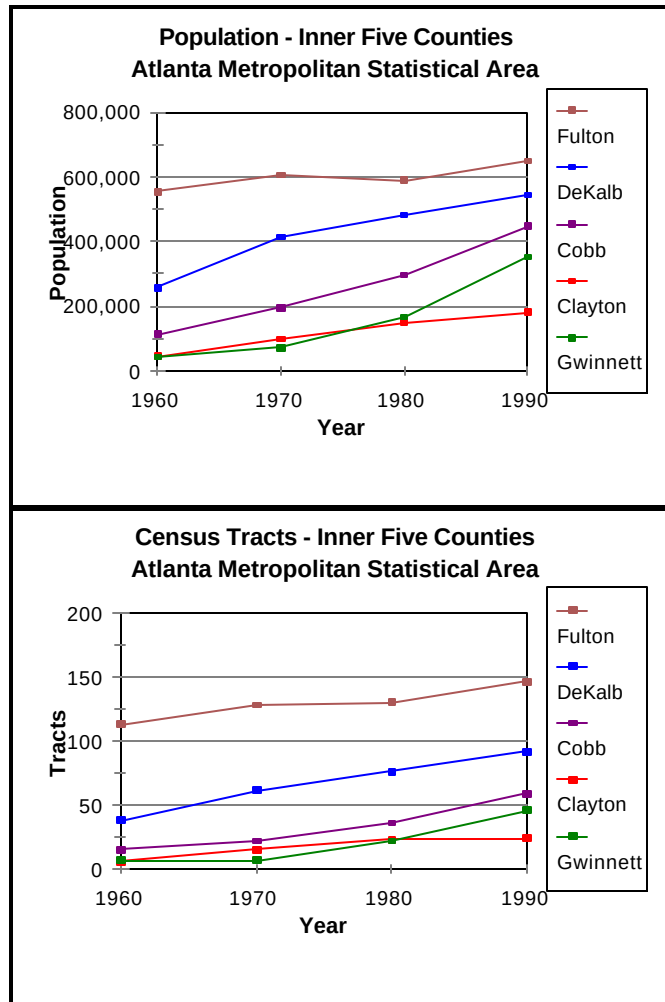


Figure 3-2: Population growth and increasing numbers of census tracts in metropolitan Atlanta.

coincident 205 percent increase in the number of census tracts. Not surprisingly, during the earlier portion of this time period, the majority of tract splits occurred toward the urban core, while during the latter years the majority of tract splits occurred toward the periphery.

The cartographic editing of the TIGER census tract data was accomplished in ArcView GIS, resulting in the production of "shapefiles" (a proprietary format commonly used for geographic feature data by the ArcView software) for each of the decennial census years. During the process, split tracts from later years were merged into larger tracts for earlier years, and the Federal Information Processing Standard (FIPS) codes were likewise edited to reflect the changes in attributes. Also, those tracts whose boundaries were modified due to changes in the physical environment or for reasons other than simple tract splits due to population growth (such as changes in the physical environment associated with various expansions of Hartsfield Atlanta International Airport) were edited to conform to boundary changes identified using the Bureau of the Census tract maps.

### 3.2 REGIONAL ORIENTATION

The inner five counties of the metropolitan Atlanta region ([Figure 3-3](#)) comprise the majority portion of





Figure 3-3: The five core counties of metropolitan Atlanta, Georgia.

population in the urban area. The city of Atlanta is found mostly within the perimeter highway (Interstate 285) that loops around the town as part of the hub, spoke, and wheel configuration of major transportation arteries in and around the city. The city of Atlanta is located primarily within central Fulton County, with a relatively small portion located in DeKalb County along the political border of those two counties. Fulton County is somewhat unusually configured, having been pieced together over the course of the past 150 years from a patchwork of former counties. It has a long, linear configuration ranging roughly sixty miles from northeast to southwest extents, with its width narrowing to approximately two miles across near the northwest corner of DeKalb County. DeKalb County, to the near east of Atlanta, is bisected by Interstate 285 and crossed by Interstates 85 and 20. Clayton County is found to the south of town, and Hartsfield Atlanta International Airport is located along its north-northwest border with Fulton County. Cobb County is found to the northwest of town, just across the Chattahoochee River that forms the border with Fulton County. Gwinnett County is located to the northeast of DeKalb County, with a long stretch of Interstate 85 passing through its more northerly extent.

There has been considerable population growth in the

region during the latter portion of the twentieth century ([Figure 3-4](#)). In 1960 most of the urban population was concentrated within an area that would become encircled by the Interstate 285 perimeter highway loop (this highway was in planning and development in 1960 and was completed during the subsequent decade). By 1970 there was evidence of population expansion in the urban area around the northern arc of Interstate 285 in north Fulton and DeKalb Counties, and in central Cobb County. This urban population expansion continued into 1980 with signs of growth in northeastern Cobb County, eastern DeKalb County, central Clayton County, and southwestern Gwinnett County. Finally, the population growth and expansion of urban area was found throughout most of the five county region under consideration by this project, with the exception of southwestern Fulton County, the southernmost tip of Clayton County, and the far east reaches of Gwinnett County.

### 3.3 PREPARING THE ANIMATIONS

Thematic maps of eleven variables for each of the decennial census years were produced in ArcView GIS (Environmental Systems Research Institute, 1998), providing snapshot views illustrating metropolitan Atlanta's changing socioeconomic landscape. ArcView is a

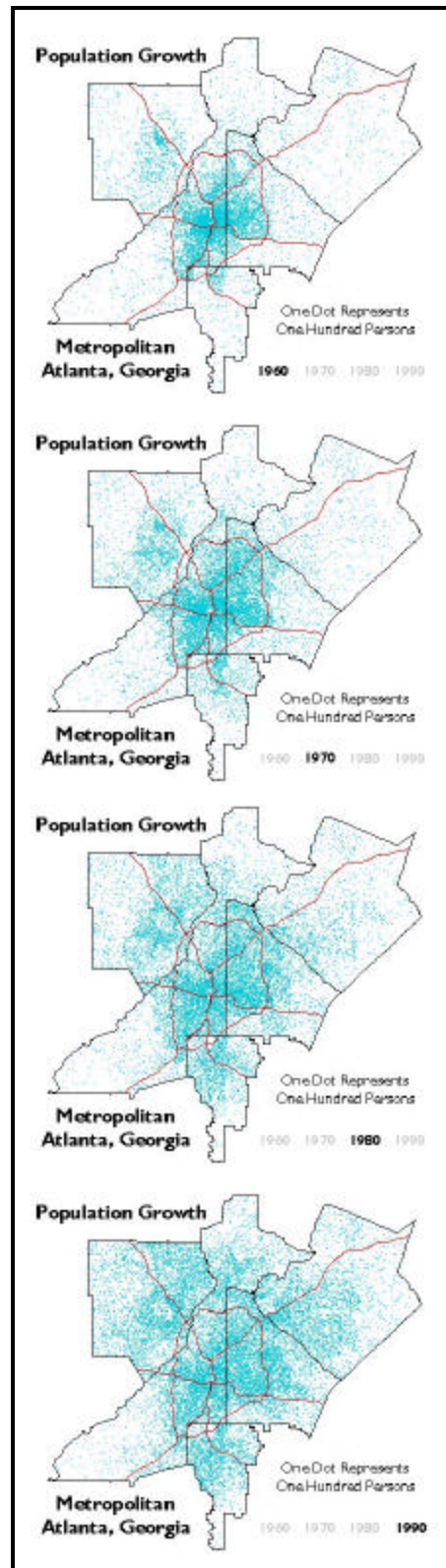


Figure 3-4: Population growth in metropolitan Atlanta, Georgia.

desktop GIS package which does not include among its standard options the ability to produce animated maps, so after the maps were developed, they were exported as bitmap images in Joint Photographic Experts Group (JPEG) format and converted to 8-bit color Graphics Interface Format (GIF) images for the construction of GIF animations. GIF is an image file format developed by CompuServe (an electronic information service and internet service provider) for use by a wide variety of computer systems (Peterson, 1995). The GIF format was developed with greater versatility than other image file formats, with the ability to show both single frames as well as incorporate sequences of images, and it offers some advantages for web-based internet animations. Primary among these advantages is the ability to run GIF animations on a web browser (such as Netscape or Internet Explorer) as streaming technology without requiring additional software or "plug-ins" for viewing (Koman, 1996).

The JPEG map files were imported into Corel Photo-Paint (Corel Corporation, 1996) for conversion to single frame GIF images, and then the individual frames were sequenced and saved as GIF animation files. The animations were produced to show maps in pairs, so that each of the selected socioeconomic variables can be

visually compared with percent white population.

### 3.4 ASSESSMENT INSTRUMENT DESIGN

The somewhat recent development of the internet and world wide web provides an opportunity for those engaged in cartographic research to distribute surveying and testing instruments to a fairly wide audience with relative ease. Both static and animated maps can be viewed using a web browser such as Netscape or Internet Explorer regardless of the computer platform (Windows PC, Macintosh, or Unix systems). Among the goals of this research is the development of a suitable cartographic evaluation and survey instrument that could be used to gather test subject responses from a wide range of locations, whether here in University of Georgia Department of Geography computer labs or from anyplace around the world with internet access.

Once the maps were prepared for viewing as GIF animations, the next step was the design and implementation of the evaluation and survey instrument. This was accomplished using HyperText Markup Language (HTML) and Common Gateway Interface (CGI) programs. HTML is the standard programming language used to create the pages viewed via web browsers and CGI is a scripting program that is commonly embedded within HTML code to

create forms for online data collection (Harder, 1998). The forms are developed using HTML's form tags, attributes, and values. However, HTML is only good for designing the forms because it doesn't have the capability to do anything with the information entered into the forms -- HTML simply provides the fields in which users enter information. CGI provides the means for gathering form input. CGI forms processing scripts can be written in any language, but they are most commonly written in UNIX-based scripting languages such as Perl, TCL, the C Shell, or the Bourne Shell (Muller, 1996). The CGI scripts used to gather the data collected in this cartographic visualization survey and evaluation instrument were written using Perl (Practical Extraction and Report Language), which is among the more popular languages used for web-based data processing.

The survey instrument ([click here to access the survey instrument](#)) for this research project was distributed via the world-wide-web. The first page of the instrument provides an introduction to the project. It identifies the research goals, provides instructions for optimizing web browser settings, briefly discusses the theoretical foundations of the project and gives a very basic description of data correlation, describes characteristics of the study area and selected data, and

it includes a form for test subjects to enter their names and contact information. This introductory page is followed by three pages of "training" animation sets, which provide the test subjects the opportunity to visually examine animated map pairs where the mean correlation values are provided in the text content found on the web page. In order to focus the test subjects attention on the map animations and prepare them for the task of visually estimating correlations among the presented data, they were asked to enter a description of the spatial and temporal patterns they observed among the data presented via animated maps. The training animations included maps showing data with a very high negative correlation, a high positive correlation, and a very low correlation. After viewing these training animations, test subjects proceeded through seven test map animation pairs representing a variety of unidentified positive and negative correlations, and they were asked to visually estimate data correlation based upon the presented information as well as verbally describe the observed spatial and temporal patterns. All of the map animation pairs utilize the percent white data as the variable against which correlations are estimated.



### 3.5 SELECTION OF TEST SUBJECTS

Visualization, whether in the broader scientific context or the more specific geographic focus considered in this research project, refers to the use of computer technologies to graphically explore and analyze growing volumes of spatially referenced data. This approach is typically, although not exclusively, employed by researchers who have an existing knowledge base of the subject of analysis, and they are able to use that knowledge base in the interpretation of data presented through visualization (Buttenfield and Mackaness, 1991). According to MacEachren *et al.* (1992, p. 101), "geographic visualization is foremost an act of cognition, a human ability to develop mental representations that allow geographers to identify patterns," in a process that involves examining virtual landscapes from a variety of perspectives.

Many, if not most, geographers are endowed with innate spatial thinking skills. These skills can provide an advantage for the interpretation of visualized geographic phenomena. Research in cognitive psychology has consistently found that expertise plays an important role in complex information processing, particularly in the interpretation of visual and graphic displays (McGuinness, 1994). The knowledge, experience, and

spatial concepts brought by geographic researchers to a visualization analysis form an important component of the overall visualization framework (Medyckyj-Scott, 1994).

The background and experience of those who employ visualization methods is of obvious importance to its effective application. For this reason, geography students (both upper-division undergraduate majors and geography graduate students) from the University of Georgia formed the pool of test subjects for this research endeavor.

### 3.6 SURVEY AND RESPONSE

By its nature, the web-based survey instrument with its introduction and ten sets of animated map pairs for visual review is a bit time consuming, taking approximately thirty minutes to complete. Questions asked of the respondents were limited to one quantitative response and one qualitative response for each of the seven test animated map pairs. Additionally, test subjects were asked to provide a qualitative assessment of observed spatial patterns from the three training animated map pairs that were used to focus their attention on the research task.

The quantitative response called for the test subjects to view the animated map pairs and estimate

based upon visual observation the degree of correlation evident between the data variables presented in the animations. They were required to select from a series of "radio buttons." Radio buttons are part of the web graphic interface that allows for the selection of one and only one option among several choices with selections recorded via CGI scripting. In this case there were twenty-one options found on a sort of correlation coefficient scale bar ranging from negative 1.0 to 0 to positive 1.0 in 0.1 increments, with the varying degrees of correlation identified as ranging from "Very Strong" to "Strong" to "Weak" for both negative and positive selections and depending on how far away from 0 the correlation estimate selection was found.

The qualitative response was included to allow test subjects the opportunity to subjectively describe any spatial patterns they might observe in the animated map pairs. It was anticipated that some of the test subjects would be more adept at perceiving the relative strength of relations among the presented data than others, and this qualitative component provided a second opportunity for them to verbalize their assessments without the limits imposed by the estimating of correlation values.

### 3.7 STATISTICAL ANALYSIS OF CORRELATION ESTIMATES

In order to statistically analyze the results of test subject estimates of correlation values for the seven test animated map pairs, two approaches were utilized. The first step involved treating the data as two groups for comparison (the averages of actual correlation coefficients for the selected data and the averages of estimated correlation coefficients for the same data) using t-test for paired samples. The second step involved analyzing test subject correlation estimates using single sample t-tests to assess whether there were significant differences between the estimated and actual correlations on an individual basis for the seven test animated map pairs. This procedure employs a test value (in this case the mean actual correlation coefficient) as the mean the test subjects' correlation estimations are compared against.

Using a t-test for paired samples provides a method to evaluate in a very general sense whether or not the correlation estimates approximate the actual correlation averages as two groups of data. For this case the null hypothesis would be that there is no statistically significant difference in the means, and the alternate hypothesis would be that there is a statistically significant difference in the means. This approach

provides an overall statistical view of the results.

