THE UNIVERSITY OF HULL

Cartographic Information Systems Research Group
C.I.S.R.G.

Hon. Co-ordinator:
Dr. M. Visvalingam
Department of Computer Science
The University
HULL HU6 7RX

Tel. (0482) 465295/465951
Telex 592530

Discussion Paper Series Editors: Dr M Visvalingam
Dr M E Turner

C.I.S.R.G. DISCUSSION PAPER 9

Visualisation, VISC and Scientific Insight

by

M Visvalingam

May 1991

Discussion Papers

1. Wade, P., Visvalingam, M. and Kirby, G.H. (1986)
   From Line Geometry to Area Topology, 48 pp.

2. Visvalingam, M. (1987)
   Problems in the Design and Implementation of a GKS-based User Interface for a Graphical Information System, 18 pp.

3. Visvalingam, M. (1988)
   Standardising Basic Spatial Units : Problems and Prospects, 19 pp.

4. Whyatt, J. D. and Wade, P. R. (1988)
   The Douglas-Peucker Algorithm for Line Simplification: an introduction with programs, 17 pp.

5. Visvalingam, M. (1988)
   Cartography, Geographical Information Systems and Maps in Perspective, 16 pp.

6. Visvalingam, M. and Whyatt, J. D. (1989)
   The Douglas-Peucker Algorithm for Line Simplification: re-evaluation through visualisation, 35 pp.

7. Visvalingam, M. (1989)
   Trends and Concerns in Digital Cartography, 37 pp.

8. Visvalingam, M. and Whyatt, J D. (1990)
   Cartographic Algorithms : problems of implementation and evaluation and the impact of digiting errors, 24 pp.

9 Visvalingam, M. (1991)
   Visualisation, VISC and Scientific Insight, 21 pp

Special Issues

1. Visvalingam, M. (ed) (1986)
   Research based on Ordnance Survey Small-Scales Digital Data Proceedings of a meeting held as part of the 1986 Annual Conference of the Institute of British Geographers (Reading, Jan 1986), **sponsored by the Ordnance Survey,** 79 pp.

2. Visvalingam, M. and Kirby, G. H. (1987)
   Directory of Research and Development based on Ordnance Survey Small Scales Digital Data, **sponsored by the Ordnance Survey,** 38 pp.

3. Visvalingam, M. and Sekouris, N. M. (1989)
   Management of Digital Map Data Using a Relational Database Model, **sponsored by the Ordnance Survey,** 50 pp.

C O N T E N T S

LIST OF FIGURES

1. Introduction

The report by McCormick et al (1987) on Visualisation in Scientific Computing (ViSC) played a major role in drawing attention to the increasing need and scope for visual computing. There is no doubt that developments in computer-based technology will greatly extend human capacity for visualisation. The invention of the microscope and telescope led to breakthroughs in many scientific disciplines. These tools not only enabled Man to see the otherwise unseeable but they also enabled empirical evaluation of pre-existing theory. Similarly, imaging systems and computer graphics are further enabling Man to see the unseeable and are becoming vital tools of research in some disciplines. A wide range of phenomena, which exist either outside our sensory limits or which exist only in our imagination, may be rendered visual. The technology for this is already well developed and the euphoria over ViSC is justifiable.

However, McCormick et al appear to limit the definition of visualisation to the technological capability to make data about phenomena visible. Haber and McNabb (1990) assumed this view; their characterisation of the process of visualisation appears dated and limited, particularly when seen in the context of the much cited statement by Hamming that "The purpose of computing is insight, not numbers".

This paper examines the views expressed by Haber and McNabb in some detail since these elaborate on the views of McCormick et al and are likely to have a major influence on further development and application of ViSC. It considers the reasons for distinguishing between visualisation (the human process) and ViSC (the emerging socio-technical system for visual computing). The latter is also known as Scientific Visualisation (SV). The paper argues the need for a comprehensive model of visualisation which takes into account the modes of scientific enquiry, the nature of creative thinking and the psychology of visualisation. Current capabilities and applications should be located within such a model so that other neglected aspects of visualisation can be identified and better served.

2. Background

McCormick et al (1987, p 3) expressed the view that "Visualisation is a method of computing. It transforms the symbolic into the geometric, enabling researchers to observe their simulations and computations. Visualisation offers a method for seeing the unseen". This view has been echoed by several other technologists. Haber and McNabb (1990, p 75) defined visualisation as "a series of transformations that convert raw simulation data into a displayable image. The goal of the transformations is to convert the information into a format amenable to understanding by the human perceptual system". They went on to characterise the process of visualisation as involving a sequence of transformational processes, namely

* data enrichment/enhancement transformations; these convert raw to derived data
* visualisation mapping; which transforms the derived data into an Abstract Visualisation Object (AVO)
* rendering; which transforms the AVO into a displayable image

Many of the ideas expressed by Haber and McNabb appear reasonable and correspond to concepts in other disciplines, such as digital cartography and Geographical Information Systems (GIS). Others are debatable. In all, their characterisation of the process and value of visualisation appears partial.

3. Discussion

3.1 Definition of visualisation

As the Oxford English Dictionary states, visualisation is generally understood to be, "the power or process of forming a mental picture or vision of something not actually present to the sight" and "a picture thus formed". The visual imagery may arise through perception but it is more commonly applied to internally generated images (The Macmillan Dictionary of Psychology, 1989). Thus, to visualise is to make visible in the mind or imagination an image (of something not visible to the sight, or an abstraction). This is the primary and popular definition of visualisation.

