Review of Visualization in the Social Sciences: A State of the Art Survey and Report

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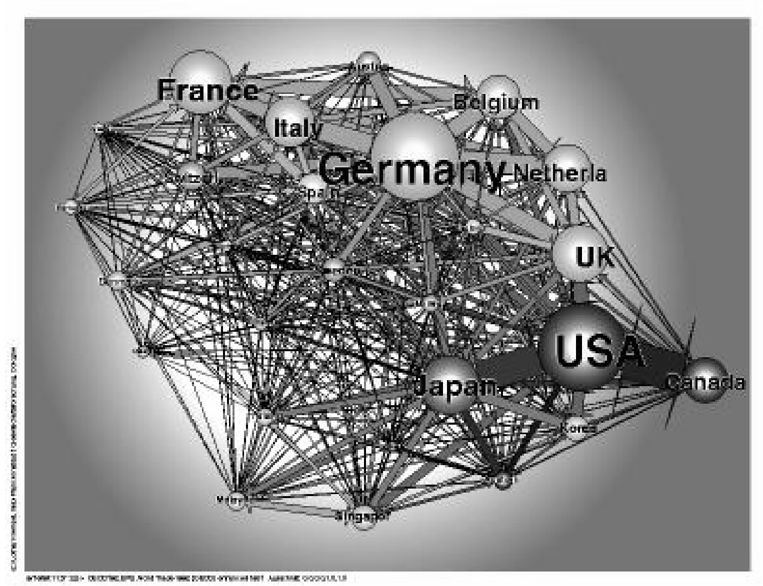

Report for the Advisory Group On Computer Graphics

Final Report 27th July 1998

Review of Visualization in the Social Sciences: A State of the Art Survey and Report

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Executive Summary:

This illustrated report on scientific visualization in the social sciences was prepared during the spring of 1998. It contains a large review of the literature and internet sources on visualization, prefaced by an overview report on the general issues this survey raises, and concludes with a summary of the key contemporary areas of activity in visualization in the social sciences. The report is made up three parts:

1. The overview report discusses the extent to which different forms of visualization are prevalent in different social sciences and how this appears to be changing over time. The overview examines the extent to which new visual paradigms are emerging in the social sciences. It concludes with an attempt to identify patterns of key initiatives, research projects and people currently involved in visualization in social science. However, those activities not well referenced through the internet or in suitably key-worded papers cannot be ensured of inclusion.

2. The detailed contemporary review includes examples from political science, psychology, statistical graphics, econometric modelling, multimedia in the social sciences, computer mapping, GIS and animation. It is illustrated with illustrations drawn from material on the World Wide Web - and fully referenced.

3. A large bibliography of examples of work published on visualization in the social sciences is also included. This was built from an existing bibliography of 1,500 visualization references to work published in the mid 1990s using various publications databases and material from postgraduate theses on visualization that have been recently submitted. It currently contains 2531 references and we estimate that the web sites referenced since 1991 add a further 1028 “paper equivalent” references.

The Staff involved:

Dr Daniel Dorling was responsible for ensuring the report was delivered on time and for most of the work on the overview report and its conclusions. His 1991 PhD bibliography on visualization in the social sciences formed the basis for the updated bibliography. Daniel is a lecturer at the School of Geographical Sciences at Bristol and teaches undergraduate courses on visualization and human cartography. He has been a member of the ICA international committee on cartography and visualization and was previously a fellow of the Joseph Rowntree Foundation and then the British Academy. His relevant publications include:

Dorling D. (1992) Visualizing people in space and time, Environment and Planning B, Vol.19, pp.613-637.

Dorling D. (1992) Stretching space and splicing time: from cartographic animation to interactive visualization, Cartography and Geographical Information Systems, Vol.19, No.4, pp.215-227, 267-270.

Dorling D. and Openshaw S. (1992) Using computer animation to visualize spacetime patterns, Environment and Planning B, Vol.19, pp.639-650.

Dorling D. (1993) Map design for census mapping, The Cartographic Journal, Vol.30, No.2, pp.167-183.

Dorling D. (1994) Cartograms for visualizing human geography, in D. Unwin and H. Hearnshaw (eds), Visualization and GIS, London: Belhaven Press. pp.85-102.

Dorling, D. (1994) Bringing elections back to life, Geographical Magazine, Vol.66, No.12, pp.20-21.

Dorling D. (1995) The visualization of local urban change across Britain, Environment and Planning B, 22., pp.269-290.

Dorling D. (1995) A New Social Atlas of Britain, London: John Wiley and Sons.

Dorling D. (1995) Visualizing the 1991 census, in S. Openshaw (ed), A Census User's Handbook, London: Longmans, pp.167-213.

Dorling D. (1995) Visualizing changing social structure from a census, Environment and Planning A, vol.27, no.2., pp.353-378.

Dorling D., Johnston R.J. and Pattie C.J. (1996), Representing, exploring and analysing electoral change using triangular graphs, Environment and Planning A, Vol.28, pp.979-998.

Dorling, D. and Fairbairn D. (1997) Mapping Ways of Representing the World, Longman (first book in the Explorations in Human Geography series)

Dorling D. (1996) Area cartograms: their use and creation, Concepts and Techniques in Modern Geography series no. 59, University of East Anglia: Environmental Publications.

Dorling, D., (1997), European micro-data availability: the special case of Britain, Chapter 6 in Geographic Information Research: Bridging the Atlantic, M.Craglia and H.Coucelis (eds), London: Taylor and Francis., pp.157-202.

Dorling, D. (1997) Mapping the UK: maps and spatial data for the 21st century, Mapping Awarness, 11, 9, 36.

Dorling, D. (1998) Mapping disease patterns, Chapter of the Encyclopedia of Biostatistics, Chichester: Wiley,

Dorling, D. and Simpson, S. (1998) Statistics in Society, Edited Collection of over forty chapters, forthcoming, London: Arnold.

Dorling, D., (1998) Human Geography - when it is good to map, Environment and Planning A, 30, 277-288.

Dr Scott Orford is the departmental computer officer, and his duties involve the installation and maintenance of software on the department's computers. He has knowledge and experience of many visualization software packages used within both the social and physical sciences, and has assisted in various departmental research projects. He has recently completed his Ph.D. (passed December 1997) in which he used state of the art Geographic Information Systems software to store, analyse and visualize his results. Scott also teaches undergraduate and postgraduate computing courses within the Geography Department at Bristol.

Richard Harris is a PhD student exploring the synthesis of Lifestyle datasets with the 1991 Census, and the subsequent visualisation of this data to identify niche (within-ED) areas of deprivation. His PhD is entitled 'Geodemographics: Information for local policy?', his advisor being Professor Paul Longley. Richard gained his first degree at Bristol geography department and his Masters in Society and Space in geography and at Bristol's School of Policy Studies. As well as being familiar with ARC/INFO, ARC View and ARC macro Language, Richard has demonstrated IDRISI GIS practicals for a couple of years.

Overview Report

Introduction

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 et al., 1987) in the same spirit as the McCormick et al. (1987) classic report. We see social sciences as being those academic subjects most usually assigned to social science faculties in British universities: economics, geography, politics and sociology; but for this review we also include planning, psychology, history and social statistics.

The need for a review of visualization in the social sciences was first made almost 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 the social sciences. Will users from these fields find this environment appropriate to their needs?" (Upson et al., 1989)

It is this question that this review seeks to answer.

The History of Visualization in the Social Sciences

The current use of the term "visualization" in social science was first made in 1987 with the publication of the report on 'scientific visualization' (McCormick et al., 1987). This report had its origins in scientific work that began in the 1960s studying chaotic systems. Scientists then found that a fuller understanding could only be made of certain processes by visualizing the results of experiments (see for instance Mandelbrot, 1983). The visualization of chaotic systems in the social sciences has following this route, perhaps most directly in the work of Batty and Longley (1994).

Social Science has also had an important role to play in understanding why visualization has become popular at various points in time. Recently, the 1987 revival may have had much to do with the declining academic support of American centres of super-computing, which needed a new product to market after the simulation of atomic explosions became less vital with the ending of the cold war (Frenkel, 1988). Frenkel argues that American paranoia over the high quality of Japanese produced micro-processors also led to an increased emphasis in software over hardware by the end of the 1980s and the simple improvements seen in graphic technologies may have made an increased interest in visualization inevitable anyway.

The history of visualization in science in general, and the social sciences in particular, is a long one and we cannot understand the present situation well if we do not couch current developments in their historical context. One of the most useful reviews of the history of visualization was conducted by Beniger and Robyn (1978) who showed that the use of graphics had gone in and out of academic fashion in cycles over a long period of time. For instance they note that Descartes himself was convinced that "imagination of visualization, and in particular the use of diagrams, has a crucial part to play in scientific investigation.". Faraday is also a good example of an early visualizer.

This review considers the history of visualization in the social sciences by providing an illustrated bibliography covering the latest period of rising interest in visualization from 1960 to 1998, with some examples of previous work of interest. The bibliography contains references to over 2500 articles and was constructed as the result of an exhaustive inter-library loan search in 1991, updated to 1998 by the use of digital databases of articles and the addition of web pages from 1994. The general trend of publication is of a slow exponential rise, with peaks in 1976 (following advances in computer graphic devices in the early 1970s) and in 1990 (following the publication of the original visualization report in 1987). Academic paper publication has been stable since then, but if we include the effect of papers now being made available on the web the exponential rise can be seen to continue.

Decade	Academic Papers	Web site 'papers'
1900s	1	0
1910s	3	0
1920s	3	0
1930s	6	0
1940s	6	0
1950s	25	0
1960s	83	0
1970s	344	0
1980s	1083	0
1990s (incomplete)	930	1028
Twentieth century:	**2484**	**1028**

At the end of each decade from the 1970s onwards we have produced a publication count of the most prolific authors in that decade. This is obviously an extremely rough indicator of output and influence, but is generally indicative of the kind of work being produce at various points in time and does produce some surprising results.

It also shows the dominance of geographers within visualization in the social sciences, which as we explain later is not particularly surprising given the cartographic origins of that discipline. The dominance of geography can be seen in the historical development of visualization. The first decade being considered here, the 1970s, was dominated by many researchers who would, at that time, have described their work as cartography: Waldo Tobler, Judy Olson, Mark Monmonier and George Jenks head the list and all hailed from America. Jean-Claude Muller and David Rhind are the only non-Americans who feature. By the 1980s Fraser Taylor and Alan MacEachren had entered the top three, so the dominance of cartography in terms of production continued. The 1990s saw a rise in output from Europeans: Peter Fisher, Menno-jan Kraak, Stan Openshaw, David Unwin and Mike Batty entered the list. So the dominance of geography continued but the cartographic emphasis changed to the visualization of computation analysis.

We hope that this visualization bibliography will be a useful tool to future researchers, allowing them to see what has gone before and how much which is currently thought of as novel is not quite as new as we would like to think.

Distribution Amongst the Different Social Sciences

The review of visualization in the social sciences in the 1990s provides the main body of evidence for this report. Because of its growing importance, we have particularly concentrated on research findings that are available on the web, but have also used the BIDS bibliographic system to check for major omissions.

The review shows that geography continues to dominate visualization in the social sciences into the 1990s and onto the web. Given the distribution of publications in the 1970s and 1980s referred to earlier this can be seen as simply an extension of earlier trends. However, the dominance is less than it was before 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.

Our review begins with a short overview of the use of key visualization technologies in use in the social sciences: advanced computer graphics, multimedia, the World Wide Web and virtual reality; and then moves on to consider particular subjects in turn, in rough order of output. We begin with geography and attempt to produce as brief an overview of work in this discipline as possible, but note the advantages that geography has as a "mixed" social science / science subject in terms of gaining access to computer literate researchers. We next consider planning as there are many similarities with geography in terms of the visualization research currently being conducted in this discipline with similar reasons. Our third subject for consideration is psychology. We were initially surprised to find so many applications of visualization technologies until we realised that psychology too is a split social science / science subject and so too has the advantages in terms of using computers of a generally more numerate and computer literate research base than many other subjects. The fourth subject area in which we found the most use of visualization was historical research and, in particular economic history. Again this is initially surprising until the links with science are considered.

We found our fewest examples of visualization research in politics, economics and sociology and explain this through a combination of traditional resistance to graphic techniques mixed with a relatively lower level of computer literacy in these subjects. Economists may use computers but they are more interested in economic theory and that subject, through its reward structure, does not encourage a heterogeneity of research methods. Finally we considered work in the field of social statistics, a relative small sub discipline, but one which currently makes much use of visualization techniques. We end our review by considering, again in overview work in data exploration and visualization in general, visualization in teaching and learning in the social sciences, the availability of software and its implications, and weblinks and gateways. We append a link of useful web links as a resource for other researchers.

Conclusion

Our review has taught us many things about visualization in the social sciences and we hope that its results will also be of more general interest and will change more widely held views. Firstly, there is no central core to this research and it is thus very difficult to define key research groups and centres, hence the need for organisations such as ACOCG, and interdisciplinary meetings within the social sciences. Consequently, most of the research is conducted largely in ignorance of much other work which either has already been done or which is currently being undertaken. Secondly, visualization research in the social sciences is dominated by subjects with the closest links to the natural sciences or/and with a tradition in graphical output. A pattern of diffusion from science to social science is clear. Thirdly the World Wide Web is quickly becoming the dominant form of research dissemination as paper journals fail to evolve, charging exorbitant prices even for the production of simple two dimensional colour illustrations. We can expect all these trends to continue as there is no single discipline likely to dominate visualization in the future and so provide a core set of methodologies.

Our original specification asked for key research groups to be identified, but as we have stated above these are very difficult to define, given the diffuse nature of work in visualization in the social sciences. If we were to identify specific groups these would include: project ARGUS from Leicester, the SigGraph ACM, the University College Research on visualization in planning in London, the MIT Urban Studies and Planning Department, Alan Maceachren's centre in Penn State, and the work on visualization sociological networks in Germany. But overall it would be unfair to many other groups not to list them and to list all groups would not produce a key list!

