Geography: Information Visualization in the Social Sciences

A State-of-the-Art Review

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This review of scientific visualization in the social sciences contains an extensive review of recent literature and Internet sources on visualization and discusses the extent to which four key visualization technologies—the World Wide Web, multimedia, virtual reality, and computer graphics—are prevalent in the different social sciences. The review includes examples taken from political science, psychology, social statistics, economics, and geography. It concludes that visualization research in the social sciences is, at present, relatively uncoordinated with no central core. It tends to be dominated by those subjects with the closest links to the natural sciences, with a clear pattern of diffusion from scientific to social scientific research.

Keywords: visualization, social sciences, World Wide Web, multimedia, virtual reality, computer graphics

Although there has been a long history of visualization in the social sciences, changes in visualization technology in the past decade are profoundly affecting the ways in which the social sciences are researched and the ways in which studies are communicated (Olson, 1997). These changes have largely been initiated by the rapid development of computer technology since the 1980s, resulting in the availability of powerful and affordable computing. Consequently, social science researchers now have access to an unprecedented range of visualization methods and technologies, which they might have very little experience in using. Integral to this is the divide within social science between disciplines that traditionally have employed visualization techniques and disciplines in which the use of visualization has been minimal. This situation is further compounded by a lack of empirical data on the current use of visualization within the social sciences. Hence, the objective of this article is to present a review of the current use of visualization within the social sciences in an attempt to resolve some of this uncertainty. The need for such a review was first made nearly a decade ago:

> The general consensus in the scientific visualization field is that a broad commonality exists among the visual needs of all numerically intensive sciences. . . . We are keenly awaiting its applications to fields with a shorter history in numerical computing such as econometrics and

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> the social sciences. Will users from these fields find this environment appropriate to their needs? (Upson et al., 1989, p. 41)

It is Upson and colleagues' (1989) question that this review seeks to answer.

A review of visualization in the social sciences is not the simplest of academic exercises to complete because there is no generally accepted definition of either *visualization* or *social science*. For the purposes of this review, we see visualization as offering "a method for seeing the unseen" (McCormick, DeFanti, & Brown, 1987) in the same spirit as the classic McCormick et al. (1987) report. We see social sciences as being those academic subjects usually assigned to social science faculties in British universities—economics, geography, politics, psychology, and sociology. But for this review, we also include planning, history, and social statistics.

The review is essentially concerned with developments in computer visualization that have occurred during the 1990s. With respect to the social sciences, four distinct visualization technologies have evolved: computer graphics, multimedia, the World Wide Web, and virtual reality (VR). The review begins with a short overview of the use of these key visualization technologies and then considers particular subjects in turn, in approximate order of output volume in the visualization literature.

RECENT DEVELOPMENTS IN VISUALIZATION

Computer Graphics

According to an estimate by Jones and Careras (1996), an incredible 2.2 trillion graphs were published during 1994. This can be linked to the growing availability of inexpensive, general-purpose computer packages that can generate graphical output with very little effort (Permaloff & Grafton, 1996). Increasingly, these visual techniques are including sophisticated computer graphics in an attempt either to visualize complexity in the data or to enhance more traditional graphical displays. However, although sophisticated displays, such as three-dimensional (3D) graphs, might be more pleasing visually, in terms of extracting information, simple two-dimensional (2D) graphs have been shown to perform better with respect to accuracy and ease (Fisher, Dempsey, & Marousky, 1997).

The most exciting innovation in computer graphics in recent years has been computer animation. Computer animation in social science research is not a new phenomenon. At the beginning of the 1970s, Tobler (1970) described a "computer movie" that he and his research student developed to show a simulation of urban growth in the Detroit region. Nevertheless, new technology has allowed computer animation to have the potential to become almost commonplace in research if desired. In particular, computer animation has a role in visualizing temporal changes, such as with respect to space-time data (Dorling & Openshaw, 1992), and this may have important implications for research in the social sciences, particularly in economic history.

Multimedia

Multimedia is the use of more than one medium such as text, still graphics, sound, animation, and video to represent and convey information. It gives users control over the order in which they see or hear this information. In its current use, multimedia implies the use of a computer and almost always implies interactivity between the computer and users. Lately, researchers also have started using "texture" for data visualization, the rationale behind this being to exploit the sensitivity of the human visual system to texture to overcome the limitations inherent in the display of multidimensional data (Rao & Lohse, 1996).

World Wide Web

The World Wide Web still is a relatively new medium, and its true potential remains unknown, particularly with respect to its use by the social sciences. However, because of its highly graphical nature and its multimedia content, a consensus exists that the Web is an ideal medium for conducting visualization research and the dissemination of its findings. Many advanced forms of data visualization and graphical interaction, such as animation, VR, and 3D graphics, now can be used or at least demonstrated via the Web.

