MultiVis: A Multimodal Visualisation System for Blind Students Using Virtual Reality

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INTRODUCTION

One of the main deprivations caused by blindness is the problem of access to information. Visualisation is an increasingly important method for people to understand complex information (using tables, graphs and 3D plots, etc.) and also to navigate around structured information. Computer-based visualisation techniques, however, depend almost entirely on high-resolution graphics and for visually-impaired users the problems of using complex visual displays are great [30]. There are currently only limited methods for presenting information non-visually and these do not provide an equivalent speed and ease of use to their graphical counterparts. This means it is impossible for blind people to use visualisation techniques, so depriving them further. We will investigate and solve this problem by using techniques from Virtual Reality (VR) that will allow users to *feel* and *hear* their data.

Being able to perceive and understand complex information is particularly important for students at school and university. This includes visually impaired students, who have similar career expectations as their sighted peers [27, 28, 54] and whose numbers have more than tripled over the last 10 years [49]. To compete on equal terms, they must be able to use the same information [26]. Improvements in access to information will lead directly to improvements in quality of life and job prospects. We will therefore focus our research on the problems of this group.

Current techniques for displaying information non-visually rely mainly on synthetic speech and Braille. Users hear a line of digits read out or, if they read Braille, feel a row of digits. Consider a sighted person reading a matrix of numbers. He/she would immediately be able to make certain inferences about the data. For example, there may be larger numbers at the bottom right or top left. A blind person would be unable to capitalise on these patterns in the data. He/she would just hear rows of numbers spoken, one after another. Properties of human short-term memory mean that listeners are unable to hold in mind enough information to make any non-trivial observations - they become overloaded [2, 9]. Things become even worse when graphs or complex 3D plots are used because there are almost no techniques for presenting these in a non-visual way.

Methods have been developed in the area of VR that allow use of senses other than sight. To create realistic virtual environments *haptic* (touch) devices have been built that allow users to feel virtual objects [47, 56]. Work has also been done on using 3D sound to position sound sources anywhere in space around a listener [58]. There has been little research into how these new techniques can be used in visualisation systems for sighted people and still less into how they can be used for blind people [36, 51]. As Edwards *et al.* [31] say "Currently the greatest obstacle to the exploitation of the variety of communications channels now available is our lack of understanding of how to use them". **The innovative aspect of this proposal is to investigate the different sensory modalities to see how they can best be used for visualisation and so create a powerful, multimodal visualisation system that makes the most of the senses our users have.** The research that will be done during the project will have a major impact because it will open up the possibilities for using these new techniques and greatly improve the quality of life of our users. The main aims of this research are to:

- Investigate the cognitive and perceptual properties of the different sensory modalities and the problems blind people face when trying to visualise information;
- Develop new visualisation techniques using VR and multimodality to allow blind people to use complex information;
- Investigate how these new techniques can be incorporated into future visualisation systems;

The research we propose is of key importance to the UK. The Government's Technology Foresight Report suggests that "Ease of interaction i.e. the use of intuitively obvious methods for controlling and interacting with systems, such as voice, touch, gesture, writing, image and so on, in addition to today's keyboard and mouse" are specific technology opportunities available to the UK. The report also makes it clear that user needs and ease of interaction are priorities. We will therefore be addressing problems that are directly relevant to UK science and industry. In addition, the Disability Discrimination Act (1995) is important because making systems which are usable by disabled people is now a legal requirement but many techniques necessary to enable this still need investigation.

Our own work provides solid foundations for this project. Brewster is one of the most active researchers in multimodal human-computer interaction using sound. He has shown that sound can be used to present complex, structured information [12, 15, 18, 35]. Burton and Dimigen bring expertise in cognition and blindness respectively [22, 23, 25]. In particular, Dimigen teaches statistics to blind Psychology students. Our unique approach has attracted attention from industry with Virtual Presence agreeing to be an industrial partner in the project. For the project we are requesting 2 RA's, equipment and travel for a period of 3 years. Our progress will be measured against the following milestones:

- First year: Produce paper outlining cognitive problems of visualising information non-visually. Demonstrate prototype systems for visualising tables and line-graphs.

- Second year: Produce paper describing results of detailed evaluations of initial experimental prototypes. Produce paper describing new multimodal visualisation techniques for complex information.
- Third year: Paper on the results of detailed evaluations of the complex, multimodal prototypes. Produce principles and final demonstrator applications for multimodal visualisation. Produce final report. Host workshop to disseminate knowledge gained.

BACKGROUND

Visualisation is a fundamental method for understanding information but at the present time it is almost completely unavailable to blind people. It is concerned with "exploring data and information in such a way as to gain understanding and insight into the data" [19]. Visualisation occurs in many aspects of life from reading a newspaper (where a graph might depict changes in the Pound against the Dollar) to statistical packages used by many students to view data from experiments in the form of tables, graphs or 3D plots (see Figure 1). This is almost always done visually so there is no way for a blind person to get at the information in a usable way [22, 23].