To take this one step further, and evaluate the results on a case by case approach, a single sample t-test is employed to assess whether there are significant differences between the estimated and actual correlations individually. The single sample t-test compares the results of the correlation estimates for each individual case of test subject consideration of animated map pairs with the average correlation coefficient from the actual data used to produce the thematic maps. Again, the null hypothesis would be that there is no difference between the estimated correlation values and the actual average value, and the alternate hypothesis would be that there is a statistically significant difference. For this procedure there are results generated for each of the seven test animated map pairs, providing a more specific indication of the relative accuracy of the correlation estimates.

### 3.8 GRAPHING THE CORRELATION RESULTS

As a follow up to the statistical analysis, bar graphs of the correlation estimates for each of the seven test animation pairs were produced, showing the relative accuracy of all responses in comparison with the average of the actual correlation coefficients. This provides an

opportunity to consider both the larger trend of the responses as well as identify outliers that might have affected the statistical analyses.

The results presented in these graphs will be subjectively evaluated in relation to overestimation, underestimation, and reasonable accuracy. Furthermore, the information they present will be considered in terms of the overall effectiveness of estimating correlations based on animated map pairs.

### 3.9 EVALUATING QUALITATIVE ASSESSMENTS

For all ten sets of animated map pairs, including the three training sets and the seven test sets, the test subjects were asked to provide verbal assessments of spatial and temporal patterns observed while viewing the animated map pairs. These qualitative assessments provided the test subjects with the opportunity to express their observations outside of the limits of the correlation estimation. It was hoped that these assessments would provide a greater breadth of response related to general spatial and temporal patterns that would go beyond the correlation estimates into more general considerations of the data under consideration.

All of the comments were compiled into separate files for each of the ten animated map pairs. Selected

representative responses will be presented for each set of the animations, and these qualitative results will be discussed.

## CHAPTER FOUR

### RESULTS

#### 4.1 CARTOGRAPHIC ANALYSIS

With all of the recent innovations in geographic information science, the development of cartographic or geographic visualization methods is a logical outcome. A sizable amount of spatially arrayed data are now being explored and analyzed using mapping technologies, and this is only the beginning.

The future is wide open for the development of new applications based on these new geographic analysis tools. Numerous modeling procedures are coming of age with the technology and spatial analysis algorithms are being tailored to the capabilities of this emerging methodology. Each new advance merits a closer examination into the nature of the insights and information offered. Yet how effective are these new procedures at providing enhanced views of the world around us?

There are so many claims being presented by those who champion the cause of cartographic or geographic



visualization. This research project addresses one aspect of those claims by investigating the ability of map users to estimate correlations among data given animated map pairs that visualize changing socioeconomic conditions across an urban landscape.

#### 4.2 TEST SUBJECTS

Fifty five geography students (twenty upper-division undergraduate and thirty five graduate) participated as test subjects in this research project. They interacted with the web-based survey instrument without difficulty and with apparent interest and enthusiasm. Although a few of the test subjects expressed doubts about their ability to visually discriminate correlations from viewing the animated map pairs, all approached the task earnestly and provided responses for each of the questions.

Most of the tests were run in one of the several University of Georgia Department of Geography computer labs, but several were conducted off-site by former department students (both undergraduate and graduate). These off-site subjects served to demonstrate that successful use of the web-based survey instrument was not limited to local implementation.

### 4.3 QUANTITATIVE MEASURES

Statistical analysis of the correlation estimates for the seven test animated map pairs was undertaken utilizing two approaches: a paired sample t-test and a single sample t-test. The paired sample t-test was employed to compare the correlation estimates with actual correlation values (using the averages of actual correlation coefficients for the selected data and the averages of estimated correlation coefficients for the same data). The single sample t-test was used to assess whether or not there were significant differences between the estimated and actual correlations on an individual basis for the seven test animated map pairs.

Before discussing the results of these procedures, it is appropriate to address a few issues related to correlation. Correlation among the selected data plays a key role in this research project, and the correlation values associated with these data display some interesting characteristics.

#### 4.3.1 DATA CORRELATION

In order to provide a measure of comparison with correlation estimates, a measure was derived from the actual correlation values for each of the test variables with percent white population (used consistently as the

independent variable in the survey instrument) in each of the decennial census years (Table 4-1). The measure used for this purpose was the mean of the actual correlation coefficients, hereafter referred to as MACC.

The correlations were calculated using SPSS (SPSS Inc., 1997), a popular statistical software package available for use in the Windows PC computing environment. These correlations were calculated as Pearson Correlation Coefficients, which are found by dividing the explained variance by the total variance and taking the square root (Fischer, 1996). Computed correlation coefficients range from a possible -1.0 to a possible +1.0, with the sign indicating the direction of the relationship. A negative value indicates an increase in the independent variable that is associated with a decrease in the dependent variable. A positive value indicates an increase in the independent variable that is associated with an increase in the dependent variable. If the correlation coefficient is neither positive nor negative -- a 0.0 value -- then there is no relationship observed between the two variables, and an increase in the independent variable results in neither an increase nor a decrease in the dependent variable. The relative strength of the relationship is indicated by how close the correlation coefficient is to 1.0 (positive or

Table 4-1  
Correlation Coefficients for Test Variables  
with Percent White Population

| <u>Variable</u>                 | <u>1960</u> | <u>1970</u> | <u>1980</u> | <u>1990</u> | <u>Mean</u> |
|---------------------------------|-------------|-------------|-------------|-------------|-------------|
| Percent Black Population        | -0.9994     | -0.9999     | -0.9996     | -0.9667     | -0.9914     |
| Median Family Income            | 0.5247      | 0.5724      | 0.6948      | 0.6984      | 0.6226      |
| Population per Household        | -0.3289     | -0.2231     | -0.1576     | -0.0585     | -0.1920     |
| Median Value Housing            | 0.3791      | 0.4606      | 0.6146      | 0.5591      | 0.5034      |
| Median Gross Rent               | 0.4446      | 0.5337      | 0.6011      | 0.6409      | 0.5551      |
| Percent Housing < 10 Years Old  | 0.2473      | 0.2843      | 0.4437      | 0.5546      | 0.3825      |
| Percent Owner-Occupied Housing  | 0.5128      | 0.4112      | 0.4660      | 0.5090      | 0.4748      |
| Percent Renter-Occupied Housing | -0.5164     | -0.4160     | -0.4295     | -0.3991     | -0.4402     |
| Percent Without H.S. Diploma    | -0.5327     | -0.5371     | -0.6274     | -0.6700     | -0.5918     |
| Percent With Bachelors Degree   | 0.3415      | 0.3780      | 0.5457      | 0.6559      | 0.4803      |

negative) as opposed to a 0.0 value. The closer the coefficient is to +/- 1.0, the stronger the relationship. Coefficient values are interpreted as follows: values of 0.0 to 0.19 are considered very weak; values of 0.20 to 0.39 are considered moderately weak; values of 0.40 to 0.59 are considered moderately strong; values of 0.60 to 0.79 are considered strong; and values of 0.80 to 1.0 are considered very strong (Fischer, 1996).

#### 4.3.2 TRENDS IN THE CORRELATIONS

There are some interesting trends to be observed among these values. Some of the correlation values increase over time, some of the correlations decrease over time, and some of them hover around the same value through the years, and one of the sets of correlations remains extraordinarily high throughout these years.

At the top of the list are the correlations between percent white and percent black populations, which are extremely high negative and show only the slightest decrease over time. This high negative correlation is not surprising because the relative proportions of percent white and percent black populations are inversely related. Nevertheless, it is readily apparent from viewing maps of these two populations that there is extremely high social separation between the two

populations, and this provides a focal point for the remaining correlations utilized in this project. Are there readily identifiable socioeconomic factors that can be associated with the spatial patterns evident within this social separation? White residential patterns appear to hold the key in this matter, and this is why percent white population is used as the independent variable for correlations with the selected socioeconomic data and is presented as such in the animated map pairs used in the visualization test interface.

In addition to the very high negative correlation between percent white population and percent black population, there were also negative correlation values found between the independent variable and population per household, percent renter-occupied housing, and percent without high school diploma. Population per household displayed a decrease in correlation through the years that, when considered with the general decrease in population per household (averaging 3.40 in 1960 and 2.89 in 1990), might indicate that the general decline of household size was fairly pervasive throughout Atlanta without regard for social characteristics. Percent renter-occupied housing also displays a decrease in correlation through the years. Perhaps this is indicative of increased accessibility to home ownership

for African-American populations, although the answer to this question is not the goal of this research. Percent without high school diploma, on the other hand, increased in correlation through the years. This is somewhat intriguing, because throughout the five county region the percent without high school diploma averaged 59 percent in 1960 and declined to an average of 22 percent by 1990, but again this is not an issue considered by this research project.

There were several positive correlation values found between the independent variable and the selected socioeconomic variables. These positive correlations were associated with median family income, median value housing, median gross rent, percent housing less than ten years old, percent owner-occupied housing, and percent with bachelors degree. Median family income (data adjusted to 1990 dollars) displayed increases in correlation throughout the years, coincident with a region-wide increase from 25,579 in 1960 to 40,818 in 1990. Correlation values for median value housing (data adjusted to 1990 dollars) also rose through most of this period, although slipping somewhat in 1990. Once again, this represents a more complex matter than addressed by this research. Median gross rent (data adjusted to 1990 dollars) is another variable that experienced increasing

correlation values through the years. Percent housing less than ten years old likewise displayed increasing correlation values through the years, and this is not surprising given the sprawling suburbanization of Whites during this period. The increased demand for houses on the ever-spreading outskirts surely drives the supply of new homes in this market. One interesting trend is associated with percent owner-occupied housing. Correlations for this variable declined a bit in 1980 then rose again by 1990 to a near 1960 value. Is there anything of significance occurring here? There appears to be insufficient data at this time to offer a meaningful interpretation. Finally, the positive correlation values for percent with bachelors degree increased to a much greater extent than any of the other variables. Significant portions of the high percent white population areas have coincident high values for percent with bachelors degree by 1990 (regional averages of percent with bachelors degree ranged from 9 percent in 1960 to 28 percent in 1990) and this trend is not reflected in many of the African-American communities represented in the map animation pairs.

#### 4.3.3 PAIRED SAMPLES TEST

The first statistical analysis of test subject



ability to visually estimate correlations among data based on animated map pairs was conducted using a t-test for paired samples. This procedure compares the means of two sets of data, computing the differences between values of the variables for each case and testing whether the average differs from zero (Barber, 1988; Hammond and McCullagh, 1974). For this test the data were evaluated as two groups, the first being the MACC and the second being the mean of the estimated correlation coefficients.

The result of the t-test for paired samples indicates that the two sets of means did not differ significantly. The values returned were  $t = -0.665$  at a significance level of 0.531. The null hypothesis for this test (there is no statistically significant difference in the means) cannot be rejected and this suggests that the test subjects generally succeeded with their collective attempt to visually estimate correlations from the animated map pairs. In addition, the two groups of means were highly correlated at 0.944, and this high positive correlation is visually apparent in a line graph of these data ([Figure 4-1](#)). These numbers indicate that the means of the estimated correlation values followed a very similar trend (in terms of high to low and positive to negative values) to that of the means of the actual correlation coefficients.

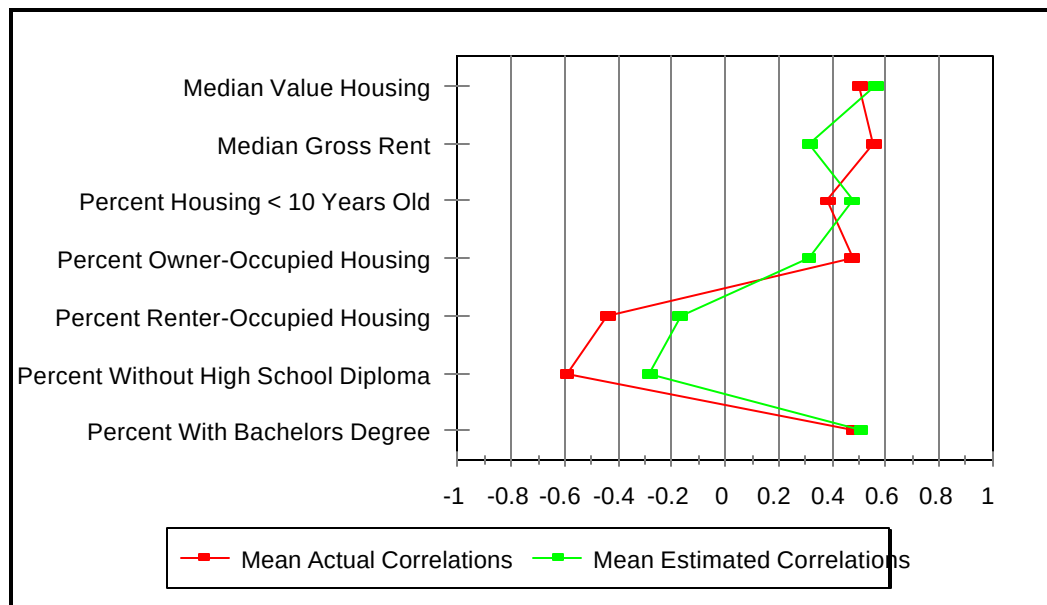


Figure 4-1: Comparison of mean actual and mean estimated correlation values.

#### 4.3.4 SINGLE SAMPLE TESTS

While the result of the paired samples t-test is encouraging, it does not provide an effective indication of how well the test subjects performed on a case by case basis. In order to assess the relative accuracy of the estimated correlation values for each of the map animation pairs, single sample t-tests were employed.

The single sample t-test procedure provides a measure indicating whether the mean of a single variable differs from a specified constant (Clark and Hosking, 1986). In this application, the specified constant -- or test value -- is the mean of the actual correlation coefficients (MACC) per instance of comparison. In other words, the test subjects' estimates of correlation for each of the map animation pairs is evaluated against the mean correlation coefficient derived from the actual data. Like the paired samples t-test, the null hypothesis is that there is no difference between the estimated correlation values and the average actual correlation value, and the alternative hypothesis is that there is a statistically significant difference.