Currently, the use of the Web as a medium for the dissemination of social science visualization research is somewhat obscure. Exhaustive use of various standard search engines such as AltaVista, Excite, Lycos, and InfoSeek on keywords and key phrases produces surprisingly little evidence of Web sites dedicated to visualization in the social sciences, and it quickly becomes apparent that the physical and natural sciences dominate this research area. This supports Carter, Kingston, and Turton's (1997) findings that, despite the discussion surrounding the potential use of the Web as a vehicle for social science research, very little has materialized to date.

This relative dearth may be explained partly by the fact that the majority of visualization Web sites tend to be concerned with the ongoing research and development of visualization tools and software.[1-4] Due to historic links with engineering, medicine, and computer science, this type of research traditionally has fallen within the domain of "science," hence the comparable lack of social science visualization Web sites. Existing Web sites are essentially "showcases" of what the software is capable of doing, usually with the opportunity to download the software with accompanying tutorials and user manuals. However, these technologies have been developed within the context of the physical sciences, using physical science data, and it is arguable that the social sciences and social science data are sufficiently distinct to require quite different techniques and/or technologies. The social science visualization Web sites that do exist tend to originate from social science disciplines closely affiliated with the physical sciences, notably geography.

Virtual Reality

It has been suggested by Newby (1993) that VR is the most promising new area for human-computer interaction since the Macintosh computer graphical user interface. He argues that VR has the potential to effect changes in the integration and convergence of technology more so than any other computer innovation in recent history. The roots of VR may be traced to the early 1960s in diverse areas such as flight simulation and art, although now it would seem that the term has become synonymous with most pseudo-3D computer presentations (Wann & Monwilliams, 1996). VR is a growing feature on the Web and appears to be the dominant visualization technology under research and development, crossing the science and social science divide. The Web's ability to provide pseudo-3D graphics and 3D worlds has been made possible through the development of Virtual Reality Modeling Language (VRML), allowing "plug-ins" into current Web browsers. These permit extremely elegant and powerful animations, 3D environments, and VR systems to be developed and displayed. As such, VR technology represents the most graphical environments within Web-based systems, and Carter (1997) sees the future of this technology as very promising, having great potential for use by the social science research community.

EXAMPLES OF RECENT VISUALIZATION RESEARCH IN THE SOCIAL SCIENCES

The review that follows has concentrated on the use of visualization in social science research, although it is acknowledged that visualization also is used in the teaching and learning of social science disciplines. An extensive Web search and a comprehensive review of several computerized bibliographic databases were undertaken using keywords and key phrases. Information from these different sources was combined using the disciplines within social science as a means of structuring the review.

Geography

Out of all the social science disciplines reviewed, geography would appear to make the greatest use of visualization. This can be attributed to two main factors. First, geography is closely affiliated with science through links with physical geography and the earth sciences. This link has facilitated the flow of computer technology across the discipline in terms of both hardware and expertise. Second, geography is relatively unique among the social sciences with its almost exclusive use of spatial data, reflected in its cartographic origins. By definition, these data have an extra dimension inherent in their structure, and it has been the necessity to visualize this extra dimension that has driven geographers to adopt and develop new visualization technologies. Hence, geography has had a long association with visualization, and due to its interdisciplinary nature, it can be argued that geography represents the dominant field in visualization research and development within the social sciences.

The principal area of development of visualization has been within the domain of geographic information systems (GIS), specifically integrating GIS with different software packages and environments. When integrated with advanced visualization tools, GIS can become very effective in the analysis and presentation of complex data in a wide range of disciplines, from planning to resource management (Bishop & Karadaglis, 1997; Conners, 1996; Davis & Keller, 1997). Increasingly, these integration strategies have been “tight,” using software packages written in the C programming language to build directly within the GIS. For example, SimLand (Wu, 1998) is a prototype model to simulate land use written in C and tightly integrated with ARC/INFO GIS. It uses a graphical user interface that allows the model to be driven by menus and automates the simulation of land conversion in the urban-rural fringe. This has several advantages such as allowing the visualization of the decision-making process and permitting easier access to spatial information. Another recent example of integrating GIS with modeling software is the Clarke, Hoppen, and Gaydos (1997) simulation of urban growth in San Francisco.

An important area of visualization in GIS is the integration of 3D visualization technology. Standard elements of GIS can imply 3D representation, but new techniques in multimedia, 3D modeling, and VR now are at the point where they might be embodied within GIS (Faust, 1995). Currently, the Environmental Systems Research Institute is developing the 3D Analyst extension for ArcView, which will enable users to create, analyze, and display data in three dimensions. However, the principal research into visualizing and analyzing 3D spatial data in a GIS has been with respect to VR techniques on the Web. These are discussed in detail in the next subsection.