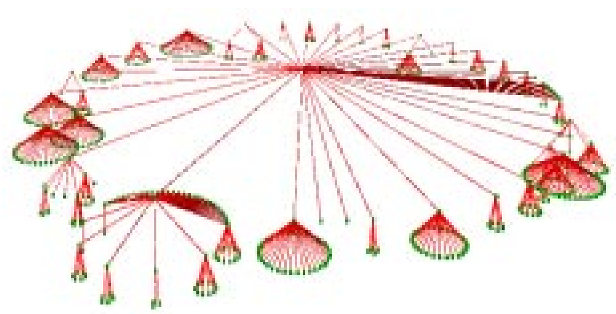

Figure 1: A cone tree representing a directory structure (described in [60]).

A blind person will typically use a screen-reader and a voice synthesiser to get access to information [30]. The screen reader extracts textual information from the computer's video memory and sends it to the speech synthesiser to speak it. The screen reader approach has a major problem in that it contains nothing of the semantics of the information presented. As Raman [46] says: "The primary shortcoming of such interfaces is their inability to convey the structure present in visually displayed information. Since the screen-reading application has only the contents of the visual display to examine, it conveys little or no contextual information about what is being displayed". When presented with a table of numbers the screen reader will extract the digits and read them individually as a constant stream. They are unlikely to be read as complete numeric literals as this semantic information will not be available to the screen reader. The information will not be presented in a tabular way for the same reason. This causes extreme problems for a person trying to make sense of the data presented.

The problems just described are worse when graphs are present. Screen-readers usually only extract alphanumeric information and so images are unavailable. A diagram, such as that in Figure 2, conveys a great deal of information to a sighted person. The power of such displays is due to the fact that the user can select the portion of the information contained within it which is pertinent to their current requirements. For instance, in order to answer certain queries, it may be the overall shape of the curve which is of interest, whereas in another context, it may be the point at which the curve crosses the *x*-axis which is important [30]. There is currently no easy way for blind people to be able to access this information. Problems get even worse when more complex visualisation techniques such as those in Figure 1 are used that utilise colour, three dimensions or animation. These are currently unusable by blind people. However, techniques developed for VR are beginning to make alternatives possible.

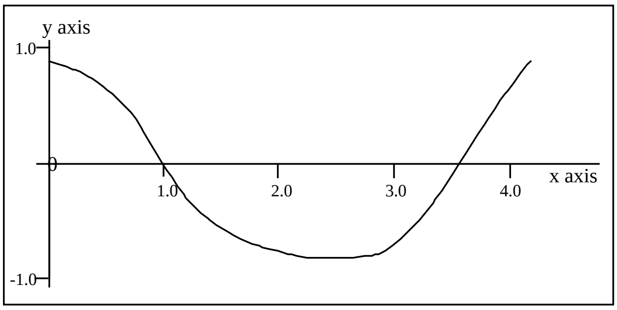

Figure 2: A typical line graph. This comprises a lot of information, but a sighted person is able to cope with all that information by focusing in on whichever aspect of it is pertinent to current needs (from [30]).

For this project we will concentrate our efforts on creating visualisation systems to provide access to the types of information and tasks required in the context of Higher and University students learning statistical analysis (Dimigen's area of teaching). This will cover a range of visualisation tasks from tables and line graphs to complex, multi-dimensional plots. Solutions we provide for users in this area will also be generalisable to problems faced by users in other domains (such as systems for blind people outside education, or systems for users whose working environment restricts the use of large, high-resolution displays).

There is often a problem with this type of research in that it can be technology, and not user, oriented [30]. This results in systems and devices that do not solve users' problems. As the Technology Foresight Report suggests, it is very important to consider users – how will they use the systems? What tasks will they use them for? We will therefore take a user-centred, *participative* approach to ensure our work focuses on user needs by having a blind consultant working with the research team.

The novel approach we propose to solve the problem of visualisation is to make use of the senses that our users do have, namely hearing and touch. Techniques emerging from the field of VR (such as 3D sound and force feedback) now make this possible. Using multiple sensory modalities can overcome problems in the visual sense. This approach is also called *perceptualisation* by Hughes &

Forrest [36]. Smith *et al.* [51] suggest that multimodality can help disabled users in several ways by increasing:

- the bandwidth of communication to improve speed;
- the number of methods for achieving tasks to provide greater choice, more situational flexibility and additional ways to cope with fatigue;
- the naturalness of interaction resulting in greater satisfaction and ease of use.

As yet few of these advantages have been utilised in visualisation systems for blind people [33, 36, 51]. It is, of course, important that we do not present information to the senses in arbitrary combinations [47, 48]. Cross-modal affects can make performance worse. One of the key areas to be investigated throughout the project will be the best ways to present information to the different senses (both individually and in combination).

