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The effects of immersion and navigation on the acquisition of spatial knowledge of abstract data networks

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Abstract

With increasing frequency immersive virtual environments (IVEs) are being used to present multi-dimensional information visualizations. Networks and graphs are a common type of abstract data; in order to understand the varied relationships between entities in a network, it is crucial to acquire some spatial knowledge about the layout and connectivity of its components. While there is a good body of evidence for the benefits of IVE displays, most work on the effects of immersion and of navigation on the acquisition of spatial knowledge has been concerned with wayfinding in realistic environments; much less is known about how to leverage IVE technology to benefit a user's spatial understanding of (abstract) data networks. In this paper we present an empirical study designed to determine what effect level of immersion and navigation technique can have on a user's acquisition of spatial knowledge of network data, specifically cell signaling pathways. For this CAVE study (CAVE Automatic Virtual Environment), the level of immersion is controlled by changing the Field-Of-Regard, while we also vary navigation between one egocentric and one exocentric technique. The results show that both immersion and navigation technique can affect the acquisition of spatial knowledge regarding abstract networks in an immersive virtual environment.

Keywords: Visualization; Immersion; 3D Navigation; User Studies

1. Introduction

Presenting complex, abstract scientific data in a clear, easy to comprehend way remains a long standing challenge. The field of information visualization has come a long way in contributing a rich set of options and is often utilized to find patterns within such data. However in some specific cases, especially when the information can be represented as a network graph, users may be best served by gaining knowledge of the spatial organization and spatial relationships within the data. One such case is cellular signaling pathways, where the structure of communication pathways may be more valuable than individual properties of any item within the data.

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There have been a number of previous studies that evaluate the benefits of immersion for spatial understanding. Many of these studies have recorded some benefit to immersion when performing particular tasks. In all other cases immersion seems to have no significant effect. This research serves as an inspiration for the study presented in this paper. However, all of these previous experiments have studied realistic virtual environments. The study in [1] does discuss the effects of immersion when viewing abstract information, however, to our knowledge, no previous work has been done on abstract networks. As defined in [2] "abstract information is information that is not normally directly perceptible in the physical world." In addition, we have found little prior work that has explored the effectiveness of different techniques for navigating three-dimensional networks.

To understand the effects that such changes in immersion and navigation might have for spatial knowledge of abstract data networks, we designed the experiment described below. To contextualize this inquiry, we refer to the traditional division of spatial knowledge into **landmark**, **route** and **survey** types. As defined in [3] "landmarks are unique objects at fixed locations, routes correspond to fixed sequences of locations as experienced in traversing a route; survey knowledge abstracts from specific sequences and integrates knowledge from different experiences into a single model."

Using these distinctions, we designed four tasks: one to test landmark identification, one that required route following, and two testing survey knowledge. These tasks are performed across four treatments created by varying the Field-Of-Regard (FOR) in combination with either an egocentric or exocentric navigation technique. We hypothesize that exocentric navigation will provide users an advantage for acquiring survey knowledge and a good understanding of the topology of the network, whereas egocentric navigation will enable the user to get better route knowledge of the network connections. We also suspect increased immersion will facilitate easier cognition in all spatial categories with the greatest benefit for survey knowledge.

The remainder of the paper is organized as follows. Section 2 presents the related work in this research area. In Section 3 we explain the details of our experiment and presenting the results of the study and a discussion of their implications. Section 4 contains the conclusion drawn from the performance of this experiment sketches future research to improve our understanding of how navigation techniques and immersive technologies can impact the acquisition of spatial understanding of abstract data networks.