Parallel to these visualization developments in GIS has been a radical transformation within cartography (Grelot, 1994; Kraak, Muller, & Ormerling, 1995; Krygier, 1995). Consequently, a significant amount of "cutting-edge" GIS visualization research and development actually is computerized cartography, recently relabeled as *scientific visualization*. Scientific visualization is a growing area of computing that has the underlying philosophy that displaying visual representations of data assists researchers in generating ideas and hypotheses about the data (Fisher, Dykes, & Wood, 1993). Accordingly, Dykes (1996) suggests that cartographic visualization systems may represent the principal technology for the scientific visualization of digital spatial information. He argues that many statistical and GIS software programs do not regard the map as a real-time tool for analyzing data or as an interface for accessing the underlying information. Cartographic visualization systems could provide intelligent assistance to GIS users by allowing data mining and/or EDA. This is examined in more detail later in the review.

Compared to merely automating previous mechanical and manual technologies, more dramatic changes in visualization in cartography have been due to developments in computer graphics. For example, cartograms (Dorling, 1996) are increasingly being recognized as a major solution to many spatial visualization problems of human societies. The gross misrepresentation of many of the groups of people on conventional topographic maps has long been seen as a major problem of thematic cartography, highlighting difficulties such as the modifiable areal unit problem. Cartograms now are being used in the visualization of high-resolution spatial social structures and in the mapping of long-run historic changes in society.[5]

The importance of GIS and cartographic visualization on the Web is exemplified by the Cartographic Project.[6] Part of the project includes a survey investigating the use of cartographic and geographic visualization on the Web undertaken between January and February 1997. The profile that emerged from the survey was that of a population engaged in a wide and varied assortment of computer graphics and cartographic research. The tools and data types that respondents used were as diverse as the projects in which they were engaged, with use of the Web being widespread, particularly for data distribution and information sharing. Although many respondents were investigating the implications and potential uses of VR, few had incorporated it into their projects in any way. It must be pointed out, however, that the majority of respondents and researchers came from science backgrounds such as physical geography and remote sensing. Social science research was seen to be lacking in the survey.

Planning

Similar to geography, planning also has had a long association with computer visualization. Lower platform costs, higher performance, and better software applications have brought visualization technology within the reach of most planning departments and urban design consultants. In a study by Levy (1995), the role of computer-aided design as a visualization tool in the planning process was critically assessed. The findings highlighted the role of such visualization technology in expanding the range of alternative planning proposals under consideration. Furthermore, a study by Bengtsson et al. (1996) indicated that computer-supported modeling and visualization eventually might serve as a common and efficient language, facilitating communication about multifaceted environmental planning issues. In particular, computer animation was discovered to be a more effective and preferable medium of communication than more established methods, such as paper drawings,

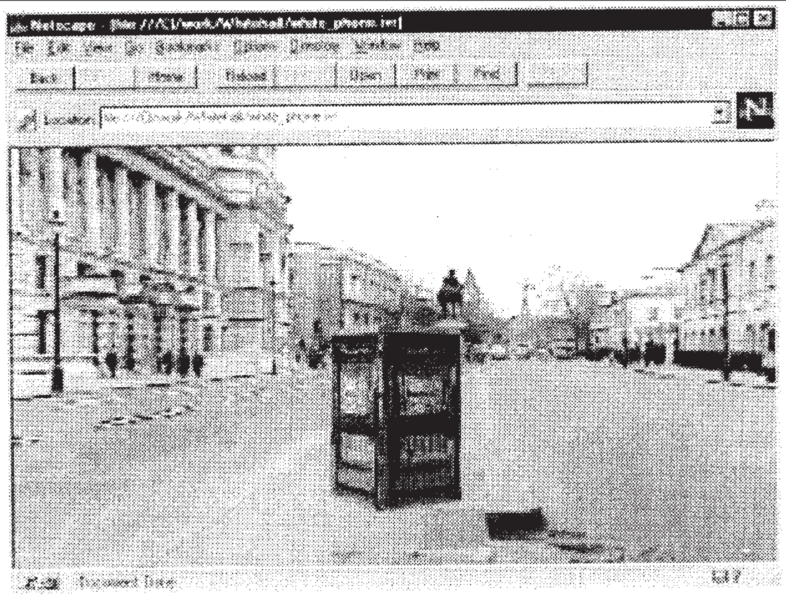

Figure 1: RealVR/VRML Object Placement (Horse Guards Parade, London)
SOURCE: `http://www.geog.ucl.ac.uk/casa/pub/viz_social_sciences/viz_paper.html`

with respect to dynamic planning issues (Bengtsson, Johansson, & Akselsson, 1997). As a consequence, computer simulation techniques might represent an accurate means of reviewing design guidelines, whether proposed or in place, and might offer the prospect of significantly opening up planning processes to public view that previously would have been restricted to professionals (Decker, 1994).

