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Pilot Study on the Effectiveness of Immersive Display Technology for Parallel Coordinates

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1 Introduction

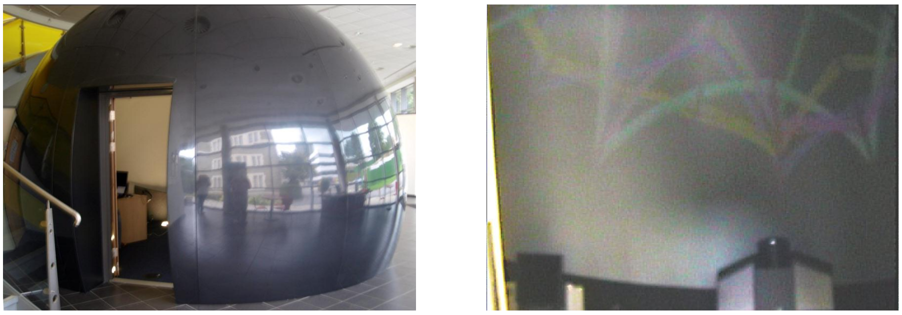
When working with data sets it is often impossible to interpret the information in its raw form. This is especially true for complex, high-dimensional sets of data, e.g. multivariate data. Data visualisation is an extremely useful aid in allowing humans to understand and analyse data more intuitively. However, the issue of effectively visualising data of more than three dimensions is a hard problem to solve.

A popular solution used by those wanting to illustrate multivariate data is the parallel coordinates technique [3]. This method involves representing each variable of the data set as an axis. The axes are drawn as uniformly spaced vertical lines, and each data element is illustrated as a series of connected points along each dimension. This method of visualising data has been found to be extremely useful in exploratory data analysis, where data is explored without knowing what relationships or trends to expect.

Whilst there has been a lot of research into the use of parallel coordinates as a method of visualising data, there has been little with regards to the most effective systems on which to display parallel coordinates, which this paper will begin to explore. The aim of this research is to use parallel coordinates to test the usability of two different visualisation systems; a Hemispherium and a standard flat screen monitor.

The Hemispherium (Figures 1a and 1b) installed in Aberystwyth University's Visualisation Centre allows for immersive, planetarium style projection of images. In theory, displaying parallel coordinates in this way should allow users to utilise their peripheral vision when attempting to interpret the data, whereas the planar nature of flat screen monitors only makes use of the user's central vision. We put forward the hypothesis that being able to make use a combination of local and global observations will allow a user to analyse parallel coordinates more effectively.

Through a user study we plan to test this hypothesis and show if the Hemispherium is better suited to the task. To begin with, it is necessary to carry out pilot of the study, which is presented in this report. The pilot study will allow us to gain preliminary results, test our experiment set up on a limited number of participants and identify any flaws in our methodology before carrying out a larger scale experiment in the future.



(a) External view

(b) Internal view; a partial view of a parallel coordinates projection

Figure 1: The Hemispherium situated in Aberystwyth Universitys Visualisation Building.

2 Method

2.1 Task

A task was designed which could be performed on both a flat screen monitor and the Hemispherium to ensure that usability could be directly compared. The basic idea was that participants would be shown parallel coordinates visualisations and asked to select the outlier, before repeating the procedure on the alternate visualisation system.

The parallel coordinate visualisations were of randomly generated sets of data, however each had a controlled number of members per cluster (of which there were five, plus one outlier) and a controlled level of variance. This varied depending on the set difficulty level (which will be discussed further in the Section 2.2), the formulae for members and variance, where d is difficulty level, were as follows: Members per cluster (rounded down to nearest whole number) was $5 + (0.5 * d)$ and variance $0.1 + (0.01 * d)$

2.2 Procedure

Before beginning the task, the participant was asked to complete a preliminary questionnaire in order to give us relevant information about their field of employment, general education level, previous experience analysing data and any prior knowledge of parallel coordinates. This will allow us to see if there are different results between differing levels of expertise and any other factors which may contribute to the results.