2. Related Works

Network visualization has long been a topic of research. Many networks of interest have no physical counterpart or are too intangible to suggest a natural representation. Also, in many cases visualizing the information associated with a network is just as important as understanding its structure. One type of network that has been the subject of a large amount of research are Telecommunication networks. In [4] and [5] network visualization techniques are developed and discussed in hopes of creating better computer network security tools. The goal of these visualizations is to provide insight into both the topology of the network (structures and patterns of connectivity) as well as the local properties of nodes and edges. To address the scalability and effectiveness of visualizing large networks, they leverage "Overview first, zoom and filter, then details-on-demand" in an interactive two-dimensional graphic space [6]. A number of design challenges were enumerated including: occlusion, filtering and providing an interface that enables users to adjust the amount of distortion and suppression in the visualization. Network visualizations such as these raise the question as to how interactive three-dimensional visualizations and immersive technologies can be leveraged to improve task performance.

Another type of network is Cellular signaling pathways, which are the system of communication relationships that allow cells to respond to internal or external biochemical cues. The STKE database was established to store data on all known cellular signaling pathways [7]. The current online visualization for analyzing this STKE networks is the 'Connection Map'. These are interactive 2D network graphs, which allow for zooming, panning, and details-on-demand. As reported on the STKE website [7], one of the main ways in which these graphical representations are used is for 'Pathway Walking'. Pathway Walking is used "to uncover the signaling 'hubs' and the network properties of the cellular signaling world." In many ways Pathway Walking suggests performing wayfinding and gaining spatial knowledge of the signaling networks. This led us to consider how traditional research in the benefits of immersion and navigation would apply when investigating spatial networks of abstract data.

One study that motivated our current experiment is [8], which compared scientific visualizations within immersive systems such as the CAVE to less immersive desktop displays such as the Fish Tank system. This study suggested that the CAVE, with its larger display size and field of view, performed better both subjectively and objectively for examining the scientific information. This study differs from our own in that it used realistic scientific models and this study changed not only the level of immersion but also the hardware being used to display the information.

Another motivating experiment is [1]. For this study abstract data in the form of 3D scatter plots were displayed in the CAVE and immersion was controlled by Field-of-Regard (FOR) and head-tracking. Field-of-Regard refers degree of surround provided by a display; for example a Head Mounted Display and a six-sided CAVE have 360 degrees horizontal and vertical FOR; two walls in a corner may provide 120 degrees horizontal and 90 degrees vertical FOR. They found that immersion tended to improve user performance and was preferred by the participants. This study is similar to our own, however, they did not use network data and their focus was not to determine the effects of immersion on spatial understanding.

Bowman and McMahan [9] discuss how the benefits of immersion depend on the complexity of the environment being viewed and hypothesis that Immersive Virtual Environments (IVEs) should assist in the discovery of spatial knowledge. Following up on this hypothesis, [10] explored the effect of immersion on the spatial understanding of realistic complex 3D structures. Immersion was controlled by changing FOR, stereoscopy, and head tracking. They found that a higher level of immersion increases both speed and accuracy when gaining spatial knowledge of complex 3D structures. Although we hypothesize that we will observe similar results as this study, we believe that abstract data networks will provide unique challenges when attempting to obtain spatial understanding.

A set of guidelines has been proposed by [9] for designing effective IVE navigation techniques. They are: absolute motion, relative motion and the amount of disorientation a given technique causes the user. This study showed that a pointing-based navigation is more effective for relative motion than gaze-based navigation, while they are equally effective for absolute motion. However, they observed that the gaze-based navigation is easier to learn and is more accurate than pointing-based navigation. For our experiment we opted for pointing-based navigation techniques. Despite the benefits of gazed-based, we felt the users' ability to gain spatial knowledge was best served by allowing them to look around the network structure while moving.

While navigating IVEs, disorientation can be a major issue. [11] explored the use of three-dimensional arrows and information-on demand techniques to support three-dimensional navigation in a virtual environment. It was observed that the user often felt "lost" in a virtual environment. One method suggested to reduce disorientation is to restrain the user's free movement by using a roller coaster type of navigation [12]. Because we focus on acquiring spatial knowledge through exploration and discovery, we must examine new techniques and solutions.