Visualization in the social sciences continues to grow as a research activity beyond the original spurt of activity following the 1987 report. However this growth is relatively uncoordinated. The activity does not fall easily within the remit of any particular discipline and the publication of results in the traditional form is very problematic. This review has attempted to illustrate the wealth of work currently being conducted into visualization in the social sciences. It has provided a reference to the historical background through the creation of a very large bibliography of past papers and a long list of current web sites providing examples of different techniques and access to many different methods. Without greater coordination the future of visualization in the social sciences is likely to be much like the past, but more diffuse and more ephemeral. This coordination is likely to arise only from direct funding for exemplar projects and centres from the research funding councils.

Visualization in the Social Sciences

"Visualization of Information and Data: Where Are We Now and Where Do We Go From Here?"

The title is taken from name of a workshop held last year in Paris [57], and it essentially summarises the aim of part of this report. According to the workshop, information visualization is crucial for the success of the so called 'information revolution'. Visualization in computer science terms involves both the conversion of 'abstract' data into 'concrete' visual representations and the creation of user interfaces to support tasks such as searching, data mining and exploratory data analysis, analysis and modelling of data, representation and display of data and teaching and learning aids.

'Recent' Developments in Visualization

There has been a long history of visualization in the social sciences (e.g. John Snow's maps of the 1854 cholera outbreak in Soho and Charles Booth's maps of poverty in London 1889). However, changes in visualization technology in the last few decades are profoundly affecting the way in which the social sciences are researched, and in which studies are communicated (Olson, 1997). These changes have been largely initiated by the rapid development of computer technology since the 1980s, resulting in the availability of powerful and affordable computing. The review will essentially be concerned with developments in computer visualization that have occurred during the 1990s. With respect to the social sciences, four distinct visualisation technologies have evolved: advanced computer graphics, multimedia, the World Wide Web and Virtual Reality.

Computer Graphics

According to an estimate by Jones & 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 output with very little effort (Permaloff & Garfton, 1996). Increasingly, these visual techniques are including sophisticated computer graphics in an attempt to either visualise complexity in the data, or enhance more traditional graphical displays. However, although sophisticated displays, such as 3D graphs, may visually be more pleasing, in terms of extracting information simple 2D graphs have been shown to perform better with respect to accuracy and ease (Fisher et al., 1997). Therefore, it may be argued that developments in visualization are not necessarily advantageous.

The most exciting innovation in computer graphics in recent years has been computer animation, from which VR developed. Computer animation in social science research is not a recent phenomenon. At the beginning of the 1970s, Tobler (1970) describes a ‘computer movie’ he and his research student developed to show a simulation of urban growth in the Detroit region. However, 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 visualising temporal changes, such as with respect to space-time data (e.g. Dorling & Openshaw, 1992), and this may have important implications for research in the social sciences. Computer animation can also be used as an approach to exploratory data analysis, which may assist the researcher in understanding the effect of uncertainty, particularly in spatial applications (Ehlschaeger et al., 1997)

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 the user control over the order in which to see or hear this information. In its current use, multimedia implies the use of a computer and almost always implies interactivity as well. While multimedia opens the doors to discover and communicate, it also raises issues such as cost, control, effectiveness, accessibility and potential negative intellectual outcomes. Lately, researchers have also started using ‘texture’ for data visualization, the rationale behind this being to exploit the sensitivity of the human visual system to texture in order to overcome the limitations inherent in the display of multidimensional data (Rao & Lohse, 1996).

The issue of sound in the context of visualization may at first seem surprising. There is, however, evidence to support the claim that sound is a viable means of representing and communicating information and can serve as a valuable addition to visual displays [12].

World Wide Web

Figure 1

The World Wide Web (or Web) is still 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 can now be used, or at least demonstrated via the Web. Examples of graphical applications range from computer games and animation, through to advanced Geographic Information Systems (GIS), virtual reality, 3D graphics, and sound. All these applications are simply not available in traditional paper based publication mediums. Moreover, the Web offers accessibility to downloadable software and electronic data stores, which in many instances are available free of charge.

Currently, the use of the Web as a medium for the dissemination of social science visualization research is somewhat obscure. This is due in part to the eclectic and unstructured nature of the Web, and also because the Web is still an unexplored medium with respect to the majority of researches in the social sciences, particularly when compared to its use by the scientific community. At first glance, the Web contains a wealth of information relating to ‘visualization’. This includes both the research and development of visualization tools and technologies and also the application of these tools and technologies to specific research problems. However, upon detailed inspection, it becomes quickly apparent that the physical and natural sciences dominate this research, with the social sciences being significantly under-represented. Exhaustive use of various standard search engines such as Alta-Vista, Excite, Lycos and InfoSeek on key words and phrases produces surprising little evidence of websites dedicated to visualization in the social sciences. This supports Carver (1997) findings that despite the discussion surrounding the potential use of the Web as a vehicle for social science research, very little has materialised to date.

This relative dearth may partly be explained by the fact that the majority of visualization websites tend to be concerned with the on-going research and development of visualization tools and software (E.g. [28],[45],[64]). Due to historic links with engineering, medicine and computer science, visualization research on the Web has traditionally fallen within the domain of ‘science’, and thus the comparable lack of social science visualization websites. However, this is not to say that these research and development websites are of no value. They are useful in as much as they provide a taster of what is now available in terms of cutting edge visualization technologies. Essentially, these websites represent ‘show cases’ of what the software is capable of, usually with the opportunity to download the software with accompanying tutorials and user manuals. Nevertheless, 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 websites that do exist tend to originate from social science disciplines closely affiliated with the physical sciences, notably Geography.

Virtual Reality

It has been argued by Newby (1993) that Virtual Reality (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 than any other innovation in recent history. The roots of VR may be traced to the early 1960s in such diverse areas as flight simulation and art, although now it would seem that the term has become synonymous with most pseudo-3D computer presentation (Wan & Monwillians, 1996). VR is a growing feature on the Web, and appears to be the dominant visualization technology under research and development, crossing both the science and social science divide. The Web's ability to provide psuedo-3D graphics and 3D worlds has been made possible through the development of Virtual Reality Modelling 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 Carver (1997) sees the future of this technology as very promising, having great potential for use by the social science research community.

The main thrust of VR research in the social sciences has occurred within the disciplines of geography, planning and psychology, principally through the marrying of GIS and urban design. The potential of visualization in the planning and design of the built environment appears to be very significant. The ability to model the built environment, and interact within it over the Web, represents a paradigm shift within the planning and design process, one which helps to communicate ideas and developments to the public at large [26].

Examples of Recent Visualization Research in the Social Sciences

This part of the report will review the recent use of visualisation in the social sciences. Specifically, the review has concentrated upon the use of visualisation in research, although other uses, such as in teaching and learning, have also been surveyed. The survey has employed two principal methods. Firstly, an extensive Web search was undertaken to ascertain the degree to which social science disciplines are using the Web as a medium to disseminate visualisation research. Secondly, a comprehensive review of several bibliographic databases, such as BIDS (Bath Information Data System), OPAC97 and the British Library's Blaise service was undertaken as a means of acquiring information on the most recent published visualisation research in the social sciences. Information from these two sources was then combined, using the different disciplines within social science as a means of structuring the report.

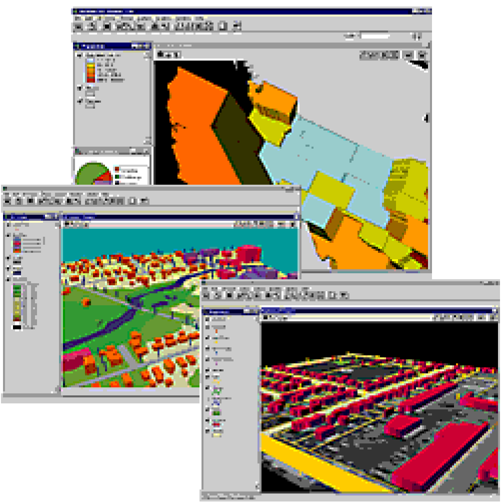
Geography

Of all the social science disciplines, 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. Secondly, geography is relatively unique amongst 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 visualise 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 this represents the dominant trend in visualization research and development within the social sciences. Consequently, geographic visualization methods tend to be more generally appreciated within the social sciences, and as a result, will not be dwelt upon in great detail in this review.

The principal area of development of visualization tools and technologies has been within the domain of GIS, specifically integrating GIS with different software packages and environments. Traditional uses of GIS in this field have been to visualise the spatial aspect of the data, particularly with respect to error visualization (e.g. Cockings et al. 1997), and spatial associations (e.g. Anselin et al., 1996). When integrated with advanced visualization tools however, GIS can become very effective in the analysis and presentation of complex data in a wide range of disciplines such as planning and resource management (e.g. Conners, 1996; Bishop & Karadaglis, 1997; 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 instance, SimLand (Wu, 1998) is a prototype model to simulate land use conversion based on cellular automata (CA) and multi-criteria evaluation (MCE) modules, written in C and tightly integrated with ARC/INFO GIS. It uses a graphical user interface (GUI) 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 modelling software is the Clarke et al (1997) simulation of urban growth in San Francisco.

Figure 2



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 modelling and VR are now at the point where they might be embodied in GIS (Faust, 1995). Faust argues that a true 3D GIS must enable the following functions:- a realistic representation of the third dimension in the data and in visualization, free movement of the user within the three dimensional representation, normal GIS functions, such as query and overlay, but within 3D data space, and visibility functions such as line of sight estimation. Currently, the Environmental Systems Research Institute (ESRI) is developing the 3D Analyst extension for ArcView, that will enables users to create, analyse and display surface data (Figure 2). However, the principal research into visualising and analysing 3D spatial data in a GIS has been with respect to VR techniques on the Web. These are discussed in detail in the planning section.

Parallel to these visualization developments in GIS has been a radical transformation within cartography (Grelot, 1994; Kraak et al, 1995; Krygier, 1995). Consequently, a significant amount of ‘cutting edge’ GIS visualization research and development on the Web is actually computerised cartography, recently re-labelled as scientific visualization. Scientific visualization is a growing area of computing with the underlying philosophy that displaying visual representations of data assists researchers in generating ideas and hypotheses about the data (Fisher et al., 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 programmes do not regard the map as a real-time tool for analysing data, or as an interface to access the underlying information. Cartographic visualization systems, however, can provide intelligent assistance to GIS users by allowing data mining and/or exploratory data analysis. This is examined in more detail in social statistics section of the report.

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 instance, cartograms (Dorling, 1995) are increasingly being recognised as a major solution to many spatial visualization problems of human societies. The gross misrepresentation of many 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 are now being used in the visualization of high-resolution spatial social structures and in the mapping of long-run historic changes in society [8].

The importance of GIS and cartographic visualization on the Web is exemplified by The Cartographic Project [14]. This is a three year special project started last year (1997) which has been commissioned by the Association of Computing Machinery (ACM) Special Interest Group on Computer Graphics (SIGGRAPH)[1] in collaboration with the International Cartographic Associations (ICA) Commission on Visualization. The project is studying how viewpoints and techniques from the computer graphics community can be effectively applied to cartographic and spatial data sets, and enhance the development of their visualization research. Part of the project includes a survey investigating the use of cartographic and geographic visualization on the Web between January and February 1997, providing a snapshot of recent computer graphic and Web tool usage. 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 a science background, such as physical geography and remote sensing. Social science research was 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 bought visualization technology within reach of most planning departments and urban design consultants (Wiggins & Ferreira, 1992). In a study by Levy (1995), the role of computer aided design (CAD) 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

[1] SIGGRAPH is an interdisciplinary community interested in research, technology, and applications in computer graphics and interactive techniques whose scope is to promote the acquisition and exchange

under consideration. Furthermore, a study by Bengtsson et al. (1996) indicated that computer-supported modelling and visualization eventually may 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, when concerning dynamic planning issues (Bengtsson et al., 1997). As a consequence, computer simulation techniques may represent an accurate means of reviewing design guidelines, whether proposed or in place, and offers the prospect of significantly opening up planning processes to public view which would have previously been restricted to professionals (Decker, 1994)

More importantly, planning has taken full advantage of advances in 3D graphics, VR and the Web. The principle research on the Web in this area concerns Virtual Worlds, and their role in visualising urban forms within multi-user environments. Virtual Worlds is a cheaper and less sophisticated variant of VR. It does not involve the creation of a 3D model of reality within which the viewer is 'immersed', but instead uses linked images to produce a 'through the window' navigable scene. The use of perspectives and user navigation allows an adequate impression of the spatial extent and a virtual environment in as much detail as it is possible to produce. Furthermore, since it does not require specialised interface devices, such as VR helmets, Virtual Worlds can be displayed on most modern PCs.

Figure 3

A number of Virtual World 'show cases' have been made available on the Web [26, 73], 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, which has been developed to assess the visual impact of new planning applications (Day, 1992). The system

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of information and opinion on the theory, design, implementation and application of computer-generated graphics and interactive techniques to facilitate communications and understanding uses hyperlinks to couple the 3D model to other related databases. Another example of the visualization and modelling of small scale urban environments using Web based VR techniques is the current research undertaken in the Centre for Advanced Spatial Analysis (CASA) as part of their Virtual Internet Design Arena (ViDA) initiative [18]. A virtual world has been constructed within a photorealistic representation of the real world. The user is able to pan around the virtual world in real time, is able to place a piece of street furniture, such as a telephone box, anywhere within the scene (Figure 3).

Within a North American context, similar research can be found on the MIT Department of Urban Studies and Planning website [73]. There, several examples of how emerging information and web technologies can improve the processing and communication of planning-related information in metropolitan planning organisations are presented. These include demonstrations of how to deliver spatially-referenced multimedia material for site planning and reviews using Washington DC, South Boston Seaport and Boston's waterfront development as case studies. Such multimedia interfaces, coupled with the accessibility of the Web, has the possibility of opening up a new paradigm within urban design; one which helps to communicate ideas and developments to other agencies and the general public (Shiffer, 1995).

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 (Carver, 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 instance, 3D visualization capabilities can be added to ArcView by using VRML and custom written Avenue scripts [47]. This has been explored in the VENUE (Virtual Environments for Urban Environments) project [47], which has linked standard GIS and RS packages to urban design packages in an exploration of 3D modelling requirements of urban designers. The project developed around several UK-based case studies - Wolverhampton, Oxford and Central London - to act demonstrators of 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.