However, some dictionaries (including Websters, Longmans and Collins) provide another definition of visualisation as the process of exposing an organ to view by surgery or by x-ray photography. This is clearly a technical definition of visualisation which could no doubt be extended easily to include the use of computer graphics and imaging systems for making visible the otherwise unseen. This narrower definition limits the role of visualisation to one of facilitating visual perception (observation and recognition) in science and engineering. Visual thinking and visual insight are not the products of visual stimuli alone. For example, an innumerate person can see a visual representation of solutions to differential equations without being able to visualise the concept. Without such visualisation it would be impossible to follow an argument based on the image. Thus, "there is more to it [visualisation] than meets the eye".

Haber and McNabb's definition of visualisation is therefore valid but it is potentially confusing and unnecessarily limiting as we shall see later.

3.2 The model of visualisation

Furthermore, the process of visualisation as characterised (modelled) by Haber and McNabb is not a new one. Many scientists recognise it as what they have been doing for some 20 years. In cartography, that sequence forms part of the familiar sequence in mapping. The visualisation steps could be mapped onto digital mapping, application-dependent modelling and visual mapping (see Figure 1). Thus, another objection to the limited definition of visualisation is that it gives the impression that it is just "a new name for an old game". This would be counter productive since ViSC offers exciting new potential which is not revealed by Haber and McNabb's model of ViSC but which is implied in Figure 1 (which incidentally is not intended to be a model of visualisation).

3.3 The visualisation system

Haber and McNabb recognised and discussed the critical role of the intellectual phases of modelling and solution in simulations. However, they excluded such mental visualisations of the nature of simulated phenomena from their model of visualisation. They restricted the latter to the visual postprocessing of raw data. The resulting images are deemed to play an important role in the interpretation, evaluation and revision of solutions. Again these cognitive activities did not feature in their model. Consequently, Haber and McNabb placed the emphasis on the variable methods

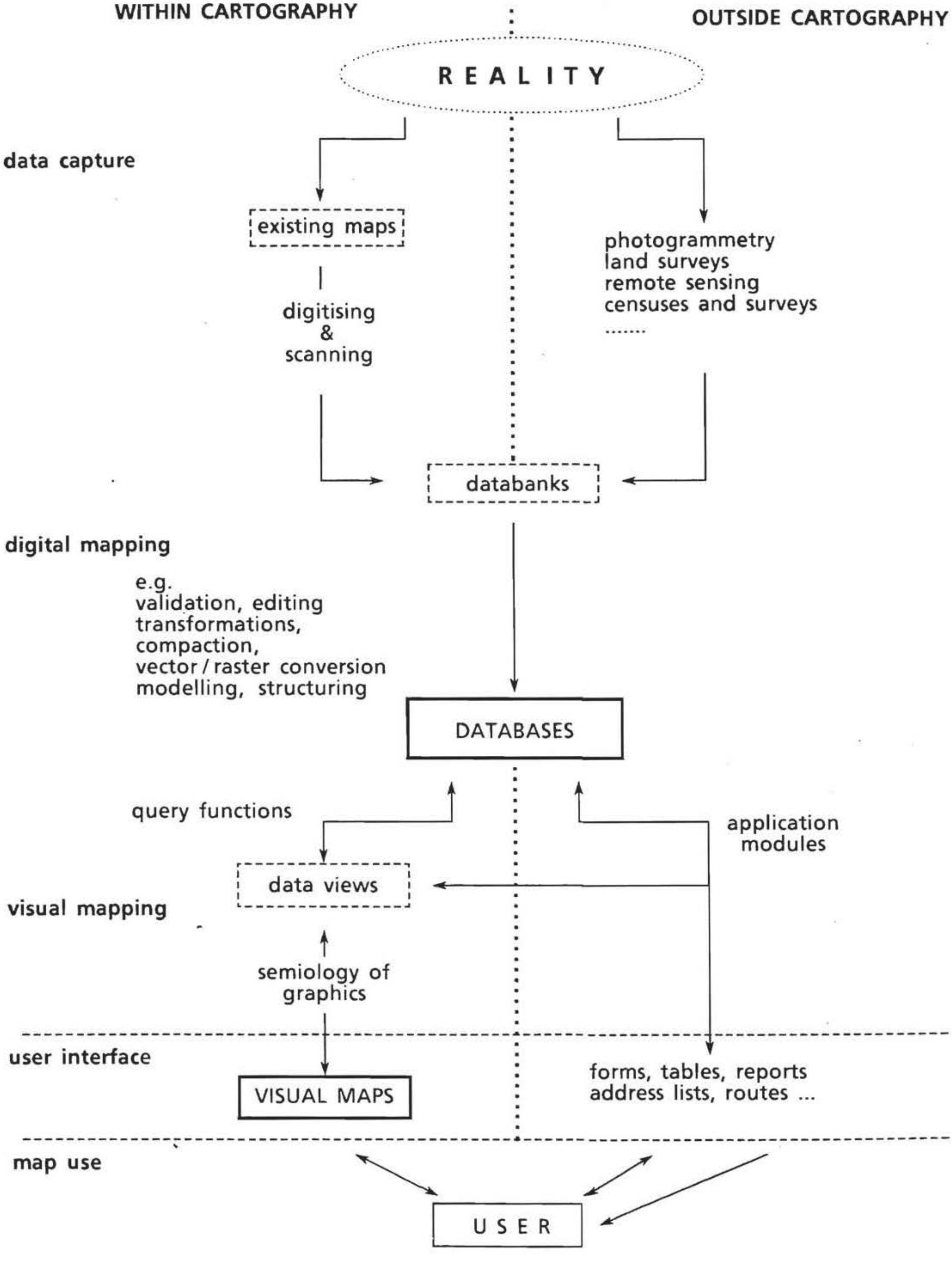

Figure 1 : Scope of Digital Cartography and Geographical Information Systems

Adapted from Visvalingam (1989)

for picture generation and deliberately excluded the critical mental processes which initially conceive and formulate and later verify these images. Their model of visualisation does not consider the potential interactions which could occur within an integrated psycho-technical system for visualisation. We consider these issues in more detail below.