3D sound is a new technique from the area of VR that allows a sound source to appear as if it is coming from anywhere in space around a listener [3]. Stereo sound has only one dimension and therefore is of limited use in displaying multidimensional data. However, when sounds can be mapped on to a two or three dimensional space then there is a greater opportunity for presenting information. Bryson [20] confirms the usefulness of our approach: "The use of three-dimensional sound in scientific visualization is relatively unexplored but holds promise". We will investigate how 3D sound can best be used to aid visualisation for blind people.

Associated with 3D sound is an emerging area of research in the presentation of complex data in sound [38, 43]. Such *sonification* has successfully been used to present, amongst others, census, geographical, environmental, fluid and neurological data [1, 4, 43]. Little of the work in this area has specifically investigated sonification for blind users (and has not used 3D sound) [40, 59]. One of the main exceptions that is applicable to the research we are proposing is the work on *Soundgraphs* begun by Mansur *et al.* [41] and developed by Edwards and colleagues [31, 32]. Dr Alistair Edwards, University of York, has done much in the field of improving interfaces for blind and partially-sighted people [29, 30]. The Soundgraphs system allows the presentation of line graphs in sound. Time is mapped to the x-axis and pitch to the y-axis. The shape of the graph can then be perceived as a rising or falling note playing over time. Results were very promising with users able to identify types of curves along with maximum/ minimum points. The problems with this work were that it only worked well with simple line graphs and it was hard for users to listen to multiple graphs at the same time to make comparisons. Movement around the graphs was by cursor keys which did not provide a natural or flexible method of interacting. We will base our initial designs on this work but use other sensory modalities for input and output to create a richer and more powerful environment for presenting and interacting with information.

In other research, Brewster worked with Edwards and colleagues on a system for presenting algebra to blind people [53]. Blind mathematicians need to get an overall feel for the complexity of an algebraic expression before they explore it - they need a visualisation of the gross features. The system developed used sounds to provide a 'glance' at the overall structure of an expression. This gave some idea of the complexity before users started to browse it with synthetic speech. The glance allowed users to choose the appropriate browsing strategy so that they were not overwhelmed with synthetic speech. We believe that this is a key method for making visualisations useful to blind people and has been neglected by other researchers. Providing a glance will give some indication of the complexity of what is being visualised without overloading the user with too much information. Once the user has some feeling for the complexity of what is being visualised, he/she can being to explore specific areas in detail. Many of the principles developed from this work and from the design of other systems for blind and partially-sighted people will be used in our project.

The auditory feedback to be used in the project will be based on structured audio messages called *Earcons* [5, 6, 15]. Prof Meera Blattner initially developed the idea of these abstract, musical sounds built up from smaller units that can be manipulated to build complex structures. Brewster has performed a series of detailed investigations of earcons showing they are a very powerful means of communicating complex information [9, 13, 15, 17]. Professor Blattner and Dr Brewster are currently working together on a book about the use of non-speech audio.

Brewster has done work on presenting multidimensional and hierarchical information using earcons [8, 10, 12]. Hierarchical structures are widely used in visualisation (e.g. file systems hierarchies, telephone-based interfaces, classification systems and see Figure 1) and there has been much interest in representing them graphically [34]. Brewster's experimental results have shown that, with sound, participants can identify nodes in complex structures with high degrees of accuracy and small amounts of training. Presenting earcons in 3D would allow higher-dimensional data to be presented. This work is also the basis for Brewster's EPSRC grant GR/L66373 (see the Previous Research section for more details). Results from that research will be used to help us design the sounds in this project.

One of the other novel aspects of this work will be the use of force-feedback, or haptic [50], technology in combination with earcons and 3D sound. Minsky *at al.* (in [4]) describe it thus: “Force display technology works by using mechanical actuators to apply forces to the user. By simulating the physics of the user’s virtual world, we can compute these forces in real-time, and then send them to the actuators so that the user feels them”. The haptic device to be used in the project is the Phantom [42] (see Figure 3). This is a very high resolution, six degrees-of-freedom device in which the user puts his/her finger in a thimble at the end of a motor-controlled, jointed arm. It provides a programmable sense of touch that allows users to feel textures and shapes of virtual objects, modulate and deform objects. Such haptic devices have been used in VR systems that allow, amongst others, remote operation of machines (tele-robotics), remote surgery or molecular docking systems [4, 56]. As Kurtz [39] suggests “touch is a very efficient modality for detailed exploration of objects” and fits well with the direct-manipulation paradigm used in modern computer interfaces.