The results of the single sample t-test (Table 4-2) provide support for the success of test subject estimation of correlation for a few of the viewed map animation pairs. Estimates of percent white population

Table 4-2  
Single Sample t-test of Correlation Estimates  
with Mean Actual Correlations

| <u>Variable</u>                 | <u>T e s t</u> | <u>t</u> | <u>Significance</u> |
|---------------------------------|----------------|----------|---------------------|
|                                 | <u>Value</u>   |          |                     |
| Median Value Housing            | 0.503          | 1.785    | 0.080               |
| Median Gross Rent               | 0.555          | -5.285   | 0.000               |
| Percent Housing < 10 Years Old  | 0.382          | 1.811    | 0.076               |
| Percent Owner-Occupied Housing  | 0.475          | -4.867   | 0.000               |
| Percent Renter-Occupied Housing | -0.440         | 5.349    | 0.000               |
| Percent Without H.S. Diploma    | -0.592         | 5.064    | 0.000               |
| Percent With Bachelors Degree   | 0.480          | 0.740    | 0.462               |

correlation with median value housing produced a t value of 1.785 at a significance level of 0.080 when compared with the MACC. The null hypothesis cannot be rejected for this case, indicating a good estimate by the test subjects. Estimates of percent white population correlation with percent housing less than ten years old produced a t value of 1.811 with a significance level of 0.076 when compared with the MACC. The null hypothesis cannot be rejected for this case either, again indicating a good estimate by the test subjects. Estimates of percent white population correlation with percent bachelors degree produced a t value of 0.740 with a significance level of 0.462 when compared with the MACC. Once more the null hypothesis cannot be rejected, likewise indicating a good estimate by the test subjects. These three cases out of seven test map animation pairs provided the positive results indicating no significant difference in the estimated and actual correlations. For the other four test cases (median gross rent, percent owner-occupied housing, percent renter-occupied housing, and percent without high school diploma) the null hypothesis was rejected due to high t values and low significance levels, and this indicates generally less reliable estimates of correlations by the test subjects. It is worth considering, however, that the use of a mean

actual correlation coefficient and its inability to provide a measure of the range of actual correlations present among the data may have affected these results. The test subjects were, after all, observing the entire range of correlation data in thematic map form during the animation loops.

#### 4.4 GRAPHS OF RESPONSES

Graphs of test subject responses were created in order to visually analyze the correlation estimate distributions for each of the animated map pairs. The responses appear as filled-area line graph overlaid with the mean of the actual correlation coefficients (MACC) as represented by a single red line and the mean of estimated correlation represented by a single green line.

The first graph presents correlation estimates for percent white population and median value housing ([Figure 4-2](#)), and it displays a slight (on average) overestimation of the correlation value, with the majority of responses positively skewed from the actual mean of correlation coefficients. Overall, this graphs presents a good showing of estimation with only a few outliers beyond the cluster of estimates that surround the MACC for this particular case (0.503). The mean of the estimated correlations for this data was 0.564.

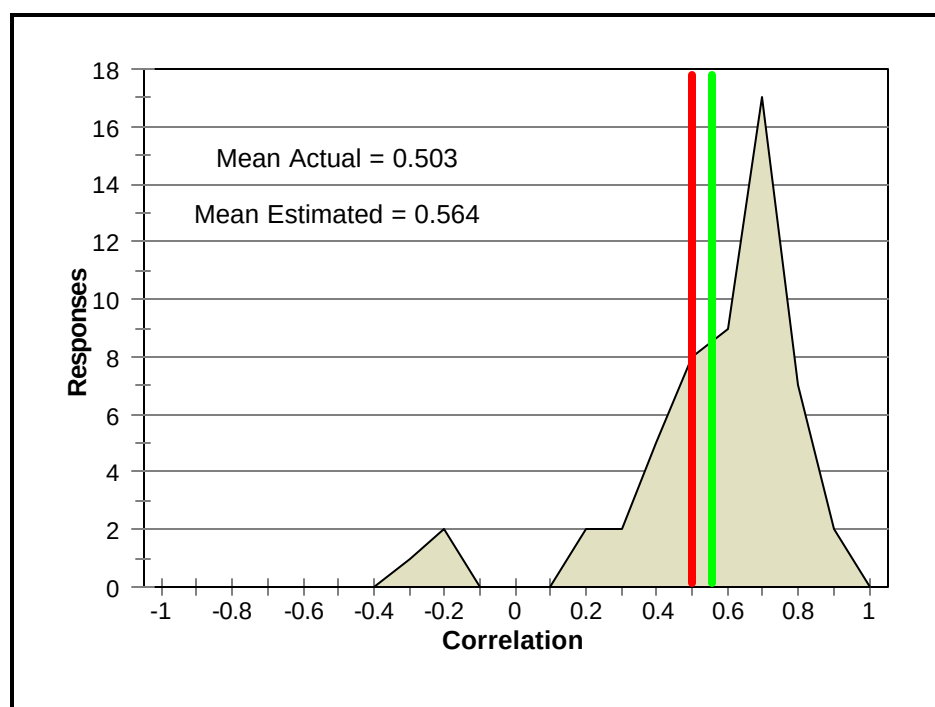


Figure 4-2: Correlation estimates for median value housing and percent white population.

Compared with the actual value this collectively represented a very good set of estimates by the test subjects.

The second graph depicts correlation estimates for percent white population and median gross rent ([Figure 4-3](#)), and this reveals a somewhat larger underestimation of the correlation value, with the majority of responses negatively skewed from the MACC for this particular case (0.555). The mean of the estimated correlations for these data was 0.316. The occurrence of several relatively extreme outliers made this collection of correlation estimates a bit less accurate than the previous collection, but it could be argued that many of the test subjects performed this estimation quite well.

The third graph displays correlation estimates for percent white population and percent housing less than ten years old ([Figure 4-4](#)), and it presents another slight overestimation (on average) of the correlation value, with the majority of responses positively skewed from the actual mean of correlation coefficients for this particular case (0.383). The mean of the estimated correlations for these data was 0.476. There were a few relatively extreme outliers that affected the relative accuracy of this collection of correlation estimates, but they actually served to balance the overall estimate in



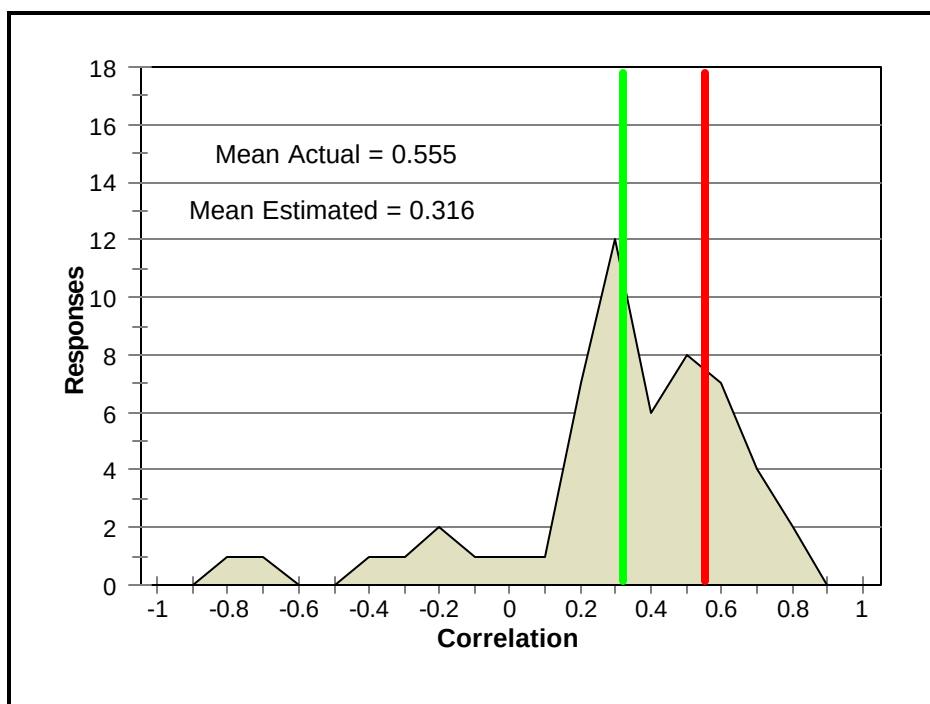


Figure 4-3: Correlation estimates for median gross rent and percent white population.

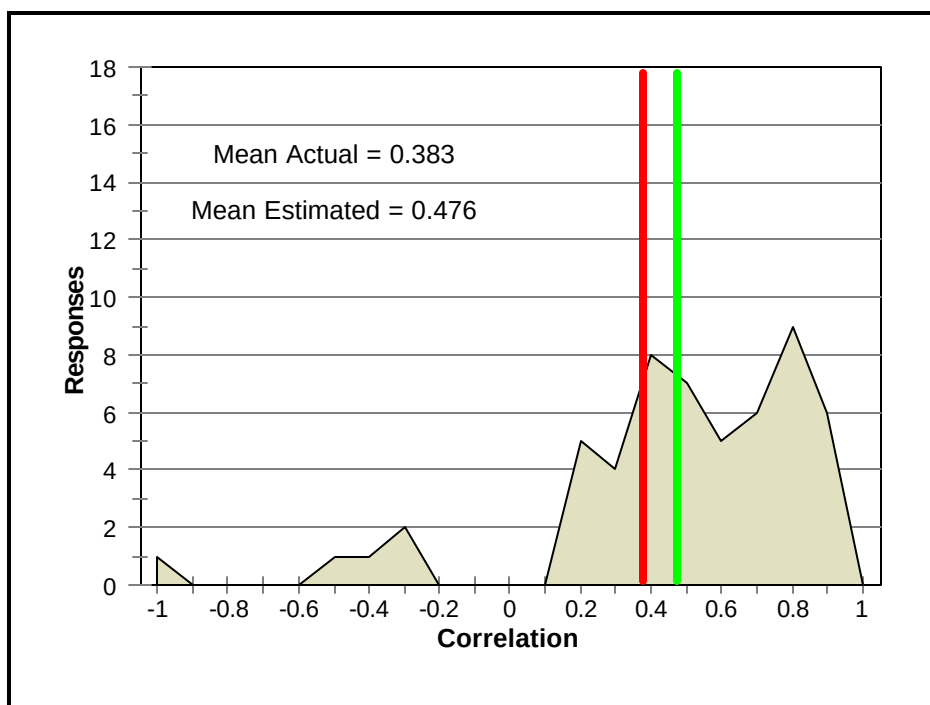


Figure 4-4: Correlation estimates for percent housing less than ten years old and percent white population.

terms of its mean value. In general, the test subjects performed the estimation task fairly well for this case.

The fourth graph provides a view of correlation estimates for percent white population and percent owner-occupied housing ([Figure 4-5](#)), and it features a bimodal distribution with the majority of responses negatively skewed from the actual mean of correlation coefficients (0.475) and the remainder positively skewed from the actual mean. The mean of the estimated correlations for these data was 0.315. There were no apparent outliers from the distribution of these responses. This is another case where it could be argued that many of the test subjects performed this estimation task quite well.

The fifth graph exhibits correlation estimates for percent white population and percent renter-occupied housing ([Figure 4-6](#)), presenting a clustering of estimates with the highest number of responses near the actual mean of correlation coefficients (-0.440), but there is a wide scattering of numerous estimates ranging from -0.9 to positive 0.9 with more than one fourth of the total responses estimating positive correlation. The mean of the estimated correlations for this data was -0.167. Overall, this was a widely scattered distribution of responses.

The sixth graph illustrated correlation estimates

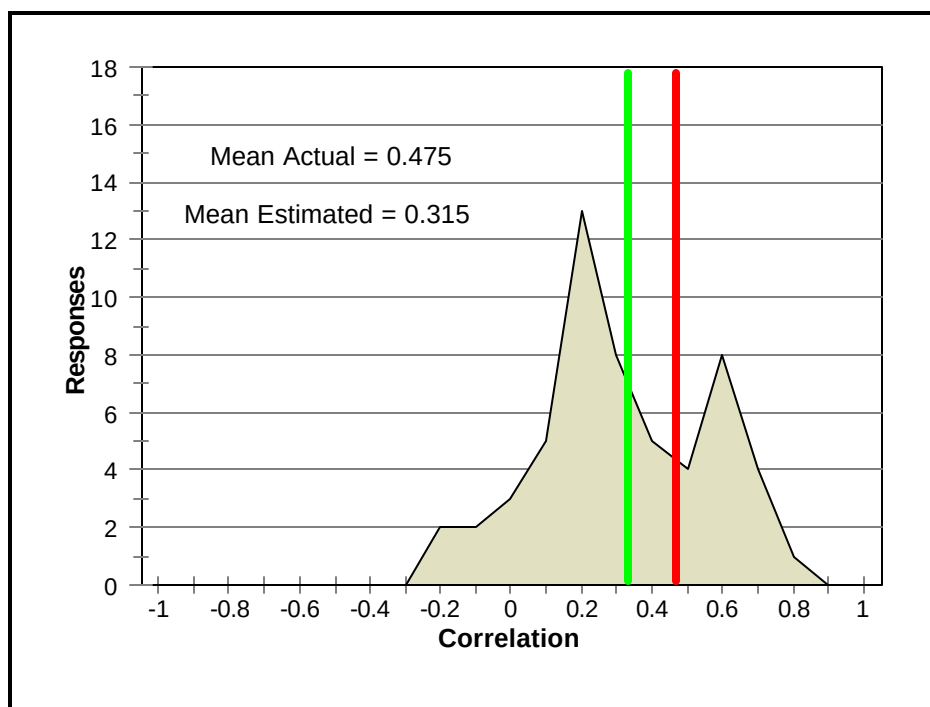


Figure 4-5: Correlation estimates for percent owner-occupied housing and percent white population.

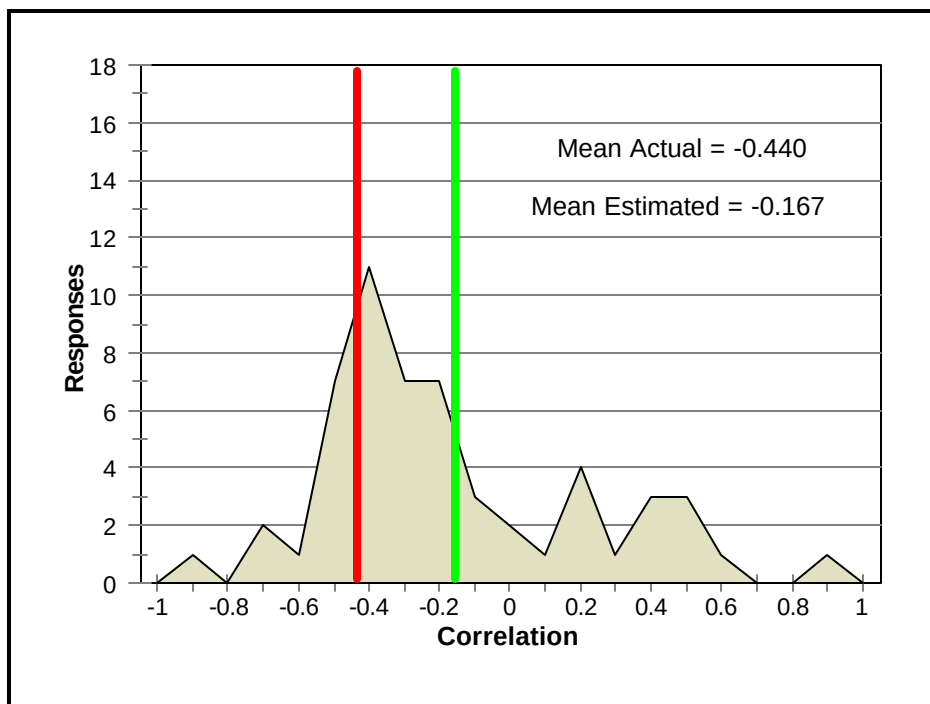


Figure 4-6: Correlation estimates for percent renter-occupied housing and percent white population.

for percent white population and percent without high school diploma ([Figure 4-7](#)), and this revealed a result quite similar to the previous collection, except with a somewhat bimodal distribution. The highest number of responses are found near the actual mean of correlation coefficients ( $-0.592$ ), but there is again a wide scattering of numerous estimates ranging from  $-1.0$  to positive  $0.8$  with nearly one fourth of the total responses estimating positive correlation. The mean of the estimated correlations for this data was  $-0.282$ . This was likewise a widely scattered distribution of responses. The similarly lackluster results for these two negative correlation cases suggests that a number of the test subjects may have been confounded somewhat by having to switch tasks from estimating positive to estimating negative correlations.