The pictures below give you a flavour of the data assembled for the case study in central Wolverhampton. The building block outlines for the central area of Wolverhampton are shown in 2D in ArcView. The circular polygon around the outside is Wolverhampton's ring road (Figure 4), whilst Figure 5 shows a view of the GIS in Live3D (viewed in the Netscape Web browser)

Figure 4

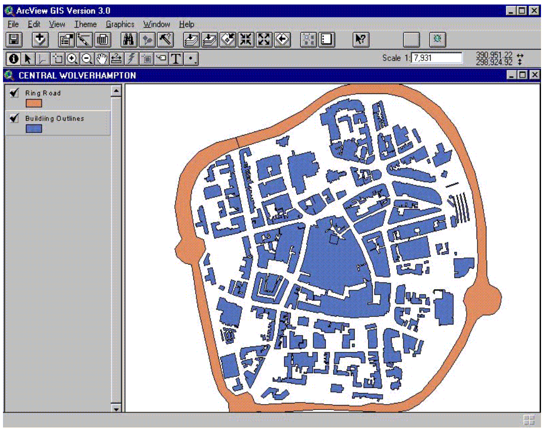
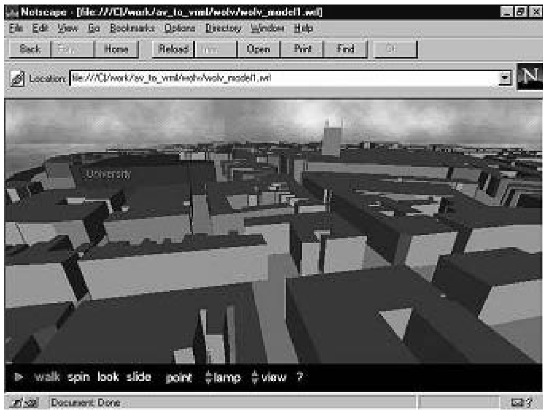


Figure 5



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 may be particularly applicable to widening public consultation and participation in development projects (Smith & Dodge 1997).

Psychology

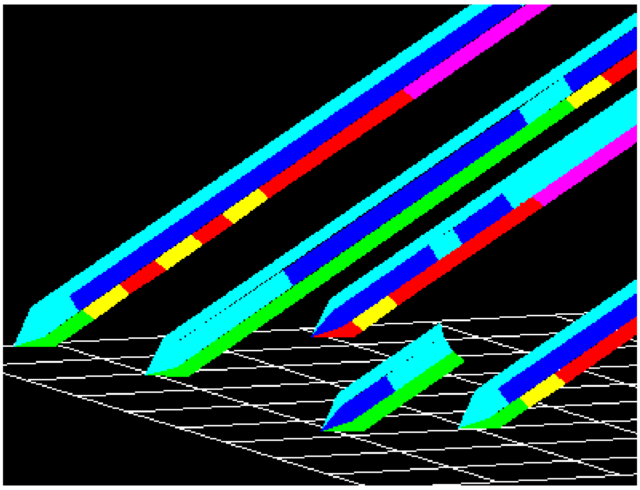
In psychology, current visualization techniques include various types of graphics such as contour plots, surface plots, scatterplot matrices and dynamic spinning (Marchak, 1994). These have previously been reviewed for their suitability in the analysis of psychological data by Ho & Behrens (1995). However, like geography, psychology is also 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 have generally been used within the experimental design stage of the research, and have supplemented existing techniques as opposed to replacing them. For instance, the use VR technology has started to supplement conventional research methods, such as in shape recognition and manipulation experiments which has traditionally used 'physical' objects, but now also uses 3D interactive computer graphics (e.g. Ainge, 1996; Duesbury & Oneil, 1996). Another example has been the use of computer based multimedia in the study of 'body-image' dissatisfaction between men and women (Gustavson et al. 1993), and the use of computer simulations in the investigation of people's perceptions from varying perspectives (Houston et al. 1995).

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

History

Although history is not strictly a social science, a number of interesting interdisciplinary examples of visualization using historical data have been surveyed, many on the Web. In circumstances similar to the visualization of spatial data, specialist techniques have also been developed for the visualization of temporal data. An example is the visualization of historical data in three-dimensional space, using event histories as a case study (Francis and Fuller, 1996). An event history is a sequence of events and states, the associations between them and their changes over time. Event histories of a similar type may be recorded for a number of individuals in a sample population. 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 histories. This has been achieved by using 3D Lexis Pencils (Figure 6), a technique developed from 2D Lexis Diagrams (Keiding, 1990), that represent changes of throughout an individual's history by using changes in the colour, shading and height of the pencil.

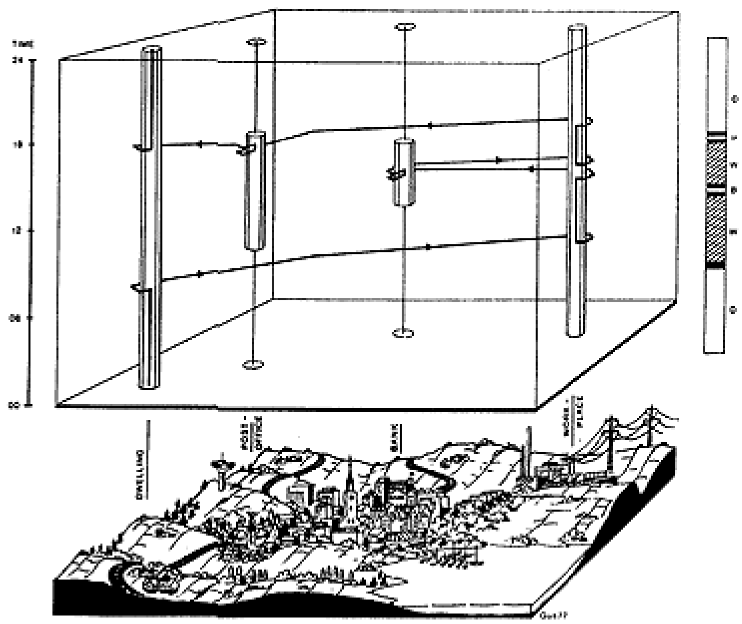
Figure 6



A Lexis pencil represents the event history of one individual or sample and consists of one or more parallel faces, aligned typically like the faces on a real pencil. As the length of the face, normally representing increasing time, is traversed, the changes of state of the variable associated with the face are denoted by changes in colour. Multiple event histories can be displayed using Lexis plots, which uses a Lexis pencil for each case history. The input event history data file contains a number of data variables, any of which may be selected for the three co-ordinate axes. Normally the Y-axis will be assigned a variable which is some measure of time whilst there will normally be one variable which is an index of the case histories. Any of the remaining variables may be used to "paint" the faces of the Lexis pencils with colours according to the value of the variable. Such display variables may take integral values while axis variables may take any real values. The resulting "geometry" is displayed in a window together with a set of axes and annotation. Examples of using Lexis pencils and Lexis plots to display event histories includes the unusual topic of the criminal careers of bigamists, which concludes that bigamists are often involved in fraud but not sex offences [49].

Other projects on the Web dedicated to exploring methods for visualising event history data in the social sciences include the Lifeline Project [8]. The Lifeline Project examines how life histories can be visualised using existing techniques developed in time geography. Time geography developed sophisticated visualization techniques to represent individual life courses, such as in Figure 7, taken from Carlstein et al (1978), 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.

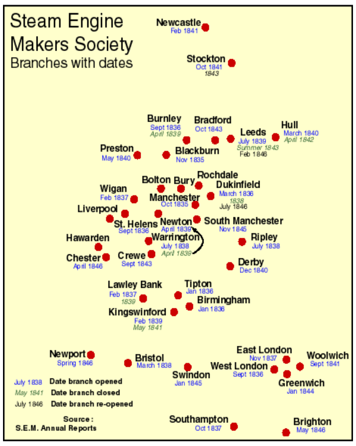
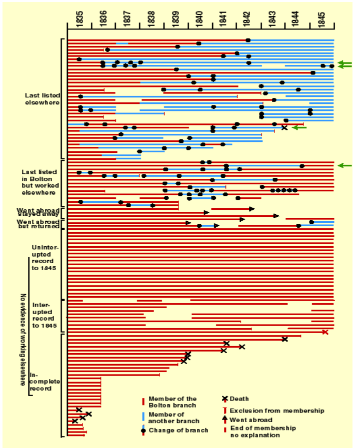
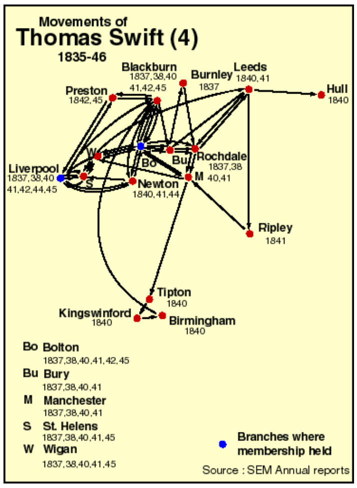
Figure 7



These constraints in space have lead to lifeline diagrams, where each life history is shown by a single line or bar and events are indicated by symbols or changes in fill patterns along the bar.

New visualization techniques however, are beginning to revitalised time-space geography due to the ability to visualise the relationship of space and time by new mapping and information retrieval techniques (e.g. 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 to move to more detailed individual data by clicking on a specific data point. This is exemplified using the migration patterns of members of the Steam Engine Makers Society, a 19th century trade union [8]. 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 members (Figure 8). Although the above example concerns people’s lives, the methods are also relevant to any entity that changes over two or more dimensions.

Figure 8

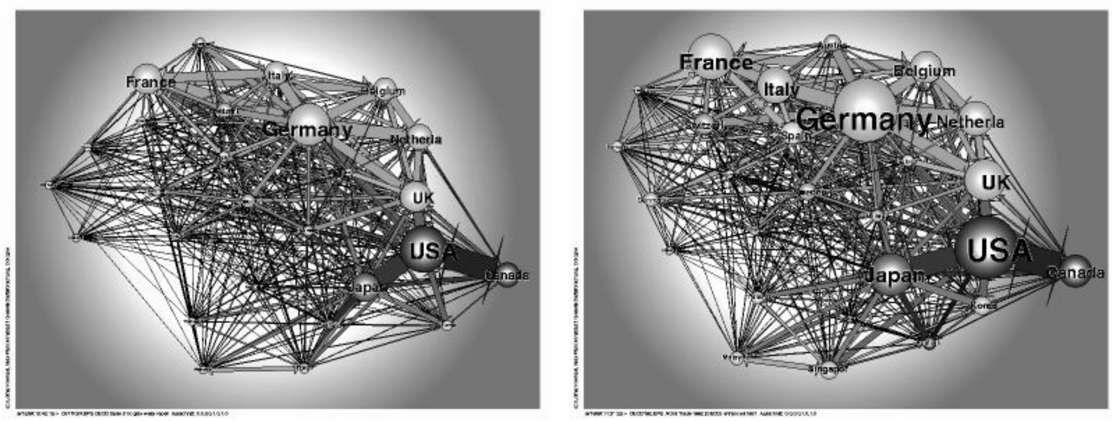
First Level	Second Level	Third Level
		

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 summarises the subsequent migratory histories of everyone who belonged to the Bolton branch of the SEM 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 1848/9.

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 available. In political science research, for instance, traditional graphical displays are commonplace (e.g. Petrocik, 1996; Gelman & King, 1993; Weisberg & Smith, 1993; Shugart, 1992), but the use of new technologies such as VR, computer simulations and multimedia remains unexplored. One of the few exceptions include 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 (e.g. Haneveld & Teunter, 1998; Davidson & MacKinnon, 1998). Notable exceptions to these standard graphical outputs include the visual representation of the structures of world trade between twenty-eight OECD countries between 1981 and 1992 [65]. The size of the links represents the volume of trade between any two countries, whilst colours give the regional membership in different trade organisations (Figure 9). In addition, research suggests that the recent advances in statistical graphics are be being used to investigate the increasing richness of econometric data (e.g. Jenkins & Lambert, 1997; Unwin, 1996; Koschat & Swayne, 1996).

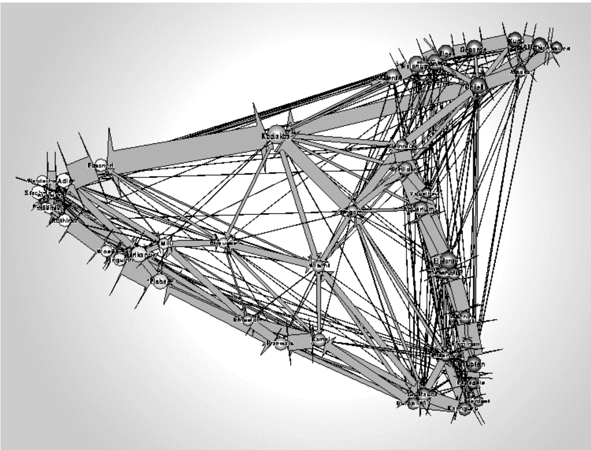
Figure 9



World Trade in 1981 World Trade in 1992

Sociology, in comparison to politics and economics, appears to have made greater use of computer visualization. The study by Feinberg & Johnson (1995), for example, used 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 (e.g. Schwendinger & Schwendinger, 1997). The most comprehensive examples of this type of research can be found at the network visualization website [65]. The aim of this work is to develop aesthetically pleasing computer visualization procedures to obtain insights into what are usually complex phenomena. Examples include visualising vistors' paths at Duisburg Zoo in Germany (Figure 10), which leads to interesting insights into visitor behaviour. Starting at the main entrance (lower right) there is a large circle on the left, with very few central places in between, where visitors switch directions. The most central area is around the Kodiakbears (Kola bears), which is the main link to a smaller circle (upper right). The area around this smaller circle is much smaller, because the presence of an autobahn has resulted in locations here being more tightly packed together. Generally though, visualization in sociological research tends to be represented by traditional graphical displays using standard software packages such as S-Plus (e.g. Schulman, 1995), Mathematica (e.g. Stine, 1995) and Lisp-Stat (e.g. Tierney, 1995).

