Investigating Differences in Two Visualisations from Observer's Fixations and Saccades

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ABSTRACT

Our long-term objective is to produce an experiment based methodology for comparing visualisations in challenging settings. We investigated observers' eye gaze fixations and saccades during their search for answers from two graph visualisations (radial and hierarchical) of public data. The data is a snapshot of the kinds of data used in compliance checking of the degree of compliance with corporate governance best practice. We asked six questions from 24 observers for each visualisation and found that observers were 80.6% and 81.3% correct for the radial and hierarchical visualisations respectively. This is the kind of challenging setting we aim to work in, where we expect no significant difference between the visualisations in the observers' correct response rates. The results show that the number of fixations can highly significantly differentiate between radial and hierarchical visualisations where observers' correct response rates cannot.

CCS CONCEPTS

Human-centered computing → Empirical studies in visualization → Empirical studies in ubiquitous and mobile computing → *Visualization design and evaluation methods*

KEYWORDS

Visualisations, Radial, Hierarchical, Fixations, Saccades

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1 INTRODUCTION

Visualisation interfaces have been developed to help users to navigate information spaces and abstract away from the inherent complexity of the underlying information [1]. This type of visualisation covers a wide range of application fields such as technology, geography, teaching, political, natural science, economic decision-making, that consist of expert-level solutions solved using well-defined techniques [2].

Visualisation can provide high levels of interaction to users to glean knowledge from the raw data, and enable learners to draw valuable conclusions at minimal cost [3], describe big data in simple and innovative ways [4], combine data in diagrams that represent information and convey messages to observers by creating mental visual images [5]. Visualisations can also have an effect on observers' comprehension and impressions [6].

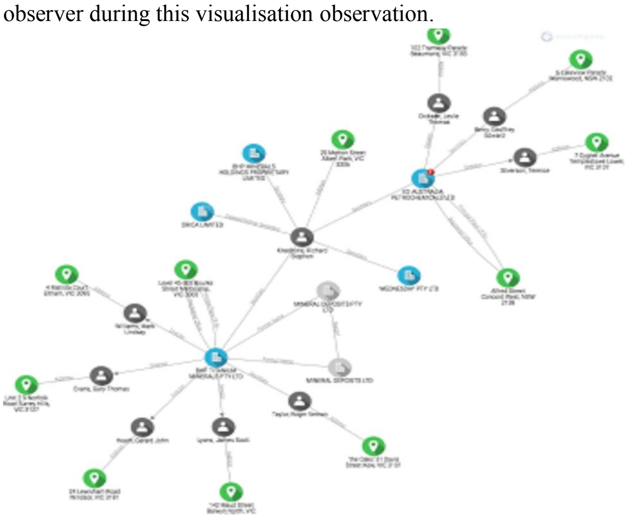
The goal of a visualisation is to transfer whole chunks of knowledge to the observers in a very short time which includes gathering, processing, pictorial rendering, analysing, and interpreting data [7]. The visual elements of such types of diagrams are able to describe the visualised story with a minimal requirement for extra text explanations [8]. Several studies support that images and graphs can capture the immediate attention of observers compared to texts [9]. When two visualisations are similar in quality, it could be hard to differentiate one from another via observers' correct response rates. This is the setting we wish to investigate. Previous work has investigated eye gaze on substantially different visualisations (radial versus linear graphs) and reported from their scan path analysis that mapping a data point to its value is slower in radial compared to linear graphs [10].

In our setting we compare two visualisations from observers' visual fixations and saccades with their correct responses rate. A visual fixation occurs when the eye gaze lingers on a single spot, and a saccade means a fast relocation of the attention point. The recorded data for radial and hierarchical visualisations are analysed and the results are discussed. The significance levels are reported using two tailed paired sample t-test. The analysis shows that observers' numbers of fixations are able to significantly differentiate between radial and hierarchical visualisations where their saccade durations and their own response rates are not.

2 METHODS AND MATERIALS

2.1 Experiment

The experiment includes two visualisations (radial and hierarchical); each contains six questions. This radial visualisation is used when there is single entity of major interest. In our case, it focuses on BHP Titanium PTY LTD and displays the connections to ICI Australia Petrochemicals, and to their board members as shown in Fig. 1. The following questions are asked from each observer during this visualisation observation.