The seventh graph depicts correlation estimates for percent white population and percent with bachelors degrees ([Figure 4-8](#)), providing a view of another bimodal distribution, with the majority of responses positively skewed from the actual mean of correlation coefficients ( $0.480$ ) and the remainder negatively skewed from the mean. The mean of the estimated correlations for this data was  $0.509$ . There was only one outlier among the distribution of these responses. Generally speaking,

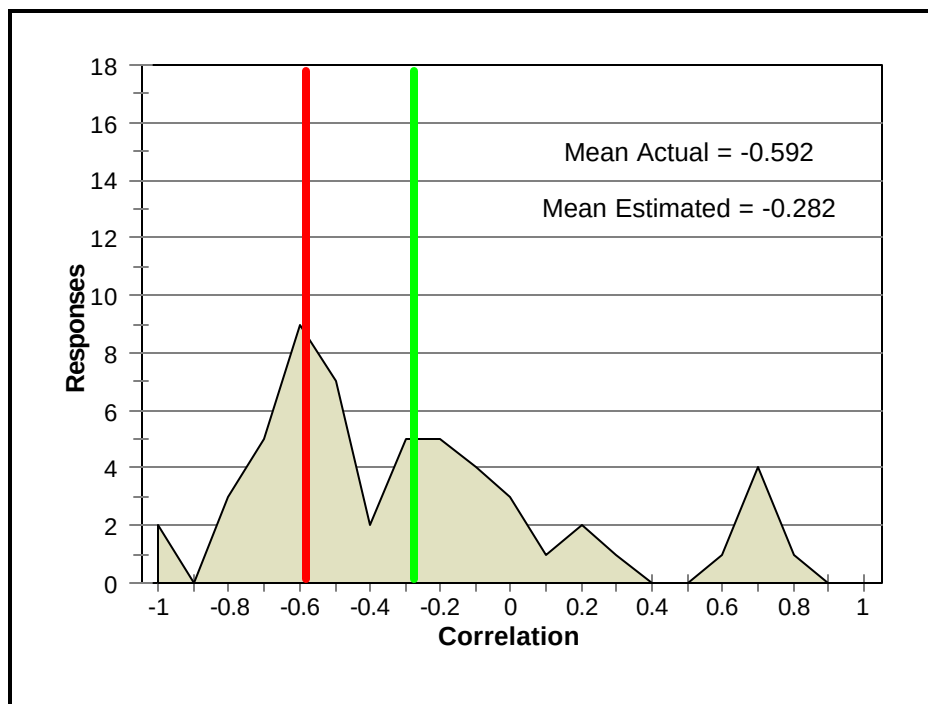


Figure 4-7: Correlation estimates for percent without high school diploma and percent white population.

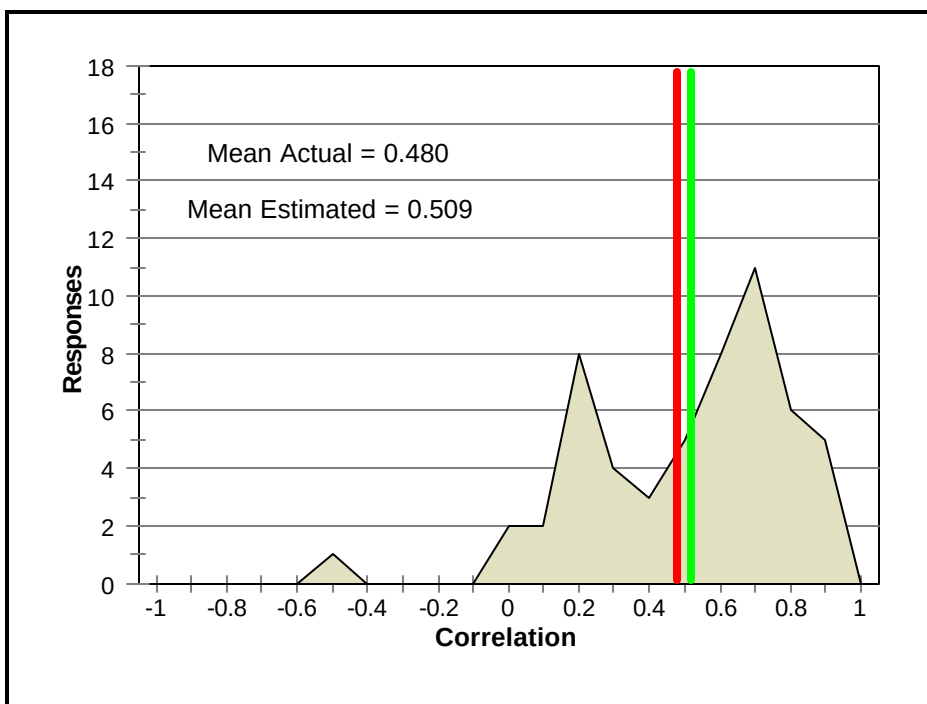


Figure 4-8: Correlation estimates for percent with bachelors degree and percent white population.



this represents a rather good set of estimates from the test subjects.

#### 4.5 QUALITATIVE ASSESSMENTS

There were ten sets of animated map pairs viewed by test subjects, with each map pair displaying a selected socioeconomic variable alongside the independent variable, percent white population. The first three sets were "training" sets designed to acclimate the test subjects to the process of estimating correlation based upon viewing the map animations prior to proceeding with the seven test animations.

In order to focus their attention on the visual estimation task during the training phase, they were asked to enter text responses describing any observed spatial and temporal patterns. They were likewise asked to enter text responses describing observed spatial and temporal patterns for the seven test animations. The comments included in the following sections were selected and compiled from the total collection of test subject qualitative assessments to provide summary views, and they capture the essence of test subject observations.

##### 4.4.1 PERCENT BLACK AND PERCENT WHITE

The first set of animated map pairs in the sequence

depicts percent white population with percent black population ([Figure 4-9](#)). These two variables are very strongly negatively correlated with a mean actual correlation coefficient (MACC) of -0.9914, and this profound negative correlation is readily apparent from viewing the maps. The test subjects easily recognized the strength of relations between these data, as evidenced by their comments:

- "From 1960-1990 Atlanta's black population took on a greater percentage in Southwest and Southeast Atlanta. This population came to dominate the areas. White population shows a near total exodus from areas beginning West of the city center and progressing Southwest and Southeast."
- "Percent black increased significantly in south-central portion of area, with the core of the black ghetto expanding to the southeast and southwest over time. At same time, percent white decreased in those areas."
- "When looking at the "Percent White", you see a decline in population for this group in the same areas you saw the increases with "Percent Black" -- thus, the negative correlation. If you focus on both of the maps at the same time, this inverse relationship is evident where darkening occurs in

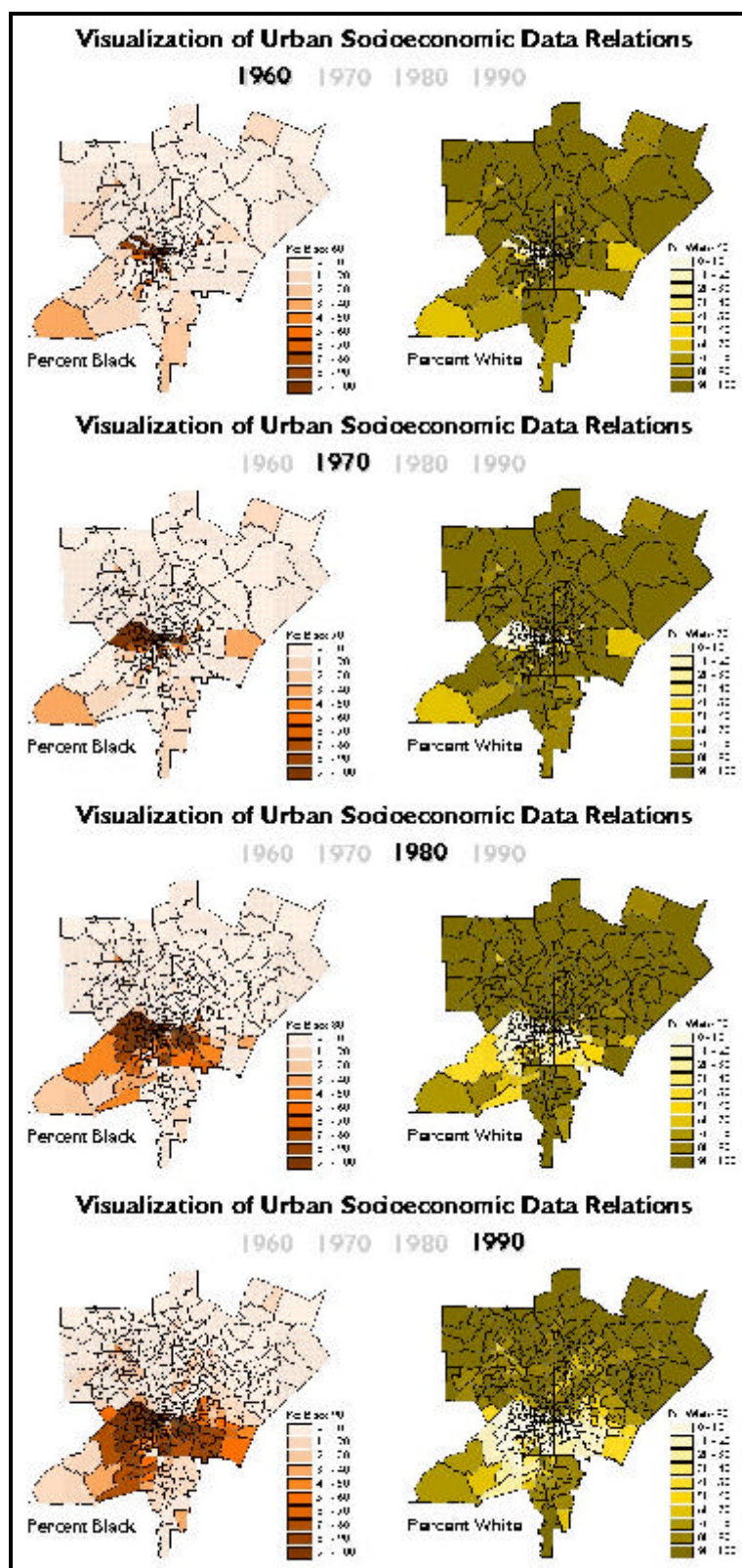


Figure 4-9: Temporal map pairs of percent black population and percent white population.

the areas lightening.”

- “There is a notable increase in the percent black occurring between 1960 and 1990 in the southeastern and southwestern core of the study region. There is a concurrent decrease in the percent white population in the same area over the time period. This would indicate a classic case of white flight.”
- “As the relative concentration of African-Americans expands or increases from the center of the metro region, the relative size the white population in these same areas decreases.”

It is quite apparent from a review of these comments that discernment of the very strong negative correlation between percent white and percent black populations for this particular region during this particular era is relatively straightforward. The very high degree of social separation between the two groups is plainly displayed in the spatial patterns illustrated by the animated map pairs, and the test subjects expressed their observations with exceeding clarity.

#### 4.4.2 MEDIAN FAMILY INCOME AND PERCENT WHITE

Median family income and percent white population were depicted in the second set of animated map pairs ([Figure 4-10](#)). These two variables have a strong

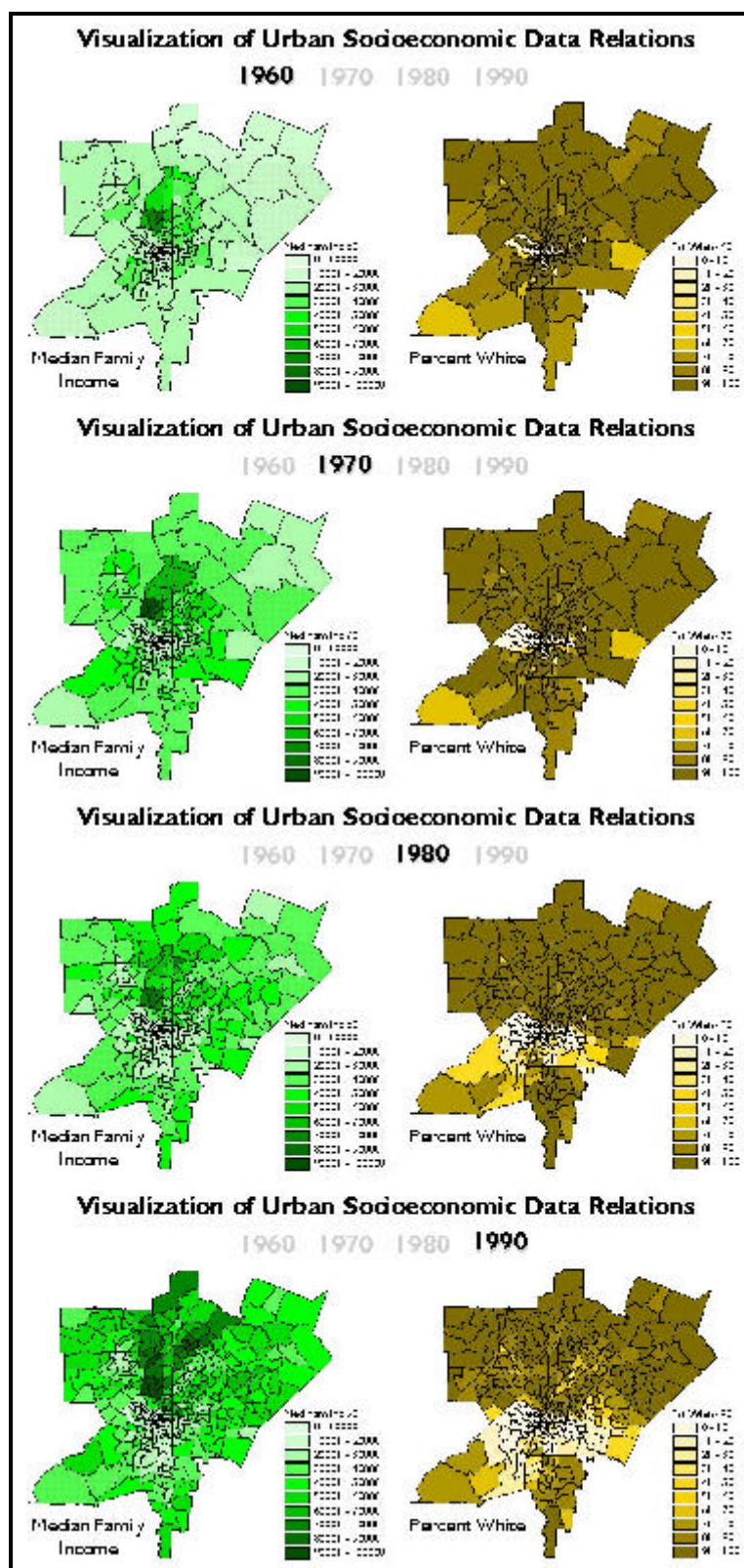


Figure 4-10: Temporal map pairs of median family income and percent white population.

positive correlation with a MACC of 0.6226, but the juxtaposition of spatiotemporal pattern between the two variables is not as clearly defined as that between percent white and percent black populations. The test subject responses were somewhat more varied in their observations:

- "Median family income increases generally over time, but increases most drastically in the north central region. The area with the least increase in median family income, is located in the central core area which is at the same time experiencing a decrease in percent white population (and an increase in percent black population.)"
- "The distribution of the white population in the tracts mimics the dispersion of higher income rates among the tracts. Both variables increasingly radiate out from the center over the years, but there appears to be a slightly lower concentration of the upper income brackets in the southwest for the 90's."
- "Median family incomes increased for nearly all of Metro Atlanta except a few places in West Atlanta and south of the city. The percent white map shows a more radical change than the median family income."