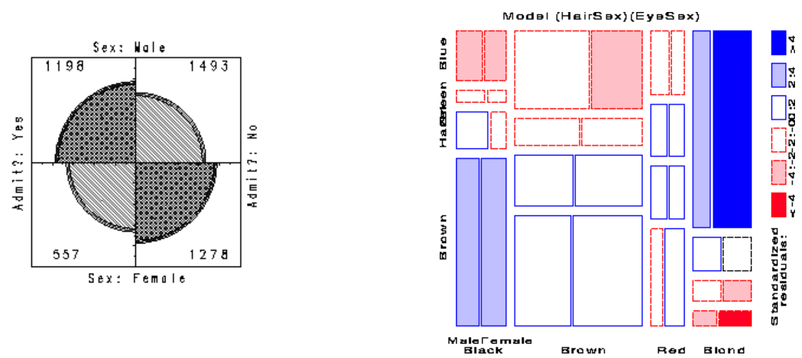
Figure 10



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) has argued that more should be made of graphs in statistics, whilst Fienberg (1979) has reprimanded statistics for its lack of graphs and graphical experiments. For instance, although graphical methods for continuous data are well developed, similar

Figure 11



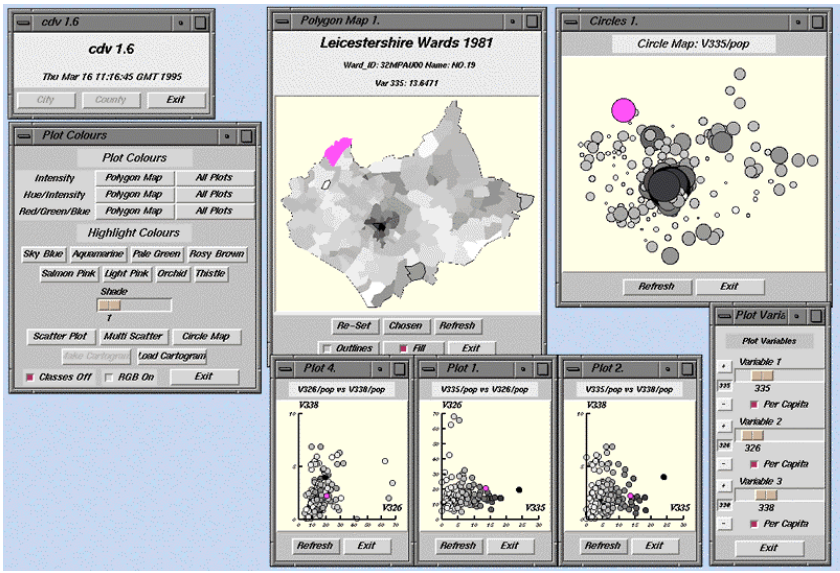
methods for categorical data are still in their infancy [54]. This situation is slowly being addressed with work such as that located on the Michael Friendly website [54]. There, numerous examples of graphical methods for categorical data can be found (Figure 11).

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 complex relationships within datasets. This is becoming more essential as the typical social science dataset becomes more complex. Converting these data into useful, meaningful information can be extremely difficult and haphazard (Ondrechen, 1997). Visualization is being used increasingly as a method to overcome these difficulties, with recent software developments providing new tools for visualising multivariate data (Colet & Aaronson, 1995). For instance, Levin & Mitra (1994) describe a curve-fitting visualization programme designed to generate initial parameter estimates for non-linear equations, illustrating the process by modelling mortality data. Non-linear equations are notoriously difficult to solve, since a given equation can have an infinite number of often quite dramatically different solutions, all meeting the same specified goodness-of-fit criteria. Advanced visualization techniques can remove some of the inevitable trial and error process involved in solving such equations.

A number of websites 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" website [28]. Another example is the MANET (Missing Are Now Equally Treated) software website [69]. This 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 datasets containing missing values. Although the package is best used with non-spatial data, spatial data can be explored by the use of linked maps. This kind 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 social statistics and increasingly statistical programming environments such as S-Plus and XLIS-STAT have been linked to GIS to allow the visualization, exploration and modelling of geographically referenced data (e.g. Gatrell & Bailey, 1996; Haining et al. 1996). This has been termed exploratory spatial data analysis (EDSA).

There are now a growing number of software environments available that allow EDSA. Project Argus at Leicester University, [5] has currently developed a series of tools that promote this approach. The key product 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 et al., 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 12). The website includes a set of tutorials on cartographic visualization, some examples and exercises that demonstrate the use of the cdv and free down loadable software.

Figure 12



Therefore, using advanced visualization techniques, EDA and EDSA can act as a means of filtering extremely complex quantitative relationships among data into relatively simple, manipulatable graphical displays (Grande & Robinson, 1992). 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 dataset, often visualization techniques fail to capture the essence of data trends. In addition, the ability to easily query any part of the data set frequently results in 'information overload', and the need, often felt by researchers, to analyse their entire dataset which can be time consuming and can result in diminishing returns (Bormel & Ferguson, 1994).

Visualization in Teaching and Learning in the Social Sciences

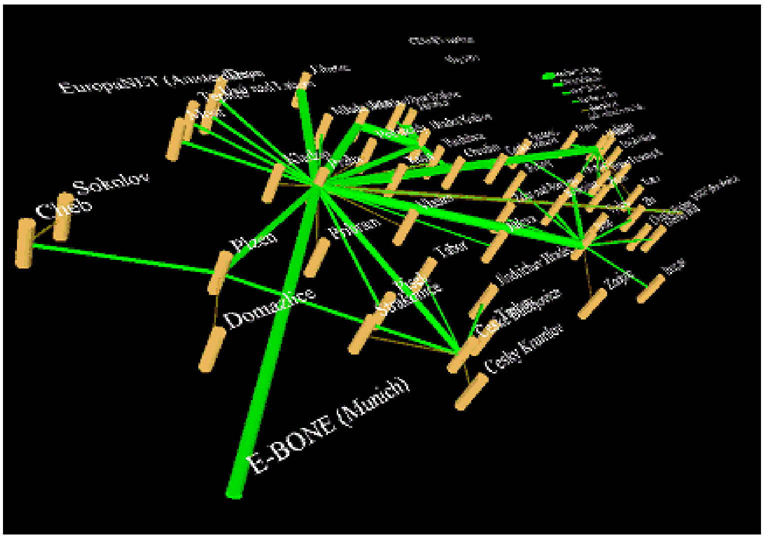
Research into the use of visualization in the social sciences has indicated that a major use of the technology is within the process of teaching and learning (Schnotz et al. 1996). Although the use of visual aids in teaching and learning is not new in itself, there would appear be an exponential trend in the use of computer-based graphics. In the same way that basic computer packages, such as word-processing, has increased students ability to learn and produce higher quality work in the social sciences (e.g. Owston, et al. 1992), recent research suggests that the same is true for visualization packages (e.g. Gordon & Pea, 1995). Visualization has the advantage of making education more accessible and provides a means for authentic scientific inquiry through inquiry driven learning. Visualization also provides a link between education and the practices of science. However, there is not much information available on how a particular discipline's subject should be visualized, and which kind of visualization is best suited for specific purposes.

Such an approach has been employed in the teaching of geography for many years, with the use of custom written graphical software, and GIS and remote sensing software, all of which have visualization at their core (Nellis, 1994; Can, 1993). Similar techniques and technologies could be embraced by the other social sciences. For example, Hassebrock & Snyder, (1997) discuss the teaching of the potentially difficult subject of bivariate statistics in psychology using Maple, a computer algebra system which uses interactive graphic displays and computer animation to explore the concepts of basic relationships, such as correlation coefficients and regression lines. Similarly, in sociology, Ploch & Hastings (1992) describe GRAFTOOL, a software package designed to help teaching of social stability and change by using graphical approaches, such as surfaces and contour graphs in cohort analysis. Gould (1994) argues that most quantitative methodologies could benefit from similar approaches, and that genuine understanding is achieved by visualization of a problem, rather than algebraic manipulation, and the teaching task could be aided greatly by employing interactive computer graphics.

Multimedia also appears to have made an impact in social science teaching, particularly video. Amesberger and Halbmayr (1996) discuss how the showing of the film Schindlers List, for example, helped to contextualise teaching of political science in Austrian Schools. The film itself helped 'to go beyond the cognitive level of knowledge transfer' of traditional teaching methods, and exemplified the importance of visualization of history. Research (e.g. Avila et al, 1995; Bergandine & Koker, 1993) has suggested that video-based teaching technologies improve students learning capabilities, and their attitudes about the course, when compared to traditional lecture-relevant visual materials, such as overhead transparencies. This learning experience is enhanced if the video is interactive allowing collection, analysis and modelling of visual digital data (Escalada & Zollman, 1997).

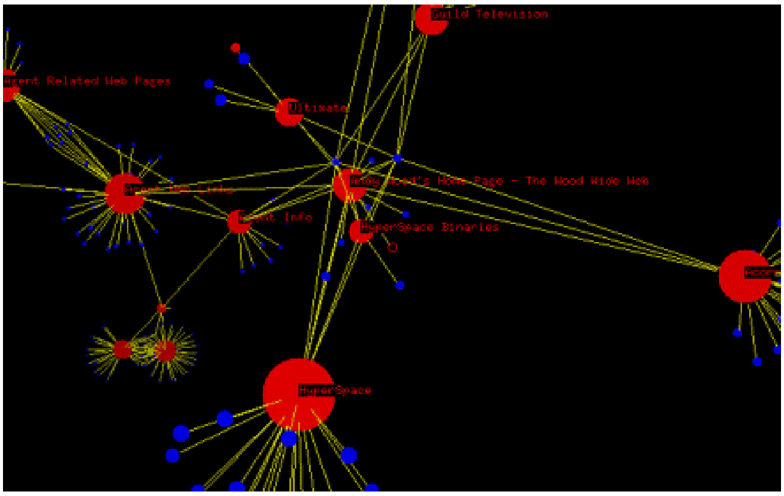
Visualizing the Web

Figure 13



One of the aims of the web search was to create an inventory of websites that act as 'gateways' to social science visualization research. Such gateways are important. Clicking one's way through the Web can be very disorientating, commonly leading to dead-ends or irrelevant information. The Web is so interconnected and huge that it is difficult to establish a mental model of its structure. Flat one-dimensional history lists are a common navigational aid, providing a way to think about many documents at once, but they offer no help in understanding the connections between them. The answer may be visualising the Web in three dimensions. The Web is far too large to see all at once, but 3D graphical representations can be built of sections of it (known as Weblets), and viewed in a 3D Web browser (Figure 13). Such browsers are becoming widespread with the recent release of VRML. Just as traditional browsers allow hypertext links to be followed, VRML provides a way to attach 3D link anchors to 3D data files.

Figure 14



Although the Web is non-linear, we can start at any document and impose a tree structure. The problem is that the tree structure can become cluttered very quickly. The solution may be to use hyperbolic visualization. Hyperbolic visualization uses non-Euclidean geometry as a convenient way to visualize exponentially growing trees (Figure 14). This representation of hyperbolic space is known as the *projective* or *Klein* model. There has been considerable work at the Geometry Center [70] on visualizing hyperbolic geometry, which provides an elegant and powerful mathematical framework for display and navigation.

Visualization Software on the Web

The Web contains a vast amount of graphical and visualization software which is available free of charge, or almost free of charge. The GNU family of products, for example, is available through the Free Software Foundation [72]. However, the range of quality of free visualization software on the Web is huge [30], with a significant amount designed by students or amateur programmers. Software produced for personal use or to satisfy a research project tends to suffer from several problems. The design may have been specified on an *ad hoc* basis because the programmers learned as they went along or lacked the time to start again. The code frequently has been tested only minimally, may break easily when modified in minor ways, and often has important features missing. For these reasons, this kind of software also tends to be "orphaned" rapidly. Amateur programmers usually have no motive to document and explain their products for others, and have no reason to respond to bug reports and modification requests or to clarify implicit assumptions. According to Uselton [30], the most effective concise statement about acquiring and using free software is, “give it a try, but don't count on it to solve all your problems.”. Nevertheless, there is some excellent software available.

An excellent annotated index to websites that allow shareware graphics and visualization software to be downloaded can be found at http://www.cs.ubc.ca/spider/ladic/software.html. Another good gateway for free software for general visualization can be found on the Frontiers of Visualization Web Pages [30], which also has links to academic and government research sites.

Conclusion

We have defined the social sciences as being those academic subjects most usually assigned to social science faculties in British universities, and have tried to answer the question posed ten years ago by Upson et al., (1998):

> "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 the social sciences. Will users from these fields find this environment appropriate to their needs?"

The social sciences have had an important role to play in understanding why visualization has become popular at various points in time. In 1988 Frenkel argued that the 1987 revival in visualization may have been related to the declining academic support of American centres of super-computing. The integration of graphical software into standard PC packages has made the use of basic visualization tools almost commonplace and the onus on researches that use these tools now means that many more graphics are now produced with less thought than ever before. This is evident from our study of 2484 academic papers and websites dating from a century ago to last year (see the main body of this report for further analysis of particular trends and concentrations of research that have been emerging). Below we find the key findings for each social science discipline.

Geography: of all the social science disciplines, geography would appear to make the greatest use of visualization techniques and technologies. 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. Geography is also relatively unique amongst the social sciences with its almost exclusive use of spatial data and its origins in the visual science and art of cartography.

Planning: the role of computer aided design (CAD) as a visualization tool in planning has expanded the range of alternative planning proposals under consideration in the professional planning arena. Computer-supported modelling and visualization may eventually serve as a common and efficient language, facilitating communication about multifaceted environmental planning issues. Within academia the principle research on the Web in this area concerns Virtual Worlds, and their role in visualising urban forms within multi-user environments. Such an interface, coupled with the accessibility of the Web, has the possibility of opening up a new paradigm within urban design that may be particularly applicable to widening public consultation and participation in development projects.

Psychology**:** similar to geography, psychology also shares the distinction of an interdisciplinary overlap between the sciences and social sciences. Current visualization techniques include various types of graphics such as contour plots, surface plots, scatterplot matrices and dynamic spinning. More recently, the use VR technology has started to supplement conventional research methods, such as in shape recognition and manipulation experiments which has traditionally used ‘physical’ objects, but now also uses 3D interactive computer graphics. In numerous cases, computer visualization techniques has improved upon previous photographic and computational techniques

History: although history is not strictly a social science, a number of interesting interdisciplinary examples of visualization using historical data have been surveyed. There are visualization tools on the web which allow a simulation of a system that enables users to 'drill down' from the population as a whole, through the collective experience of members in a selected place to the histories of individual members. Other examples include Lexis pencils, LifeLine Projects and 3D Time-Space Visualization.