More important, planning has taken full advantage of advances in 3D graphics, VR, and the Web. The principal research on the Web in this area concerns virtual worlds and their role in visualizing urban forms within multiuser environments. Virtual worlds is a cheaper and less sophisticated variant of VR. It does not involve the creation of a 3D model of reality; instead, it uses linked images to produce a navigable scene. Furthermore, because it does not require specialized interface devices such as VR helmets, virtual worlds can be displayed on most modern personal computers.

A number of virtual world "showcases" have been made available on the Web,[7] and these are mainly related to relatively small-scale urban planning databases. An example of this is the 3D model of the City of Bath, United Kingdom, that has been developed to assess the visual impact of new planning applications (Day, 1992). The system uses hyperlinks to couple the 3D model to other related databases. Another example of the visualization and modeling of small-scale urban environments using Web-based VR techniques is the research disseminated by the Centre for Advanced Spatial Analysis as part of its Virtual Internet Design Arena initiative.[8] A virtual world has been constructed within a photorealistic representation of the real world. Users are able to pan around the virtual world in real time and are able to place a piece of street furniture, such as a telephone booth, anywhere within the scene (Figure 1). Such an interface, coupled with the accessibility of the Web, has opened up a new paradigm within urban design.

These projects also illustrate the importance of making GIS relevant to urban design. In fact, the evolution of Web GIS is seen as a critical component in the development of virtual cities (Carter, 1997). New visualization and VR technologies have made it possible to display pictures in a GIS, to run animation based on abstract maps as well as video clips and photorealistic VR panoramas, and to link such media to many of the data and functions of the GIS. For example, 3D visualization capabilities can be added to ArcView by using VRML and custom-written Avenue scripts. This has been explored in the Virtual Environments for Urban Environments project,[9] which has linked standard GIS and remote sensing packages to urban design packages in an exploration of the 3D modeling requirements of urban designers. The project has been developed around several U.K.-based case studies (Wolverhampton, Oxford, and Central London), demonstrating the range of detailed digital data that is becoming available to urban designers. A wide range of conventional spatial data has been assembled in the GIS along with multimedia and VR type data.

Therefore, the use of GIS and Web-based VR technologies has significant potential as visualization tools for adaptation in the planning and design arena. As these powerful software visualization tools become widely available on the Web, the potential exists to undertake networked urban planning and design, which might be particularly applicable to widening public consultation and participation in development projects.

Psychology

Like geography, psychology also is distinguished by an interdisciplinary overlap between the sciences and social sciences. Similarly, this overlap has been cogent in the apparent uptake of advanced computer visualization technologies including both VR and computer animation as well as more general multimedia tools. These technologies generally have been used within the experimental design stage of the research and have supplemented existing techniques as opposed to replacing them. For example, the use of VR technology has started to supplement conventional research methods such as in shape recognition and manipulation experiments that traditionally have used “physical” objects but now also use 3D interactive computer graphics (Ainge, 1996; Duesbury & Oneil, 1996). Another example is the use of computer-based multimedia in the study of “body image” dissatisfaction between men and women (Gustavson, Gustavson, & Gabaldon, 1993) and the use of computer simulations in the investigation of people’s perceptions from varying perspectives (Houston, Joiner, Uddo, Harper, & Stroll, 1995).

Multimedia and animation also are increasingly being used in psychological experiments. For example, computer images and animation have been used to test theories on perception and cognitive visualization. Accordingly, Stappers and Waller (1993) tested people’s ability to use the “free fall” of computer-animated objects as a scale referent in a 2D display, whereas Mayer and Sims (1994) used computer-generated animation to investigate the dual-coding theory of multimedia learning. Winer, Cottrell, Karefilaki, and Gregg (1996) used similar computer-animated techniques to investigate the beliefs among children and adults concerning the act of seeing. In numerous cases, these visualization techniques have improved on previous photographic and computational techniques (Benson & Perrett, 1993).