The study in [13] focused on countering disorientation while wayfinding in large virtual environments. They observed that using environments that provide recognizable structure through coordinate systems or built in landmarks such as unique coastlines can benefit virtual wayfinding performance. They also noted participants using orienting techniques typical in the real world, such as dead reckoning and path following. Although this study focused on large-scale realistic environments, we believe many of their findings are applicable to our experiment. In order to mitigate disorientation while viewing abstract data networks we provided a compact and organized structure divided into subgroups of nodes with shared attributes using a modified force-directed layout. In addition we added a horizon line and sky to serve as a constant plane of reference.

Motivated by the previous work in this field, our primary goal for this project was to assess the impact of immersion and navigation technique on participants' accuracy and speed at acquiring landmark, survey, and route knowledge of three-dimensional graphs. To do this we conducted an empirical study observing the performance of participants acquiring knowledge using varying Field-Of-Regard (FOR) in combination with either an egocentric or exocentric navigation technique. We hypothesize that three-dimensional graph structures representing the cell signaling pathways will be sufficiently complex to bring out the benefits of immersion. As a result, we expect to see accuracy and speed increase when using four walls as opposed to one. Also based on the prior work above, we expect to see improved performance for: egocentric navigation for route discovery and exocentric navigation for survey knowledge.

While research ([10, 8]) has been done that demonstrates that the differences between men and women as well as between individuals of different cognitive predispositions can greatly impact the benefits gained from both level of immersion and interaction technique, we had no hypothesis in this regard.

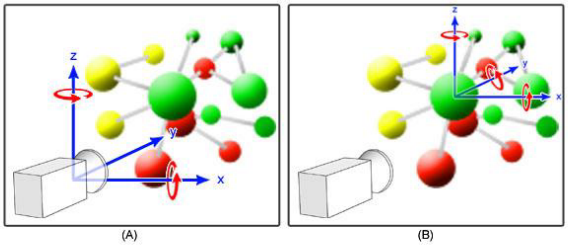

Fig. 1: Rotational navigation (A = Egocentric) and flying navigation (B = Exocentric). The camera icon identifies the point of view, the blue lines represent the axes originating from the pivot point, and the red arrows signify degrees of freedom.

3. Experiment

We devised the following experiment to assess the impact of level of immersion (FOR) and navigation technique (ego vs. exo -centric) on user performance during the acquisition of landmark, survey, and route knowledge when a three-dimensional graph is displayed in a stereoscopic and tracked IVE. During the experiment the three-dimensional graphs were shown on either one wall or four walls and the participant navigated using an egocentric ‘flying’ approach or an exocentric ‘rotating’ method.

Using the **egocentric** navigation technique, users *flew* through the network using forward and backward movements on the wand joystick that guided the camera in the corresponding direction within the environment along a vector defined by the heading, pitch and roll of the wand. In other words, as the user pointed the wand in a direction and held the joystick forward, the camera moved in the direction the wand was pointed. Moving the joystick to the left or right rotated the camera around the Z-axis. While using this technique, nodes could be selected, however the selection had no impact on navigation.

With the **exocentric** navigation technique the user *rotated* the network about its X,Y and Z axes using the wand joystick. The pivot point for rotation began as the origin and then became the currently selected node once a selection was made. Zooming in and out was achieved using the two bottom buttons (left and right) on the wand. The speed of the zoom was equal to the max speed moving forward or backward while using the egocentric flying navigation.

It is important to note that we did not allow for roll control in the egocentric flying technique. Therefore, the egocentric \ technique provided one less degree-of-freedom (DOF) than the exocentric rotation technique. In both of the navigation techniques, nodes could be selected using the top right button on the wand. A diagram of these navigation techniques can be seen in Figure 1.

These immersion and navigation options created four separate conditions in which participants could be tested by asking them four different questions meant to expose the participant’s landmark, survey, and route knowledge of the graph being displayed. We also used a questionnaire after the experiment to collect subjective information on the participant’s experience. For this study we used a Balanced Incomplete Block Design (BIBD) which allowed us to perform within-subjects and between-subjects evaluations while decreasing the time required of each participant.