- “For the most part, median family income increased throughout the region, particularly in the north-central portions of Fulton County. This measure did not increase in the central portion of region, and a core area of low median income actually grew southwards over time. This growth of this core area of low income corresponded to the growth of residential areas having low values of percent white.”
- “While the median family income has increased throughout the area over the time frame shown here, there is an apparent concentration in the central northern portion of the study area.”

Once again the test subjects performed well in their assessment of the strong positive correlation between percent white population and median family income. Interpretation of this set of maps was complicated somewhat by an increasing correlation over time (0.525 in 1960, 0.572 in 1970, 0.695 in 1980, and 0.698 in 1990) as well as the overall temporal increase in general affluence across the region (from \$25,579 in 1960 to \$40,818 in 1990, as adjusted to 1990 dollar values). This temporal trend was readily discernible the maps of median family income, and this was reflected in the test subjects' responses.

#### 4.4.3 POPULATION PER HOUSEHOLD AND PERCENT WHITE

The third set of animated map pairs presented percent white population with population per household ([Figure 4-11](#)). These two variables have very little in common, with a very weak negative correlation (a MACC of -0.1920), and consequently any spatiotemporal pattern between the two variables is very difficult to discern. It was not at all surprising, therefore, to find test subject responses that acknowledge these weak relations:

- "Over time the population per household decreased but there is no visual correlation between pop per household and percent white."
- "Population per household appears to have generally declined through time, but not in any meaningful pattern."
- "Animation shows that the data patterns on the maps do not parallel each other; in fact, little relationship can be seen. As noted, the relationship is weak."
- "I cannot tell a definite positive or negative correlation among these maps. The only thing that I noticed was the overall population per household has decreased over time."
- "There seems an across the board decrease in population per household with a few anomalies, but



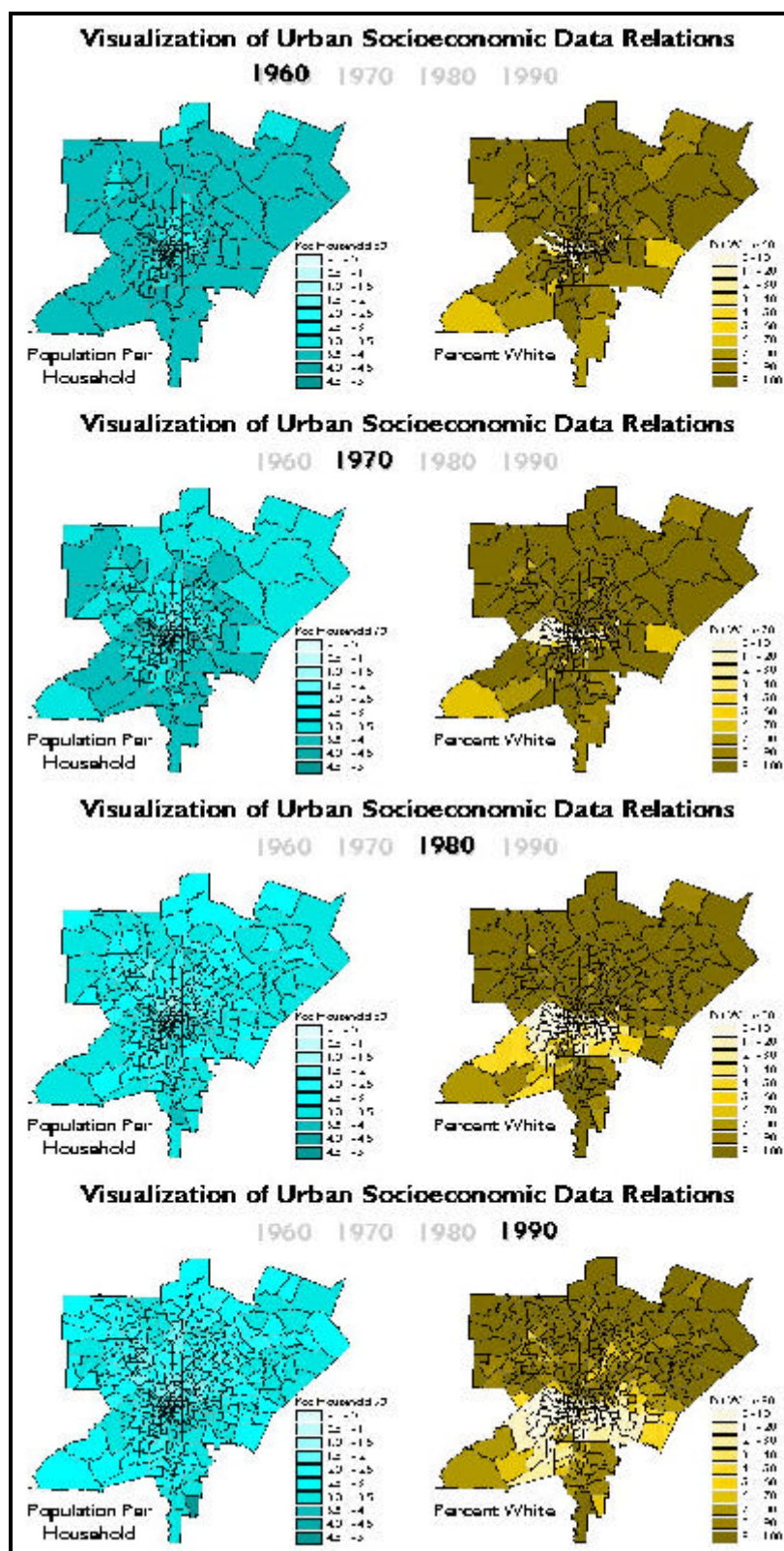


Figure 4-11: Temporal map pairs of population per household and percent white population.

not a strong spatial pattern emerging. Of course the percent white map has very strong spatial clustering. So it is clear that there is not a strong relationship between these two maps."

What is clear from these comments is that the test subjects were able to comprehend that while the trend in population per household was declining over time, there was little apparent associated spatial pattern that could be significantly linked with percent white. This very weak relationship between percent white population and population per household was readily perceived by the test subjects. The widespread decline in population per household (from 3.40 in 1960 and 2.89 in 1990) was likewise readily apparent to the test subjects. This was the last of the 'training' animations wherein test subjects were informed of the MACC by textual information in the survey instrument on the map animation web page.

#### 4.4.4 MEDIAN VALUE HOUSING AND PERCENT WHITE

The fourth set of animated map pairs was the first of the test animations where the test subjects were not given any information regarding the degree of correlation that existed between the represented data. This set displayed percent white population with median value housing ([Figure 4-12](#)). These two variables have a

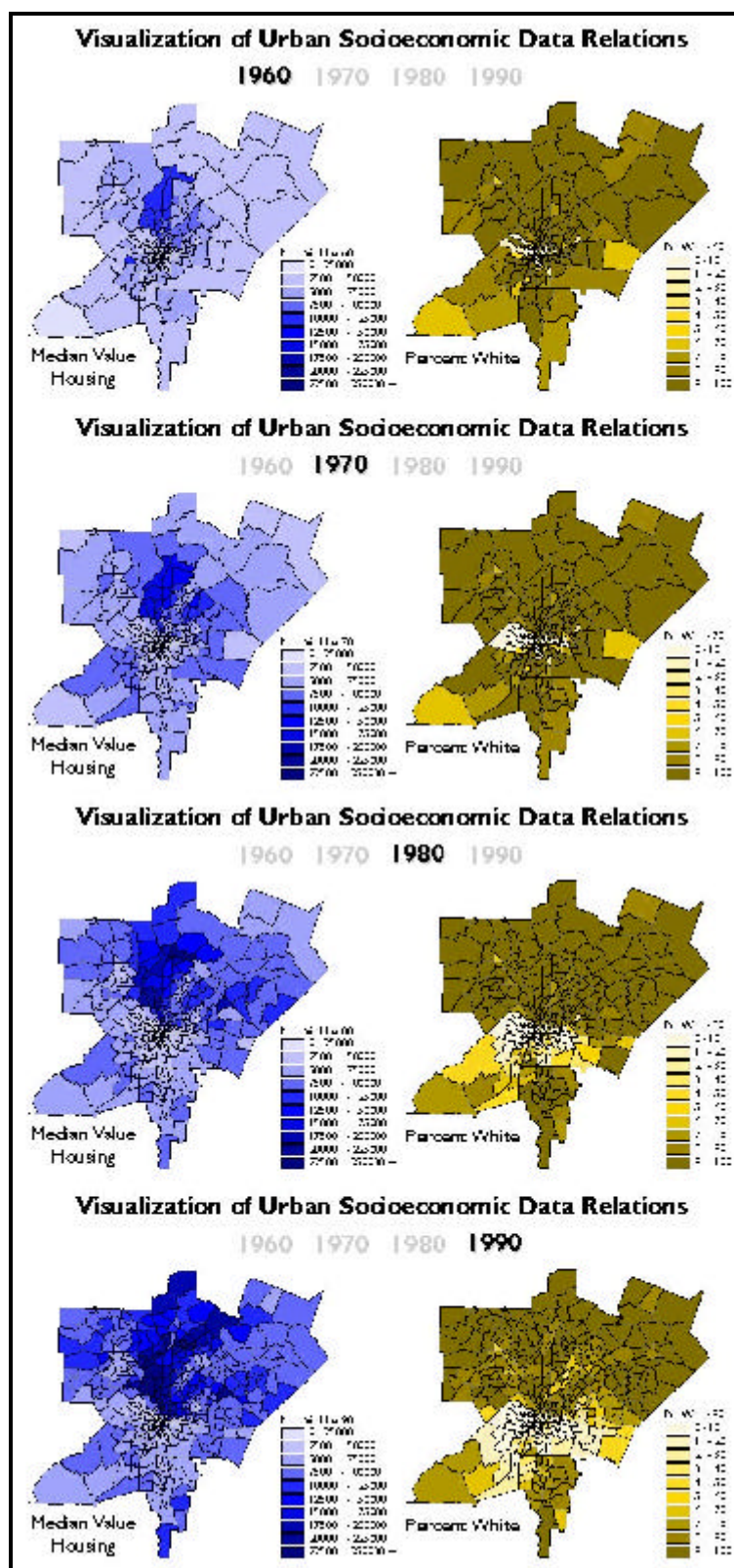


Figure 4-12: Temporal map pairs of median value housing and percent white population.

moderately strong positive correlation with a MACC of 0.5034, and there is apparent spatial direction to the pattern of median value housing over time. The test subject responses were in considerable agreement in their observations:

- "As highest percent white shifts from core to periphery, median value housing increases in the periphery. The greatest increase in median value housing occurs in the north central region."
- "Median value housing increases more in the north over time. The strongest increase is in the central portion of the north."
- "Map patterns seem to show a strong relationship between median value housing and percent white."
- "It is evident by these maps that overall median value housing is increasing, however, more so in the north central region. In looking at the percent white, you see that the population does correlate with the areas of highest median value housing. It is important to note though, there are areas of high median value housing with only about 70 percent white -- thus other minority groups may also be prospering."
- "Tracts in the north of Atlanta that maintained high percentages of white residents tended to experience

greater increases in median housing value. Tracts in the south of Atlanta that experienced a decline in the percentage white tended to experience less increase in median housing value. However, there were several tracts that experienced extreme decline in white population and a moderate increase in median housing value."

Test subjects generally recognized the strong positive correlation between percent white population and median value housing for this region. This view was relatively straightforward because the spatiotemporal pattern of median value housing roughly approximated that of percent white population. An interesting visual artifact noticed by many was the overall increase in median housing value that occurred over time (from \$52,469 in 1960 to \$96,898 in 1990, as adjusted to 1990 dollars). This was another case that was complicated by increasing correlations over time (0.3791 in 1960, 0.4606 in 1970, 0.6146 in 1980, and 0.5591 in 1990), but the test subjects still managed to hit the target fairly well with their assessments.

#### 4.4.5 MEDIAN GROSS RENT AND PERCENT WHITE

Median gross rent and percent white were highlighted in the fifth set of animated map pairs ([Figure 4-13](#)).