Haber and McNabb identified three visualisation modes, namely post-simulation analysis, runtime monitoring and interactive steering. They pointed out that high-end hardware performance has improved dramatically and that their exploitation for interactive visualisation is hindered by the lack of appropriate systems. We agree here. The goal of their RIVERS project was to extend visualisation from a batch procedure to a real-time interactive process. They stated that real-time interactive steering closes the loop between the simulation and visualisation systems. This gives the analyst immediate visual feedback about the effects of making changes at run-time to parameters of the various transformations in the visualisation sequence. However, even after elaboration for user configuration at run-time, their data-flow diagrams (p 88 - 89) indicate only a one-way flow of data. Consequently, the interaction effectively supports only iterative picture generation. Their ambition was to upgrade the mode of visualisation from a batch to an interactive one. Whilst this is necessary and laudable, it offers only a dated and uninspiring vision of the potential scope of scientific visualisation systems. With the growing popularity of object-oriented WIMP systems and the escalating interest in multimedia hypertext, even the general public are aware of the growing potential for interactive exploration of data and/or information.

Researchers in disciplines such as cartography, are excited not just by the convenience with which they may generate and fine-tune alternative visualisations of complex phenomena and processes, but more so by the expanding scope for treating such displays as two-way virtual devices for probing and investigating the phenomena by direct exploration of the abstract data model and of raw data as indicated in Figure 1. Just as the left and right hemispheres of the brain hold and communicate separate encodings of the same phenomena, there is a need for interaction between the dual complementary representations of the same phenomena in the database (digital map) and in image form (visual maps).

The ability to transform geometrically, animate, slice, expose layers and change the colour mappings of three-dimensional and volume visualisations is no doubt of great value to many scientific applications. Haber and McNabb's data flow diagrams accommodated these forms of investigation. However, visual thinking requires much greater flexibility. Already image processing systems offer the scope for not only generating multiple views of the same data but also for effecting changes in related displays by direct manipulation of the underlying model through key displays, such as histograms. A Tektronix 4406 AI Workstation running Smalltalk was supplied to us in 1986 with a prototype expert system for trouble-shooting by cross-referencing of displays of a printed circuit board and its network schematics, a table of component parts, a rule set and help information to the operator. Visvalingam (1985) described how manual cross-referencing of a set of displays and tables of data led to insights about socio-spatial data. Visvalingam and Whyatt (1990 and 1991) described the value of such visual cross-referencing in the evaluation of line simplification algorithms.

These and similar investigations, conducted since the mid-1970s, have relied on laborious manual cross-referencing of elements on different displays with the help of basic computer graphics. Often when embarking on such visual explorations, it is not possible to predict in advance the number or type of displays required nor the manner in which they will be cross-referenced. There is a two-way, fine-grained connection between displays and the applications which drive them. An application module must not only be capable of generating the initial display according to set parameters and modifying it when parameters are changed, it must also be capable of selectively responding to user manipulations of the display. Each display process too must be capable of responding at any time to either direct manipulation by the user or to transformations of user input routed through the driving application. Moreover, the operation of two-way virtual graphic devices requires the definition of an appropriate minimal set of mappings for effecting transformations in the reverse direction to that indicated by Haber and McNabb. Some of these ideas were explored by Visvalingam (1987), who was concerned with the inadequacy of the Graphical Kernel System for this purpose.

3.4 The focus on scientific insight

Computer graphics is already serving a variety of uses, from graphic design and art to communication of information. Systems for scientific visualisation must subsume some of these functions, especially the concepts and techniques for communication of information. However, as stressed by McCormick et al, the new quest of ViSC is the exploitation of developments in technology for invoking scientific insight. We too believe that ViSC could become part of the apparatus of science but we do not believe that it does so adequately at present. This is partly because computer graphics has been concerned mainly with the achievement of realism. Pretty pictures and entrancing movies may tickle the senses and generate visual insight but can they on their own generate intellectual insight? No doubt, developments in imaging and computer graphics technology, spurred initially by the lucrative markets in advertising and media communications, are already finding uses in engineering and medicine. But, can this technology be used to extend the frontiers of science? Science seeks to explain phenomena not just understand data. We also need to examine the nature of scientific insight and its perceived role within the broader spectrum of science lest we distort the role of ViSC within science. We will now outline our thoughts on these matters in the hope that it spurs wider discussion.

The direction of advance in computer graphics

Although two-dimensional computer graphics continues to have many uses, the thrust of computer graphics has been towards the achievement of simulated realism in three-dimensional, volumetric and animated graphics. These developments have been spurred by many sponsoring applications, from flight simulation and media advertising to medical imaging and environmental impact analysis. Within science such realism articulates the requirements of empiricism. However, as Einstein pointed out, empiricism is only the beginning and end of science - it is not the major source of scientific insight. He believed that "pure thought is competent to comprehend the real as the ancients dreamed" (see Madden, 1960, p 83). He expressed the view that every attempt at logical deduction of the basic concepts and postulates of mechanics from elementary experiences is doomed to failure. Scientific insights are often grounded on successive layers of logically-derived concepts. The capacity to derive such abstractions varies from individual to individual but it is believed to be essential for pattern recognition, a task which humans can still perform better than computers.