1. Where does <name> live?
2. Who lives at <address>?
3. Who lives at <address>?
4. How many directors does <core entity> have?
5. Which state do most directors of <other entity> live in?
6. What connects <other entity> and <core entity>?

Figure 1: Radial Visualization, Questions asked

A very similar six questions are asked from the same observers shown a hierarchical visualisation as in Fig. 2. This hierarchical visualisation is structural to show the key interconnections between hierarchies. Please note that the datasets are different, but similar (see §4). A limitation of our work is that given the nature of the information extraction task, we need to have two datasets, if we wish to have a meaningful similarity to the real world application.

The duration of questions was 45 seconds. The visualisations and each question were displayed in an order balanced way, so differed for each participant (i.e. observer). If an observer did not answer in 45 sec, than s/he was shown the next question automatically. There was no break between the two visualisations.

Along with the duration of the task, the other properties such as the colours used and symbols, font size, graphical elements, and lighting environment were kept constant.

The questions from both visualisations were presented at the top left corner with an empty box to the right of each question for typing the answer. The observers were able to see the visualisation while answering each question. They were able to scroll up and down to observe the whole diagram properly. There was a 'next' button at the bottom where the observer was able to go to advance to the next question, subject to the 45 second limit.

Thus, each experiment took about 12 minutes to be completed. The process of the experiment was straightforward and no other interaction was made with the observers. The visualisations are superficially quite similar, but follow different standards. The radial visualisation is a complex groups of linked entities that highlights the structure of associations, and the hierarchical visualisation highlights each single entity of major interest, in this case the National Australia Bank and Sydney 2001 Olympics.

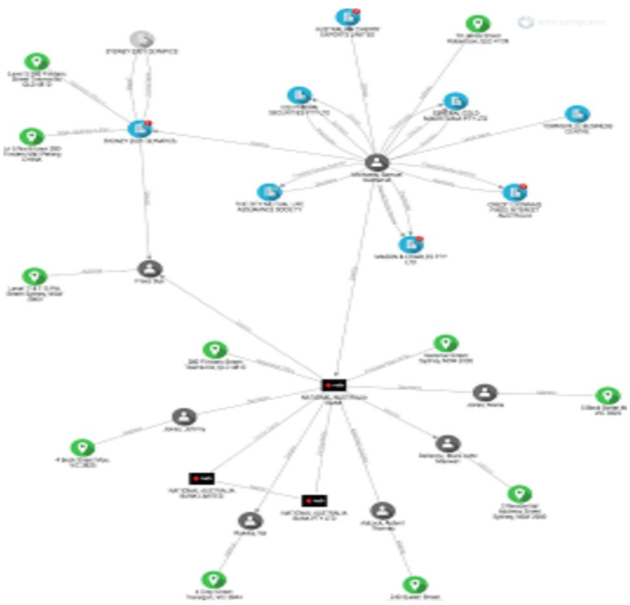


Figure 2: Hierarchical Visualization

2.2 Observers

Twenty-four students (11 male, 13 female) participated as observers in this study, with mean age of 22.1±5.5 (mean±std.) years. Among them, 14 were undergraduate students who gained course credits for choosing to participate in experiments (and voluntarily chose to participate in *this* experiment), while the rest were graduate students who participated voluntarily, without course credits. All observers had normal or corrected to normal vision. They signed an informed consent form prior to their participation.

Ethics approval was received from our Australian National University's Human Research Ethics Committee, prior to performing the study.

2.3 Apparatus

Fixations and saccades of each observer were recorded using The Eye Tribe (https://theeyetribe.com/) remote eye-tracker system with a sampling rate of 60 Hz. A 15.6" Dell laptop and a computer mouse were peripherals for interaction between observer and the laptop running the web-based visualisations. The chair of the observer was moved forward or backwards to adjust the distance between the observer and eye tracker. Observers were asked to track a spot displayed on the laptop screen for calibrating the eye tracker and starting the experiment. Observers were asked to limit their movements in order to reduce undesired artefacts in the signals. In order to achieve the best results, the calibration of the eye tracker was adjusted based on the height of each observer.

3 RESULTS AND DISCUSSION

In order to explore the correct response rates of the observers, scores of the answers to the questions are calculated and depicted in Fig. 3. The correct response rate (CR) of 50% for radial means an observer correctly judged 3 questions among all 6 questions from the radial visualisation. It can be seen from Fig. 3 that observer 9 (O9) has the highest CR of 100% for both visualisations, and O1 and O15 show lowest CR of 50% for radial and 66.7% for hierarchical respectively.