Such devices have advantages for our users. The use of the standard mouse is difficult for blind people as it is a relative device [30] - the position of the mouse on the desk has no direct mapping to the pointer on screen. The user can pick up the mouse, put it down in a new position and the pointer on the screen will not move. However, the force-feedback devices are absolute, making them much more appropriate. Such devices can constrain the movements a user is allowed to make and can also guide the user’s hand. Mynatt *et al.* [44] found that spatial layout caused problems when trying to present a graphical interface to blind people - users could not find things. The haptic device will solve this, as we will be able to guide users to particular points in the data by controlling their movements (for example tracing out the shape of the graph in Figure 2 for the user).

As yet these devices have been little used in visualisation systems for blind people [33]. One reason for this, as Bryson [20] says, is “The immaturity of haptic technology, however, makes it very difficult to implement a haptic display in a general, easily reproducible visualization system”. Our novel work will address this problem with systematic evaluation and testing and show how best this new technology can be used to aid blind people.

Dr Helen Petrie and colleagues have done key initial work in the use of haptic devices for blind people [21]. They have shown that, for example, blind people are more discriminating than sighted in their assessment of roughness and texture when presented via a haptic device. She has also shown that the perception of larger objects is easier than smaller. We will use the results of her work as a base for our own.

The most common form of tactile output for blind people is Braille. We will use Braille as part of the project but it is not the solution to all visualisation problems; for example, only 26% of blind university students read it. Tactile graphics for the blind is an area that has been studied for some time [39, 45]. The aim of work in this area is to present graphical images via touch. This is most often done by Braille printers or special paper that, when drawn on, leaves raised lines [39]. There has been, however, almost no use of force-back or 3D audio in this area which can provide dynamic presentation of information. We will use work done by researchers such as Kurtz [39] who has begun to develop guidelines which allow simple images to be presented that are understandable and recognisable by blind users and apply them to visualisation.

How would such a system as the one we are suggesting work? For the simplest case of tables, the value in each cell could be mapped to height and so a 3D surface could be created. Users would move their fingers around, using the haptic device on the surface, to feel the data without overloading short-term memory. This would allow them to quickly and easily feel trends and large and small values.

When presenting graphs users would be able to feel the shape of the graph via the haptic device. They could trace out the shape of a graph with a finger, hearing a change in pitch (as in Soundgraphs [30]) to indicate the slope, and have specific values spoken with synthetic speech when necessary. The haptic device would be able to guide the user over the graph, constraining movement so that the finger is always on the graph. Several graphs could be presented simultaneously, the sound from each being presented from a different 3D spatial location, with a different timbre and surface texture, so that the graphs would not be confused.

For complex 3D plots speech input could be used (in addition to the above) so that the user could ask for the current value, which could then be spoken via synthetic speech. As the user moved the pointer over the highly-dimensional data structured non-speech sounds would be played representing some of the dimensions is sound - instrument might represent one dimension, pitch another,

Figure 3: The Phantom 3D force-feedback device from SensAble Corp.

rhythm yet another [12]. The sounds will be played coming from the 3D location of the data point in the visualisation, to reinforce the structure of the data. Users might also feel different textures as they move over the data, for example the roughness or softness of the pointer location might indicate other dimensions in the data. In all of these examples it will be important to fully investigate the cognitive/memory aspects of the systems to ensure that they are effective and users can extract the information they require without being overloaded.

PROGRAMME AND METHODOLOGY

As discussed above, there are many advantages to using multiple-modalities for visualisation. However, most previous examples were *ad hoc* solutions because the use of these new techniques is still in its infancy and there is little to build upon [20]. We will therefore undertake a systematic experimental evaluation to find out how sonic and haptic technologies can be used in visualisation systems for blind people. The results of the experiments and the principles produced will allow others to use these new techniques in more structured ways. **The innovative aspect of this proposal is to investigate the different sensory modalities to see how they can best be used for visualisation and so create a powerful, multimodal visualisation system that makes the most of the senses our users have.** This research is needed now so that the UK can secure a place at the forefront of world-wide work in this area. There are four main stages to this project:

1. Investigate the inherent cognitive/memory problems blind people face when trying to visualise information;
2. Build prototype systems to allow us to evaluate the VR techniques for visualisation;
3. Carry out detailed experiments to investigate the most appropriate methods of conveying information in the different sensory modalities;
4. Develop guidelines and demonstrator applications to enable future visualisation system designers to use the knowledge gained;

Papers will be produced after each of these stages and can be used as milestones against which our progress through the project can be measured.

We are applying for a part-time blind consultant so that we can investigate problems and initial solutions with someone who has first hand knowledge of the difficulties involved. We also have strong contacts with Dr Archie Roy, Student Adviser for the RNIB Employment and Student Support Network, who can answer specific questions and provide participants for our large-scale experiments. We will also use blind students from local schools, universities and colleges with whom we have contact.