Haber and McNabb referred to the very important issue of accuracy versus efficiency in rendering and noted that accuracy should not imply photorealism. Simple models, such as Lambert's cosine law of diffuse reflection, were regarded as potentially more useful than more elaborate ones, such as radiosity and ray tracing. This merely limits the degree of realism for reasons of computational efficiency. We need to promote efficient human processing through abstraction. The latter runs counter (in reverse direction) to the traditional pre-occupation of computer graphics with realism. Visual thinking involves abstraction and graphic notation. The process of adding calculated realism to abstract descriptions of objects and scenes is thus contrary to the requirements of visual thinking. Scientific applications of Cartography employ a variety of transformational processes to derive abstractions about reality and then to describe these through generalised graphic symbolism. The map is a graphic precis of reality.

Whilst there have been considerable advances in the achievement of realism there have not been corresponding advances in automated generalisation nor map design. Automated map production is still limited to the realm of map reproduction rather than creative visualisation. Despite more than 20 years of research we still do not have algorithms which can emulate the cartographer's skill in map generalisation and name placement. Kasturi et al (1989) pointed to some contemporary research on aspects of this problem. Even seemingly trivial tasks, like line simplification, are not performed adequately by even the most celebrated line simplification algorithm in cartography, which is also used in pattern recognition (Visvalingam and Whyatt, 1990 & 1991). Consequently, the ideal goal of a scale-free database is not yet feasible (DoE, 1987). Existing systems for visualisation cannot as yet produce the stylised images which a skilled cartographer can create. This is because we do not fully understand the process of visualisation, which is partly unconscious and intuitive.

Creative thinking

Wallas (1926) suggested that creative thinking involves four stages, namely preparation, incubation, illumination and verification. ViSC can facilitate preparation and verification but incubation and illumination are mental stages. As Gregory and Zangwell (1987) put it, in order to innovate, scientists must break the grip imposed on our imagination by the powers of logical story-telling; we must be willing to subvert the conventional wisdom on which our everyday competence depends. We do this without difficulty in dreams. The unconscious is known to have led to many a "Eureka" in science. Often the vision is symbolic. For example, the dream of a snake biting its tail was seen by Kekule as the clue to the structure of the benzene ring.

Scientific visualisation need not be spontaneous; it could be directed but it implies the power and the process of abstracting and representing the essence of a complex problem in symbolic or schematic, and not just photorealistic, form. In discussions about the psychology of his creative work, Einstein (see Madden, 1960, p 90) stated that the "physical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be 'voluntarily' reproduced and combined.... taken from the psychological viewpoint, this combinatory play seems to be the essential feature in productive thought." It is only when this associated play is sufficiently established and can be produced at will does the laborious process of "connection with the logical construction in words or other signs which can be communicated to others" begin.

We are not all Einsteins and we need to externalise our visualisations in order to develop and refine our thoughts and spur our imagination. Productive thinking is characterised by divergent thinking (Gregory and Zangwell, 1987). Divergent, like lateral, thinking does not rely necessarily on logical deduction. Current systems for visualisation do not encourage a "combinatory play" with multiple images; they do, however, offer opportunities for brain storming which could reveal anomalies or unexpected trends and patterns during the preparation stage. But the current euphoria over the prospect brain storming with ViSC must be tempered by at least a basic understanding of the nature of the scientific apparatus.

The apparatus of science

The scientific apparatus, like all good tools, is constructed and used in a manner which fits its purpose. Some instruments, like the barometer, were specifically developed to fit in with and further the process of scientific explanation. When the existence of a prototype telescope was brought to the attention of Galileo, he saw the potential that it offered and sought to understand and modify the principles underpinning its construction so that it could become an instrument of science. Scientists do not normally use any tool at hand without it first becoming a part of the framework of science. The euphoric literature on ViSC gives the impression that sheer eye-balling of coloured displays and entrancing movies could somehow generate insight although McCormick et al did point out that "the most exciting potential of widespread availability of visualisation tools is not the entrancing movies produced, but the insight gained and mistakes understood by spotting visual anomalies while computing". Even this requires some a priori expectations.

The skill in seeing

Scientific instruments, particularly when in prototype form, do not reveal the hitherto unseen in a direct and unproblematic way. It is theory that helps the prepared mind extract significant objects and relationships from artefacts, noise and other contextual information. Many readers will have come across images which may be seen in different ways, for example as a young woman or an old hag. The presence of illusions, subjective contours, ambiguities and artefacts in images are discussed in the texts by Rock (1990) and Gordon (1989). It is well known that visual images have the power not only to add clarity and spur insight but equally to distort reality and mislead the uncritical. Reichmann (1961) wrote on the use and misuse of statistics. Others, such as Monmonier (1977), Bertin (1983) and Tufte (1983), have shown that it is equally easy to become confused, even if not deceived, by graphics.

Furthermore, as Comte is reported to have pointed out in 1829, our eyes would not even notice relevant facts unless they were guided by prior expectations. Unless we are actively looking for an insight the meaning of an image may be completely lost. The snake in the dream would have meant nothing to most chemists but Kekule recognised its significance and appreciated that it was the shape and not any logical or mystical significance of the serpent that was significant as it was in many cultures and religions, including Christianity. The mind of Kekule was looking for the shape.