The participant was then shown an instructional video. This ensured that all those taking part in the experiment received exactly the same information for exactly the same length of time. The video gave a simple explanation of parallel coordinates and multivariate data, the task they would be asked to complete and instructions on how to navigate to and select values within the display.

After watching the video, it was randomly determined which system the participant would perform the task on first, to eliminate one possible source of bias in the results. Once this had been decided, the participant was taken to their decided visualisation system to complete the first of the tasks.

To begin with, the participant completed a practice session in order to familiarise themselves with the system and the task, and also to help us to assess that they know what they're doing and that their results are going to be meaningful.

The participant used a computer keyboard to navigate to any axis in the display using the left and right arrow keys, and then to any value on that axis using the up and down arrow keys. Once they had highlighted their desired value they used the ENTER key to select it.

Each time a value was selected by the user, feedback was provided to indicate whether the selection was correct or incorrect and the reason for this. The values in display became coloured (Figures 2a and 2b) and either a tick or cross appeared on the screen. The participant could then press the ENTER key to move onto the next visualisation, but only once the tick or cross had completely faded off the screen, thus ensuring that they had a chance to see where the outlier was and understand why they were right or wrong in their selection.

The practice session was completed on a difficulty level of 1, lasted a minimum of 2 minutes, and required the user to successfully select the outlier 5 times before they progressed onto the actual trials. This gave the person running the trials a chance to verify that the participant had understood both the task and the interface, in order to eliminate any possible results from users who were simply pressing random buttons.

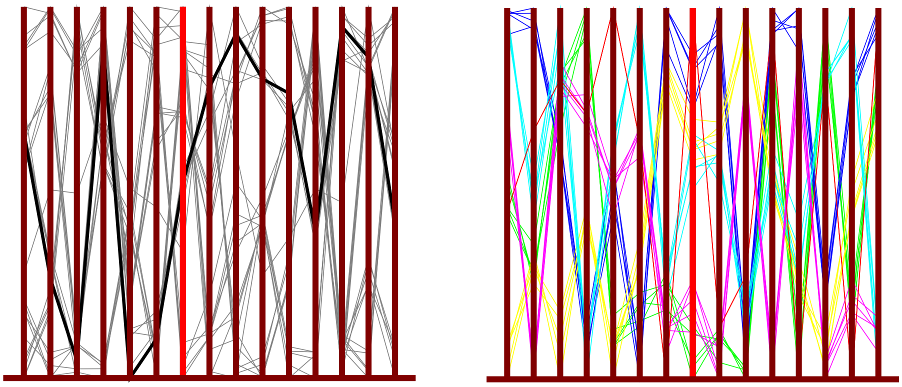
The next stage was used to calibrate a suitable difficulty level for the participant, to make sure that they were completing the task at a level where they had to think about the answers to stand a chance of getting it right. This, in theory, should ensure that interaction with the displays isn't the limiting factor in the times taken to select an answer. As they had done in the practice session, the participant selected what they believed to be the outlier, however this time their answers adjusted the difficulty level; if their answer was correct the difficulty level increased by one (in terms of the formulae mentioned in the previous section) and if their answer was incorrect the difficulty level decreased by one. This continued until a rolling average, over a window size of 20, gave a success rate of 0.5. At this point the stage of difficulty locked and the participant was required to continue selecting the outlier in the visualisations at this level until they had successfully done so 15 times.

The participant was then given a short break before moving on to the alternate visualisation system. This time the participant was not given a practice session, since the controls and task remained identical. Rather than completing another difficulty calibration stage, they began on the level of difficulty they had ended on when using the first display and were again required to make 15 successful selections. This provided us with directly comparable results to analyse.

Following the completion of the set tasks, the participant completed a post-test questionnaire. This included open ended questions about which system they preferred, which they felt they performed better on, whether one was notably easier to use than the other and whether they felt the immersive display of the Hemispherium was a help or hindrance when performing the task.

2.3 Environment

It had originally been hoped that both tests would be carried out within the Hemispherium, to ensure that its dark, quiet environment would remain con-



(a) Before selection has been made

(b) After selection has been made; outlier becomes red whilst all other members are coloured according to the cluster they belong to

Figure 2: Parallel coordinates visualisation.