Dr Dimigen will provide example task datasets for visualisation. These will be of the type typically used by social science students. This will allow us to test out ideas for relatively simple visualisations, and will permit subsequent comparison with blind students who routinely manipulate this type of information, and to whom we have access. More complex, multi-dimensional data sets will be needed for testing our other ideas. The Department of Computing Science can provide these, others are available over the web and others will be generated by software [37].

The overall structure of the project is as follows. There will be regular contact between the researchers in the Department of Computing Science (DCS) and those in Psychology (PSY), though the responsibility for different aspects of the project will be divided up as follows. In year 1, DCS will develop the initial set of experimental prototypes. In year 2, DCS will develop novel visualisation techniques, as well as taking part in the evaluation of those developed in year 1. In year 3, DCS will develop demonstrator applications and produce guidelines for product development. Researchers in PSY will work in parallel with DCS. In year 1, PSY will carry out a series of fundamental experiments on human subjects (sighted and blind) in order to establish the working characteristics (e.g. memory load in different sensory modalities) which will guide the development of the prototypes. In year 2, PSY will test experimental prototypes developed by DCS in year 1. We envisage an iterative cycle of development and testing in which results from formal experiments are fed back into the software development process. In year 3, PSY will experimentally examine the usability of artefacts developed in year 2 by DCS. PSY will also contribute to the production of guidelines for developers. More detailed breakdowns follow.

First Year

Dr Brewster and the RA in DCS will begin by building prototype systems incorporating the different technologies to be used. We will concentrate on basic tables and linegraphs for this year. This will allow us to understand the basic problems students face when visualising such information and then to build on these for more complex visualisations in subsequent years. This will involve writing low-level software to allow us to control and synchronise the earcons and present them in 3D space, and to control the speech input, Braille and force-feedback devices. Each of these technologies will come with its own set of drivers and software. These must be integrated so that they work together. We must also write software to allow us to control them in the ways necessary to present and interact with our visualisations.

Much of the work necessary to use sound in the prototypes has been done by Brewster in his previous research into sonification [8, 9]. Brewster has much experience at developing audio and MIDI software and his existing tools will be used for the development of prototypes.

Speech input will be included in the prototypes to allow users to control the system when their hands are occupied (one hand maybe using the haptic device and the other on the Braille display). Off-the-shelf speech recognition software will be used as only a restricted, task specific vocabulary will be needed (e.g. controls for zooming, changing views, changing modes, etc.).

We anticipate that the prototypes will be built around the Model View Controller interaction architecture used by Smalltalk and Java [55]. This is being used in Brewster's grant GR/L79212 and has proved effective, so we will build on it here. This will give us an existing, well-developed architecture to use rather than starting from scratch. This architecture easily accommodates different input and output methods so it will be possible to try different ways of presenting and interacting with information - both key parts of the work in the first year.

The prototypes will be built using an iterative design methodology. As part of the design is completed, it will be tested with the help of our blind consultant. This participative approach will help us focus on key issues and tasks, and provide a fast turn-around time for the initial prototypes. We will also use blind subjects, as appropriate, but we aim to conserve our supply of suitable blind participants for more formal tests later on. For these initial tests we will use the testing framework developed by Brewster for evaluation of sonically-enhanced interfaces [9, 16], which has proved very successful. This uses a within-groups method to test one design against another. Error rates, time to complete tasks and workload (based on NASA TLX) are measured to give a full measure of usability. The tests at this stage will be small-scale and will help us to explore the design space we have available. Formal, detailed studies will occur later. Papers will be written describing the prototypes and their evaluation.

In parallel to the work in DCS, Burton, Dimigen and the RA in PSY will start a series of experiments examining the working memory capacity of sighted and blind students. Traditional work in psychology examines memorisation for linear data only. For example, people are asked to remember strings of numbers or words, which may be presented to them aurally or visually. In these experiments we will examine the capacity of memory for structured information, which is the type our users will have to deal with when using visualisation systems. We will begin by studying sighted subjects, and using memory materials based on simple matrix form (one of our main tasks is visualising tables). We will ask whether memory capacity is dependent on: i) the two-dimensional structure of the data (e.g. could they better remember a series of numbers of the form 1102 11 1108 24 1117 35 than a series of the form 2 11 8 24 17 35?); ii) the mode of presentation (e.g. to what extent is structured information harder to remember when presented aurally or by touch, rather than visually?); iii) the integration of arbitrary stimulus cues in materials (e.g. is it easier to recall <high voice> 12 27 38 <medium voice> 34 23 42 <deep voice> 46 24 25 than all these numbers in the same pitch). It is possible that none of these manipulations will make any difference to the short-term memory span (generally around seven items). However, our pilot work suggests that we will be able to increase our subjects' working memory spans considerably by some of these techniques. We will also investigate the effects of combining presentation of information in the two different modalities. Research by Ramstein has shown that arbitrary combination can degrade performance and it is vital that we avoid this to maximise usability [47, 48].

