The impact of form on movement within virtual environments

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ABSTRACT: This paper reports some results from a research project investigating users experience of space and movement in a Virtual Environment.

KEY WORDS: Virtual Environment; Space; User Experience.

1. A framework for the design of space in virtual environments

This paper presents a part of a research project (Charitos, 1998), dealing with the architectural aspects of virtual environment (VE) design. The project proposed a framework for the design of space in VEs which consists of a taxonomy of the spatial and space-establishing elements that a VE may consist of, the structure of these elements, and their significance for human wayfinding behaviour. This work is summarised in Bridges, Charitos and Rutherford (1997). Additionally, the project evaluated aspects of the framework by experimental methods and concluded with a series of guidelines for the design of space in VEs. These guidelines could also inform the design of space in VRML worlds, the spatial characteristics of which are similar to the characteristics of the desktop VEs which were used for the experimental evaluation phase.

The proposed framework defines the spatial elements of a VE as:

i. Place. A “place” is a location where certain relatively static actions “take place” and which determine the character of the place. Behaviour is place specific in the sense that “people do different things in different places” (Ward et al., 1988). A space is subjectively defined and remembered as a place and is thus tightly related to individual actions and intentions.

ii. Path. A “path” (Burnette, 1974, p.181) could be described as a “movement channel”. In a VE, a path is a kind of space which implies movement and within which directions are always evident due to the formal qualities of its spatial arrangement.

iii. Intersection. An “intersection” is defined as the space of interaction between other spatial elements in a VE. Certain points along a path where navigational choices are made are likely to be intersections of paths. Scenes at intersections are more likely to be remembered because subjects have several actual or potential navigation choices to choose from and also because such scenes are usually visually richer and more complex (Gale et al., 1990, pp.20-22).

iv. Domain. A “domain” is considered as a subset of the whole VE, which consists of a system of paths and places. In the same sense that humans feel a need to structure the chaos of the real environment into domains in order to imagine their world as an “ordered cosmos within an unordered chaos” (Norberg-Schulz, 1971, p.23), there is a need to structure a VE into domains by means of paths and places.

v. Portal. A “portal” is an element which links two remote locations, within the same VE or within different VEs. This linking could be triggered through an event, initiated by the participant by passing through the portal. The portal may be seen as the physical expression of the characteristic of spatial discontinuity in VEs.
vi. **Buffer.** A “buffer” could be defined as an intermediate type of space which accommodates the need for adjustment of the participant’s viewpoint when moving from one space into another. In this sense a buffer is relative to an intersection, in that they both divert navigation within a domain. However, an intersection is seen as a larger-scale space where certain other activities may take place whereas a buffer is a smaller scale space, the only function of which is aiding navigation within the VE.

These spatial elements are defined by the following types of space-establishing elements (or objects) which are appropriately positioned in three-dimensional space:

i. **Landmarks.** “Landmarks” are the objects which are singled out from alternative possibilities available in the environment, by virtue of their form or function. They act as points of reference for identification, structuring or orientation. Landmarks are seen as being external to the participant who experiences them and to whom they usually communicate some meaning.

ii. **Boundaries.** “Boundaries” define all spatial elements in a VE by suggesting a spatial form out of the void, in varying degrees of explicitness. It is important that “collision detection” is implemented so that boundaries do not afford movement through themselves. Maintaining this real world constraint guarantees that boundaries are experienced as “solid” objects and thus define spaces not only visually but also physically and functionally.

iii. **Thresholds.** “Thresholds” are an intermediate type of object, which signify the transition between spaces, while navigating in a VE. Thresholds may be visible objects, similar to boundaries because they still define spaces by binding them. At the same time, they functionally differ from boundaries in that they afford movement through themselves, if collision detection is not implemented on them.

iv. **Signs.** “Signs” (Passini, 1992, pp.90-92) communicate specific environmental information needed to make wayfinding decisions; they tell the viewer what is where and they also specify when and how an event is likely to occur.

2. **The Experiments**

This paper presents the results of two of the six experiments which were conducted to investigate the way that certain formal characteristics of an enclosure may affect the impression of movement or the way that a subject may move within a VE. All subjects experienced all options within each experiment, although the order of experiencing the spaces was randomised to avoid learning and other effects. In each option, the setting comprised a series of places and/or paths, the position or form of which differed in only one aspect amongst all the options. The aspect which differed was considered the independent variable of the experiment and the effect of this variable on several dependent variables was investigated. Given such an experimental design the analysis of results was carried out by means of a general linear model ANOVA procedure, which would identify contrasts among within-subjects factors (different kinds of experienced spaces) on different kinds of measurements (the dependent variables). A standard questionnaire was used to elicit the subjects responses and all experimental sessions were videotaped for later subjective analysis. Prior to carrying out the experiments a pilot study was undertaken to refine the experimental procedures. None of the participants of the pilot study were included in the final study.