Seeing is a subjective process; this is why the sciences have sought more objective and replicable quantitative procedures.

ViSC within the process of science

ViSC is being offered as a tool for understanding data and invoking insight. We do not deny the potential offered by ViSC for this purpose. However, this under-sells the potential role and value of ViSC to science. Insight plays an undeniable role within science. It does not have to be massive nor revolutionise to advance science. A fertile mind can derive insight from a variety of sources - past experience, intuition, dreams, accidents and false starts. While ViSC can serve the insightful mind, it must be appreciated that mere technology cannot of itself make competent but conventional and conforming minds more creative. There is, however, the distinct danger that ViSC could become a sophisticated game. The UK Science and Engineering Research Council (1989, p 8) cautioned postgraduates and their supervisors that a common reason for students not completing their thesis within the allotted time is because they get 'hooked on' computing. Whether ViSC contributes towards the making of genius, to mental constipation or to diversionary activities depends upon the mind and inclinations of the individual scientist.

The source of insight is not the central concern within modern science; it appears to be of greater interest to the history and philosophy of science since even modern psychology seems more inclined towards investigating matters which may be subjected to the scientific method. An insight only assumes a place within science if it is productive, verifiable and proven to be probably true and useful. The insight therefore must lead to the formulation of useful and testable hypotheses. As science advances it becomes more theoretical. Whereas facts may be verified by an appeal to primary sources of knowledge and immediate experience, hypotheses and theories are often verified by laborious and indirect means which involve semantic mapping of abstract concepts and symbols onto everyday concepts and experiences. Unlike an artist who is free to express his personal insight and visualisation in a free and unfettered manner, the scientist must explore the many ramifications and implications of his unique insight and develop a convincing argument in support of his propositions. ViSC can expedite this stage of verification. Once the evidence is sufficiently established to win support, the process of verification is continued as a part of the humdrum of normal science by a community of scientists. The bulk of scientific activity is concerned with the verification, refinement and application of insights. This relies on the existence of a pool of tacit knowledge about the domain of inquiry and appropriate methods of investigation.

The language of mathematics has been the primary tool for symbolic abstraction and manipulation of concepts. The emerging field of Scientific Visualisation is based on the proposition that the symbolic language of graphics is an equally powerful tool for visual thinking. The French cartographer Bertin (1983) had already advocated this in 1967 noting that the eye-brain system can 'see' multiple and complex patterns in a single well-designed visual display of data. If ViSC can transcend photorealism and address the need for a "combinatory play" with symbolic graphics through direct manipulation, it can become a powerful tool not just for observation and simulation but also for ideation and expression; i.e. it will become valued not just as another means for invoking insight but also, and perhaps more importantly, as a convenient and flexible apparatus for developing and verifying it.

3.5 Visualisation Idioms

Haber and McNabb (p 87) pointed out that "scientists and engineers are no more willing to get involved with graphics languages, windowing systems, communications mechanisms, and the like than they are to write low-level device drivers". Scientists are equally likely to be put off by unnecessary jargon such as the term, 'visualisation idiom', coined by Haber and McNabb. This jargon does not really convey anything new. Moreover, inadvertantly, it places the emphasis on the communicative, rather than on the exploratory, role of graphics as explained below.

Haber and McNabb cited Websters Dictionary definition of an idiom as "an accepted phrase, construction or expression .... having a meaning different from the literal". The term idiom also has a further connotation; it is often a discrete expression characteristic of a particular form of spoken or written language which is not logically or grammatically explicable (Chambers 20th Century Dictionary). This implies that an idiom has a specific meaning, endowed by usage, which need not necessarily be derived from the logical meaning or grammatical structure of the words, as in the idiom "It is raining cats and dogs".

Haber and McNabb stated that just as a listener has difficulty understanding a verbal idiom in a foreign language, a viewer is unable to interpret a graphic display without understanding the steps in the 'visualisation idiom' used to generate it. They defined a 'visualisation idiom' as any specific sequence of the transformations (see Section 2) that produce an abstract display of a scientific data set. They used different examples of 'visualisation idioms' to demonstrate the scope for user configurability and to point out that minor variations in the mapping transformations (note this reversal to the phrase "mapping transformations", which has been more widely used in the past in place of visualisation) can lead to dramatic changes in the final images. They suggested that proper technical documentation and visual aids are essential for proper understanding of both the process of visualisation and the display. Equally, they believed that visualisation idioms should not require excessive effort or explanation for qualitative understanding; AVOs should therefore be based on intuitive analogies which take into account human factors.

Scientists have an obligation to be precise about the meaning of jargon they use. We found it difficult to understand and thus adopt the term, 'visualisation idiom', because we cannot grasp its intended value. We suggest below that this is due to differences in our assumptions about the formal language of graphics and its role in scientific enquiry.

It is difficult to generalise about the complex medium of visual imagery since it takes different forms to serve a variety of quite different purposes. A full exploration of the nature of graphics is irrelevant to our objection to the phrase, 'visualisation idiom'. The thread of our argument starts with the popular assumption that graphics is a natural language for communication. The ease of use of Graphical User Interfaces (GUIs) by direct manipulation of widgets and icons has persuaded many to accept the vendor's claim that graphics is natural. They have thus come to expect that all graphics should be natural. Haber and McNabb, for example, believed that AVOs could be made intuitive by use of appropriate analogies.