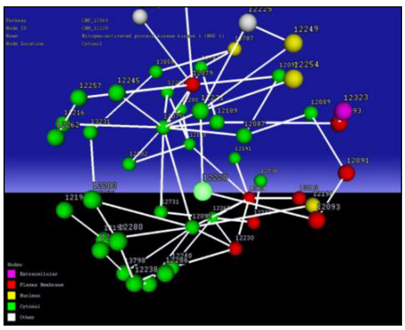

Fig. 2: Example of a 3D graph of an abstract network representing a cellular signaling pathway.

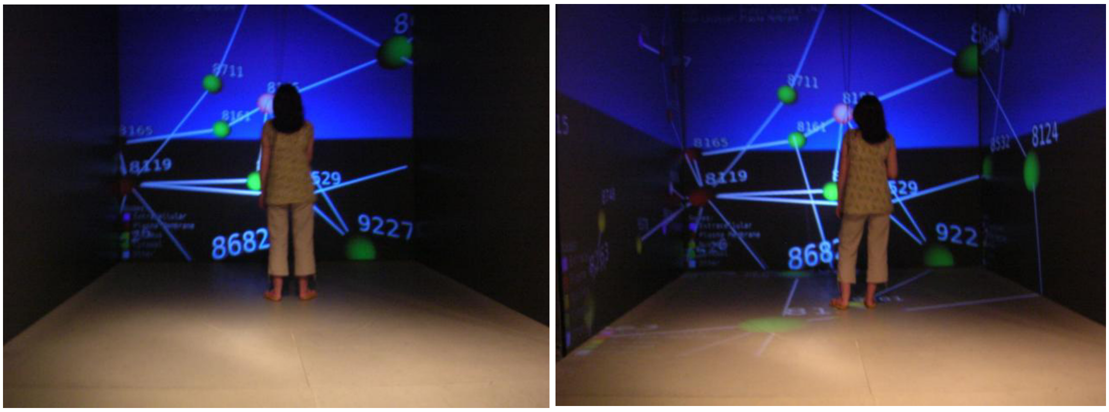

Fig. 3: (a) A user experiencing on wall in the CAVE; (b) A user experiencing four walls within the CAVE. (Note: the highlighted red node in the center of the front wall is selected)

Each of the twenty-four participants was tested in three of the four possible treatments. The participant was asked to answer the same four questions as quickly as possible during each of the treatments.

3.1 Dataset and Representation

The data used for this project was a collection of cellular signaling pathways from the STKE database. Each pathway represents the interactions of various biochemical components of a cell; these nodes can share multiple connections with one another (edges) (Figure 2). To maintain a consistent complexity between all of the graphs used throughout the experiment we chose pathways that each contained between 33 and 42 nodes. This was the most compact range that would provide the level of complexity and number of graphs required for this experiment. In addition, different pathways used for the same question between treatments were selected for sharing a similar number and arrangement of edges.

The graphs representing the pathways were arranged using a modified force-directed layout algorithm. We began by implementing a typical force-based algorithm using Hooke's law and Coulomb's law. In addition to the basic form of the algorithm, we also took into account the attributes of the objects being represented. First, we grouped nodes from the same (physical) location within the cell and ensured that no two of these nodes were ever more than a given distance away from each other. This initial step resulted in more organized and spatially-grouped networks as opposed to the more flat graphs created by the unmodified (ungrouped) force-directed algorithm.