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 available. One of the few exceptions in politics is the investigation of the political power of the media, and particularly television, in constructing and influencing global events. A notable exception for economics is the visual representation of the structures of world trade between twenty-eight OECD countries between 1981 and 1992. An innovative use of computer graphics in sociology is the visualization of social networks. Examples include visualising vistors’ paths at Duisburg Zoo in Germany, resulting in interesting insights into the behaviour of visitors.

Social Statistics: in terms of complex visualization techniques one of the leading uses in social statistics has been in exploratory data analysis. This is becoming increasingly more essential as the typical social science dataset becomes more complex. Exploratory data analysis 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, the ability to easily query any part of the data set frequently can result in ‘information overload’, which can often have detrimental outcomes.

In short, our review has taught us many things about visualization in the social sciences and we hope that its results will also be of more general interest and will change more widely held views. Firstly, there is no central core to this research and it is thus very difficult to define key research groups and centres, hence the need for organisations such as ACOCG, and interdisciplinary meetings within the social sciences. Consequently, most of the research is conducted largely in ignorance of much other work which either has already been done or which is currently being undertaken. Secondly, visualization in the social sciences is dominated by subjects with the closest links to the natural sciences or/and with a tradition in graphical output. A pattern of diffusion from science to social science is clear. Thirdly the World Wide Web is quickly becoming the dominant form of research dissemination as paper journals fail to evolve, charging exorbitant prices even for the production of simple two dimensional colour illustrations. We can expect all these trends to continue as there is no single discipline likely to dominate visualization in the future and so provide a core set of methodologies.

Our original specification asked for key research groups to be identified, but as we have stated above these are very difficult to define, given the diffuse nature of work in visualization in the social sciences. If we were to identify specific groups these would include: project ARGUS from Leicester, the SigGraph ACM, the University College Research on visualization in planning in London, the MIT Urban Studies and Planning Department, Alan Maceachren's centre in Penn State, and the work on visualization sociological networks in Germany. But overall it would be unfair to many other groups not to list them and to list all groups would not produce a key list!

Visualization in the social sciences continues to grow as a research activity beyond the original spurt of activity following the 1987 report. However this growth is relatively uncoordinated. The activity does not fall easily within the remit of any particular discipline and the publication of results in the traditional form is very problematic. This review has attempted to illustrate the wealth of work currently being conducted into visualization in the social sciences. It has provided a reference to the historical background through the creation of a very large bibliography of past papers and a long list of current web sites providing examples of different techniques and access to many different methods. Without greater coordination the future of visualization in the social sciences is likely to be much like the past, but more diffuse and more ephemeral. This coordination is likely to arise only from direct funding for exemplar projects and centres from the research funding councils.

Weblinks and Gateways

Generally, websites pertaining to visualization in the social sciences include websites advertising conferences (such as the Open University Conference on Visualising Multivaraite Data), individual researchers home pages, websites relating to specific projects such as the ACOCG project and The Cartographic Project, and individuals and companies developing visualization tools and technologies.

Usually a good starting point is the Social Science Information Gateway (SOSIG) [71]. SOSIG is an online catalogue of thousands of Internet resources relevant to social science education and research. Every resource has been selected and described by a librarian or subject specialist. In terms of visualization links though, very little are currently stored in SOSIG. Below is a list of websites that may act as gateways to social science visualization sites.

A List of Potential Web Gateways

http://www.geom.umn.edu/	The Geometry Center for the computation and visualization of geometric structures
http://www.geog.psu.edu/ica/icavis/ICAvis-research(1).html	International Cartographic Association Commission on Visualization
http://www.cgrer.uiowa.edu/servers/servers_references.html	Center for Global and Regional Environmental Research
http://www.iko.unit.no/gis/gisen.htm	Department of Survey and mapping at the Norwegian University of Science and Technology (NTNU) and can be used as a starting point to find various sites related to GIS and Cartography
http://www.man.ac.uk/MVC/	Manchester Visualization Centre The MVC performs both service provision and R&D in high-performance interactive computer graphics, multimedia, image processing and visualization on the computers of the University of Manchester and UMIST

	(about 6,500 machines).
http://www.utexas.edu/depts/grg/gcraft/notes/notes.html	Notes and study material for GIS and the Geographers Craft
http://www.gvu.gatech.edu/user_surveys/survey-1997-10/	Graphic, Visualization and Usability Centers 8th Web User Survey
http://www.cs.umd.edu/projects/hc...le/brainj/VisualizationResources/	Visualization & HCI (Human-Computer Interaction) Resources
http://www.uiowa.edu/~itsarcs/visual.html	Visualization Showcase VisLab Facilities. Science and engineering links
http://library.ust.hk/res/beyond/hum-social-sci.html	52 Humanities & Social Science Resources on the Interest Social Science Web virtual Library - meta-sites
http://www.clas.ufl.edu/users/gthursby/socsci/index.htm	The scout report for the social sciences. Biweekly issue offers a selective collection of internet resources covering topics in the field that have been chosen by librarians and content specialists in the given area of study
http://www.math.tau.ac.il/visualization.html	General visualization links - mainly science, but includes software sites.
http://www.evl.uic.edu/EVL/index.html	Electronic Visualization Laboratory (EVL) is a state of the art research facility for computer graphics and interactive technology. As a research centre and educational establishment EVL works to further the development of graphics hardware, software and display devices.
http://www.fgdc.gov/clearinghouse/index.html	Geospatial Data Clearinghouse Activity Digital data dump (US)
http://thoth.sbs.ohio-state.edu/osugisbib/wais.html	GIS Mater Bibliography Project. A Comprehensive bibliography of GIS related research and literature A database form which a

	comprehensive picture of the current state of development in GIS can be established
http://www.css.tayloru.edu/instrmat/graphics/hypervis/vistoc.htm	Definitions, History and Goals of Visualization
http://www.math.yorku.ca/SCS/friendly.html	Michael Friendly's Home Page Good one for mathematical / statistical visualization Statistical Graphs - software, tutorials, examples Data Visualization discussion group Data visualization weblinks
http://www.icase.edu/docs/hilites/index.cs.viz.html	Visualization and Graphics research. ICASE's visualization research program focuses on advancing the start of the art as it applies to complex three-dimensional problems encountered in engineering and the sciences. Bibliography of publications and reports.
http://www.esri.com/base/common/jumpstation/jumpstation.html	ESRI Web jump station
http://www.siggraph.org/~rhyne/carto/	The Cartographic Project has complied an inventory of websites that deal with geographic visualization
http://www.shef.ac.uk/uni/projects/sc/index.html	Society of Cartographers Web site

Cited and Uncited Web References

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2	http://www.geog.leeds.ac.uk/staff/s.openshaw/w3agw.html	The AGW Spatial Interaction Modelling Workstation
3	http://stats-www.open.ac.uk/ouconf96/abstract/francis.html	Visualising Multivariate Data
4	http://www.geom.umn.edu/	The Geometry Center for the computation and visualisation of geometric structures
5	http://midas.ac.uk/argus/Software/CartoViz/	Cartographic Visualization Software
6	http://www.geog.psu.edu/ica/icavis/ICAvis-research(1).html	International Cartographic Association Commission on Visualisation
8	http://www.geog.qmw.ac.uk/gbhgis/index.html	The Great Britain Historical GIS Programme
9	http://www.ccg.leeds.ac.uk/agocg/report.htm	AGOCG Report - Leeds
10	http://www.imersiva.ch/	3D graphics to GIS
11	http://www.geog.le.ac.uk/vfc/	Virtual Field Course
12	http://www.geog.buffalo.edu/~jkrygier/krygier_html/research.html	Geography Research in Visualisation
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15	http://www.geo.ed.ac.uk/home/research/purple.html	The University of Edinburgh, Department of Geography; GIS in practice.
16	http://cs.joensuu.fi:8000/0x83ea6001_0x0001b467	Basics of Visualization
17	http://www.agocg.ac.uk/TechReports/report33.html	Graphics, Visualization and the Social Sciences
18	http://www.geog.ucl.ac.uk/casa/pub/viz_social_sciences/viz_paper.html	Visualising urban environments for planning and design
20	http://www.iko.unit.no/gis/gisen.html	Starting Point for GIS / cartography
22	http://www.man.ac.uk/MVC/	Manchester Visualisation Centre
24	http://www.utexas.edu/depts/grg/gcraft/notes/notes.html	Notes and study material for GIS and the Geographers Craft
25	http://acorn.educ.nottingham.ac.uk/Shellcent/maps	Making Maps Easy to Read - research project
26	http://giswww.kingston.ac.uk/vworlds.html	Virtual worlds technology? The ultimate visualization tool?
27	http://thoth.sbs.ohio-state.edu/osugisbib/wais.html	GIS Mater Bibliography Project
28	http://allanon.gmd.de/and/chi97/gla1.html	knowledge-based support for visual exploration of spatial data
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47	http://www.casa/ucl.ac.uk/venue/venue.html	The Venue Project
48	http://www.qub.ac.uk/ss/esh/visual/	Survey of Visualisation tools in the Social Sciences
49	http://www.cas.lancs.ac.uk/alcd/visual/index.html	Visualisation of Event History Data
50	http://www.uiowa.edu/~itsarcs/visual.html	Visualisation Showcase VisLab Facilities
51	http://www.icase.edu/docs/hilites/index.cs.viz.html	ICASE Visualisation and Graphics research
52	*http://library.ust.hk/res/beyond/hum-social-sci.html*	*Humanities & Social Science Resources on the Interest - Social Science*
53	http://www.clas.ufl.edu/users/gthursby/socsci/index.htm	Social Sciences Virtual Library
54	http://www.math.yorku.ca/SCS/friendl	Michael Friendly's Home Page

	y.html	
56	http://www.css.tayloru.edu/instrmat/graphics/hypervis/vistoc.htm	Definitions, History and Goals of Visualisation
57	http://www.cse.ogi.edu/CSLU/isgw97/reports/brown.html	Euro-American Workshop on Visualization of Information and Data
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59	http://www.evl.uic.edu/EVL/index.html	Electronic Visualization Laboratory
61	http://www.mailbase.ac.uk/lists/visualisation-tools/	Visualisation Tools Mail Server
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63	http://www.almaden.ibm.com/dx/vis96/proceedings/ELVINS/index.htm	Integration, Visualization and Analysis of GIS data
64	http://www.almaden.ibm.com/dx/DXUsers.html	IBM Highlights from the Data Explorer user Community
65	http://www-mpi-fg-koeln.mpg.de/~lk/netvis/SocMorph.html	A Gallery of Social Structures
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67	http://www.vislab.usyd.edu.au/about/about_index.html	Sydney Regional Scientific Visualisation Laboratory
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73	http://gis.mit.edu/projects/	MIT Urban Studies and Planning Department
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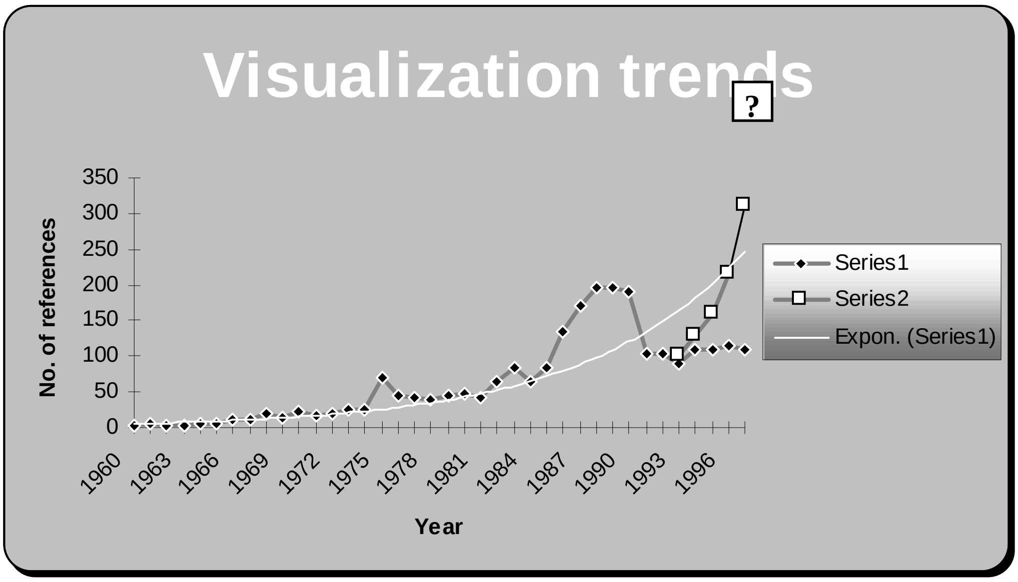
Visualization: A bibliographic history



Series 1 shows the estimated number of visualization-relevant conference papers, journal articles, books and chapters published between 1960-1997. An exponential trend line has been fitted to this data. Estimates from 1960-1990 are based on Dorling, DFL (1991) 'The visualization of spatial social structures', Unpublished PhD thesis, University of Newcastle. Other estimates are based on the following bibliography.