There is no doubt that graphic representations of experienced reality may be grasped intuitively. Such reproductions need not be real nor photo-realistic. Neither do we need to know how they were produced to share the dreams (visualisations) of the creators of Luxor Jnr and Snow White nor to experience virtual reality in a simulator. However, as noted earlier, scientific visualisation is not always about the tangible and it is not always possible to map abstract concepts onto intuitively grasped forms. Directed thinking is expedited by symbolic languages, such as mathematics, chemical nomenclatures and notations (Cooke-Fox et al, 1989), and the natural languages. We do not expect a scientist to perceive intuitively some insight in some mathematical expression without some appreciation of mathematical principles and notations. A scientist cannot write papers without a grasp of the vocabulary and grammar, let alone the nuances, of the language of communication. Yet, it appears that we somehow assume that graphicacy (a term coined by Balchin, 1972) is universal.

Haber and McNabb recognised that not all visualisations are intuitively grasped and implied that this is due to a lack of consideration of human factors and the presence of idioms. They also implied that these problems may be resolved by user-centred design, technical documentation and on-screen keys and legend. We are not questioning the value or requirement for such measures. Instead, we are concerned a) by the assumption that a need for explanatory legend implies the presence of idioms and b) by the lack of stress on the need for education and training in mental visualisation.

In theory, using ViSC systems, even 5 year olds should be able to turn out displays by plugging together modules from libraries in the same way that many are already able to produce pretty maps of dubious value given a base map on a 'paint' system. Whilst catchy phrases like 'hi' or 'the mind boggles' can easily become idioms of a language by popular usage, arbitrary mappings seldom become a part of the idiolect of a science. The abstractions and the graphic representations must be logically derived to facilitate the intended mental visualisations even though disciplines, such as cartography, do encourage some limited measure of artistic licence. This is to provide some latitude for minor adjustment to facilitate a stretch of the imagination which is necessary to achieve the desired mental visualisation. Cartographic maps are of different kinds (Robinson et al, 1984). Intuitively perceived maps are largely used for purposes of communication, especially when directed at those not trained in the use of graphics. Analytical maps, which support scientific research, can be much more complicated. It is expected that the scientist has been educated and trained in the processes of construction and use of these logically-derived graphic formalisms as a part of his apprenticeship.

For a cartographic map communicates more by implication than by direct representation. The US Weather Service began to automate the production of daily weather maps in 1960. Despite the sophistication of modern computer graphics systems and some 30 years of progress, computers still cannot automatically insert the frontal systems depicted in Figure 2 satisfactorily (Chris Little, UK Meteorological Office, personal communication). Note that weather forecasters are required to add elements of the display manually in order to facilitate the required mental visualisation; computers merely assist by performing the necessary housekeeping, calculation and drafting tasks. Similarly, given a complex colour-coded geological map, skilled geologists can not only see the two-dimensional representation that we all see, but they can also visualise the pattern of outcrop of the lithology on the three-dimensional terrain, infer the form of the underlying geology and derive the geological history of the area (Boulter, 1989). Scientific displays are not idiomatic; mere understanding of the mechanics of construction and of the legend and other explanatory information, on their own, cannot enable naive users to correctly visualise what they see. Those uneducated in the use of graphics often confuse a bar chart with a histogram. Visual manipulation of even the relatively simple histogram requires some elementary knowledge of statistical concepts and training in the interpretation of histogram shapes. Authors of documentation, accompanying some leading business graphics packages, appear to lack such elementary knowledge.

To recapitulate, we have argued that scientific graphics need not be intuitive and that visualisation is not only dependent on the availability of other key information but, more so, on education and training. However, the emerging discipline of Scientific Visualisation seeks to expedite the extra-ordinary science which leads to insights and breakthroughs. The scientist pursuing extra-ordinary science should not be limited by the practices of normal, or what Kuhn (1970) called paradigmatic, science. Haber and McNabb's notion that a visualisation may be like an 'idiom' in a foreign language implies either