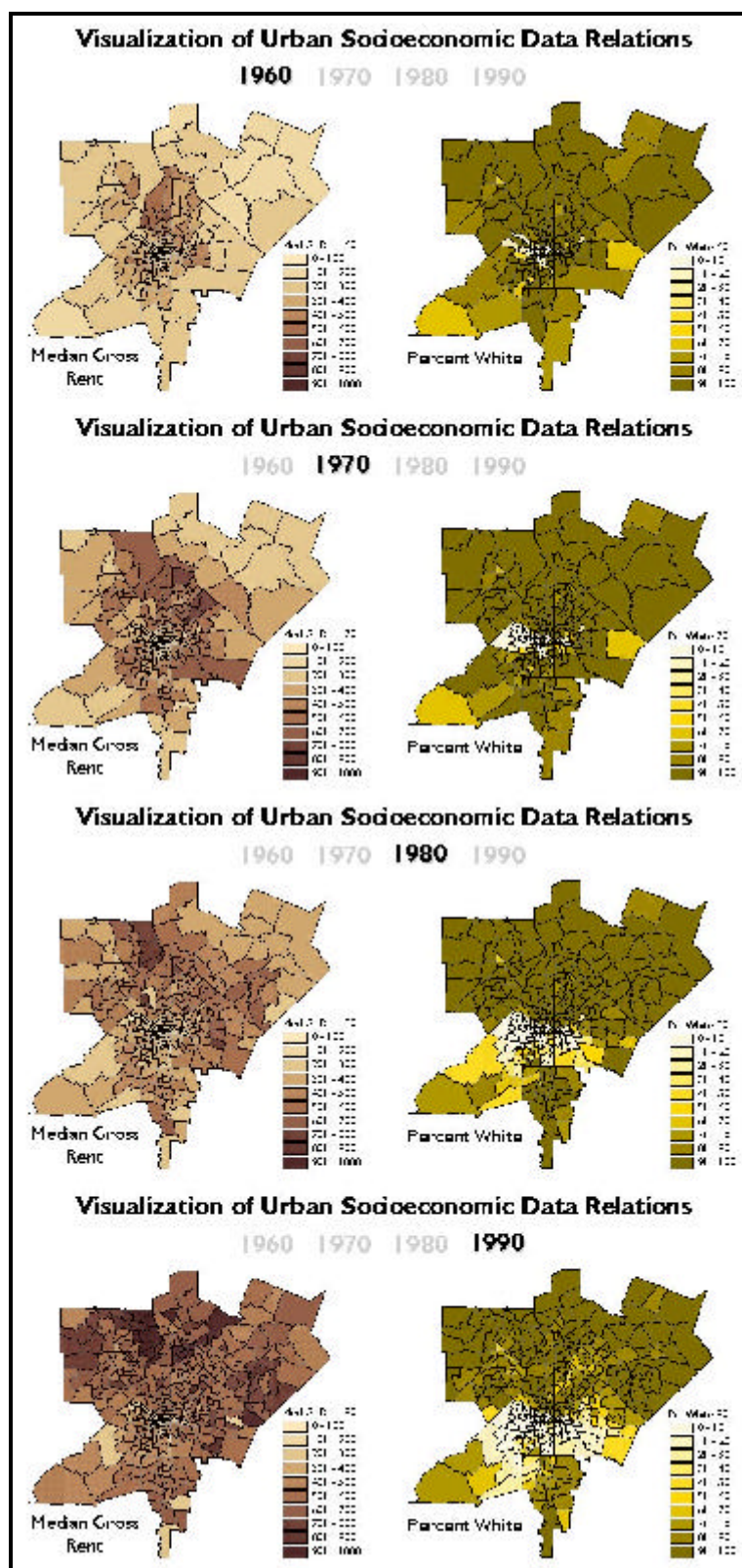


Figure 4-13: Temporal map pairs of median gross rent and percent white population.

These two variables have a moderately strong positive correlation with a MACC of 0.5551, but the spatiotemporal pattern displayed in the median gross rent maps is somewhat less focused than the median value housing maps. As a consequence, the test subject responses were a bit less uniform in their reported observations:

- "Overall the rent increases tremendously over time everywhere even in the poor black region. The rent increases more in the white area to the north.
- "The median rent decreases in central Atlanta, while rising in the suburbs. However, the rent increases everywhere in Atlanta. The rent in 1990 is highest in north Atlanta, where there is the highest percent white population."
- "There is not a totally clear relationship here, but the highest rents do tend to be found in the areas of higher white percentages. However, many areas of lower white percentages have experienced a sharp increase in rents."
- "Rents rise everywhere over time. Some of the non-white tracts have high rent by 1990, but the pattern appears to follow northward into the higher percentage white areas. In some of the non-white areas, rent falls slightly in the 70s, then goes back up in the 80s and 90s."

- “Rents went up almost everywhere except for a few tracts near the central city area and in the south half of the area. The pattern of the increase seems to follow areas of new development as it moves out from the central city area, but it doesn't really follow the same pattern as the change in white population.”

In general, recognition of the strong positive correlation between percent white population and median gross rent for this region during this era was somewhat more challenging because the spatiotemporal pattern of distribution in the median gross rent maps was less uniform than the percent white population maps.

Furthermore, the ability to assess the relations among these data was complicated by an increasing correlation over time (0.4446 in 1960, 0.5337 in 1970, 0.6011 in 1980, and 0.6409 in 1990). Still, the test subject responses revealed comprehension of the temporal increase in median gross rent (from \$313 in 1960 to \$538 in 1990) and a fairly commendable recognition of the positive correlation found among the mapped data.

#### 4.4.6 PERCENT NEW HOUSING AND PERCENT WHITE

The sixth set of animated map pairs portrayed percent white population with percent housing less than



ten years old ([Figure 4-14](#)). These two variables have a moderate positive correlation with a MACC of 0.3825. The degree of correlation increased from moderately weak to moderately strong over the course of time ( from 0.2473 in 1960 to 0.5546 in 1990), rendering the estimation of correlation a bit of a moving target. Nevertheless, the development of new housing in the metropolitan Atlanta area mirrored somewhat the exodus away from the central city associated with white flight and suburbanization, and the test subjects were fairly uniform in their observations in this regard:

- “The trend in the map on the left clearly shows the expansion of the suburbs over time. The radius of the ‘ring’ of newer houses has expanded fairly steadily. There would seem to be a fair amount of correlation between the two data sets, however -- the areas with the largest white populations clearly have increasing shares of the newest houses.”
- “Clearly shows the diffusion of subdivisions into the outer reaches of the Metropolitan Statistical Area.”
- “Ring of construction expands outward from Atlanta, with the front of construction being the the most intense in the north. West side of Atlanta has the strongest correlation -- least new homes and lowest

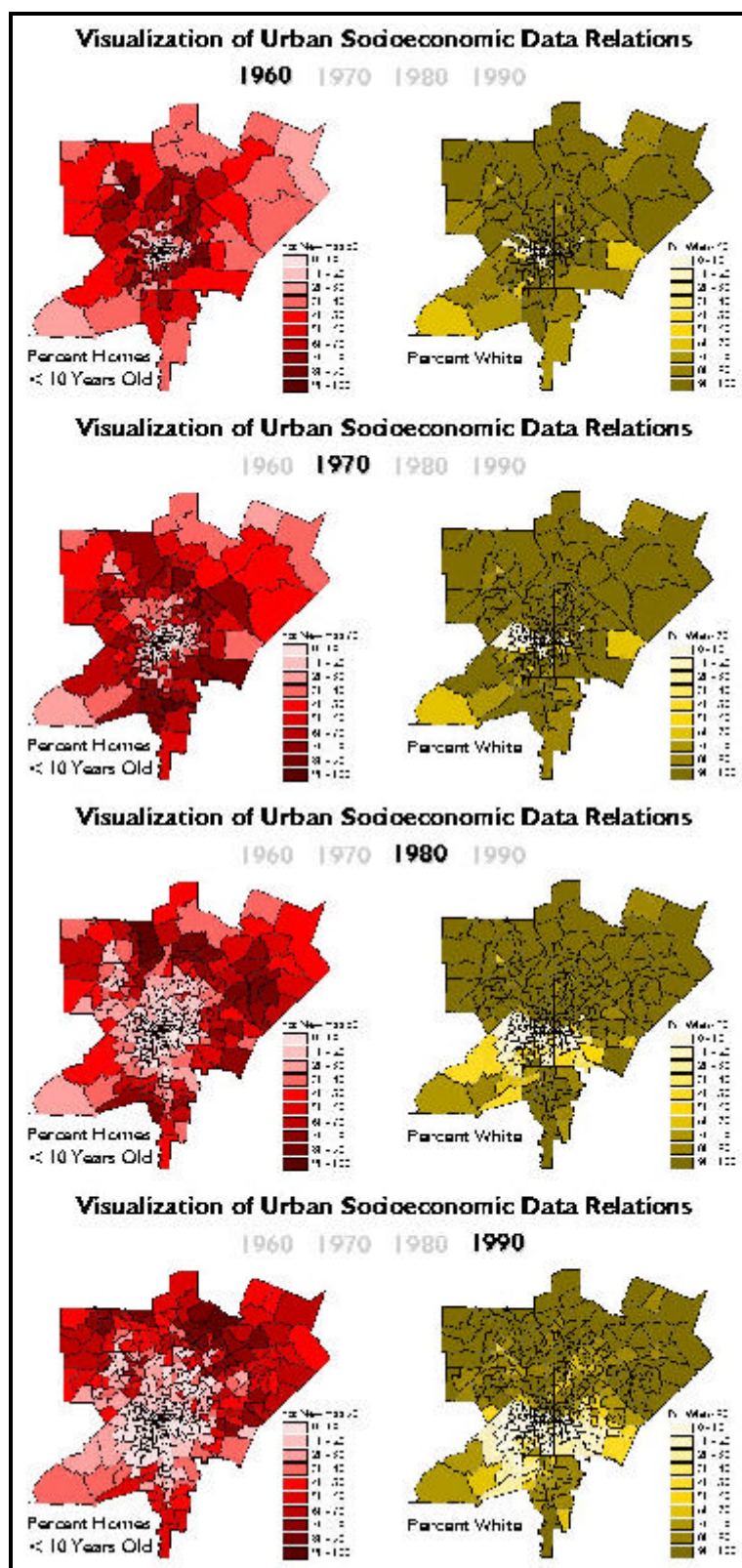


Figure 4-14: Temporal map pairs of percent housing less than ten years old and percent white population.

percent white."

- "There is a strong positive relationship between these two variables. The correlation is not perfect however. This is evident from the more symmetrical pattern of change in house ages, which radiates out from the center of the city, while the decline in white populations is really focused in the southern part of the city. There seems to be an expanding ripple of new houses radiating from the center, which is left with older houses."
- "The percent homes < 10 yrs correlates with white flight and the preference of new white households (moved from somewhere else) for new suburbs."

Recognizing the moderate correlation between percent white population and percent housing less than ten years old was somewhat challenging because of the increasing correlation over time (0.2473 in 1960, 0.2843 in 1970, 0.4437 in 1980, and 0.5546 in 1990). The highly apparent outward wave of development through the years served to provide a strong visual cue for the relationship between the two variables, however, and this was evident in the test subjects' responses.

#### 4.4.7 PERCENT OWNER-OCCUPIED HOUSING AND PERCENT WHITE

The seventh set of animated map pairs exhibited

percent white population with percent owner-occupied housing ([Figure 4-15](#)). These two variables have a moderately strong correlation with a MACC of 0.4748, and the pattern of percent owner-occupied housing around the metropolitan Atlanta area is not particularly uniform in distribution. This resulted in a somewhat challenging prospect for correlation estimation. Not surprisingly, test subject responses were a bit varied in their observations:

- "Ownership of homes is generally higher in high percent white areas, but is notably high in many non-white areas (particularly southwest Atlanta)."
- "Both variables concentrate around the outskirts with time. The percent white population decreases from central Atlanta, but not all the areas with a high percentage of white have a high percent of owner occupied homes."
- "Abandonment of central city by homeowners. It does look like some of the neighborhoods in the central city have a resurgence in 1990. The diffusion trend appears to be consistent until 1990 when the maps looks chaotic."
- "The pattern here looks as if there is simply more renting going on closer to the city, and less renting going on away from the city.....along with

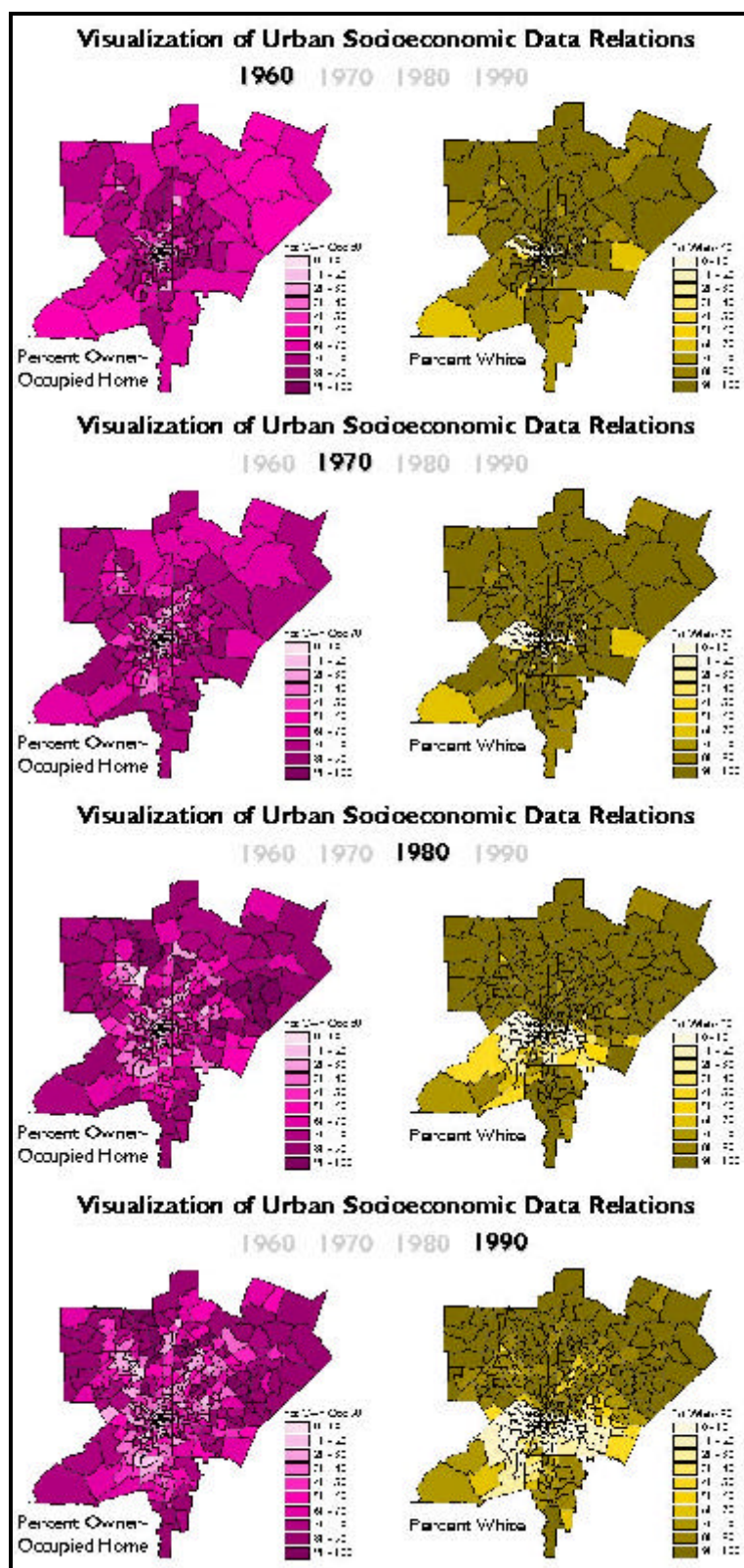


Figure 4-15: Temporal map pairs of percent owner-occupied housing and percent white population.

more renting overall through time. But the higher percent of home OWNERS are in the white north."

