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Wayfinding/Navigation within a QTVR Virtual Environment: Preliminary Results

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Abstract: This paper reports on an investigation into wayfinding principles, and their effectiveness within a virtual environment. To investigate these principles, a virtual environment of an actual museum was created using QuickTime Virtual Reality. Wayfinding principles used in the real world were identified and used to design the interaction of the virtual environment. The initial findings of this study suggests that real-world navigation principles, such as the use of map and landmark principles, can significantly help navigation within this virtual environment. However, navigation difficulties were discovered through an Activity Theory-based Cognitive Task Analysis.

Keywords: wayfinding, navigation, QTVR, virtual environments, activity theory.

1 Introduction

Research into wayfinding in virtual worlds has been concerned with how people interact with the environment, rather than why. Experiments have concentrated on gathering empirical data on wayfinding paths, time to completion, and the number of errors for each Participant (Darken & Sibert, 1995; Navigation et al., 1995; Elvins et al., 1998; Plante et al., 1998). Though these studies have been important in identifying wayfinding principles, they provide little information about how to improve the user interface to virtual worlds. They also do not give an understanding of why people adopt certain wayfinding principles or strategies over others, or what causes people to change their strategy. This study attempts to address the following two questions:

1. Can wayfinding principles used in the real world translate to QTVR (QuickTime Virtual Reality) virtual environments?
2. What difficulties do users have in navigating and searching for objects in QTVR virtual environments, and what strategies do they use to overcome these difficulties?

The purpose of this study is to firstly identify whether 'traditional' wayfinding principles used in the 'real world' could be as effective within a virtual environment such as a QuickTime Virtual Reality (QTVR) environment. Secondly, this study tries to identify the difficulties that users might have with the QTVR environment, and whether these difficulties are influenced by the wayfinding principles that are being tested. A combination of Activity Theory and Cognitive Task Analysis was used to answer these questions. Cognitive Task Analysis was used to elicit the type of information required for study, and Activity Theory was then used to place it in a meaningful context. Wayfinding performance was also measured to provide further insights to the questions. In building the virtual environment for the study, concepts from spatial knowledge theory and environmental design methodology were employed to guide the design of the virtual environment.

The interaction design for the virtual environment is based on spatial knowledge theory (Thorndyke & Goldin (1983) cited by Darken (1995)) and environmental design methodology (Lynch, 1960). Finding new principles that are unique to Virtual Environments is outside the scope of this study. Rather, the aim of the study is to determine whether spatial knowledge theory and environmental design principles are useful for designing QTVR virtual environments.

2 Spatial Knowledge

Lynch (1960) describes spatial knowledge as:

> "... the generalised mental picture of the exterior physical world that is held by the individual".

This 'environmental image' is the 'strategic link' in the process of wayfinding. As this mental picture improves or becomes more detailed, wayfinding performance generally improves. This environmental image consists of three specific types of information (Darken, 1995):

Landmark knowledge: Information about the visual details of specific locations in the environment. This represents notable perceptual features of an environment, such as a unique building, that is stored in a person's memory.

Procedural knowledge: Information about a sequence of actions required to follow a particular route. Procedural knowledge is built by connecting isolated bits of landmark knowledge into larger, more complex structures.

Survey knowledge: Configurable or topological information. Object locations and inter-object distances are encoded in terms of a global, fixed, map-like frame of reference.

Wayfinding in general requires the navigator to visualise the space as a whole. This topological knowledge or spatial knowledge as described above is significantly different from procedural knowledge which is defined as the sequence of actions required to follow a particular route. The route may make use of landmark knowledge which is static information about the visual details of a specific location.

3 Environmental Design

Based on what is known about spatial knowledge theory and its application in wayfinding tasks, environmental designers have developed a design methodology focused on environmental organization and map use. City planners and engineers have long since used spatial knowledge in designing cities that are easy to navigate and to find your way around. Lynch (1960) describes five elements of the contents of city images, which also seem to reappear in many types of environmental images. These elements are:

Paths: Channels of movement. They include streets, walkways, canals, transit lines, and railroads. Paths are predominantly in the eye of the beholder.

Edges: Linear elements not used or considered as paths. They are boundaries or linear breaks between two regions. They include shores, railroad cuts, edges of developed walls, etc.

Districts: Medium to large sections of the city. The observer mentally enters 'inside of' the district. They are recognized as having some common identifying characteristics.

Nodes: Strategic spots into which an observer can enter the city. They are typically linked to travel and are usually transportation breaks, crossings or convergence of paths.