We choose our modified algorithm because it created relatively clean three-dimensional structures and substructures. There are certainly a number of trade-offs in the use of various graph layout algorithms. In particular, it is clear that the complexity of a network layout is closely related to how easy it is to acquire knowledge about its spatial properties. We apply the same network layout algorithm to all the stimuli, the how and why these factors are related is outside the scope of this work and must be left for future work. Our objective is to explore the navigation and immersion within three-dimensional graphs in general. Therefore we decided to represent only a small number of additional key features of each node specific to the cell signaling pathways. The node's physical location within the cell (e.g. Nucleus, Cytosol, Membrane, etc.) was also represented by the color of the node. At most, a graph could contain nodes of five different colours. Components (nodes) in the graph were also spatially grouped by the same cellular location (see above). A Heads-Up-Display (HUD) provided a key for interpreting the colours as well as providing details about the selected node. In an attempt to reduce user disorientation, we added a horizon line with a blue sky. An example of the final network representation rendered in the CAVE is shown in Figure 3.

3.1.1. Apparatus

Our implementation utilized three main components: the Virginia Tech CAVE, the DIVERSE toolkit, and the OpenSceneGraph toolkit. The CAVE Automatic Virtual Environment [14] at VT is an immersive virtual reality display system with three wall surfaces that are back-projected and a floor that is down-projected. Thus, it is a cubic 10'x10'x10' area on which the three-dimensional environment is rendered with active stereoscopy. The Virginia Tech CAVE consists of several hardware components including six networked computers, one as a console, one for I/O, and four in a DIVERSE Adaptable Display System (DADS). The VT CAVE uses an InterSense IS-900 for six degree-of-freedom tracking for both the user's head and a wand device. The wand had 4 buttons and a 2 DOF analog thumbstick. The wand had a selection ray pointing out of its tip and selection feedback was indicated by a change in the luminosity of the node and by a change in the information displayed on the head-up display. We used the DIVERSE software [15] to facilitate communication between the CAVE hardware and OpenSceneGraph (OSG) [16] to implement this testbed. The software written to run this experiment is available on our group's research page at: http://snoid.sv.vt.edu/~npolys/projects/stke.

3.2 Participants & Procedure

In total, 24 undergraduate participants were involved in this study covering 16 majors. None of the participants had any prior experience using the CAVE and all were unaware of the hypothesis of the experiment. Theirs ages ranged from 18 to 24, and they included 14 males and 10 females. The majority of the participants reported that they had average PC experience, with males having a slightly higher average PC experience than females. Also, males self-reported a slightly above-average gaming experience while females self-reported below-average game experience.

All participants were given an explanation of the experiment, signed a consent form and then given a demographic questionnaire. The collected information included age, gender, major, PC experience, game experience, and any prior CAVE experience. Once they had completed the questionnaire they were given a brief introduction to the CAVE hardware, put on the head-tracked stereo glasses and shown an example cell signaling graph including the information available in the Heads-Up-Display (HUD). Three-dimensional graph terminology was explained including "connected node", "neighbor nodes", and "path between nodes". Participants were shown each wand navigation technique and given the chance to practice; when users verbally confirmed they were comfortable and capable with each technique, the experiment began.

We used a Balanced Incomplete Block Design in this experiment. In such a design, a user participates in only a subset of all possible treatments, but in a structured way so that a full factorial analysis of variance can still be valid. This means that each of the 24 participants was treated with 3 out of the four possible scenarios (four wall + flying, four wall + rotating, one wall + flying, one wall + rotating). While participants were all shown the same graph environments in the same order, to avoid an ordering effect they experienced different arrangements of treatments, resulting in unique combinations of treatment and environment. Care was taken so that each treatment was given equal number of times.

In each of the treatments, the participants were asked to perform the following four tasks:

1. Identify all of the neighbors of node X (**survey**)
2. Identify how many nodes are between nodes X and Y (**route**)
3. Identify the most connected node in the graph (**landmark**)
4. Identify how many nodes of type Z are in the graph (**survey**)

These questions were chosen because they require the participant's landmark, route, and survey knowledge of the displayed graph. These questions allow us to test whether the changing level of immersion and egocentric or exocentric navigation have an impact on the speed or accuracy with which one can gain landmark, route, and survey knowledge. In particular the first and fourth questions require survey knowledge of the three-dimensional graph, while the second question involves route knowledge and the third question requires landmark knowledge. In total, each participant would perform twelve trials (four tasks per treatment). To ensure that every task was independent and unaffected by the knowledge of the graphs gained from previous tasks, a different cell signaling pathway with consistent properties was given for each of the 12 trials.