History

Although history is not strictly a social science, a number of interesting interdisciplinary examples of visualization using historical data have been reviewed, many of them on the Web. In circumstances similar to the visualization of spatial data, specialist techniques also have been developed for the visualization of temporal data. An example is the visualization

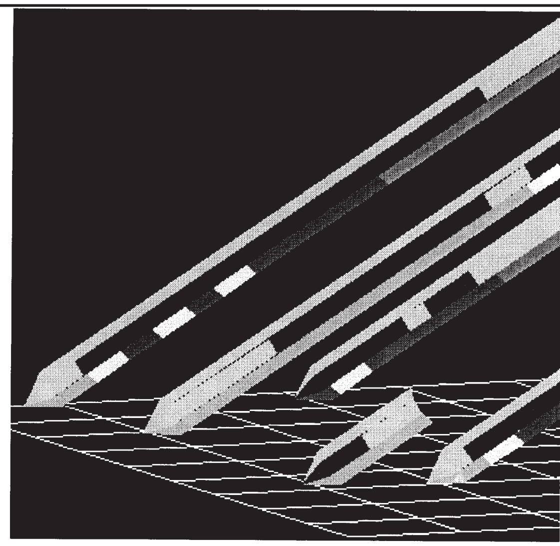

Figure 2: A Lexis Plot
SOURCE: `http://www.cas.lancs.ac.uk/alcd/visual/lexis_plot.html`

of historical data in 3D space using event histories as a case study.[10] An event history is a sequence of events and states, the associations between them, and their changes over time. The problem is to display a number of event histories in such a way that relationships between variables in any event history are readily viewed, as are trends in all the event histories. This has been achieved by using 3D Lexis pencils (Francis & Fuller, 1996) that represent changes of state throughout an individual's history by using changes in the color, shading, and height of the pencil. As the length of the "face" (i.e., one of the edges of the pencil), normally representing increasing time, is traversed, the changes of state of the variable associated with the face are denoted by changes in color. Multiple event histories can be displayed using a Lexis plot, which uses a Lexis pencil for each case history (Figure 2).

Other projects on the Web dedicated to exploring methods for visualizing event history data include the Lifeline Project.[11] The Lifeline Project examines how life histories can be visualized using existing techniques from time geography. Time geography developed sophisticated visualization techniques to represent individual life courses, but they have been used only rarely due to the great cost in time of producing them manually. A further problem is that by representing the experience of a group on paper, the graphic begins to run short of dimensions.

However, new visualization techniques are beginning to revitalize time geography through the use of new mapping and information retrieval techniques (Spiekermann & Wegener, 1994). By combining the traditional visualization techniques of time geography with hyperlink technology, it is possible to start from aggregated data and then move to more detailed individual data by clicking on specific data points. This is exemplified using the migration patterns of members of the Steam Engine Makers Society, a 19th-century English trade union.[12] The Steam Engine Makers' database contains a mass of information on the life histories of several thousand individual members. The visualization tool on the Web allows a simulation of a system that enables users to "drill down" from the union as a whole, through the collective experience of members in a selected town, to the histories of individual mem-

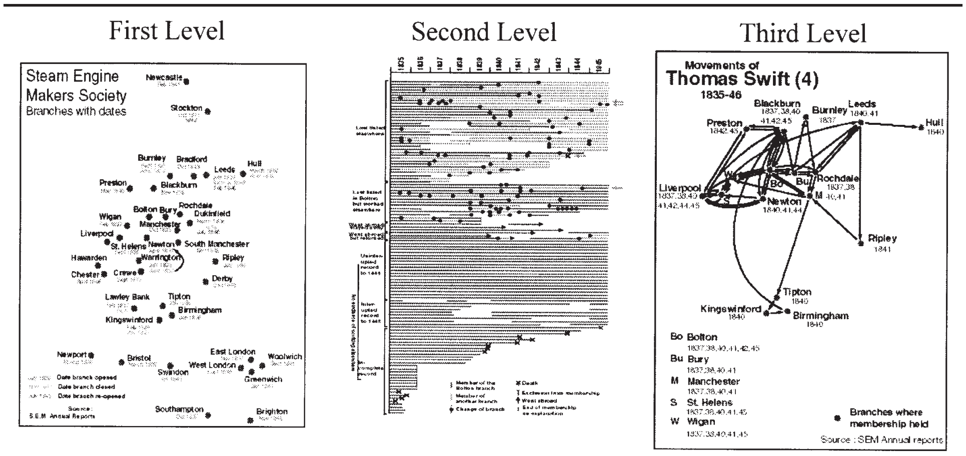

Figure 3: Visualizing the Life Course of the Steam Engine Makers Society
SOURCE: `http://www.geog.qmw.ac.uk/lifeline/sem_demo/sem_map.html`

bers (Figure 3). Although the preceding example concerns people's lives, the methods also are relevant to any entity that changes over two or more dimensions.