There is no reason to suppose that blind subjects' working memory structure is qualitatively different from that of sighted subjects. However, it is quite plausible that blind people have elaborated working memory capacity in order to cope with demands of daily life. Having established the optimum data presentation strategy for sighted subjects, we will then begin parallel experiments with blind subjects. These will be students at various colleges and universities with which Dimigen already works. It is important to note that this subject pool is limited, and we are particularly anxious only to ask these subjects to participate in experiments once a clear set of hypotheses has been derived from the studies with sighted subjects.

The results of these studies will guide the ways in which systems built by DCS in year 1 will develop. Using this iterative approach will allow us to refine and improve our designs throughout the first year. They will also constrain the development of further artefacts in year 2. The results of the evaluations will be published in a paper.

Second Year

At this stage of the project DCS and PSY will work closely together. By this stage, DCS will have developed prototypes that will enable blind participants to explore simple data representations, such as matrices or linegraphs. We will conduct a series of formal experiments to establish whether this is the case. In the first instance, we will use our blind consultant and sighted subjects (as pilot studies). We will present subjects with a series of data structures (for example matrices), either through normal visual presentation or through the non-visual means developed in year 1. There will be two types of question asked. First, we will ask subjects to describe the data. Second, they will be asked particular questions about the data. In the first case, we might expect answers such as "columns alternate between high and low values" or "numbers on top left are largest". In the second, we might ask subjects to identify the largest number, or to find the biggest gap between adjacent numbers. Comparing the visual with the non-visual case (for the same data) will allow us to hone the non-visual systems. The aim is to develop a system good enough to match subjects' performance in the visual case.

This stage of the project will inevitably be cyclical. It is impossible to predict where particular problems may occur, and there is no theoretical position from which we can predict the sources of potential problems. Instead, we will adopt a pragmatic approach of simply engaging in a development/test cycle. The experiments will be designed and executed in PSY and the results fed back to DCS so that the prototypes can be improved. Once we are sure that the basic visualisation methods work, we will conduct full and detailed trials with blind participants. These will be based on the design suggested above. A paper will be written describing the results of the experiments.

In parallel with these experiments, DCS will begin to develop advanced multimodal visualisation techniques for visualising complex, multidimensional data (such as that shown in Figure 1), building on the techniques from year 1. As described above, combinations of speech input, speech and non-speech sound output, Braille and force-feedback have the potential to provide a rich way to interact with and visualise data. DCS will investigate the design possibilities, constrained by the results from PSY.

We cannot just present all of the complex data to users at once, as they will become overloaded. As Stevens [52] suggests, we need to give control to users so that they can browse the data in the most effective way. We will use the idea of a non-visual glance (described above) to give users an overall ‘view’ of their data, extending the work of Edwards so that the glance combines multiple sensory modalities to make it more effective. It is important that users do not become overloaded with information - the glance will ensure this: users will be able to feel and hear an overview of the data as they move around it. Details will be hidden and gross features presented. This will help them get an overall feel for the shape of the data and build a map of it in their heads. They will then be able to focus in on areas of key interest and investigate them in detail.

We will examine the potential of a *multimodal databrush* as one method of providing this glance. A databrush is a mechanism for interactively selecting subsets of the data so that they may be highlighted, deleted, or masked [57]. They are very effective and are commonly found in graphical visualisation systems. We will explore the idea of using the haptic device, earcons and 3D sound to provide a non-visual databrush so users can explore their data. When glancing this will give only the gross features, when browsing in detail it will provide access to all of the data needed.

One novel method of presenting other data dimensions is virtual texture (Minsky et al. in [4], [21]). By making different data points feel rough, smooth or soft (using the haptic device) they can be used to present data. This could be accompanied by changes in musical instrument to present further dimensions. We will investigate the usability of such a presentation technique.

DCS will again use an iterative approach to build the prototypes: designing visualisation methods and then conducting simple, rapid, evaluations to see if they are effective. These will be with our blind consultant, sighted and blind users. Complex datasets will be presented with different combinations of modalities. Participants will be set tasks typical of those required of our user group. They will then be monitored whilst they perform these. As with the experiments in DCS in year 1, a wide range of measurements will be taken to assess the usability of our different designs. Of particular importance will be the workload measures - it is important that we do not overload our users with information. Any problems found will be fed into the next iteration of the designs. A paper will be published describing the designs we develop.

Third Year

In year 3 DCS and PSY will be concerned primarily with the full testing of the complex multimodal visualisation techniques developed in year 2. Analogues of the experiments used previously will be developed for these new techniques (with a focus on cognitive overload), and a similar develop/test cycle with DCS will operate. DCS will not only fine-tune these techniques but also build robust demonstrators for sharing with others in the community. A paper will be published on the results. We will also carry out classroom-based studies to ensure that the prototypes are effective in the context of use for which they were designed (using Dimigen’s expertise in this area).