Each task required an answer that consisted of a node name (a four or five digit number) or a count of nodes; for task 1, the answer consisted of, on average, six nodes. For task 2 the number of nodes included in the answers averaged out to be 5 nodes. Task 3 had a single answer and the average number of nodes for task 4 was 10.The participants verbally indicated their answers as they discovered them and stated when they were finished answering.

The experimenter inside the CAVE recorded the answers as they were given and the time spent answering was recorded once the participant indicated they were finished with that question. If the participant made an error that they explicitly corrected, then their incorrect answer was ignored; otherwise their responses were recorded exactly as given. After completing the all of the tasks, participants filled out a post-experiment questionnaire asking them to rate their display and navigation preference and the difficultly of each question (on a scale of one to seven).

3.3 Results

The following section describes the results of our study. We present the results of the objective measures, subjective measures, and the demographic questionnaire. Statistical results are derived using Analysis of Variance (ANOVA) on a General Linear Model (GLM) and Pearson's R correlation coefficient. Finally, we collect a few qualitative observations about user strategies and behaviors. Scores across all tasks have been normalized to a percentage of 100.

3.3.1 Objective

We began by assessing the overall effects of the task (the type of spatial knowledge required) on both time ($p < 0.0001$) and score ($p < 0.0001$). For structural Survey knowledge (task 1) the average score was 90% correct in 79.79 sec. For counting Survey knowledge (task 4), average score was 87% in 39.90 sec. For Landmark tasks (task 3) it was 100% in 40.79 sec. For Route knowledge (task 2) correctness averaged 53% in 86.23 sec.

We performed a three-factor ANOVA for the dependent measures of user response time and score. Participants tended to be faster ($p = 0.0613$) on Route knowledge using one wall; Users completed task 2 on average in 75.97 seconds (Standard Error (SE) = 7.68) while it took on average 96.49 seconds (SE = 7.87) when using four walls.

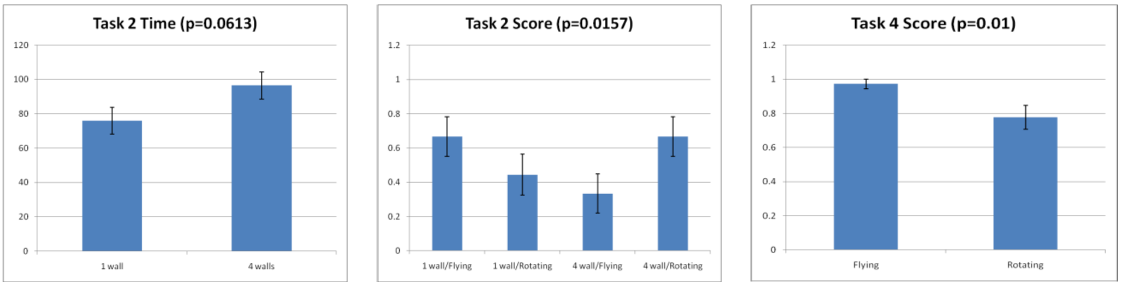

Fig. 4: (a) Mean times to complete Task 2 using one wall (75.97 sec.) and four walls (96.49 sec.); (b) Mean scores for Task 2 using each of the four treatments. 1 wall/flying (0.66), 1 wall/rotating (0.44), 4 wall/flying (0.33), 4 wall/rotating (0.66); (c) Mean score for Task 4 when using flying (0.97) and rotating (0.77)

FOR in combination with navigation technique yielded significant differences in the score for task 2 ($p = 0.0157$). Participants scored significantly better on task 2 while using a combination of one wall and flying with an average score of 0.66 (SE = 0.114) or while using 4 walls and rotating together with the same score and standard error; for one wall/rotating and four wall/flying, the average scores were 0.44 (SE = 0.120) and 0.33 (SE = 0.114).