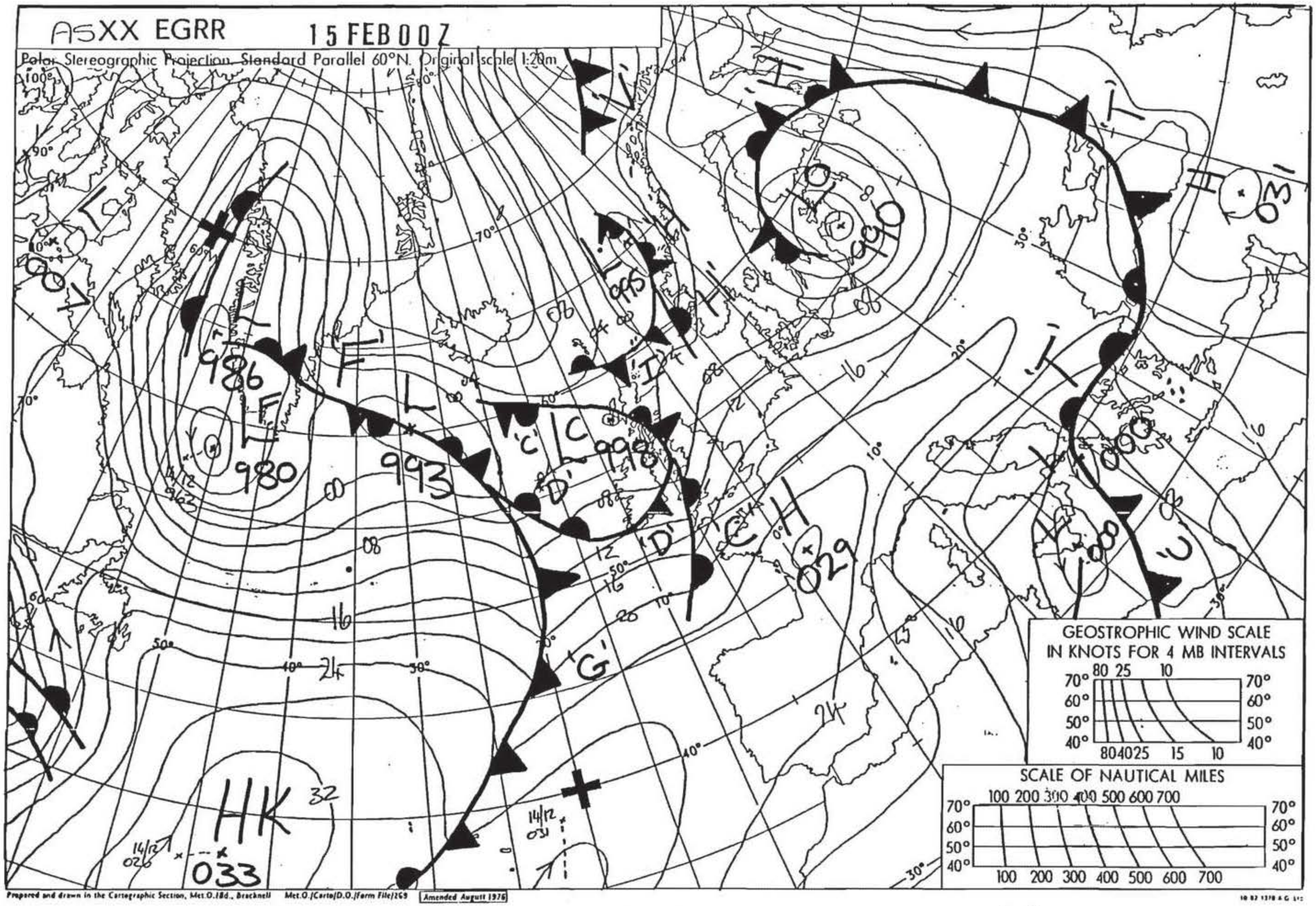

Figure 2 : Visualisation of surface pressure and fronts in North Atlantic

(Source: Crown Copywright, courtesy of Chris Little, UK Meteorological Office)

that the scientist is not driving the visualisation but is a mere viewer or that he is pursuing the visualisation for purposes of communication rather than for gaining insight. If Haber and McNabb were actually suggesting that scientists, untrained in mapping, may find it helpful to copy and adapt 'visualisation idioms' (exemplary mapping styles embodying proven strategies?), this could be construed as fostering the reproductive thinking of paradigmatic science, rather than the divergent productive thinking which underpins blue sky research. We hope that they were implying instead that it might be useful to compile catalogues of exemplary mapping styles and their applications since there is obviously a need for education and training in ViSC-assisted visualisation. (Incidentally, even when we use nominally similar styles, they could carry different interpretations because of other implied factors. Visvalingam (1990) considered how a great deal of confusion about Geographical Information Systems is generated by misinterpretation of superficially similar processes and forms within applications which have widely varying concerns with disparate data and analytical requirements.)

The insightful scientist must be free to dream his own 'dreams'. ViSC must support both ordinary and extra-ordinary science but if its distinctive aim is to spur insight then it must become more flexible; it should not constrain the scientist's scope for a 'combinatory play' with his own 'dreams'.

3.6 Dimensionality

This leads us to a further observation, namely the disdain with which some technologists (we do not class Haber and McNabb in this group) view mere black and white two-dimensional displays. When appropriate, we ought to take advantage of the additional potential offered by colour, 3D projections, animation, virtual reality, sensory feedback and other developments. However, it is important to stress that scientific phenomena co-exist within the multidimensional complex of space, time and other variables, which may themselves be complex. Technology now offers the scope for turning out 'lively' visualisations which simultaneously portray as many of these dimensions as possible on a single display through conjoint use of a variety of perceptual cues. Such elaborate pictures of elementary data can block (in)sight of trends and patterns. Understanding is facilitated by simplification. This often involves a reduction in the dimensionality, scale of measurement, categorisation and/or other characterisations of the phenomena. There is no reason why exploratory visual thinking should not involve a 'combinatory play' with alternative two-dimensional representations of complex phenomena if, by their very simplicity, they facilitated the flight of the individual scientist's imagination. Some technologists appear to confuse picture generation with visualisation and graphic sophistication with scientific progress. Where would organic chemistry be without its two-dimensional, monochrome, chemical structure diagrams?

4. Conclusion

Although ViSC represents an amalgam of relatively more mature disciplines, such as Computer Graphics, Image Processing and Human-Computer Interaction, and subsumes some of their aims, it is regarded as a new field. This status is not just related to the desire to harnass the potential of high performance hardware or to comprehend the vast volumes of automatically gathered data through graphic and other means of direct perception. Scientists and technologists alike believe that ViSC could be shaped into a unique scientific apparatus, capable to engendering insight and new breakthroughs in science. ViSC products are already in the market. It is important that the concepts underpinning ViSC are debated before current 'prototypes' assume the status of standards by their sheer leading presence. The contribution by Haber and McNabb provided a useful starting point for this debate because it is an authoritative source which described some of the major ideas underpinning and shaping this technology.

Many writers, including Haber and McNabb and McCormick et al, appear to mistake ViSC for visualisation. Diagrammatic depictions of ViSC present it as a one-way process, ignoring the current vogue for exploration of graphical elements on related displays through direct manipulation. The model of visualisation is inadequate if ViSC is intended to provoke intellectual insight. There is also a danger that the introduction of poorly defined buzzwords, such as 'visualisation idiom', could lead to confusion over fundamental aims and objectives.