The two tailed paired sample t-test between the two interfaces shows that there is no significant difference in the correct response rate (CR) for radial (M=4.83 (80.6%), SD=0.96) and hierarchical (M=4.88 (81.3%), SD=0.80) visualisations; t (23) = 0.18, p=0.86. This meets the criteria we set for a challenging setting as described earlier.

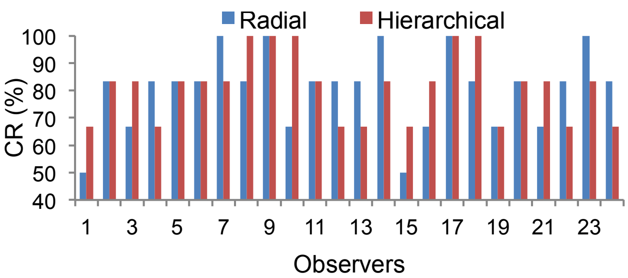


Figure 3: Observers' correct response rate (CR) over all questions for each visualisation.

In the case of average response time (RT), two tailed paired sample t-test shows that hierarchical visualisation (M=26.1, SD=5.8) is faster, and significantly different from radial (M=28.5, SD=5.8) visualisation; t (23) = 2.03, p=0.05 shown in Fig. 4. It can be seen from Fig. 4 that O1 spent the highest time of 44.6s and O13 spent lowest time of 19.4s for radial visualisation, and O20 spent the highest time of 40.4s and O13 spent lowest time of 18.2s for hierarchical visualisation, respectively.

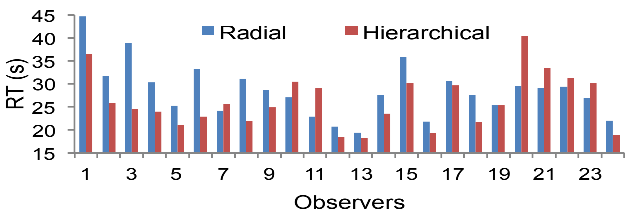


Figure 4: Observers' average response time over all questions for each visualisation.

The fixation durations (FD) are calculated from the output of the eye tracker and illustrated in Fig. 5. The highest FD is reported from O16 (481.2ms) and O22 (510.1ms) for radial and hierarchical visualisations where lowest FD is reported for O20 in both cases (190.4ms for radial and 82.2ms for hierarchical) respectively. The two tailed paired sample t-test shows that there is no significant difference between radial (M=352.4, SD=79.1) and hierarchical (M=380.3, SD=192.1) visualisations; t (23) = 0.62, p=0.54 from computed FD.

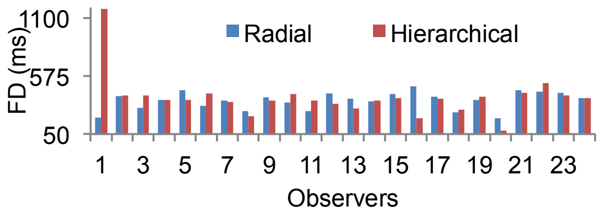


Figure 5: Average fixation duration (FD) over all questions for each visualisation.

The two tailed paired sample t-test shows that the number of fixations (NoF) can significantly differentiate between radial (M=587.2, SD=185.2) and hierarchical visualisations (M=486.9, SD=195.3); t (23) = 4.45, p<0.001 and the results from each observer are shown in Fig. 6. It is observed from the Fig. 6 that the highest NoF is 896.2 (from O3) and 808.8 (from O23) for radial and hierarchical visualisations where lowest NoF is 200.8 and 69.0 (both from O20) for both visualisations respectively. We are clearly finding effects which are consistent over visualisations as well as observers.

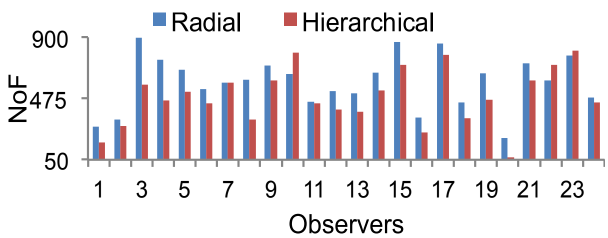


Figure 6: Average number of fixation (NoF) over all questions for each visualisation.