Landmarks: Another type of point reference but the observer does not enter them. They are usually a rather simply defined physical object, building, sign, store, or mountain. They are frequently used clues of identity and are increasingly relied upon as a journey becomes more familiar. A landmark should stand out from its surroundings and have direction information as well.

Landmarks, nodes, and districts divide the city into *places*, which are connected by paths and bounded by edges.

4 Activity Theory

The previous sections highlight the wayfinding principles that are used in the real world. However, these principles do not indicate what difficulties people have in navigating and searching within virtual environments, nor the strategies that they use to overcome these difficulties.

Activity Theory (AT) is a framework designed to facilitate understanding of purposeful human activity. The framework is grounded in Russian socio-psychology of the 1920s. Although it was traditionally applied in the area of child psychology and development, AT has recently gained popularity in the realm of Human-Computer Interaction Nardi (1996).

Activity Theory states that breakdowns occur when the outcome of a Participant's action does not match his or her expected outcome. Once this happens, the Participant 'unrolls' their mental representation of the action. The action is no longer an automatic succession of steps, requiring little or no conscious thought. Instead, the Participant now consciously thinks about each step to determine what caused the unexpected results. During this stage, the Participant will also look for alternative strategies for the successful completion of the action. Once a successful strategy is found, and practiced enough, it 'rolls up' back into subconscious thought.

5 Wayfinding Tasks

Wayfinding can be thought of as three mutually exclusive, yet usually successive, tasks. They are:

Naïve search: Any searching task in which the Participant has no prior knowledge of the whereabouts of the target in question. A Naïve search implies that an exhaustive search must be performed.

Primed search: Any searching task in which the Participant knows the location of the target. The search is non-exhaustive.

Exploration: Any wayfinding task in which there is no target. (Darken & Sibert, 1996)

The tasks can be successive in the sense that a Participant will switch between tasks as conditions change. For example, if a Participant knows roughly where the target is located, they may initially use a primed search strategy to get to the approximate location. Next, they use a naïve search strategy to find the target. Darken & Sibert (1996) state that although naïve searches are rare in the real world, they are common in first time explorers of the virtual environment.

6 The Virtual Environment

Virtual Reality describes a range of experiences that enable a person to interact with and explore a spatial environment through the use of a computer. These virtual environments are usually renderings of simple or complex computer models and offer us the opportunity to:

> "be in worlds that only exist in our imaginations" (Biocca & Levy, 1995, p.vii)

Until recently, most VR applications required specialised hardware or accessories, such as high-end graphics workstations, stereo displays, or 3D goggles or gloves. Research using these 3D Head Mounted Displays (HMD) over the last decade has found that the spatial knowledge and environmental design principles that influence wayfinding in the real world can be effectively translated into these rendered HMD environments (Navigation et al., 1995; Darken & Sibert, 1996).

This specialised hardware has now given way to the desktop VR systems due to their cost and availability. The two main VR technologies that run off a desktop or window system are Virtual Reality Modelling Language (VRML) and QuickTime Virtual Reality (QTVR). These technologies allow the VR experience to be created and viewed using software.

VRML came about from the explosion of interest in the internet or World Wide Web (WWW). It is "a language for describing multi-participant interactive simulations — virtual worlds networked via the global Internet and hyper-linked with the World Wide Web." (Bell et al., 1995). VRML environments are non photo-realistic graphical interpretations of worlds created and limited only by the authors mind.

Apple's QuickTime VR allows Macintosh and Windows users to experience kinds of spatial interactions using only a personal computer. Furthermore, through an innovative use of 360 degree panoramic photography, QuickTime VR enables these interactions to use real-world representations, as well as computer simulations. The technology works by electronically stitching a series of photos (or rendered images) together. The photos are taken by pivoting the camera in regular steps (along the horizon) from a fixed point, in order to create a 360-degree panoramic view. The viewer sees only a part of the image at a time, but can use the mouse cursor to 'turn' and look up and down. The overall effect is much like standing at a fixed point in a room, turning your head from side to side, looking up and down, and turning your body around to explore your environment.

These QTVR nodes can be linked together by hotspots to create a scene or multi-node environment. QTVR includes:

> "continuous camera panning and zooming, jumping to selected points and object rotation using frame indexing." (Chen, 1995)

Currently QTVR uses cylindrical environment maps or panoramic images to accomplish camera rotation. QTVR includes an interactive environment, which uses a software based real-time image-processing engine for navigating in space and an authoring environment for the creation of the QTVR movies.

6.1 Designing the QTVR Virtual Environment

Most research into navigational aids for virtual environments have all dealt with VRML based environments (Darken & Sibert, 1995). These environments have the users point of perspective continuously changing. QTVR on the other hand has the point of perspective constant at all times.