- "There is definitely a positive relationship between these variables but there is a fair amount of noise in the data as well. The same general pattern of an outward radiation of home ownership, but it is not too clean. The spread is less contained than the decline in white populations."

Test subject perception of the moderately strong positive correlation between percent white population and percent owner-occupied housing was challenged somewhat by the widespread nature of the percent owner-occupied housing distribution, and this was reflected in the test subjects' responses. Still, their assessments indicated a fairly reasonable recognition of the characteristics of relations among the depicted data.

#### 4.4.8 PERCENT RENTER-OCCUPIED HOUSING AND PERCENT WHITE

Percent renter-occupied housing and percent white population were illustrated by the eighth set of animated map pairs ([Figure 4-16](#)). These two variables have a moderately strong negative correlation (a MACC of -0.4402). The pattern of percent renter-occupied housing around the metropolitan Atlanta area is not uniformly distributed, and this somewhat complicates the prospect



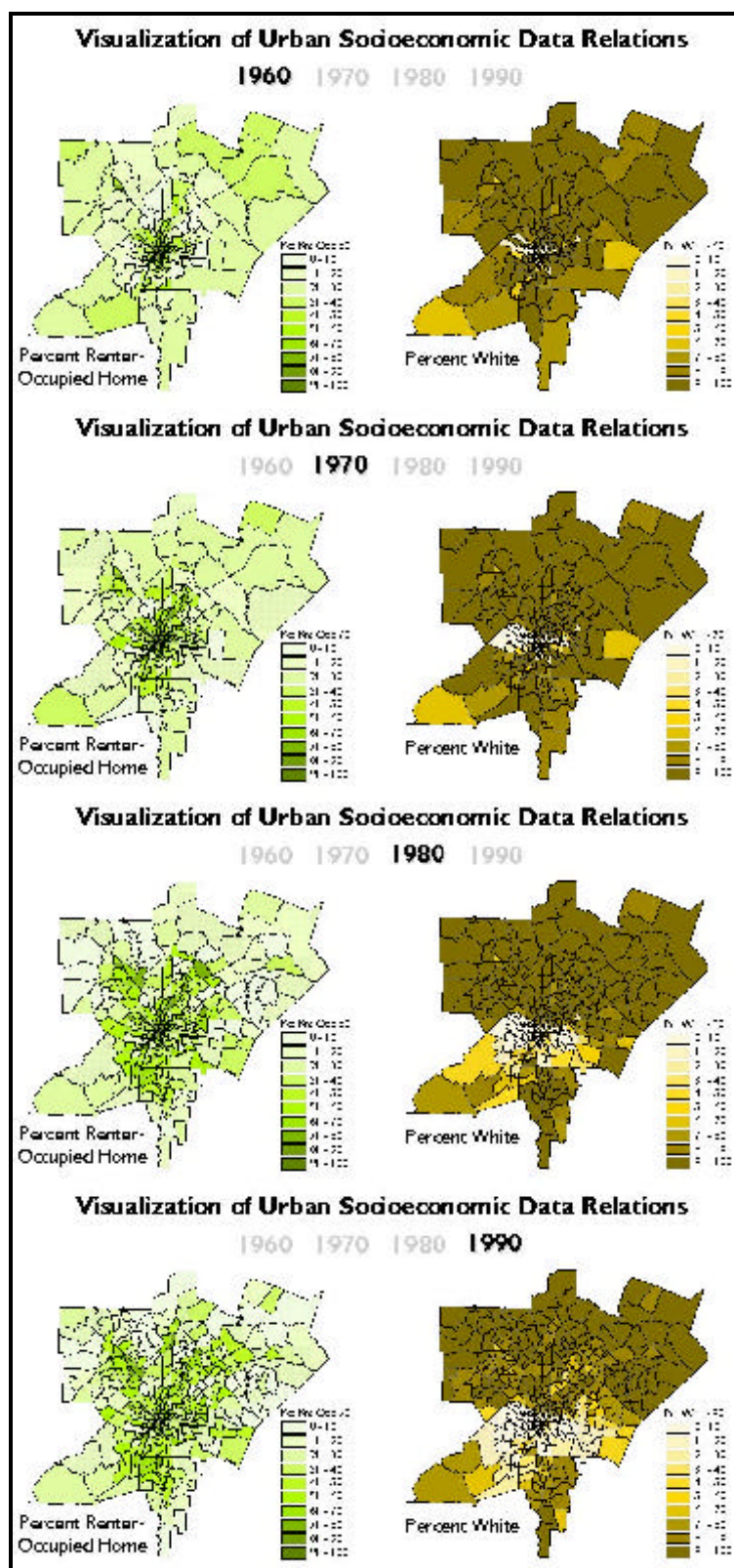


Figure 4-16: Temporal map pairs of percent renter-occupied housing and percent white population.

for correlation estimation. Once again, test subject responses were a bit varied in their observations:

- "Over the years the renting area moves from central Atlanta outwards like a spiders web in all directions."
- "There would appear to be a very weak relationship between percent renter-occupied housing data and the geographic polarization of race. The growth of proportion rentals has radiated outward from the center of Atlanta."
- "The percent renter occupied homes has increased particularly in the central city and in northern sections of the city. The percentage has not increased in southwestern Atlanta."
- "It appears that the percent renter occupied is increasing in the central portion of the study area over time. This is occurring in an area that is experiencing a decline in the white population."
- "It seems that renter occupied housing has remained closer to the Central city and usually expanded in neighborhoods with lower percent white populations. The percent of renter occupied housing declines in neighborhoods on the urban fringe, especially in the Northern part of the region, where white populations have increased. But it closer in to the city, the



inverse relationship between percent White and percent renter occupied housing seems to weaken.”

Recognizing the moderately strong negative correlation between percent white population and percent renter-occupied housing was somewhat difficult due in part to the relatively widespread pattern of percent renter-occupied housing distribution, and this was reflected by the test subjects’ observations. The task was further complicated by a steady decrease in correlations over time (from -0.5164 in 1960 to -0.3991 in 1990). It appears that, relative to the correlation estimation associated with the positively related data, some of the test subjects were a bit confounded by this representation of negatively related data.

#### 4.4.9 PERCENT WITHOUT HIGH SCHOOL DIPLOMA AND PERCENT WHITE

The ninth set of animated map pairs displays percent white population with percent without high school diploma ([Figure 4-17](#)). The two variables have a strong negative correlation (a MACC of -0.5918), and the correlation increases over time. To further complicate matters, the overall percent without high school diploma decreases overall throughout the region during the represented years. This undoubtedly renders the correlation

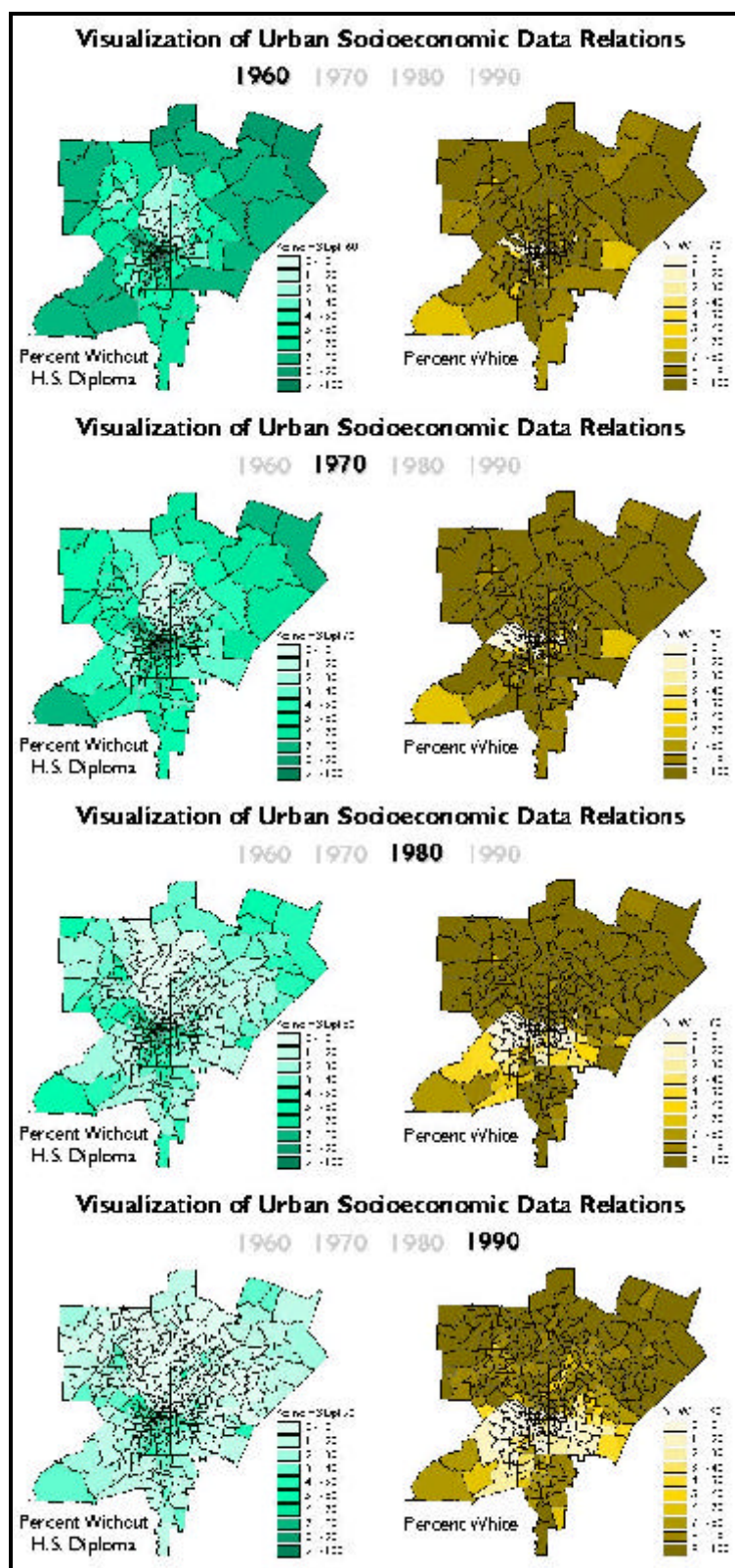


Figure 4-17: Temporal map pairs of percent without high school diploma and percent white population.

estimation task somewhat more difficult, a prospect supported by the variability of test subject responses:

- "Overall, percent without diplomas are decreasing. Appears to hold true everywhere but with less effect in the Atlanta core."
- "Percent without high school diploma has declined in general, but more slowly in inner south side neighborhoods than northern suburbs. This appears to have a fairly negative correlation with percent white, particularly in early years."
- "The data starts out in 1960 not showing much correlation, but in 1990 there is a pretty high negative correlation. The data in 1960 shows high areas in the outer metro area and high areas right in downtown. The areas in 1990 are pretty high mostly just in downtown Atlanta."
- "Over time the percent without a high school diploma decreases as a total. However, the central city remains a place where people are still not obtaining their high school diplomas."
- "Negative correlation - overall, percent without high school diploma has decreased over time, however, the higher values are clustered in the center of the area; at the same time, percent white has decreased in that center area."

Many of the test subjects recognized the negative relationship among the presented data, particularly because of the clustering of high values in percent without high school diploma in and around the urban core. They likewise noted the regional decline in percent without high school diploma over time (from 59 percent in 1960 to 28 percent in 1990). However, recognizing the moderately strong negative correlation between percent white population and percent without high school diploma was complicated by the contrast between a temporal trend of decreasing percentage without high school diploma and the increasing negative correlations found among these data (from -0.5327 in 1960 to -0.6700 in 1990). Nevertheless, the ability of many of the test subjects to provide meaningful assessments based on visual observation is apparent in these responses.

#### 4.4.10 PERCENT WITH BACHELORS DEGREE AND PERCENT WHITE

The tenth and final set of animated map pairs in the sequence presented percent white population with percent with bachelors degree ([Figure 4-18](#)). The two variables have a moderately strong positive correlation with a MACC of 0.4803, but this correlation value changed fairly dramatically over time (0.3415 in 1960, 0.3780 in 1970, 0.5457 in 1980, and 0.6559 in 1990). Due to a relatively

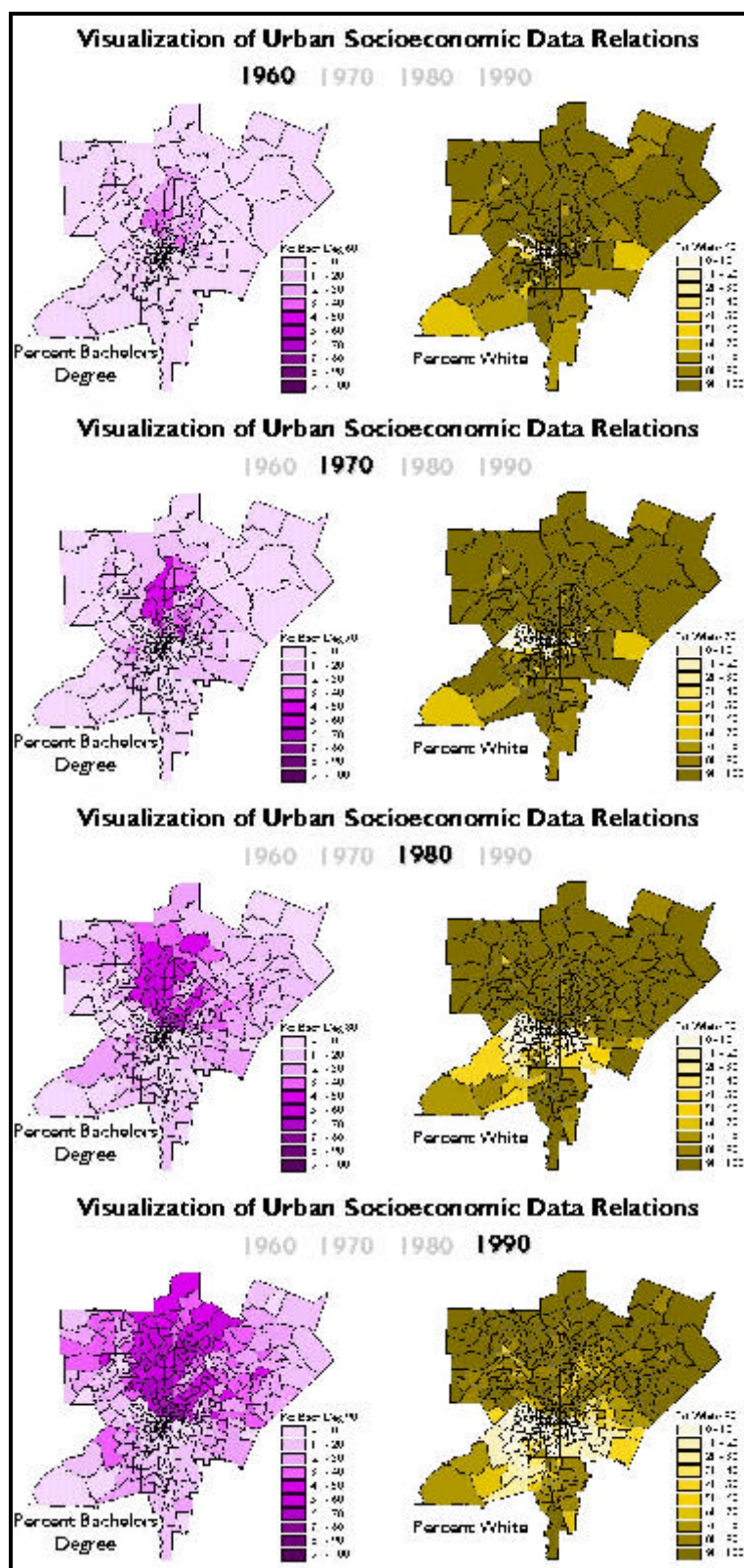


Figure 4-18: Temporal map pairs of percent with bachelors degree and percent white population.