Another parameter which is analysed in this paper is saccade duration (SD) which is very helpful to provide the scan path of the visualisations. The average SD over all questions for both visualisations are calculated from the eye tracker output and illustrated in Fig. 7. The highest SD is 3907.6ms and 3950.3ms for radial and hierarchical (both from O20) visualisations where lowest SD is found 393.4ms (from O5) and 414.4ms (from O7) for them respectively.

The two tailed paired sample t-test shows that there is no significant difference between radial (M=720.5, SD=774.8) and hierarchical visualisations (M=752.0, SD=770.7); t (23) = 1.50, p=0.15 from computed SD.

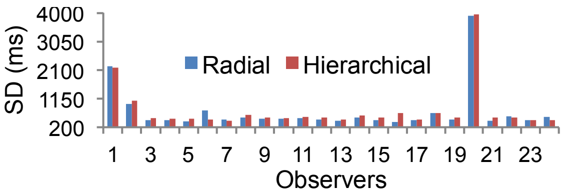


Figure 7: Average saccade duration (SD) over all questions for each visualisation.

We note that because of the short period for which observers get to see the visualisation, and which is seen together with the questions at the top of the visualisation, long-term memory is not involved.

It can be seen from our overall analysis of the average results that observers' CR, FD, and SD are higher in the hierarchical visualisation compared to radial visualisation where the other two parameters (RT and NoF) are lower in hierarchical visualisation compared to the radial visualisation.

4 COMPLEXITY OF DATA SETS

In §2.1 we mentioned that the two data sets shown in the radial and hierarchical visualisations were, and needed to be, different. We analysed the complexity of the two data sets, as reflected in the visualisations we used in this experiment. For simplicity we refer to them by the visualisation used here, so we call them the *radial* data set (BHP is core entity) and the *hierarchical* data set (NAB is core entity).

The notable differences are the numbers of vertices, edges, the *E/V* (edges to vertices) ratio and the diameter (Table 1). The diameter is the maximum over all ordered pairs *(u,v)* of the longest path from *u* to *v*. This is also the maximum eccentricity of the vertices.

Table 1: Graph Complexity Analysis of the Visualisations (only different properties are shown)

Visualisation	Radial	Hierarchical
Vertices	27	30
Edges	52	63
E/V ratio	1.93	2.10
Diameter	6	4

It is generally considered that the visual complexity of a graph is the visual density, i.e. the amount of ink or clutter, and thus the number of nodes and edges [11]. Thus, the *hierarchical* data set is more complex. The *E/V* ratio is also higher and the diameter is lower, which indicates that the vertices are more highly connected, hence also showing that the *hierarchical* data set is more complex. The increased complexity of the hierarchical dataset may have led to higher fixation durations (FD) and saccade durations (SD), but lower number of fixations (NoF).

5 CONCLUSIONS

In this study, two visualisations (radial and hierarchical) are presented, and we asked six very similar questions about each visualisation from the observers, in a setting where the correct response rates could not be used to differentiate the visualisations. We investigated five parameters (observers' correct response rate, response time, fixation duration, number of fixation, and saccades duration) to differentiate between them. Individual analysis on each parameter shows that observers' correct response rates are very similar for both cases where two tailed paired sample t-test shows that none of the correct response rate, the fixation duration, or saccade duration is able to differentiate between these two visualisations. This is to be expected in a compliance setting, in that the high cost of mistakes leads to behaviour in general such that people will make sure they have found the correct answer, so any difference in quality (or usability) of the visualisation will show up as time or other behaviours. The other parameters, response time and number of fixations, are able to differentiate between these two visualisations.

We compared two similar visualisations, and demonstrated that as designed, the user correct response rates were not able to show any statistically significant differences. We showed from eye gaze data that it is still possible to differentiate between these two visualisation examples using simple eye gaze metrics. Further, we demonstrated that the hierarchical visualisation is superior to the radial in this setting, as we also showed that users were significantly quicker on the hierarchical visualisation even though it was displaying more complex data in graph analysis terms.

We propose that our methodology of demonstrating benefit of 'stress testing' a visualisation using eye gaze factors may have wider utility. In future, we aim to test more visualisations of different natures, with a number of different levels of complexity to replicate and extend our results, and extend this experiment beyond our use of similar core entities. We should also record subjective data with our performance data, such as asking the observers to comment on their perceptions of comparable difficulties and prior experience with similar visualisations.

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