Series 2 includes Internet references. By 1997 an estimated 50 websites included visualization-relevant pages and links to further sites. Assuming three 'articles' per site yields 150 articles for 1997. If the number of Internet articles is proportional to the growth in the number of Internet hosts then Series 2 may be estimated from the Network Wizards Internet Domain Survey, July, 1997 (http://www.nw.com/zone/WWW.report.htm)

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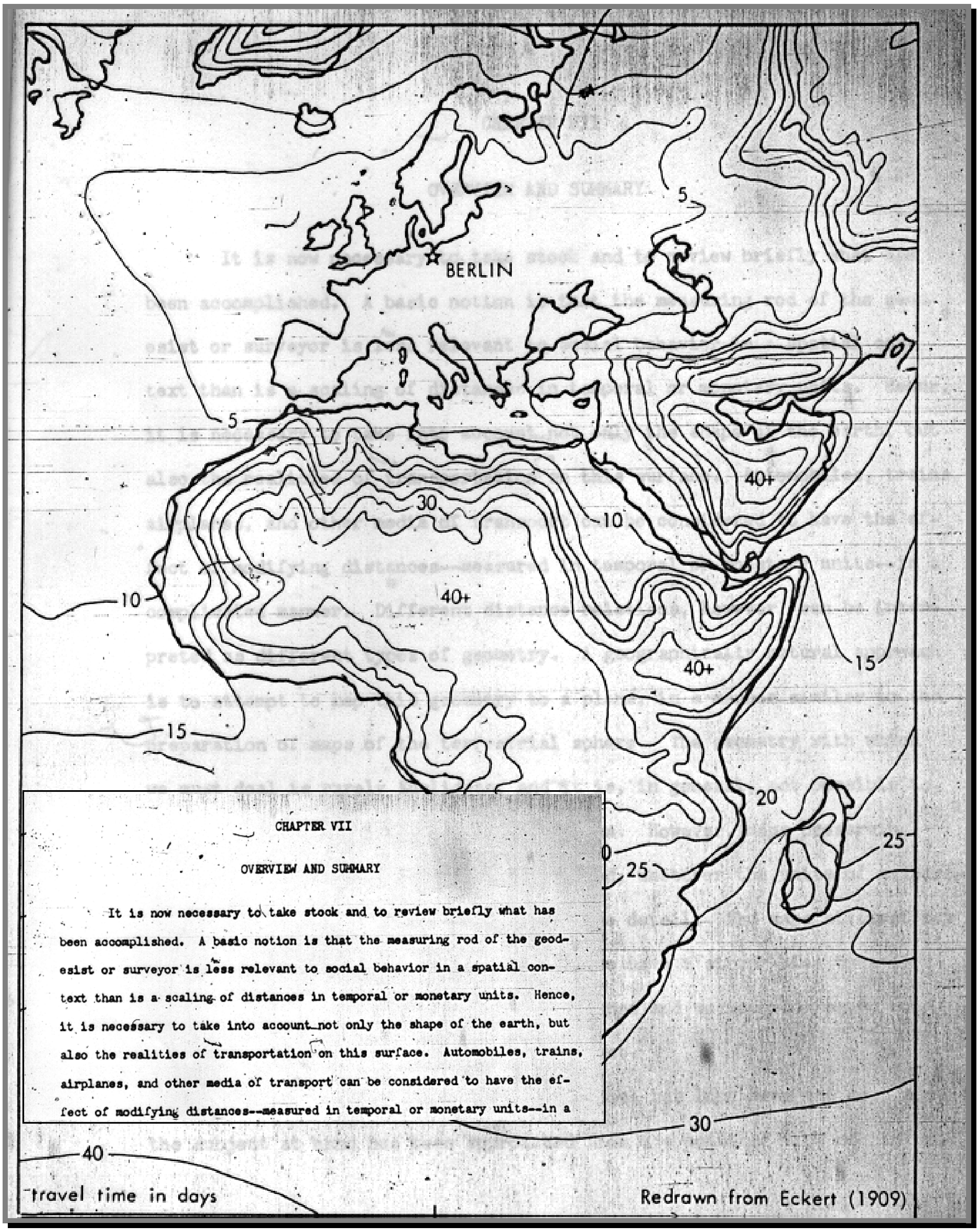

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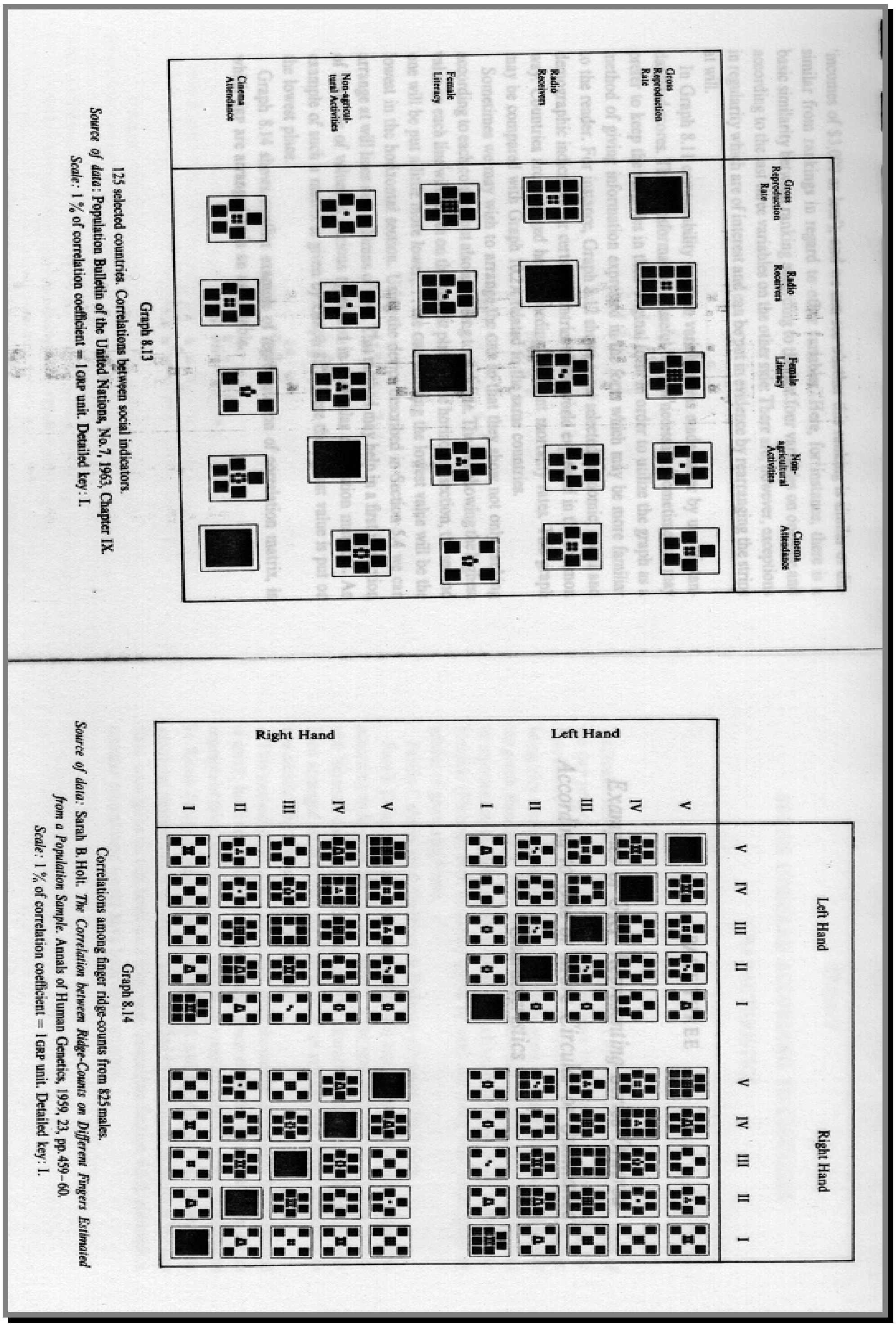

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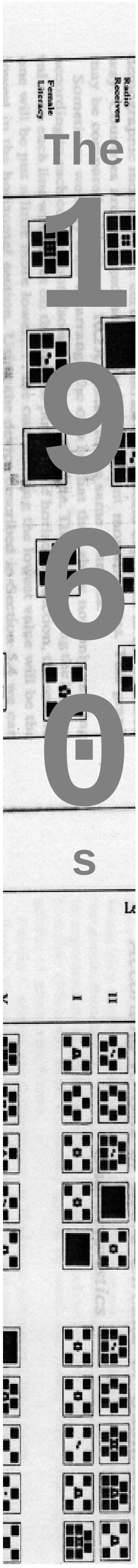

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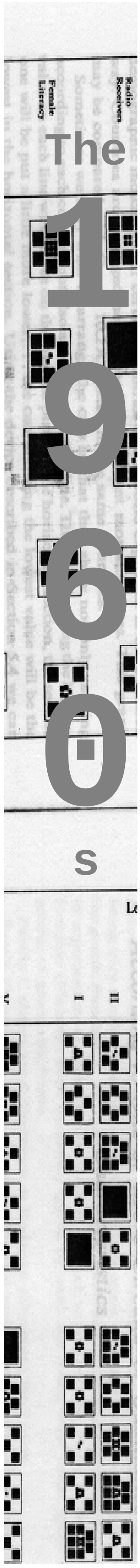

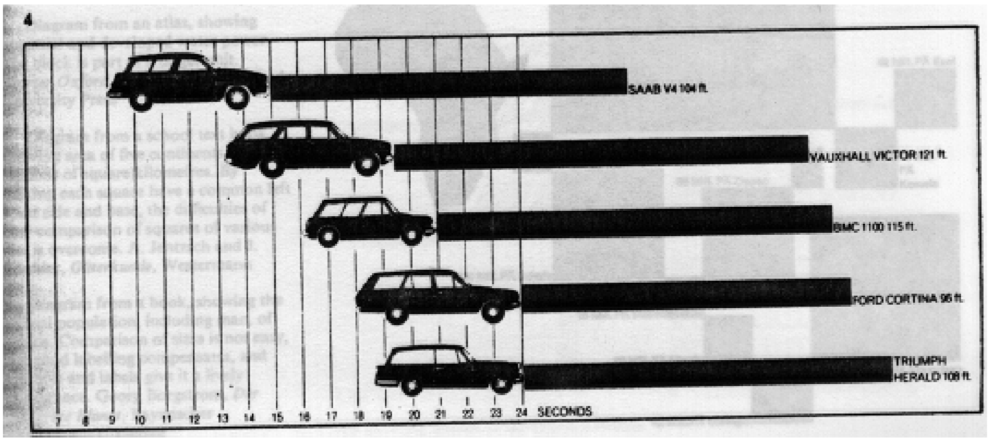

Acceleration, 0-60mph and braking From the *Sunday Times* newspaper, source: Lockwood, A. (1969)

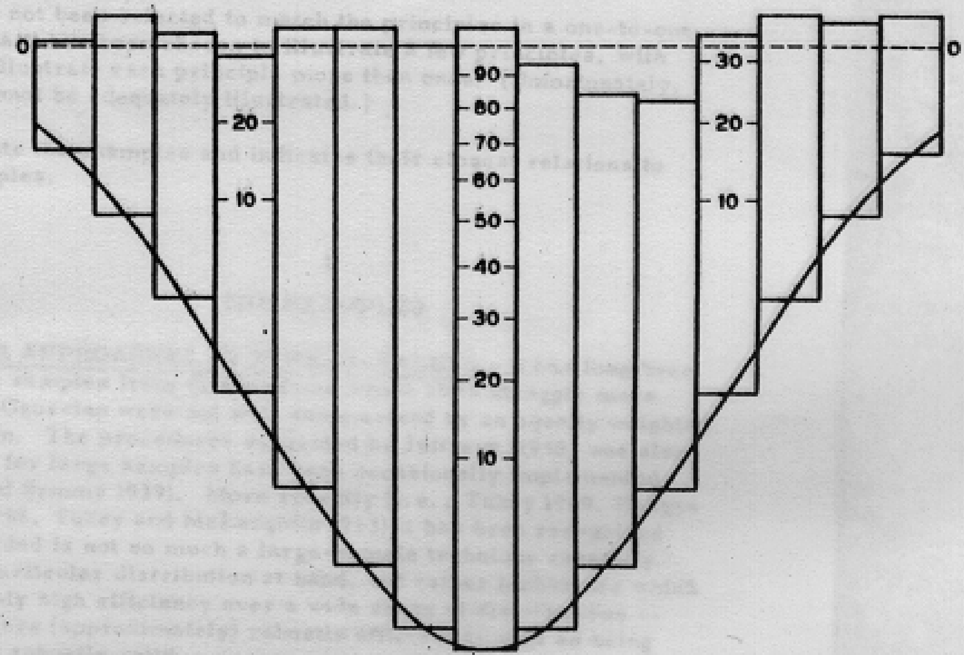

FIG. 4
SUSPENDED ROOTOGRAM

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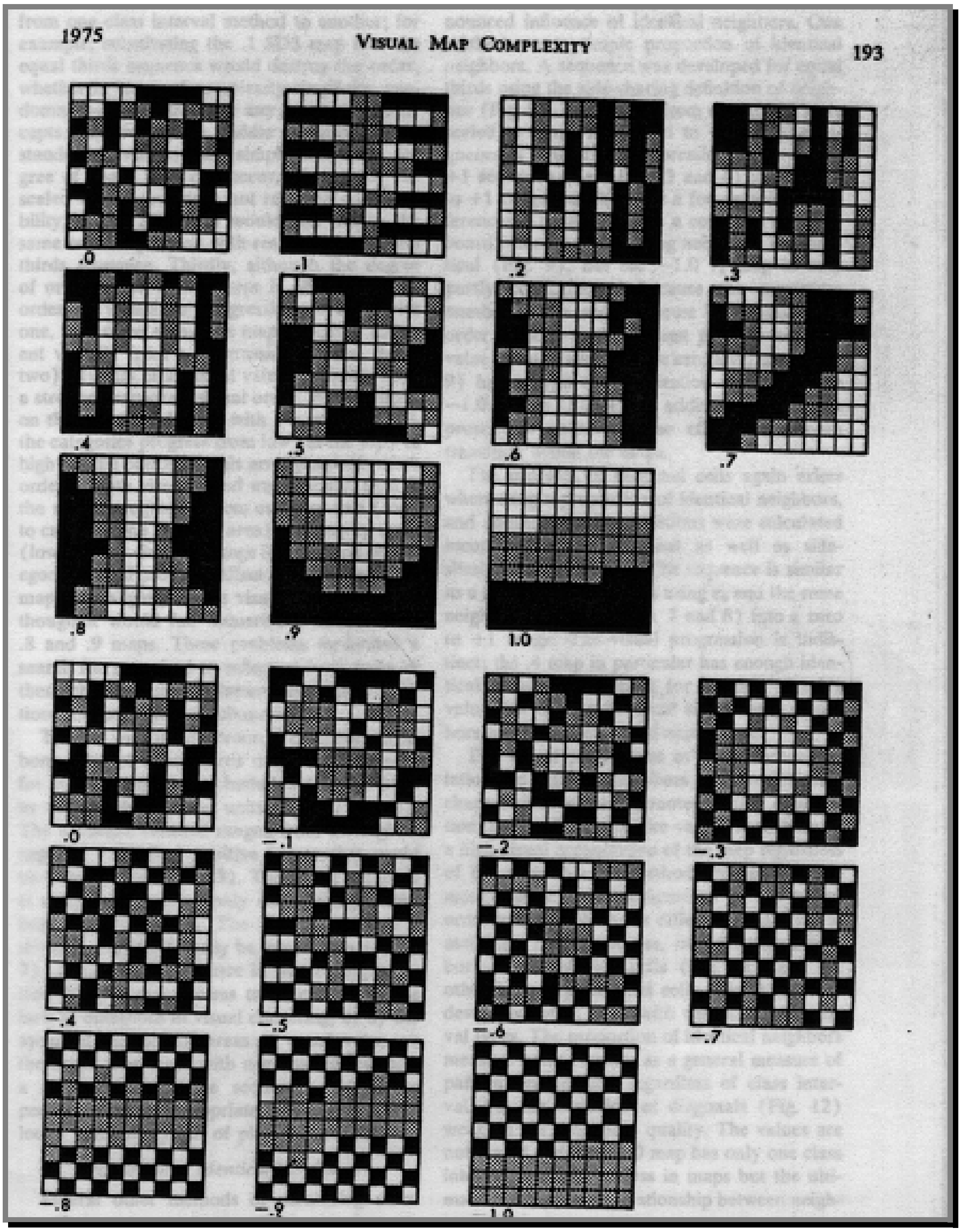

map of autocorrelation and visual map complexity
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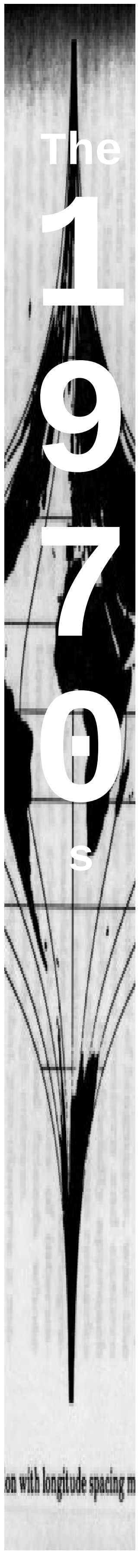