DCS and PSY together will develop a set of principles for industrial and academic visualisation system designers. It is important to point out that these will not be based on a ‘best practice’ model, but rather on the results of formal experimental testing from across all three years. If (as is quite plausible) we discover fundamental characteristics of working memory in non-visual domains, it will be important to have these laid-down as principles constraining further developments. We will publish the results in a paper.

The demonstrator applications will be based on the experimental prototypes used throughout the project. However, they will be brought up-to-date to include all of the results and principles developed. They will be usable by teachers and blind people to visualise information.

As the final part of this project, we will hold a workshop to allow us to communicate our findings to academia and industry. The work will then all be brought together and published in a final report.

RELEVANCE TO BENEFICIARIES

Blind students and computer users will benefit because they will gain access to information currently impossible for them to use. This will be a major advantage because being able to visualise information is very important. Visualisation is needed in all areas of life from newspapers showing graphs of economic performance, to student textbooks where graphs, bar charts etc. are used to convey complex information. Not having access to this information makes it very hard for blind students to work alongside their sighted colleagues. It will also be much faster for the students to get at the data. They will no longer have to send off for information to be printed onto special paper, for example, but will be able to use it at the same time as their sighted colleagues. Therefore, this project will add greatly to their quality of life.

Teachers of classes of mixed students will benefit as they will be able to use graphs, tables and complex visualisation techniques knowing that all of their students will be able to use the information they contain. This means that the teachers will have to spend less time making the information accessible to the blind students and more time discussing the data and what it means. We aim to use the systems developed within our own teaching at the University.

Visualisation system developers will also benefit because they will be able to use richer interaction techniques than are currently possible to display information. Using the principles we develop, they will be able to make their systems more widely usable. They will also be able to present data in the appropriate modality and to improve the effectiveness and power of their systems.

DISSEMINATION AND EXPLOITATION

The results of each stage of the work will be presented at national and international conferences so that industry and academia can see the work. Conferences will be targeted that attract delegates from both academia and industry such as BCS HCI, ACM CHI and ACM ASSETS, and IEEE Visualization. The work will also be published in a more detailed form in journals, including journals relating specifically to blindness, and those addressing applied issues in cognitive psychology.

The results of the research will be made available on the Web so that they will be available to all who want them. It is particularly important that this work is presented in an interactive form because the results cannot easily be understood by just reading about them. We will make available the principles and several demonstrator applications. Other parts of the work will be reserved for future commercial exploitation. We will also host a workshop in the final year of the project to communicate our ideas to academia and industry.

JUSTIFICATION OF RESOURCES

Two RA posts for three years is the minimum required to do the design, implementation and testing of the visualisation systems. One RA will work in DCS and one in PSY. For the DCS RA we envisage employing a computer science graduate with knowledge of human-computer interaction. He/she will be expected to gain a deep understanding of visualisation and multimodal devices. The PSY RA will be a cognitive psychologist skilled in experimental design and analysis. He/she will be expected to gain a deep understanding of the problems faced by blind people accessing complex information.

We are also requesting funds a part-time blind consultant for 2.5 years to help us in all aspects of the design and testing. This is necessary as none of the investigators are blind themselves and it is important to ensure that we address problems actually faced by blind people. We are also requesting funding to pay subjects as volunteers. We estimate 200 subject-hours per year with sighted students, at the normal rate within behavioural research. We also estimate 100 subject-hours per year with blind students. These will be paid at a higher rate as they are likely to be inconvenienced more than sighted students, and to act as an incentive for an already heavily-tested population.

The project requires three Windows NT machines to which the force-feedback and 3D sound hardware can be connected: Two desktop machines and one portable. They must be powerful machines with multimedia capabilities to be able to create and process sounds, and control the force feedback hardware in real-time. These machines will also be used for the design and development of the software, the experiments to evaluate our systems, the production of papers, and the analysis of results. The portable machine is needed so that we can take our systems out to our participants to test them. As they will be blind we will need to visit them, rather than them coming to us.

We require one Phantom haptic device. This is the most sophisticated device available and will allow our users to feel objects in 3D. This will complement the much simpler device that we already have (and which will be used in this project if appropriate). Virtual Presence (the UK Phantom distributor) will give a substantial discount off the price of the device and will be an industrial partner in the project.

Travel funds are necessary to ensure the adequate dissemination of our work. As the work is based on sound and force-feedback it is very difficult to describe without demonstrations. Presenting the work at conferences is the most suitable way of demonstrating our results to academia and industry. We have also requested funding for a workshop at the end of the project so that our knowledge can be passed on to industry and academia.