Another significant result was observed when we considered the effects of immersion and navigation together. It shows participants scored significantly ($p = 0.01$) better on task 4, which tested their survey knowledge, while using flying as opposed to rotating with average scores of 0.972 (SE = 0.027) and 0.77 (SE = 0.070) respectively. Other than these three conditions, level-of-immersion (FOR) and navigation technique did not significantly impact speed or accuracy in any other treatments. Figure 4 shows these significant results.

3.3.2 Subjective

We analyzed the responses given in the pre and post experiment questionnaires. Display preference was strongly correlated to both PC experience ($R = 0.641$, $p < 0.0001$) and gaming experience ($R = 0.624$, $p < 0.0001$). In other words, those participants with more gaming and/or PC experience significantly preferred four walls. In addition, navigation preference was strongly correlated to PC experience ($R = -0.2902$, $p < 0.0001$), meaning users with more PC experience preferred the exocentric (rotating) navigation technique.

We also attempted to discover any correlations between the objective and subjective measures. We found that while performing task 2 (route) using four walls, score was significantly associated to the display preference ($R = 0.349$, $p = 0.036$). This means that participants who scored better on task 2 using four walls recorded liking four walls as opposed to one. We also found within task 4 (survey) that participants who responded more quickly while using the flying technique also recorded a preference for flying ($R = -0.341$, $p = 0.041$). Finally, for task 4, better scores under exocentric (rotation) navigation correlated with higher PC experience ($R = 0.333$, $p = 0.046$).

3.3.3 Observations

While performing the study we observed and noted common user behaviours. One of the most significant observations was the strong tendency for participants to maintain focus on the front wall - even when there was imagery on four walls. Because of this orientation forward, users navigated in a way to bring regions of interest from other walls to the front wall. In addition, the majority of participants made little physical motion within the CAVE despite being shown that they were free to move about.

Also of interest are observations regarding participant actions within the virtual environment. Users were conservative in their navigation of the space and rarely lost sight of the network in any treatment. While attempting to gain survey and landmark knowledge, users tended to navigate away from the graph so that more of it would be visible. This behaviour was most prevalent in the landmark task (task 3) and the survey counting task (task 4). On some tasks (especially the structure survey task (task 1) and the route task (task 2)), users adopted a strategy for wayfinding that takes advantage of a node's selected state to provide an obvious, user-defined landmark. This highlighted node can then serve as a visual reference while navigating.

3.4 Discussion

We hypothesized that exocentric navigation would provide users an advantage for acquiring survey knowledge and an overall understanding of the topology of the network, whereas egocentric navigation would enable the user to gain better route knowledge of the network connections. We also suspected that increased immersion would facilitate easier cognition in all spatial categories with the greatest benefit for survey knowledge. It is not surprising that time varied significantly depending on the task being performed. While designing the study we were aware that some tasks are more complicated than others, indeed normalized accuracy scores differed significantly. This suggests that some spatial knowledge of abstract networks, such as route understanding, is more difficult to attain than landmark or survey knowledge (in a static 3D graph).

In our route task, users were given a starting node and a target node and asked to count the hops between them. On single wall displays, we observed a trend towards faster performance on route knowledge tasks. This conflicts with our hypothesis that more FOR would better support route tasks. Recall that users generally maintained their focus on the front wall. This may explain the result if they were able to complete this task (follow the route) only on the front wall (where all their attention was), all that is left in the increased FOR is irrelevant information. As a consequence, users do not seem to naturally take advantage of the increased FOR for this task. Because our environments are abstract, users cannot easily leverage the perceptual strategies they may use in the real world. Indeed, the spheres, lines and text in our stimuli do not provide many cues for differentiation or recognition. Thus, for extracting route knowledge from our presentations, it seems that there is some task time overhead when presenting information with a large FOR.