The purpose of this research is to determine whether the wayfinding principles identified previously are affected by this apparent lack of continuous change and photo-realistic representation.

Of particular relevance to the study is Lynch's (1960) description of nodes. QTVR allows movement between panoramic images by embedding 'hotspots' in the image. As a user moves the mouse cursor over a hotspot, the mouse cursor changes; indicating the possibility of movement to another 'node'. If the user presses the mouse button, they will find themselves at a new node. Lynch's (1960) identification and definition of nodes further justifies QTVR's close approximation to real-world spatial environments.

As QTVR is a node based representation of a larger environment, 'jumps', or transitions, between nodes could sometimes become disorienting. A solution was devised using concept of display overlap (Woods, 1984; Wickens, 1993). Display overlap (and subsequently, visual momentum) can be achieved by integrating data across successive glances This was achieved this by adjusting the size and location of each hotspot to match (albeit, as a smaller version) exactly what the user would see upon entering the next node. In this way, before pressing the mouse button over a hotspot, the user's attention would be in the region of the screen that matched what they would see at the next node. In addition, adjusting the starting angles, both horizontally and vertically, from node to node, helped to better support this overlap.

7 Methodology

In order to explore the significance of the spatial knowledge and environmental design principles in wayfinding in virtual worlds, four variations of a virtual environment, a virtual museum, were constructed. A 2 × 2 (map vs. landmark) factorial experimental design was adopted to evaluate the effect of different wayfinding principles on wayfinding performance.

The four treatments were:

Control: No wayfinding assistance.

Map: The use of Map principles.

Landmark: The use of Landmark elements.

Map and Landmark: The use of both Map principles and Landmark elements.

In the Landmark treatment, we embedded textual labels or 'signs' within the environment, to indicate various areas. The labels identified the contents of the area and, hence, enhanced landmark knowledge. For example, the link to the Egyptian section had the words 'Ancient Egypt' written above it. When creating the labels, MacMinner (1996) list several important things to consider. These are:

1. Use a visual guidance system to ensure successful use of the space by the user.
2. Use architectural elements and interior treatments whenever possible.
3. Signs should be placed at decision making areas.
4. Choose appropriate signs for the main group of users.
5. Graphics should be legible, direct to the point, and visible from a reasonable distance.
6. Graphics should be designed and placed consistently throughout the space.
7. Avoid creating visual clutter.
8. Choose visual guidance and orientation devices which are compatible with and are part of your design concept.

Similarly, we supported map principles by providing a map (on the left side of the screen) showing the general layout of the virtual room. The map also identified where the participant was in the room, by showing a red circle (corresponding to the position of the current node) on the map. Darken's (1995) guidelines, with respect to maps, include the following:

1. Show all organizational elements (paths, landmarks, districts, etc.).
2. Always show the observers position. The final treatment, Map and Landmark, made use of both the Map principles and the Landmark principles.

7.1 Apparatus

Photographs were taken of a local museum and used to make 27 QTVR panoramic nodes. These nodes were linked to each other by hotspots. The nodes were then incorporated into one QuickTime VR movie with the use of QuickTime Virtual Reality Authoring Suite (QTVRAS) (Apple Computer Inc, 1997). This VR movie became the control treatment. The map and landmark principles, as discussed earlier, were added to this movie to make the other three treatments. An example of the map condition is shown in Figure 1.

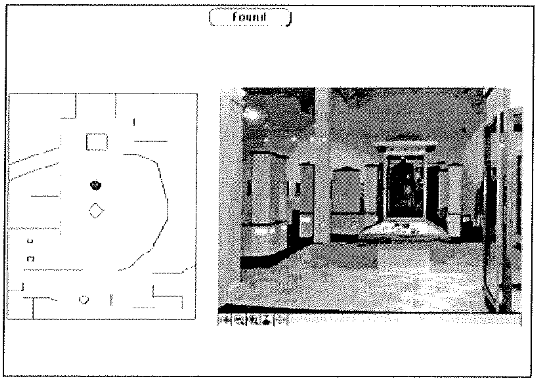

Figure 1: Map condition interface.

The four treatments were implemented on Macintosh PowerPC desktop computers of identical configuration. The testing environment was created in Hypercard 2.4.1 (Apple Computer Inc., 1998), an interactive multimedia authoring tool. All movement and interaction with the virtual world was achieved through the use of the mouse.