More details of the members in Bolton, and particularly their migration histories, can be found by clicking on either the name "Bolton" or the circle that marks the town's location. This lifeline diagram summarizes the subsequent migratory histories of everyone who belonged to the Bolton branch of the Steam Engine Makers in 1835. The length of the line shows how far they can be traced. It is possible to find out more by clicking on their lifeline. Thomas Swift joined Bolton in January 1834. He remained a member of Bolton until January 1842, when he moved to Liverpool. He returned from Liverpool to Bolton in January 1845 and remained a member through 1848-1849.

Politics, Economics, and Sociology

Despite being central to the social sciences, politics, economics, and sociology appear to use very little of the cutting-edge visualization technology under review. In political science research, for example, traditional graphical displays are commonplace (Gelman & King, 1993; Petrocik, 1996; Weisberg & Smith, 1993), but the use of new technologies such as VR, computer simulations, and multimedia remains unexplored. One of the few exceptions is the investigation of the political power of the media, and particularly television, in constructing and influencing global events (Luke & O'Tuathail, 1997). A similar situation occurs in economics, which traditionally uses graphical frameworks in the analysis and presentation of its research (Davidson & MacKinnon, 1998; Haneveld & Teunter, 1998). Nevertheless, there are indications that the advances in statistical computer graphics gradually are being used as a means of investigating the increasing richness of econometric data (Jenkins & Lambert, 1997; Koschat & Swayne, 1996; Unwin, 1996). Notable exceptions to these standard graphical outputs include the visual representation of the structures of world trade among 28 Organization for Economic Development and Cooperation countries between 1981 and 1992 (Figure 4).[13] The size of the links represents the volume of trade between any two countries, whereas colors give the regional membership in different trade organizations.

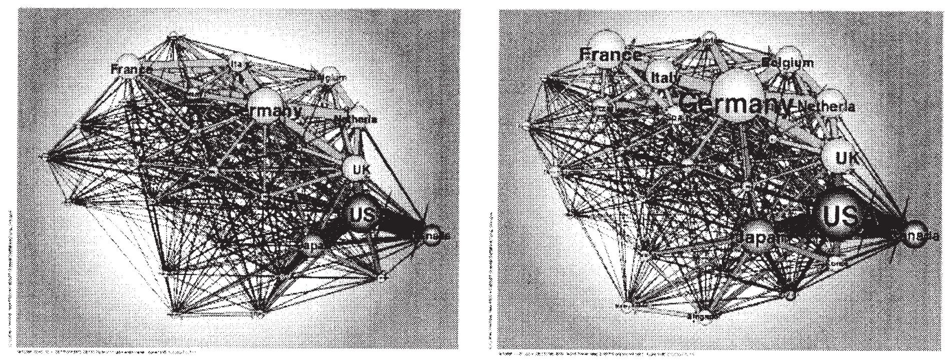

Figure 4: Structures of World Trade
SOURCE: `http://www.mpi-fg-koeln.mpg.de/~lk/netvis/trade/worldtrade.html`

Sociology, in comparison to politics and economics, appears to have made greater use of computer visualization. The study by Feinberg and Johnson (1995), for example, uses computer simulations to model the response to a fire alarm, graphically presenting the status of individuals and couples in a room as they initiated the evacuation. Another innovative use of computer graphics in sociology is the visualization of social networks (Schwendinger & Schwendinger, 1997). The most comprehensive examples of this type of research can be found at the network visualization Web site.[14] The aim of this work is to develop aesthetically pleasing computer visualizations of what usually are regarded as complex phenomena. Examples include visualizing visitors' paths at Duisburg Zoo in Germany (Figure 5), which leads to interesting insights into visitor behavior. Generally, however, visualization in sociological research tends to be represented by traditional graphical displays using standard software packages such as S-Plus (Schulman, Campbell, & Kostello, 1995), Mathematica (Stine, 1995), and Lisp-Stat (Tierney, 1995).

Social Statistics

Graphical methods in statistics have a long, if debated, history. Although they appear to be commonplace adjuncts to most methods of statistical analysis, Anscombe (1973) argues that more should be made of graphs in statistics, whereas Fienberg (1979) reprimands statistics for its lack of graphs and graphical experiments. For example, although graphical methods for continuous data analysis are well developed, similar methods for categorical data still are in their infancy. This situation is slowly being addressed with work such as that located on the Michael Friendly Web site.[15] There, numerous examples of graphical methods for categorical data can be found.