focused spatiotemporal pattern, however, the test subjects responses were fairly uniform in their observations:

- "As high percent white population shifts to the periphery, percent bachelor's degrees increases in the periphery. Increase in bachelor's degrees in most prominent in the north central region."
- "Like the white population, those with a bachelor degree tend to be located away from the city and growth of each continues outward. The number of people with a bachelor degree increases through the years."
- "The percentage of bachelors degrees has grown since 1960s, particularly in areas of white population in northern Atlanta."
- "There is clearly a strong positive correspondence between areas with high percent degrees and high white percent. It is also clear however that not all areas with high percent white people have high percent college degrees. There is a clear clustering of degrees in the north atlanta area, small patches of increasing degrees occur in south Atlanta, but they are the exception."
- "The percent of population with a bachelor's degree is increasing over time with a spatial concentration

in the northern sector of the study area."

The relatively focused pattern of percent with bachelors degree provided strong visual evidence of positive correlation, despite being complicated somewhat by the increasing proportion of bachelors degrees as the years passed (from 9 percent in 1960 to 28 percent in 1990). Furthermore, while the percent with bachelors degree increased dramatically in the region during this time, there was a coincident and likewise dramatic increase in the positive correlations among this data (from 0.3415 in 1960 to 0.6559 in 1990). Overall, the test subjects identified the relations in this set of data very well.

#### 4.4.11 SUMMARY OF QUALITATIVE ASSESSMENTS

The test subjects' qualitative responses provide support for the value of visualization as a companion tool for quantitative spatial analysis. It is readily apparent that these individuals performed the task of interpreting represented data quite well, and were able to communicate this information clearly and succinctly.

Certainly there were some cases where they were able to interpret the visualized data more effectively than others, but considered collectively these results are encouraging. There remains the issue of novice versus

expert in the use of visualization tools, and although there was an attempt made to access test subjects with a greater degree of expertise as students of geography, it cannot be denied that some of these test subjects were more expert than others.

Nevertheless, it does indeed appear that based on these results, visualization methods have excellent potential for utilization in the spatial analysis of urban social phenomena. It is expected that further refinements of this survey instrument and distribution to a wider audience with a greater degree of expertise will result in (at the very least) similar results.



## CHAPTER FIVE

### CONCLUSIONS

#### 5.1 CARTOGRAPHY FOR THE NEW MILLENNIUM

The dramatic emergence of new computer technologies in the latter twentieth century has fostered a new paradigm in cartography. This advancement has enabled the development of analytical cartography and geographic visualization, wherein map designers are now engaged in the use of cartographic displays for the analysis of spatially arrayed phenomena. Before this new era academic cartographers explored aspects of map use and communication, we now find many of them exploring relationships found deep within digital data sets.

Geographic visualization is beginning to find widespread application throughout the discipline. As a methodology it allows for the exploration, analysis, and subsequent presentation of data, running the gamut from private to public domain according to its stage within the process. Visualization is touted by numerous quantitatively oriented geographers as an important new companion to statistical methods for spatial analysis

(Fotheringham, 1993; Gould, 1993; MacEachren, 1995; Openshaw *et al.*, 1994). As the volume of spatially referenced data continues to grow -- and it already exists in staggering proportions -- the value and usefulness of geographic visualization methods will also increase.

A large share of the currently available spatially referenced data is related to environmental conditions. But large volumes of socioeconomic and culturally oriented data are likewise being produced, and the amount of these data are also growing at a rapid pace. Businesses are beginning to recognize the usefulness of geographic data applications in the management of their resources and accessing new markets, and public planners have a need for enhancing their own understandings of population and housing trends in urban areas.

Part of the excitement surrounding the emergence of cartographic visualization methods is related to the ability to examine data from virtually unlimited perspectives. Scale can be easily adjusted. Physical or statistical surfaces can be explored with rapid changes in the point of view. Temporal processes can be represented through the use of a variety of animation techniques.

This new cartographic paradigm serves the

empowerment of the map user, who will be able to employ ever greater control over visualizations of a vast array of phenomena. The new challenge for cartographic designers will involve the development of interactive tools and facilitative interfaces to aid map users as they explore the expansive new world of spatial data. Whether these new age users are experts in a given field desiring efficient and manageable tools for applying their expertise or relative novices who are seeking broader awareness of the world around them, the development of enhanced visualization methods is expected to serve an ever-greater variety of map user needs.

Because these developments are so fresh and have such a profound impact on the nature of cartography, it has caused many within the discipline to call for an across the board rethinking of traditional map use and cartographic design issues (Buttenfield and Beard, 1994; DiBiase *et al.*, 1992; Krygier, 1996; MacEachren, 1995; Muehrcke, 1996; Peterson, 1994; Taylor, 1996). This rethinking requires the evaluation of individual interaction with the new and developing components of cartographic visualization, and the research undertaken in this project represents one modest step in that direction.

This research project was designed to explore the

viability of cartographic visualization as a supporting tool for spatial analysis in the examination of urban social problems. Specifically, it sought to provide both a quantifiable measure and a qualitative assessment of test subjects ability to discriminate correlations among urban social data using animated map pairs as geographic visualizations of the selected socioeconomic data as a component of several objectives stated in the introduction. The following objectives were accomplished in this research endeavor: 1) several animations of socioeconomic data were created; 2) a world-wide-web survey instrument was designed and implemented, and the survey instrument was used both for web-based delivery and data collection; 3 and 4) the data was collected both as quantitative estimates and as qualitative assessments; 5 and 6) the quantitative portion was assessed using common statistical measures; 7) the results were graphed for visual assessment; and 8) the qualitative assessments were reviewed for additional insight.

## 5.2 ANIMATIONS AND SURVEY INSTRUMENT

The web-based survey instrument developed and employed for this research endeavor provided an effective means for test subject evaluation of cartographic visualization, in that it was easily disseminated and was

consistent in both delivery of animations and the collection of entered data.

The animations ran in continuous loop while the test subjects viewed the screen, selected correlation estimates, and entered comments about observed spatial and temporal patterns. The information entered via the survey instrument was collected as programmed through CGI scripts and saved to a file on the web server.

There were eleven web pages that formed the body of the survey instrument: an introduction to the project with a registration form for collecting information about the test subjects; three "training" pages with animated map pairs and a form for entering qualitative observations of spatial and temporal patterns; and seven test pages with animated map pairs and forms for both quantitative estimates of correlation and qualitative observations of spatial and temporal patterns. As the data were collected for each page, the test subjects were automatically directed to subsequent pages for each next step in the process. At the conclusion of the exercise, test subjects response data was appended to a file on the web server and they were thanked for their participation.

This component of the research project operated without hitch and was an unqualified success in its implementation. It did, however, become apparent that a

number of design enhancements should be considered, and they will be discussed later in this chapter.

### 5.3 QUANTITATIVE CONSIDERATIONS

The use of t-tests for the evaluation of correlation estimation effectiveness produced mixed results. On the one hand, the matched pairs t-test indicated a general pattern of relative accuracy in the overall collective mean estimation of correlation by test subjects. On the other hand, the single sample t-test used to compare all test subject responses indicated that four out of seven test cases represented significant differences between estimated correlations and the mean actual correlation coefficient.

What does this mean? Perhaps the problem with this component was related to the use of a mean correlation value as a surrogate for comparison with the test subjects' estimated correlations. For some of the data correlations used in this project, there was a fair amount of change (both increases and decreases) that occurred through the temporal period. A method must be devised to account for this issue in future research efforts. Unrecorded verbal comments offered by a few test subjects following their experience with the exercise indicated that this had an effect on their

responses. Were they estimating correlation based on what they saw at the beginning of the animated temporal period or was it based on observations from the later views? Within this context, they might have provided a correlation estimate that was relatively accurate for one year in the but less accurate for the actual mean of correlation coefficients. Again, this is an issue that warrants further consideration.

#### 5.4 GRAPHS AND DATA VISUALIZATION

The inclusion of areal-fill line graphs of correlation estimates provided a useful visual means for the analysis of test subject responses, when used in conjunction with the statistical analyses. These graphs clearly showed clustering in the responses, as well as outliers (and in a few cases extreme outliers) found in test subject responses.

It can be argued that the graphs provide a strong indication of the relative success of the test subjects correlation estimation. Certainly one aspect was clear from viewing these graphs: the greatest struggles apparently involved estimating correlations associated with the negatively related variables, which had the greatest spread of correlation estimates and the largest number of outliers.

## 5.5 QUALITATIVE CONSIDERATIONS

In addition to the quantitative correlation estimates, the test subjects were asked to provide subjective assessments of observed spatial and temporal patterns. These comments were requested as qualitative reinforcement for the quantitative estimates.

These qualitative assessments gave the test subjects an opportunity to verbally express the nature of the spatial and temporal patterns without the restrictions of imposing numerical measures. Overall, these subjective observations provided a much stronger indication of test subject awareness and comprehension of the represented data than indicated by the single sample t-test. This is perhaps analogous to the difference between multiple choice and short answer exams. Given the opportunity to express themselves, many of the test subjects demonstrated considerable curiosity regarding the observed patterns, and some of these offered insights into likely processes that were contributing to these patterns. In some cases the test subjects exhibited considerable expertise in their evaluation of the map animations of urban socioeconomic data. It was obvious that the views of these animated map pairs were stimulating test subjects thinking about the urban geography of metropolitan Atlanta.



## 5.6 RESEARCH ENHANCEMENT AND EXTENSION

At this point it is appropriate to recognize a number of enhancements and extensions that would be useful in a continuation of this research track. These can be divided into four categories: modifications in research design; improvements in technical aspects of the survey instrument; selection considerations of various potential test subject pools; and differentiating parameters in companion survey instrument in order to control for and explore potential effects of survey design decisions.

Modification in research design involves the inclusion of additional questions in the survey instrument. Is the correlation changing over the course of the time period viewed in the exercise? If so, is the correlation increasing or decreasing? What year in the viewing period has the lower correlation value? What year in the viewing period has the higher correlation value? What is the estimated range of low and high correlations? It would also be useful for test subjects to have the opportunity at the end of the exercise to provide general feedback about the survey, the instrument, and any other issues about the experience they might deem important. The research design can also be improved by expanding the presented correlations

beyond percent white population to include a sampling of correlations among each of the presented variables (such as median family income and percent with bachelors degree or percent with bachelors degree and median value housing, for instance).

Improvement in technical aspects of the survey instrument has to do with enhancing the test subjects' ability to interact with the interface. A primary direction for this category would involve the utilization of Java programming code for improved data entry and data collection capability. Another important enhancement would be the use of JavaScript GIF animations to provide test subjects with the ability to exercise greater control over map animations, including the ability to pause and adjust tempo. And the experience be improved by zooming in a bit tighter on the study area, changing the viewpoint scale in order to enhance the visibility of the smaller census tracts at the urban core and minimize through elimination the somewhat extraneous oversized and underpopulated tracts on the periphery.

Selection considerations of various potential test subject pools could enhance the ability to evaluate results. There are a number of obvious test subject audiences (i.e. Association of American Geographers Specialty Groups in Urban, Cartography, GIS, and

Quantitative Methods) that would be suitable and relatively easy to access via email distribution lists. The use of a web-based survey instrument would enable effective world-wide distribution.

Finally it might be interesting to produce comparisons of responses given different sets of criteria. With the collection of information about the educational/professional background of test subjects (area of expertise, professional position, years of training, years of service in specialization) comparisons could be made regarding the relative abilities of test subjects with different characteristics, and results could also be compare according relative level of expertise (novice versus expert). The effects of color selections could be weighed by comparing standardized color schemes (use of a single color scheme for all animations) with differing color palettes for each animated map set. Also, the use of identified variables can be compared with the use of unidentified variables to determine the extent of bias in responses based on preconceived notions about the nature of the data being visualized.

## 5.7 GOALS AND OBJECTIVES REVISITED

The goal of this project was the evaluation of

cartographic visualization's utility as a tool for the spatial analysis of urban social dynamics. This research project specifically examined the human ability to recognize the strength of relations among urban social data via animated representations of a changing socioeconomic landscape. Correlations among the selected data were used to provide a test value against which test subject estimates were measured. The results of this research provided evidence supporting the usefulness of visualization as a means for the exploration, analysis, and representation of urban population dynamics. The demonstration of cartographic visualization's viability as a tool for urban socioeconomic research is an important step in the evolution of both urban spatial analysis and the geographic discipline.

The success of this research project must be qualified somewhat by the nature of its approach. A decision was made during the project's development to provide information regarding the nature of the data (in terms of both spatial location and selected socioeconomic data) involved in the evaluation. This decision was rendered within the context that visualization applications are most commonly employed by experts actively involved in the analysis of data and locations with which they had considerable familiarity. Certainly,

a review of the comments expressed during the qualitative component of this project reinforced the notion that a number of the test subjects were indeed familiar with the metropolitan Atlanta region. Furthermore, it is recognized that all of the test subjects were subject to the possibility of preconceived notions regarding the nature and strength of relations among the selected data. With this in mind, it is acknowledged that test subject responses were collected in a manner introducing an unspecified degree of bias into the results. Nevertheless, it is maintained that, given the nature of the visualization process and the manner in which it is typically employed (by experts familiar with both study area and data), this research presents strong case for the merits of urban visualizations.

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