PREVIOUS RESEARCH AND TRACK RECORD

This project brings together two strong research teams from the Computing Science and Psychology Departments at the University of Glasgow. They are uniquely placed within the UK to carry out the proposed research.

Stephen Brewster

Dr Brewster has been a lecturer in the Department of Computing Science at the University of Glasgow since October 1995. From September 1994 until October 1995 he was an ERCIM Research Fellow working at VTT in Finland and SINTEF DELAB in Norway. He has over 20 publications in scientific conferences and journals.

The main theme of Brewster’s work is multimodality, and especially the use of sound and touch. One of his main research areas is the use of sound to improve graphical human-computer interfaces, and the presentation of complex, structured information in sound. For his PhD research [7] he carried out a detailed series of experiments to discover the most effective ways of constructing non-speech sounds called *earcons* [15, 18] and then used them to correct usability errors. Results showed significant improvements in time to recover from errors, time to complete tasks and reduced workload [9, 11, 14, 16].

Dr Brewster is principal investigator on an EPSRC grant GR/L66373 investigating “Principles for Improving Interaction in Telephone-Based Interfaces” (in co-llaboration with Telecom Sciences Ltd). This project focuses on the problems when interacting with telephone-based services such as phone-banking and voicemail. During this project principles will be developed to allow designers to use non-speech sounds to provide navigation cues to stop users becoming lost. Initial results have been promising [8, 10, 12]. This work has also demonstrated how multidimensional data can be presented in sound. Results from this grant will feed into the design of the sounds for the project described in this proposal.

Dr Brewster is also principle investigator on EPSRC grant GR/L79212 “Guidelines for the use of sound in multimedia human-computer interfaces”. Again, the use of sounds in this project will feed into the current proposal. Brewster is also working with Prof Stuart Reid, of the Veterinary School at the University of Glasgow, developing non-invasive techniques for surgical training using haptic interaction.

A. Michael Burton

A. M. Burton is Professor and Head of the Department of Psychology at the University of Glasgow. He previously held lectureships at Nottingham and Stirling Universities. He has a B.Sc. Joint Honours Mathematics and Psychology (Nottingham, 1980) and Ph.D. in Psychology (Nottingham, 1983). He has published over 40 refereed journal articles, and over 20 further articles in proceedings or edited collections.

Burton's primary research interest is in face recognition. This is an interdisciplinary subject, and he has held previous grants with medical physicists, mathematicians, engineers and computer scientists, as well as psychologists. He also has an interest in applying psychological evaluation techniques to problems in automation. His early postdoctoral work was in the problem of "knowledge elicitation for expert systems", a psychological issue which causes problems for those working in AI. Essentially the problem is how to capture the knowledge of experts who perform tasks with ease, but are unable to articulate their reasoning. This early research was funded by Alvey and ESPRIT grants, and some of the techniques developed in this field will apply in the current grant.

Other funded research has concentrated on face recognition, and particularly on tying together human experimental work in that field with simulations intended to model face recognition, and implement it for applications. This work has been funded by four SERC and five ESRC grants. In addition, he receives an annual grant from ATR (a Japanese telecoms research company) for work in this area. Burton's contribution to this project will be to bring the techniques of empirical psychology to the study of an applied problem.

Gisela Dimigen

Dr Dimigen is a Senior Lecturer in the Department of Psychology at Glasgow University. She has published over thirty articles in refereed journals and books. During the last ten years, she has become increasingly concerned about the learning environment of visually impaired students at universities and colleges. She subsequently became a founder of the Resource Centre for the Blind at Glasgow University which was established in 1994 with funding from the RNIB, VIA and SHEFC [24].

As one of the directors she is particularly involved in upgrading and developing the information technology available to the blind. She has recently carried out two feasibility studies into SPSS, investigating how best to make the programme accessible to blind users. Her current research is investigating the use of speech recognition systems and screen readers as means of making SPSS more user friendly for visually impaired users.

Over the years she has established close links with the RNIB. Several papers have been published with the RNIB's student adviser for Scotland, concerning the employability prospects of visually impaired graduates and their need to become computer literate.

Local Expertise

There is much local expertise that can be used to provide feedback and support to this proposal. Computing Science is a 5* rated department with a very strong research culture. Dr Brewster is part of the internationally-renowned GIST Group. This multidisciplinary group contains skills in all areas of human-computer interface design and visualisation from computing science to psychology. Members will be able to provide feedback on all areas of the research. This work also ties in to the SHEFC-funded Revelations Project led by Prof Malcolm Atkinson in Computing Science. This project is investigating the use of multimedia to improve education.

The Psychology Department was rated grade 4 in the last RAE. One of its areas of research excellence is vision, and we anticipate broad discussion and interaction with researchers in this field. There is also a good history of research with blind students – the University has a blindness resource centre that is managed by Dr Dimigen.

PART 3: DIAGRAMMATIC PROJECT PLAN

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