7.2 Procedure

67 university students attending a course in Human Factors in Information Science participated in this study. The study was conducted in two phases. The first phase was an experiment to assess the effectiveness of the various wayfinding principles. The second phase was a cognitive task analysis to identify the difficulties participants encountered while navigating the virtual environment.

In the experiment phase, the participants were asked to do a naïve search for four objects within the virtual environment. Participants were given a picture of each target object and were instructed to find it and then to return to the start point before being given a picture of the next object to find.

The Hypercard system recorded various measures as the participants tried to find the target objects. These measures were:

- Errors made in identifying the target object.
- Errors made in identifying the start point.
- Incomplete search for the object.
- Incomplete search for the start point.
- Time taken to find the object.
- Time taken to find the start point.

After the Participant had found all four objects they were asked to fill out a user satisfaction questionnaire and also to sketch a map of the environment, showing the location of the targets and their rough proximity to each other. Participants were given up to 15 minutes to find the object and to return to the start point. If a Participant got past this time limit, they would receive help to find their way. An incomplete result would then be recorded. They would then proceed with the rest of the experiment. The experiment could be terminated at any time at the Participants' request.

In the second phase, a Cognitive Task Analysis (CTA) was conducted. The Critical Decision Method (Klein, 1993), a retrospective verbal protocol technique that used critical decision points as points for further probing, was the technique used. During the CTA, participants were first asked to identify situations in which they had experienced difficulty using the interface to the virtual environment. The researchers then probed each Participant about the difficulties they had identified. In addition, several computers displaying the virtual environment were made available to those participants who wanted to re-familiarise themselves with the system.

Next, the Participants were asked to identify what they were doing (or trying to do) just before experiencing the difficulty, and what they did just after. The researchers then probed the Participants further to clarify their ideas and ensuring that Participants' responses were specific enough to be of use in subsequent analysis. For example, "I was trying to find the object" (the broad purpose of the task) is less useful than the response "I was trying to find the hotspot for the next node".

After this was completed, participants engaged in a fifteen-minute, general discussion about their experiences in the environment. The discussion was recorded.

The data gathered during the CTA was then analysed within the framework of Activity Theory (Kuutti, 1996). The 'difficulties' identified during the CTA correspond to AT's 'Breakdowns' (Winograd & Flores (1986) cited by Bødker (1996)). Similarly, taken together the 'before' and 'after' form AT's concept of a 'focus shift'.

8 Results

For this report, only the significant numerical results from the system and the significant results acquired from the Activity Theory analysis will be discussed.

Eight sets of results of the original 67 were excluded from the analysis due to computer crashes and Participants familiarity with the actual museum. Hence, only 59 sets of results were used in the subsequent analysis. The distribution of Participants across conditions is as follows:

Control: 24 Participants.

Map: 8 Participants.

Landmark: 11 Participants.

Map and Landmark: 16 Participants.

The empirical results from the first phase were analysed with SPSS 6.1.1 (SPSS 1995), a statistical analysis package. A series of T-Tests were performed on the data collected from the experiment. Based on a significance of $p < 0.05$, Table 1 shows any significant difference between the means of the control and other conditions.

Variables	Control vs. Map	Control vs. Landmark	Control vs. Map/ Landmark
Overall Time	No	Yes	No
Time for finding the object	No	Yes	No
Time to get back to the starting point	Yes	No	No
Overall Errors	No	No	No
Errors in finding the object	No	No	No
Errors in getting back to the start point	No	No	No
Total Incompletes	No	Yes	No
Incompletes in finding the object	No	Yes	No
Incompletes in getting back to the start point	No	No	No

Table 1: T-Test results (p¡0.05).

The data collected from the second phase was analysed using Activity Theory, as stated earlier. Breakdowns and Focus Shifts were extracted from the before and after data that was gathered for the participants' experiences. The subjects' notes were gathered and collated on the basis of similar experiences. These experiences were identified as breakdowns according to Activity Theory. Once these main breakdowns were identified, the subject's actions before and after this breakdown identified the subsequent focus shift from what actions the subject expected to work, to what actions they used to overcome the breakdown. These breakdowns and the percentage of Participants who had the breakdown are shown in Figure 2.

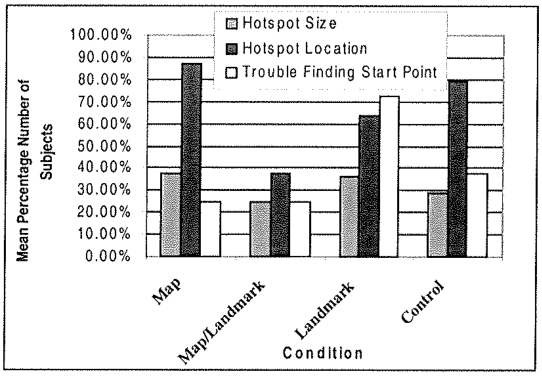

Figure 2: Significant CTA breakdowns.