This paper has drawn together some relevant ideas from other disciplines, notably the history and philosophy of science, psychology and cartography to suggest that we need to see ViSC within its proper context. The discussion may be summarised as follows.

Visualisation is a human process which has led to insights since time immemorial. It is independent of the technology of the day and its definition should not be limited by current technological capabilities nor their applications. If the distinctive purpose of the field of Scientific Visualisation is the stimulation, verification and application of visual and intellectual insight, we must include the psycho-technical linkages when specifying the technical apparatus, ViSC. We need to widen our definition and model of the process of visualisation and re-configure the architecture of ViSC systems. Despite the potential offered by modern technology, ViSC does not as yet facilitate a "combinatory play" with multiple images. There is a need for research into the problematic areas of generalisation of information and of displays based on them. Also, we must educate and train scientists in the use of graphic formalisms and encourage them to 'play' with their own 'dreams' but communicate the results in meaningful ways.

ACKNOWLEDGEMENTS

The views presented in this paper were first presented in February 1991 at a Workshop on Scientific Visualisation organised by the UK Advisory Group on Computer Graphics. While accepting full responsibility for the views expressed in this paper, I would like to thank the following for their helpful comments and criticisms : Dr. Graham Kirby and Alan Reese of the Cartographic Information Systems Research Group of the University of Hull, Dave Unwin and Hilary Hearnshaw of the ESRC Midlands Regional Research Laboratory in Leicester University, Dr. Roger Hubbold of the Department of Computer Science of the University of Manchester and Chris Little of the UK Meteorological Office; thanks are also due to Dr. Alan Bowers, Head of the Department of English at the University of Hull, for discussive comments on the use of the term, idiom.

REFERENCES

Balchin, W. G. V. (1972) "Graphicacy", **Geography** 57, 185 - 195

Bertin, J. (1983) **Semiology of Graphics - Diagrams Networks Maps** (University of Wisconsin Press), original in French published in 1967.

Boulter, C. A. (1989) **Four Dimensional Analysis of Geological Maps** (Wiley, Chichester)

Cooke-Fox, D. I., Kirby, G. H. and Rayner, J. D. (1989) "Computer translation of IUPAC Systematic Organic Chemical Nomenclature. 1. Introduction and Background to a Grammar-based Approach", **J. Chem. Inf. and Comp. Sci.** 29, 101 -

DoE - UK Department of the Environment (1987) **Handling Geographic Information**, (HMSO, London)

Gordon, I. E. (1989) **Theories of Visual Perception** (Wiley)

Gregory R. L. and Zangwell O. L. (eds, 1987) **Oxford Companion to the Mind**

Haber, R. B. and McNabb, D. A. (1990) 'Visualization Idioms : a conceptual model for Scientific Visualization Systems', in Neilson, G. M. and Shriver, B. D. (eds.) **Visualization in Scientific Computing**, 74 - 93.

Kasturi, R., Fernandez, R., Amlani, M. L. and Feng, W. (1989) "Map Data Processing in Geographic Information Systems", **IEEE Computer** vol 22 (12), 10 - 21

Kuhn, T. S. (1970) **The Structure of Scientific Revolutions** (The University of Chicago Press) Second Edition.

Madden, E. H. (1960) **The Structure of Scientific Thought : an introduction to Philosophy of Science** (Routledge and Kegan Paul, London)

McCormick, B. H., DeFanti, T. A., Brown, M. D. (Eds, Nov 1987) 'Visualization in Scientific Computing', **ACM SIGGRAPH Computer Graphics**, vol 21, No 6

Monmonier, M. S. (1977) **Maps, Distortion and Meaning**, (Association of American Geographers, Washington D C)

Reichmann, W. J. (1961) **Use and Abuse of Statistics** (Pelican)

Robinson, A. H., Sale, R. D., Morrison, J. L. and Meuhrcke, P. C. (1984) **Elements of Cartography** (Wiley, New York) 5th edition.

Rock, I. (1990) **The Perceptual World : Readings from the Scientific American** (W H Freeman & Co, New York)

SERC - UK Science and Engineering Council (1989) Research Student and Supervisor - an approach to good supervisory practice (SERC, Swindon).

Tufte, E. R. (1983) **The Visual Display of Quantitative Information** (Graphics Press, Cheshire, Connecticut)

Visvalingam, M. (1985) "Concept refinement in social planning through the graphic representation of large data sets", in Shackel, B. (ed.) **Human-Computer Interaction - INTERACT '84**, North-Holland, Amsterdam, 376 - 381.

Visvalingam, M. (1987) "Problems in the design and implementation of a GKS-based user interface for a graphical information system", **The GKS Review**, Proc. of Eurographics Association Workshop Sept. 1987, ISO/TC9/SC24 N5, 16pp.

Visvalingam, M. (1990) "Trends and concerns in Digital Cartography", **CAD** 22 (3), 115 - 130.

Visvalingam, M. and Whyatt, J. D. (1990) "The Douglas-Peucker algorithm for line simplification : re-evaluation through visualization" **Computer Graphics Forum** 9 (3), 213 - 228.

Visvalingam, M. and Whyatt, J. D. (1991) "Cartographic algorithms : problems of implementation and evaluation and the impact of digitising errors" **Computer Graphics Forum** 10 (3), in press.

Wallas, G. (1926) **The Art of Thought** (Jonathan Cape, London)