In terms of complex visualization techniques, however, one of the leading uses in social statistics has been in exploratory data analysis (EDA). EDA is an inductive approach to statistical analysis and can be extremely useful for investigating diverse relationships within data sets. This is becoming increasingly more essential as the typical social science data set becomes more complex. Converting these data into useful, meaningful information can be extremely difficult and haphazard (Ondrechen, 1997). Visualization increasingly is being used as a method to overcome these difficulties, with recent software developments provid-

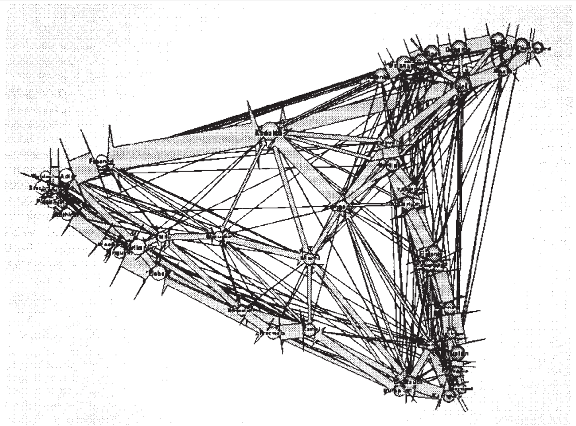

Figure 5: Visitor Paths at Duisburg Zoo
SOURCE: http://www.mpi-fg-koeln.mpg.de/~lk/netvis/zoo2.html

ing new tools for visualizing multivariate data (Colet & Aaronson, 1995). For example, Levin and Mitra (1994) describe a curve-fitting visualization program designed to generate initial parameter estimates for nonlinear equations, illustrating the process by modeling mortality data. Such advanced visualization techniques can help to remove some of the inevitable trial-and-error process involved in solving such equations.

A number of Web sites exist that promote statistical software packages that explore data in a highly visual way such as the "Research Issues in Intelligent Data Visualization for Exploration and Communication" Web site.[16] Another example is the MANET (Missing Are Now Equally Treated) software Web site.[17] This software has been specifically developed to provide highly visible facilities for the graphical exploration of multivariate data whose structure may prevent the use of analytic methods, particularly data sets containing missing values. Although the package is best used with nonspatial data, spatial data can be explored by the use of linked maps. This type of dynamic mapping represents one of the most innovative uses of visualization in social statistics. Statistical maps have long served as the dominant technique for visualizing spatial statistics, and statistical programming environments such as S-Plus and XLIS-STAT increasingly have been linked to GIS to allow the visualization, exploration, and modeling of geographically referenced data (Gatrell & Bailey, 1996; Haining, Ma, & Wise, 1996).

There now are a growing number of software environments available that allow such spatial statistical analysis. Project Argus at Leicester University[18] currently is developing a series of tools that promote this approach. At its crux is the Cartographic Data Visualiser (CDV) developed by Dykes (1996). This is principally a map visualization toolkit with relatively modest computational and statistical capability (Wise, Haining, & Signoretta, 1998). The bulk of CDV's facilities consist of graphical tools for viewing data including a wide range of mapping options and some traditional graphs (Figure 6).

Hence, using advanced visualization techniques, EDA can act as a means of filtering extremely complex quantitative relationships among data into relatively simple, manipulatable graphical displays. This has allowed users to interact with their databases in real time, dramatically increasing the amount of information they can extract. However, although visualization can provide a simple yet comprehensive overview of a large data set, visualization techniques often fail to capture the essence of data trends. In addition, the ability to easily

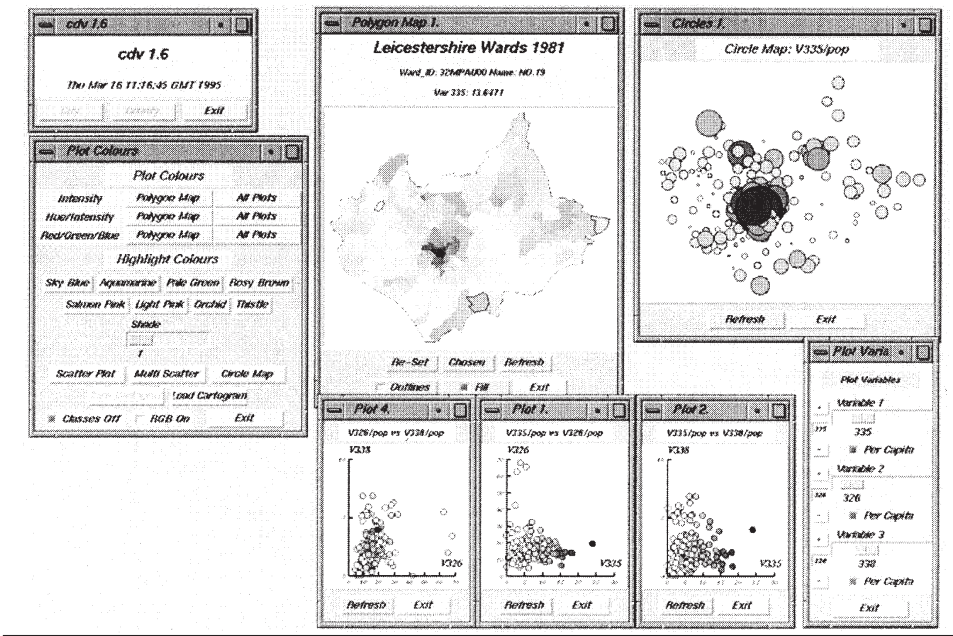

Figure 6: Cartographic Visualization for Enumerated Data
SOURCE: `http://midas.ac.uk/argus/research/cartoviz/model.html`