9 Discussion

The first major finding that the analysis identified was the effectiveness of the map principles. This was shown in Table 1. There was a significant difference ($p = 0.013$) between the mean time to get back to the start point after finding the target object of the control and map conditions.

Common sense tells us that this would be the case as the participants could use the map as an additional navigational aid. The statistical analysis from SPSS give indications that map principles can effectively help wayfinding back to a point within a QTVR virtual environment, but it does not give any indication of the difficulties that the subjects faced with the use of, or lack of, map principles.

Activity Theory, on the other hand, shows us that participants had problems with finding their way back to the start point after finding one of the objects. As Figure 2 shows, only 25% of participants using maps had this breakdown, whereas 73% of participants from the landmark condition and 38% from the control condition had this breakdown. One participant wrote:

> "I was able to use the map to assess where I was when I needed to return to the starting location."

Another participant stated that they:

> " … can't recognize it by sight 100%, have to refer to the map to make sure you are actually at the right place".

This notion of not being able to identify their position, due to the fact that the museum cases all looked the same, was expressed by several participants.

Landmark principles were shown to enhance wayfinding performance. The data from phase one

(Table 1) showed that those participants whose virtual world used the landmark principles had a significant difference ($p = 0.005$) between means when compared to the control condition for the average time. Also the results showed a significant difference ($p = 0.003$) between the means of the control and landmark conditions for the average number of Incompletes in finding the target object. Preliminary analysis of the data collected from phase two has not come up with a related breakdown, but further analysis is still to be done. One participant wrote in phase two:

> "When looking for certain items I was able to use the signs that were situated up by the ceiling".

These results indicate that landmark principles are effective wayfinding principles when looking for a target object.

One issue that was not picked up by phase one experimentation was the difficulty subjects had when dealing with the hotspots that were used to navigate from node to node within the virtual environment. It appears that most participants, no matter which condition they were using, had a behaviour breakdown with the hotspots. Figure 2 shows that these breakdowns could be separated into two different issues, the first being the location of the hotspot and the second being the size and shape of the hotspot. Participants were recorded as saying:

> "... I was in an area and wanted to move into a section I could see but there was no hotspot to go there",

and

> "The hotspots were all different sizes and shapes, which made it difficult to find them".

The subsequent focus shift had the participants either just moving the mouse till they found the hotspot, or the participants would use the hotspot finder. This breakdown was not anticipated, it was due to design oversights of the researcher. The nodes were not placed in uniform distances from each other, which caused the hotspots to vary in size and shape. The issue of hotspots can easily be rectified by either having all hotspots visible (Plante et al., 1998), or by uniformly laying out the nodes so all links (hotspots) are in areas where participants logically would move. This would mean the jumps would be all the same distance, therefore the size and shape of the hotspots would be uniform.

Other noted difficulties identified through Activity Theory were the window or movie size, and the fact that the map did not show the subjects orientation. Participants were recorded expressing these difficulties:

> "... window size of the experiments were too small. I walked passed objects due to size of window"

and

> ' ... I still don't know which directions will be turned on the map when I turned left/right. It is confusing ... ".

Re-orienting the map as the user pans left or right, and increasing the window or movie size with an increase in processor speed and memory, can eliminate these breakdowns with the environment.

10 Conclusion

Preliminary findings have indicated that the use of map principles enhance wayfinding when the participant has to get back to a place they have been, whereas landmark principles enhance finding new areas or places. These findings identify which wayfinding principles should be used and when.

The expected outcomes of a particular action are based on a participant's experience. In those cases where participants are unfamiliar with virtual worlds (as was the case with our study), yet familiar with computers, their experiences in wayfinding will be based solely on their experiences with the real world. This means that when a breakdown occurs, it occurs because interaction during a wayfinding task in the virtual world fails to conform to the participant's mental representation (based on years of experience) of interaction during a wayfinding task in the real world. This study has identified several design issues that have been found to cause difficulties in wayfinding within a QTVR virtual environment. These are hotspot identification, size of window or movie, and map orientation. These difficulties can all be rectified with a greater attention to applying real world navigation principles to the design.

The preliminary results have showed that wayfinding principles used in the real world can be effectively applied into the virtual environment. Other issues of the virtual environment design have also been identified as influencing this translation. Further analysis on the data from phases one and two is ongoing and will be reported in future papers.

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