Table 1: Results when task was performed on Hemispherium

Participant	1	2	3	4
Total time taken	321	1418	899	398
Number of attempts	23	27	20	22
Accuracy	65.2%	55.6%	75%	68.2%

stant for both tasks. Unfortunately, due to technical complications this was not possible and when completing the task on the flat screen monitor, participants had to do so sat at a desk in an office in which a small number of staff were working on computers. In the Hemispherium participants were given a wireless keyboard to navigate within the display, so that they were free to move around to view all of the display.

2.4 Participants

Four participants took part in our pilot study. The ages of the participants ranged from 17 to 50 years old. All had achieved at least a GCSE qualification in Maths or Maths-related subject, and two had gained a doctoral degree. Only two of the participants had previously used the Hemispherium.

3 Results

The time taken to select an answer, and the accuracy of that answer were recorded once the difficulty level had been locked. The table of results in Table 1 shows the total time taken to complete the whole task (make 15 correct selections of the outlier), the number of attempts and a percentage accuracy for the Hemispherium. Table 2 shows the same information for when the task was performed on the flat screen monitor.

Table 2: Results when task was performed on flat screen monitor

Participant	1	2	3	4
Total time taken	482	782	873	350
Number of attempts	32	23	22	26
Accuracy	46.9%	65.2%	68.3%	57.7%

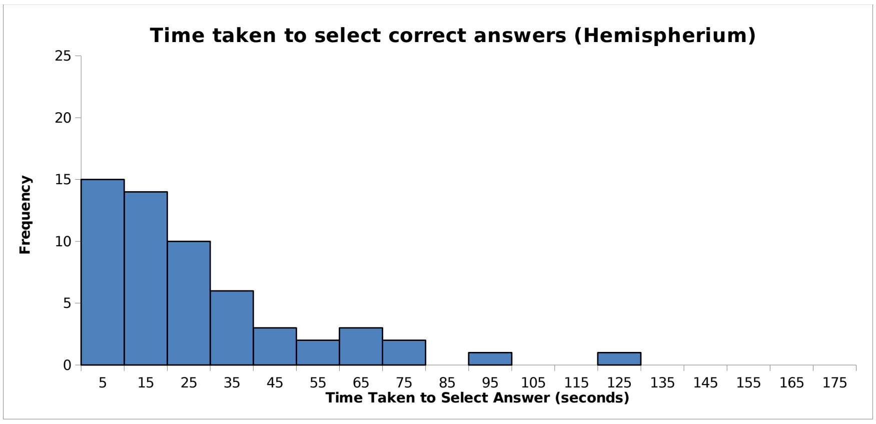


Figure 3: Times taken to select correct answers whilst using the Hemispherium

In addition to gaining preliminary results regarding which system the participants performed faster and more accurately on, the aim of the study was also to assess the experiment setup. In order to assess this, it is necessary to look at the distribution of the times taken to provide both correct and incorrect answers on each display. (See Figures 3, 4, 5, 6)

4 Discussion

As shown in the results tables, the only participant to complete the task fastest on the Hemispherium was Participant 1. Although interestingly, for all participants with the exception of Participant 2, the number of attempts was greater when using the flat screen monitor, and therefore the overall accuracy of participants was higher when using the Hemispherium.

This could suggest that participants identified the outlier more easily while using the Hemispherium, but simply took longer to navigate to it and select it. On the other hand it could be because participants took longer to study the display before making a decision than they did on the flat screen monitor. Figures 7 to 10 certainly support the latter statement as they show that participants took less time to select both correct and incorrect answers when using the flat screen. However, in both cases the strong bias towards low times in both the correct and incorrect answers implies that users spending most of the time simply navigating to find the answer they want and not thinking particularly thoroughly about their decision on either display.