query any part of the data set frequently results in “information overload” and the need, often felt by researchers, to analyze their entire data sets, which can be time-consuming and can result in diminishing returns (Bormel & Ferguson, 1994).

CONCLUSION

This review has attempted to illustrate the wealth of work currently being conducted in visualization in the social sciences. Such a review is timely given that it has been a decade since Upson et al. (1989) inquired whether scientific visualization was appropriate to the needs of the social sciences. Accordingly, the review concentrated on the use of four key visualization technologies that have evolved since 1988—computer graphics, multimedia, the World Wide Web, and VR—and considered particular social science subjects in turn. As a result, the review highlighted several features concerning the current use of visualization in the social sciences.

First, there is no central core to this visualization research; thus, it is very difficult to define key research areas. Most of the research is being conducted largely in ignorance of much other work that either has been completed or currently is being undertaken.

Second, visualization in the social sciences is dominated by those subjects with the closest links to the natural sciences and that work within a tradition of graphical output. A pattern of diffusion from science to social science is clear. Consequently, the majority of visualization research is found in geography, planning, and psychology, with the fewest examples in politics, economics, and sociology. The dominance of geography can be seen within the historical development of visualization given its cartographic origins. However, this dominance is less than it was in previous decades, as geographers move away from their traditional cartographic routes and as other subject areas become more familiar and at ease with the use of graphical and visualization techniques.

Third, the Web is quickly becoming the dominant form of research dissemination in this area as paper journals fail to evolve, even with respect to the affordable production of simple 2D color illustrations. Furthermore, the article demonstrated the Web's ability to exhibit dynamic illustrations, including interactive displays, that are beyond traditional paper journals. Currently, the use of the Web by social scientists is somewhat disappointing, particularly when compared to its use by the science community. However, we can expect this to improve as the Web slowly becomes an accepted medium for research and publication within the social science community.

We can expect visualization in the social sciences to continue to grow as a research activity beyond the original spurt of activity following the McCormick et al. (1987) report. However, this growth is at present relatively uncoordinated because the activity does not fall easily within the realm of any particular discipline and because the publication of results in the traditional form is very problematic. It is expected that this situation will continue because there is no discipline likely to dominate visualization in the future and to provide a core set of methodologies, whereas there still is much work to be diffused from science. Such a situation contrasts with Upson et al.'s (1989) comments of a general commonality already existing among the visual needs of the "numerically intensive" science community. Without greater coordination, the future of visualization in the social sciences is likely to be much like in the past but more diffuse and more ephemeral. This coordination is likely to arise only from direct academic funding for exemplar projects and research centers.

NOTES

1. See `http://allanon.gmd.de/and/chi97/gla1.html`
2. See `http://webspace.sgi.com/moving-worlds/`
3. See `http://www.almaden.ibm.com/dx/DXUsers.html`
4. See `http://www.geog.buffalo.edu/~jkrygier/krygier_html/research.html`
5. See `http://www.geog.qmw.ac.uk/gbhgis/index.html`
6. See `http://www.siggraph.org/~rhyne/carto/`
7. See `http://giswww.kingston.ac.uk/vworlds.html`
8. See `http://www.geog.ucl.ac.uk/casa/pub/viz_social_sciences/viz_paper.html`
9. See `http://www.casa/ucl.ac.uk/venue/venue.html`
10. See `http://www.cas.lancs.ac.uk/alcd/visual/index.html`
11. See `http://www.geog.qmw.ac.uk/gbhgis/index.html`
12. See `http://www.geog.qmw.ac.uk/gbhgis/index.html`
13. See `http://www.mpi-fg-koeln.mpg.de/~lk/netvis/socmorph.html`
14. See `http://www.mpi-fg-koeln.mpg.de/~lk/netvis/socmorph.html`
15. See `http://www.math.yorku.ca/SCS/friendly.html`
16. See `http://allanon.gmd.de/and/chi97/gla1.html`
17. See `http://www1.math.uni-augsburg.de/manet/`
18. See `http://midas.ac.uk/argus/software/cartoviz/`

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