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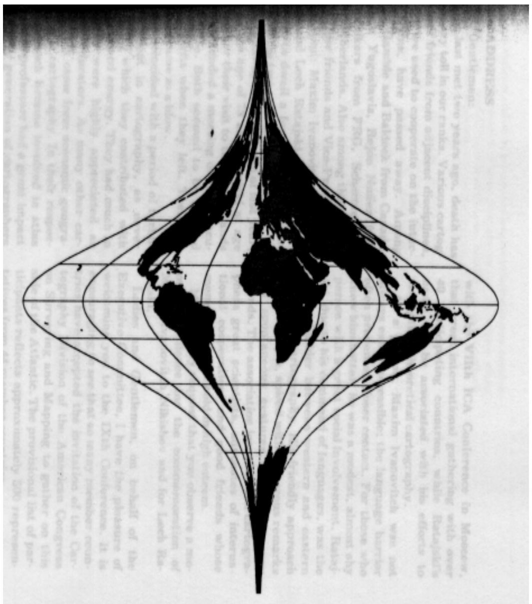


Fig. 4. A Mercator projection with longitude spacing modified to result in equal area.

The 1970s

source: Tobler, WR (1978)

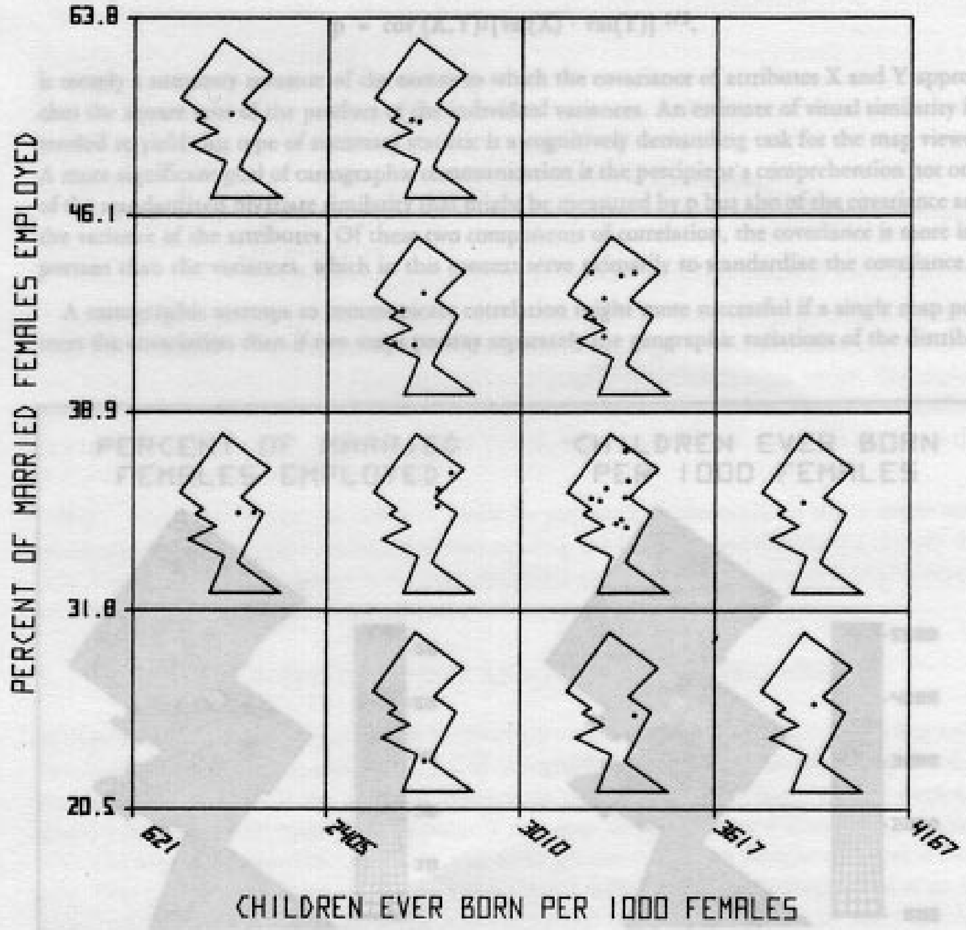
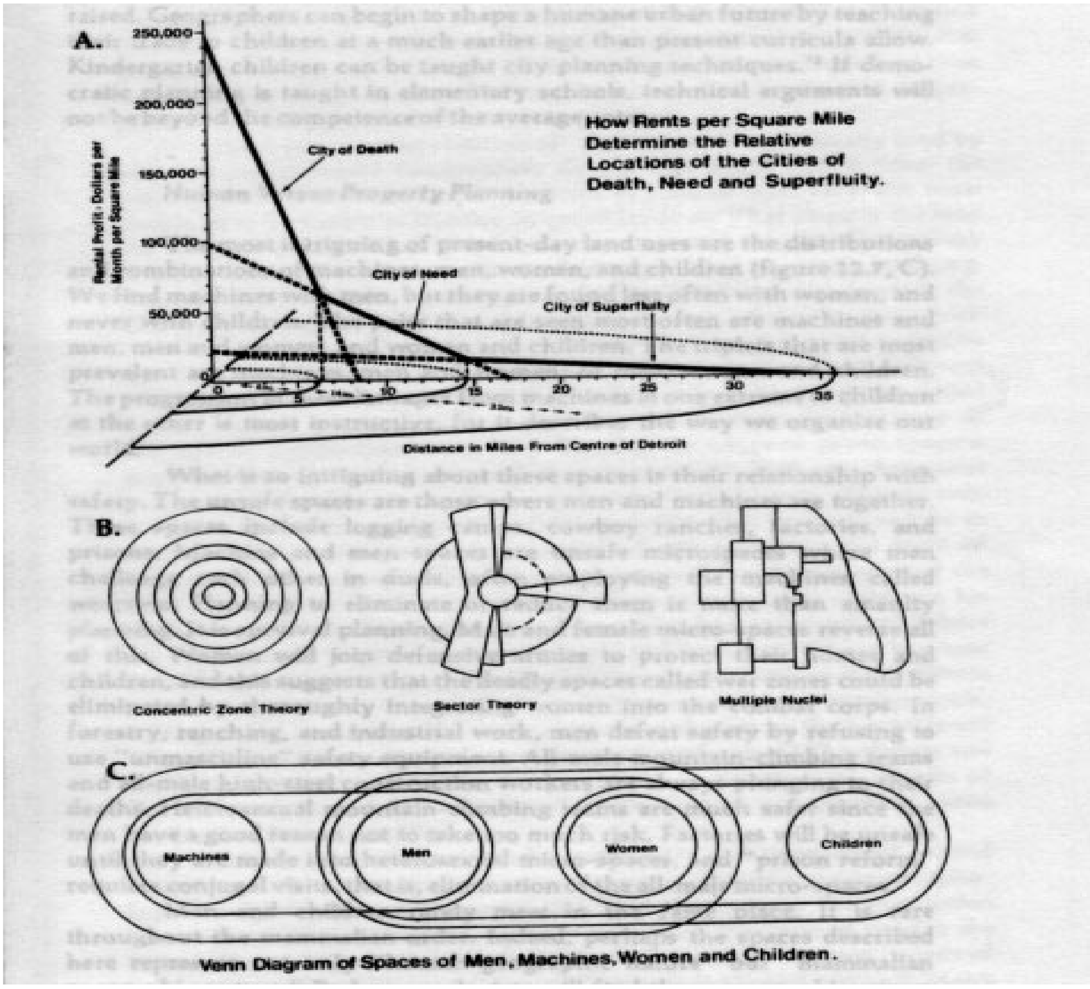


Fig. 8 — Aggregation of attribute values into categories permits a cartographic crossclassification array to represent the geographic covariation of the distributions shown in Figure 7.

source: Monmonier, MS (1979)

	The 1970s: some key authors
1●	Tobler, W
2●	Olson, J
3●	Monmonier, M
	Cuff, D
	Dobson, M
	Jenks, G
	Muller, J
	Rhind, D
	Robinson, A
	based upon 1970s bibliography



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The 1980s

The 1980s

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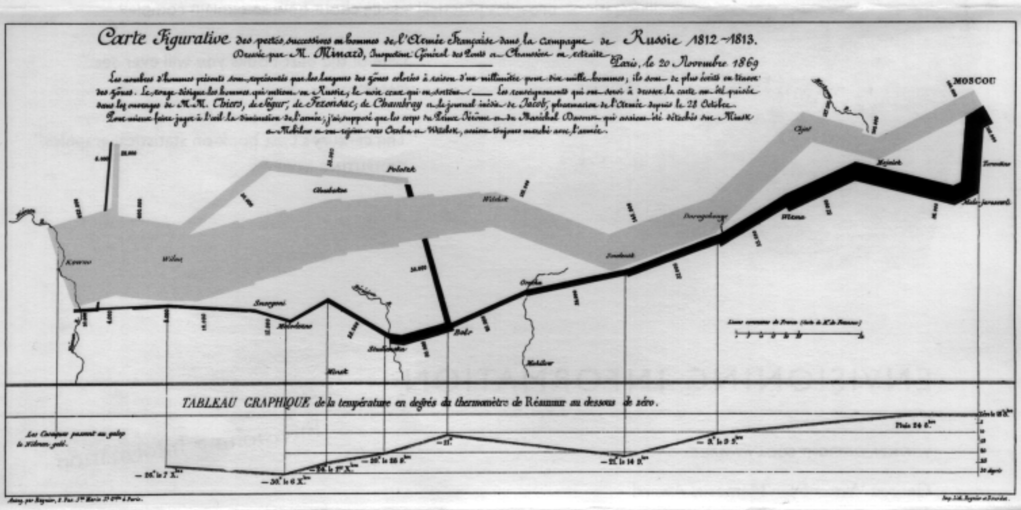
The Visual Display of Quantitative Information contains 250 illustrations of the best (and a few of the worst) statistical charts, graphics, and tables, with a detailed analysis of how to display quantitative data for precise, quick, effective analysis. Highest quality book design and production throughout.

This map drawn by Charles Joseph Minard portrays the losses suffered by Napoleon's army in the Russian campaign of 1812. Beginning at the left on the Polish-Russian border near the Niemen, the thick band shows the size



of the army (442,000 men) as it invaded Russia. The width of the band indicates the size of the army at each position. In September, the army reached Moscow with 100,000 men. The path of Napoleon's retreat from Moscow in the bitterly cold winter is depicted by the dark lower band, which is tied to temperature and time scales. The remains of the Grande Armée struggled out of Russia with 10,000 men. Minard's graphic tells a rich, coherent story with its multivariate data, far more enlightening than just a single number bouncing along over time. Six variables are plotted: the size of the army, its location on a two-dimensional surface, direction of the army's movement, and temperature on various dates during the retreat from Moscow. It may well be the best statistical graphic ever drawn.