However, participants scored equally well on the route task using one wall with egocentric flying as with four walls with the exocentric rotation technique. In the egocentric navigation, the user is moving relative to the nodes and thus users have to track or re-find the route while exploring the environment. Because participants predominantly focused on the front wall, they adopted a navigational strategy that could keep the target route on the front wall. As a result, when using flying, the side and floor walls serve mainly as a distraction - resulting in more frequent loss of the focus route. This can explain our observation that egocentric flying for routes is more accurate with one wall rather than four.

In contrast, with exocentric navigation the user rotates about a stationary selected node; therefore if the target route is on the front wall it stays on the front wall and the user does not have to track or re-find it while exploring. In this case, the user has a stable point of reference (recall the user is required to select a node as the pivot point) and the peripheral information provided by the extra FOR can be moved and explored without fear of losing the focus route. Therefore exocentric navigation makes searching for the route in question on four walls easier while not adding unnecessary maneuvers. The results show this combination of navigation technique and FOR is a top competitor for accuracy.

In opposition to our original hypothesis, participants responded more accurately on task 4 (survey knowledge) while using the egocentric navigation technique. Recall that for this task many participants navigated away from the graph in order to attain an overview. We suggest that this advantage for the egocentric technique is due to the ergonomics of the device mapping we used: in the egocentric technique, no buttons were required to complete any navigation intent. In contrast, the switching between joystick and buttons for an exocentric zoom navigation was costly. Once the participant could see the entire graph, they could insure that all of the nodes of a particular type had been located.

It is also interesting to note that the some participants tended to perform more accurately on task 2 (route) and significantly quicker on task 1 and task 4 (survey) across all conditions. This suggests that especially for survey knowledge (and to a lesser degree route knowledge), individual differences seem to be a big factor in performance. A more thorough questionnaire would be helpful in narrowing down which of these individual differences are significant.

We believe the correlation between PC experience, gaming experience, and display preference for four walls can be attributed to better skills at managing attention in high stimulus environments and better competency in navigating virtual environments. These characteristics allow those with PC and/or gaming experience deal with the complexity of the abstract network being displayed without becoming overwhelmed. The connection between PC experience and a preference for the exocentric rotating navigation could be a result of these participants being accustomed to viewing and manipulating their PCs from exocentric points of view. The final set of results shows that in many cases users reported liking the conditions that they perform with best. This suggests to us that in these conditions users are able to recognize their own ability to gain spatial understanding.

4. Conclusions & Future Work

The effect of Field of Regard and navigation technique on the acquisition of spatial knowledge of abstract data networks is clearly an issue that requires more attention. In many cases, utilizing human intuition of their surroundings gained through spatial understanding may be the key to discovering new insights into complex and abstract scientific data. This study has worked to better understand the benefits that immersive virtual environments may have when viewing this type of data without 'realistic' navigation metaphors.

Our results suggest that IVE designers should consider task and navigation technique together with the display venue. This study has shown that different navigation techniques can be advantageous for different search and integration tasks. For example, to obtain accurate and timely route knowledge of such abstract networks, users should able to maintain focus on the data relevant to their task with as little effort as possible. This becomes especially important in immersive (high FOR) environments. Also we note that even in graphs of modest complexity, it may be beneficial to provide additional orienting cues for the user; for example more salient landmarks in the background and/or periphery. In addition it seems that user experience can have a large impact on how users perform with various navigation techniques and FOR to acquire different kinds of spatial understanding.

These results help shed light on the effects of screen surround and navigation technique when viewing abstract data networks in immersive virtual environments; the fact that some results of this study do not support our initial hypothesis highlights the need for more research in this area. We sample only two navigation techniques and one regime of network size and connectivity. A separate but related study could also be done focusing on the impact of network layout algorithms on spatial understanding in IVEs. Undoubtedly there are more rich relationships to discover. In response to our specific results, we hope to perform further studies to better understand the effects of immersion on a user's ability to gain route knowledge of an abstract network graph.

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