In addition to these quantitative results, information was also collected through our post-test questionnaires. The first participant both preferred using

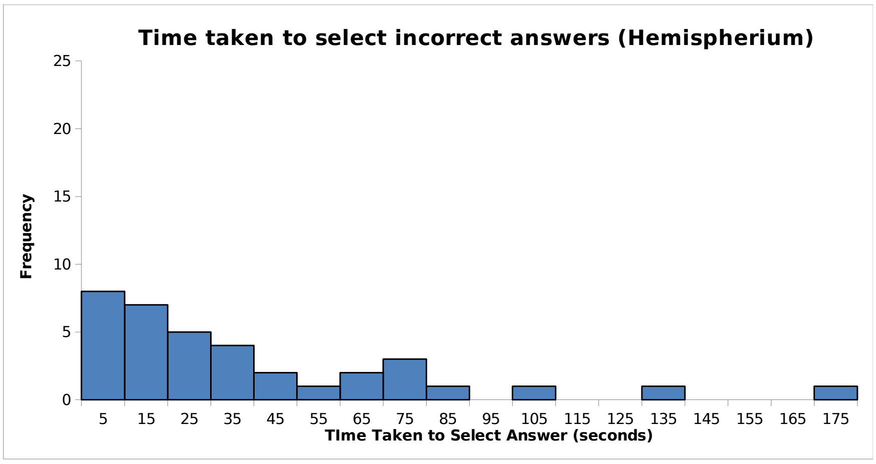


Figure 4: Times taken to select incorrect answers whilst using the Hemispherium

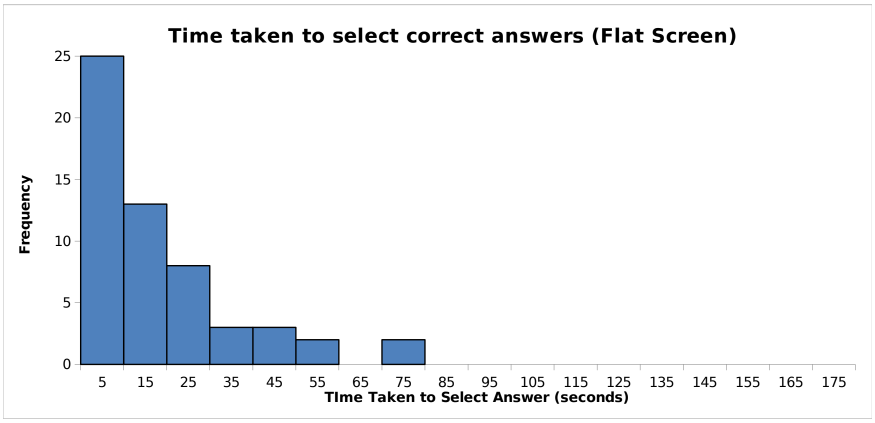


Figure 5: Times taken to select correct answers whilst using the flat screen monitor

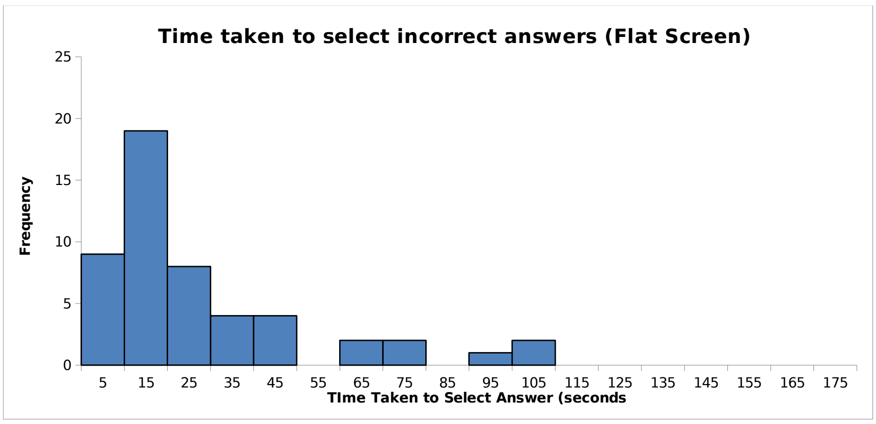


Figure 6: Times taken to select incorrect answers whilst using the flat screen monitor

the Hemispherium and correctly predicted that it was the system they performed better on. They put this partly down to values being easier to distinguish in this display. Participant 4 reiterated this in their answer, saying that when using the Hemispherium there was more room and therefore more separation between lines in some parts of the display, which suggests in future experiments larger flat screen monitors should be used to ensure this variable is eliminated from the experiment. This participant also remarked on the problem of differing environment between the two tasks which was highlighted in the Section 2.3. He could not comment on whether the immersive display of the Hemispherium was a help or hindrance in performing the task because of the entirely different environment in which the monitor was situated.