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Promotional leaflet for Tufte, ER (1983)

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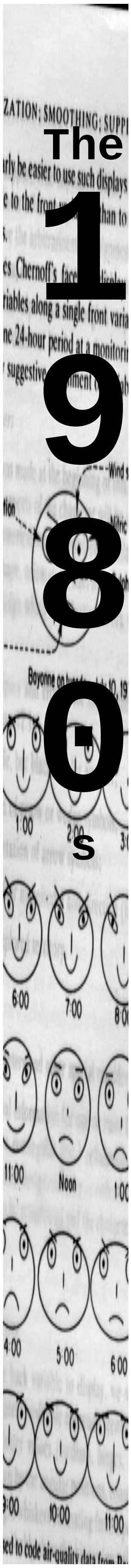

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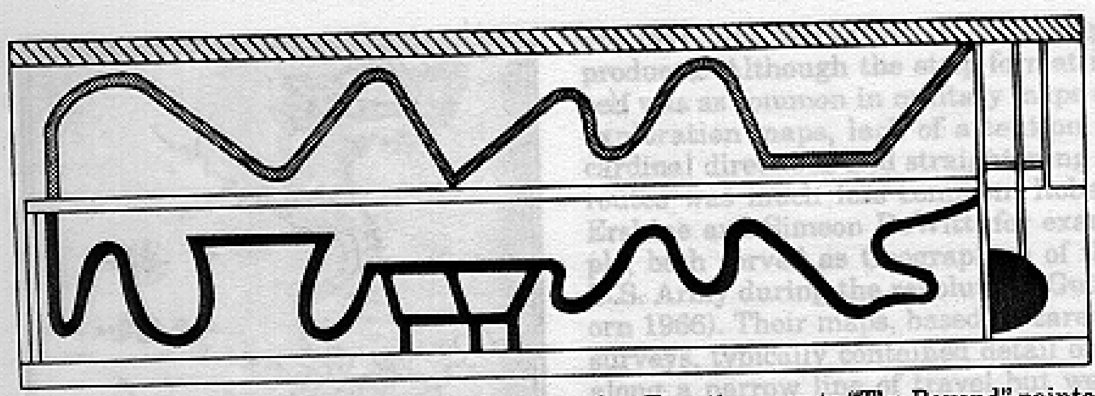

Figure 1. A representation of the main features of an Egyptian map to "The Beyond" painted on a coffin bottom. The water-way is on top and was represented in blue with the land-way in black on the lower half (after Bonacker, Figure 5, p. 13).

source: MacEachren, (1986)

	The 1980s: some key authors
1➲	Tobler, W
2●	Taylor, D
3●	MacEachren, A
	Carstensen, L
	Dobson, M
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	Monmonier, M
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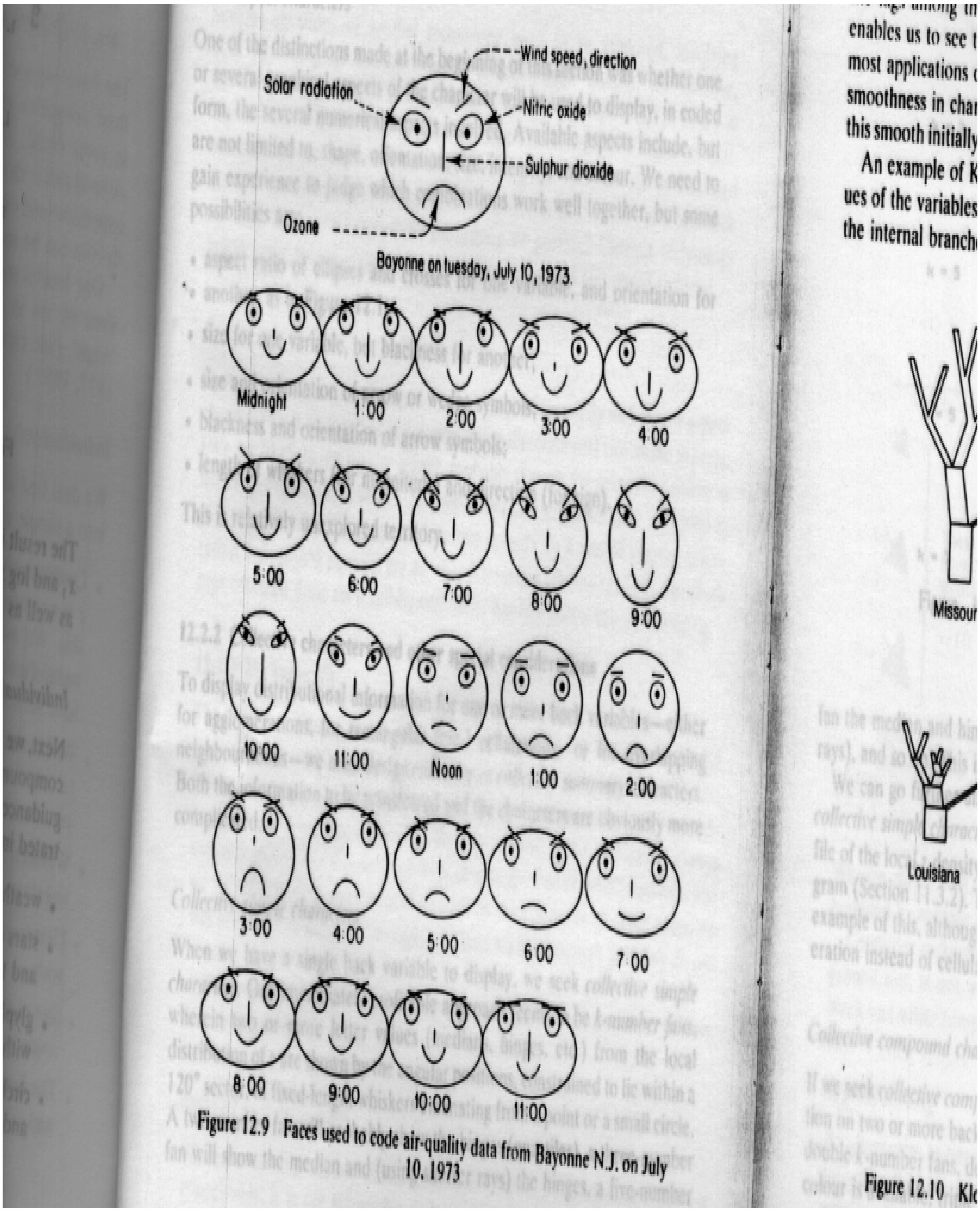

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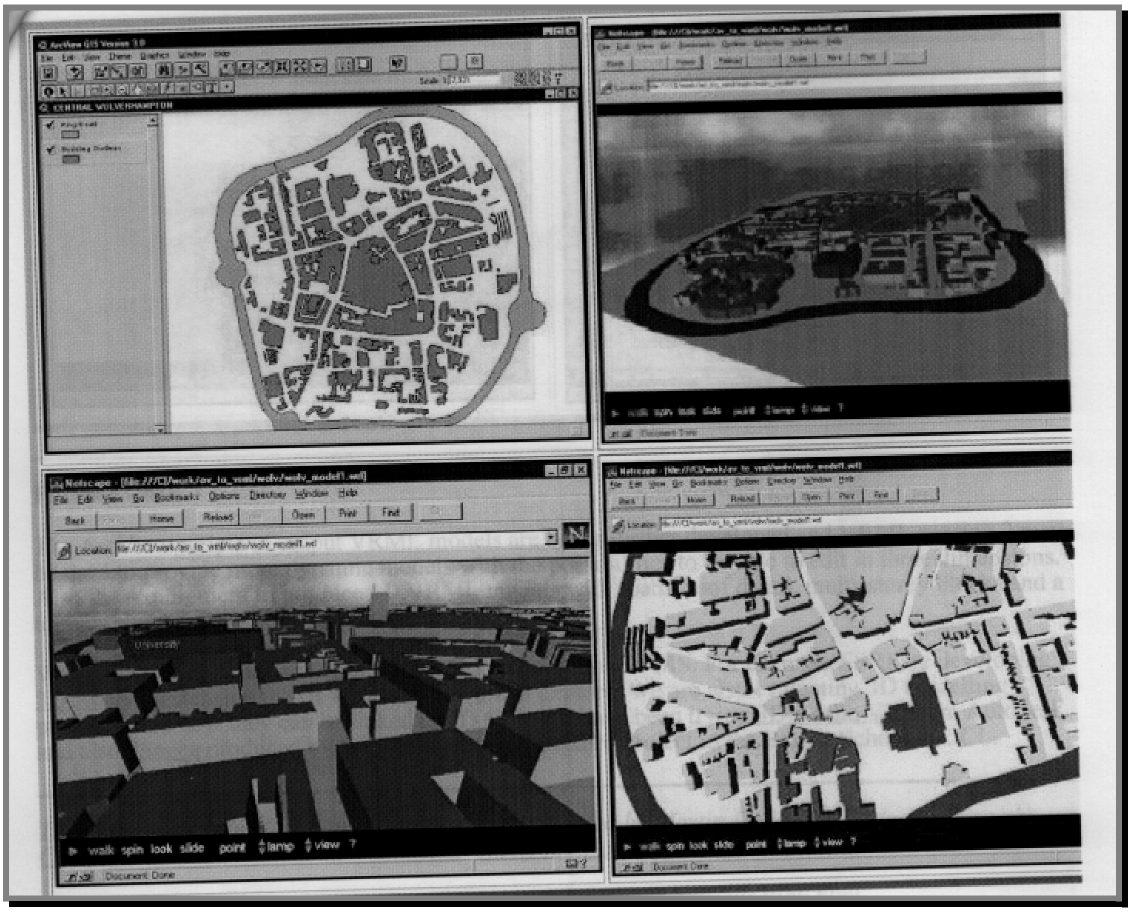

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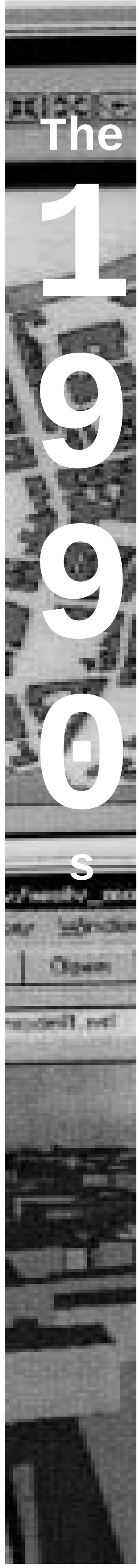

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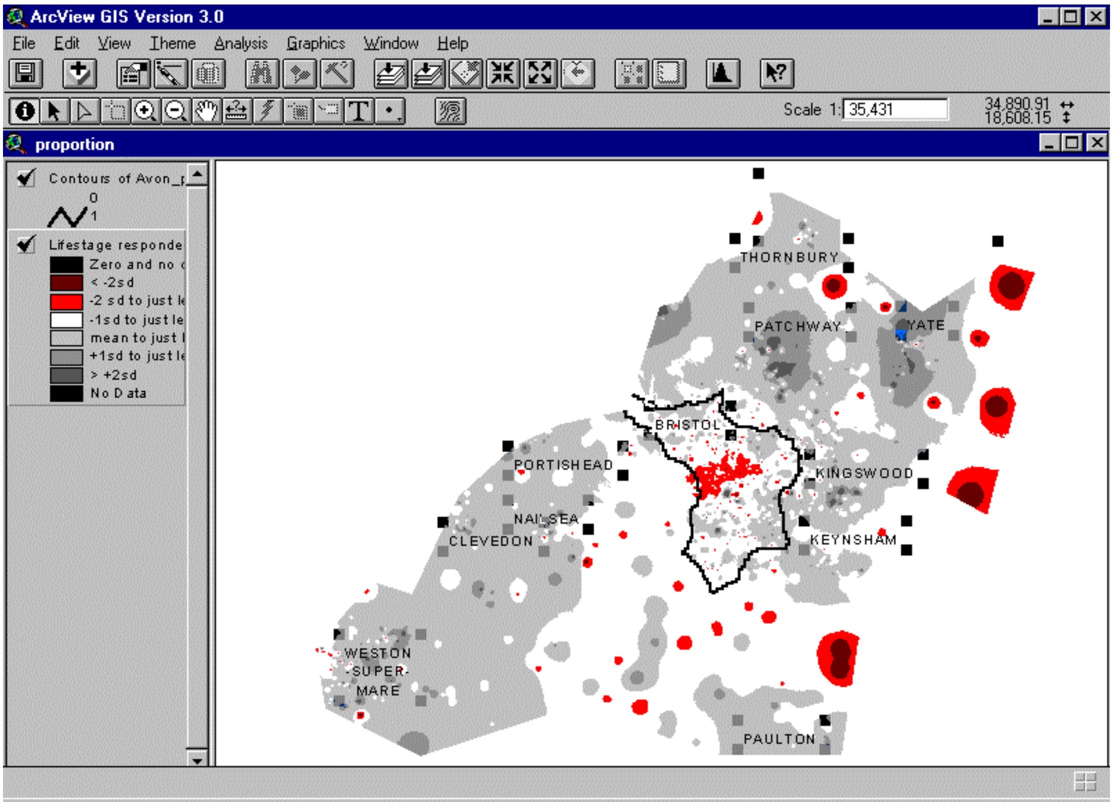
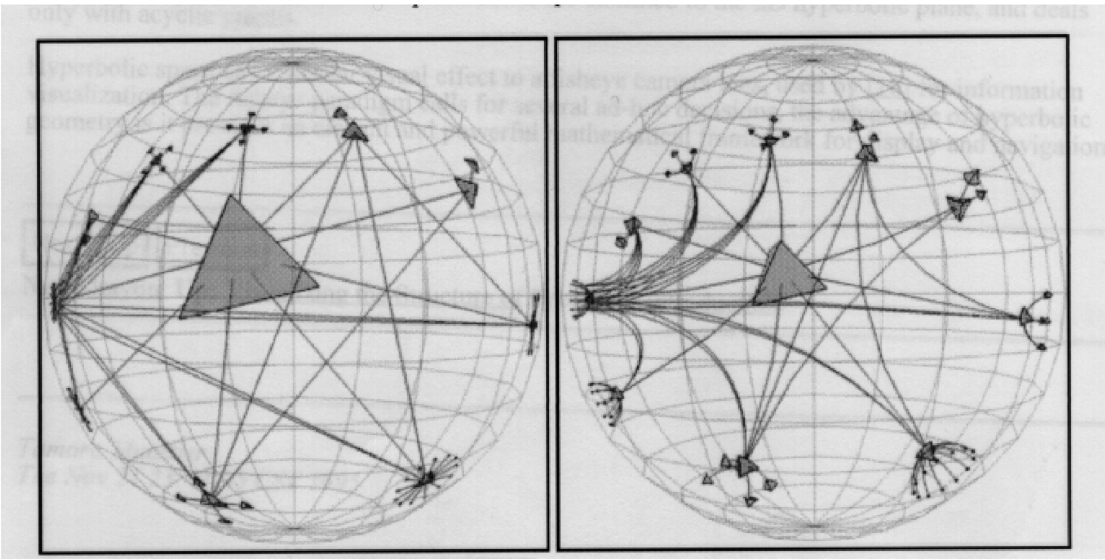


Screenshot from ESRI's ArcView GIS showing an interpolated surface of response rates to a 'consumer survey'
source: anon.

	The 1990s: some key authors
1◐	MacEachren, A
2●	Fisher, P
3●	Kraak, M-J
	Batty, M
	Bullenfield, D
	Dorling, D
	Jiang, B
	Monmonier, M
	Openshaw, S
	Unwin, D
	based upon 1990s bliography

The 1990s



'hyperbolic visualization'
source:
`http://www.geom.umn.edu/docs/research/webviz/webviz/node2.html`

The 1990s