Participant 2 did not find it notably easier to use one display over the other, but preferred using the monitor due to neck strain experienced when using the Hemispherium. They also believed they performed better when using the monitor due to the fatigue experienced when using the Hemispherium. Our fourth participant also found these issues arose when they were completing the experiment. When asked which display they preferred working with, Participant 4 said the monitor, due to the fact that they could sit on a chair and did not put strain on their neck as using the Hemispherium had done. The obvious solution to this would be to provide a chair for participants however this would make it harder for them to move around and view the whole visualisation. Either a swivel chair or chair which reclined would have to be used.

5 Conclusion and evaluation

It is difficult to draw conclusions as to whether the Hemispherium is beneficial in analysing parallel coordinates at this point in time, due to the fact that we only have 4 sets of results to look at. However, the preliminary results that have been obtained show that there is a difference between the accuracy and time taken to complete tasks on the two different systems.

It seems that in general the task is completed faster on the flat screen monitor, but more accurately on the Hemispherium. This could be taken positively, in that the immersive display of the Hemispherium could encourage participants to take in the visualisation as a whole and study it before making a decision. Equally it could be seen as a negative, in that it may simply mean participants cannot perceive and analyse the visualisation when projected in the Hemispherium.

Further investigation could reveal if this pattern continues when there are more sets of data, and help to confirm the reason behind this.

In terms of the setup of the experiment, there are a number of issues which have arisen through this experiment that can be acted upon in order to make future experiments more successful; primarily, ensuring that all variables other than display are eliminated. The environment is a key issue, carrying out the experiments on the flat screen monitor within the Hemispherium would eliminate any possible distractions and make it easier for participants to directly compare their experiences on each system. The additional issue of fatigue and neck strain would also need to be addressed. Providing some form of seating would, I believe, reduce this and ensure that the participant was at all times concentrating on the task in hand and not in the discomfort they were experiencing.

The issue of fatigue is interesting — in order to get a meaningful number of results once the difficulty calibration is completed a large number of repetitions is required. This clearly takes time on the part of the participant, which can build up and lead to “are we done yet?” questions. This could be addressed in a number of ways: firstly we could include better feedback about the progress of the trial, for example with a small progress bar on an unused part of the display (in the Hemispherium for example the area near the ground is not used), secondly the gap between displays could be increased (and should be more precisely controlled anyway), although a large gap would inconvenience some participants and risk them not completing the study.

Addressing both the fatigue and environment issues would help to ensure that when collecting opinions in the post-test questionnaires any preferences express was due to ease of use of the display rather than comfort, providing us with more useful insights.

Lastly, the view held by two of the participants that lines were easier to distinguish in the Hemispherium suggests that display size itself may simply be an issue, even thought the number of pixels in each of the two displays was almost identical. Acting upon this and using a bigger screen might also eliminate the size variable.

By using a parallel coordinates visualisation which is a closer size those projected in the Hemispherium, the only remaining difference between the two displays would be the Hemispheriums immersive display which is what we are most interested in discovering the impact of.

With hindsight the post-test question ought to have included a question encouraging participants to describe in words the method they used for solving the task. This would have provided considerable insight into both the variation in approach amongst the participants and potentially the relation between this method and the display technology used.

It may also be interesting to corroborate these statements of technique with the use of eye-tracking hardware.

I believe there is a considerable amount left to research on this topic, both in terms of acquiring larger sets of results to come to a more valid conclusion about the effectiveness of immersive display technology for interpreting parallel coordinates, and also through further user studies discovering other tasks which may benefit from it.

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