Forty-seven subjects participated in the experiments, just over one third of them female. The majority of the subjects were architects (12 students, 16 graduates, 9 postgraduate researchers) but a reference group of 10 non-architects was also included. It was believed that the spatial aspects being investigated would be more critically analysed by trained architects but the feedback from the non-architect group proved to be of considerable interest.
A desktop VE system was used for the experiment, partly because of the resources available at the time, but also because we considered that the use of an immersive system would introduce a further level of complexity in the control of parameters which may affect the specific variables being investigated. A “six degree of freedom” input device (a Magellen mouse from Space Control GmbH) was used to control navigation. All subjects trained in a separate virtual world until comfortable with the navigation device; no time constraints were imposed but the usual length of time needed was 10-15 minutes. All of the experimental worlds were built using WorldUp (Release 3) software from Sense8 Corporation.

3. Investigating the impact of formal elements on the impression of movement within paths.

3.1 Experiment design

The aim of this experiment was to investigate what impact certain formal elements, applied to the surfaces of path boundaries, would have on the impression of movement experienced by subjects who moved along these paths. The elements investigated were:

- Texture maps with a certain “dynamic” kind of pattern, mapped on the surfaces of a path. The dynamic pattern on this texture was considered to simulate the impression of flow perspective, as defined by Gibson (1986, p.227), that a subject experiences while moving in a real environment. Moreover, the perspective correction of the texture was thought to be contributing to the sense of movement in three-dimensional space.

- A series of three-dimensional objects with the form of a “frame”, positioned at equal intervals along the path. These frames were rectangular in shape and their dimensions were slightly larger than those of the section of the path so that the sequence of frames enveloped the form of the path. This frame sequence created a rhythmically repetitive pattern, which was expected to inform subjects of their velocity of movement along the path and of the distance covered at a moment in time.

These formal elements were assumed to have an impact on parameters which contribute to the sense of movement, felt by a subject navigating along a path.

During the design of several pilot VEs various different types of path were modelled. It was observed that certain paths, which had the above-mentioned elements integrated in their form, gave an improved impression of movement, which was accompanied, at times, by a sense of enjoyment or excitement. This phenomenon indicated the possibility for developing a useful guideline, to inform the design of functional and enjoyable paths. Therefore an experiment was designed for the purpose of evaluating the hypothesis that “the use of texture maps and rhythmically repeated “frame” objects improves the perceived sense of movement while moving along a path.”

For the needs of this experiment a VE comprising of a central hall, three different numbered paths and three small “target places” at the end of each path, was built. Collision detection was implemented since it was considered to be a constraint that would help subjects navigate within the limits of the spatial boundaries and consequently enhance the realistic character of the VE. Additionally, transparency was applied to materials of the surfaces which define the paths and the places at their end. The use of such transparencies aimed at providing subjects with certain views to the exterior of the VE and consequently with cues informing them of where they are in relation to the context, while navigating in this VE.
All three paths had exactly the same length, the same rectangular section and the same place attached to their end. They differed, however, in the type of material or formal element applied to the boundaries which defined the path:

i. The first path was defined by semi-transparent shaded boundaries;

ii. In the second path, a certain dynamic semi-transparent texture was applied on its boundaries;

iii. In the third path the same semi-transparent texture was applied on its boundaries and additionally, a series of rhythmically repeated frames were positioned along its length.
Each subject was asked to move along each one of the three paths, to the place at its end and back through the path to the entrance hall. On arrival to the central hall, each subject responded by giving an indication of the impression of movement, experienced while navigating along each of the three paths. 34 subjects took part in this experiment (12 female, 22 male). All subjects experienced all three paths, thus providing three values of the dependent variable for each subject, corresponding to each of the paths. A repeated measures General Linear Model was used to analyse the results, the within-subjects factor being “path” (3 levels) and the measure recorded for each level was the “sense of movement”. The null hypothesis to be tested was that all three paths gave the same impression of movement.

3.2 Results

The analysis of the results allowed us to reject the null hypothesis. F for within-subject effects was significant (F=38.3, df=1.7, p<0.05)

- subjects felt significantly more that they were moving in path3 than path2 (F=16.2, df=1, p<0.05)
- subjects felt significantly more that they were moving in path2 than path1 (F=25.6, df=1, p<0.05) and consequently that
- subjects felt significantly more that they were moving in path3 than path1 (F=61.6, df=1, p<0.05).

In other words, the impression of movement:

- was significantly enhanced for subjects who navigated in path2, on the boundaries of which a dynamic texture had been applied and
- was even more enhanced for subjects who navigated in path3, on the boundaries of which a series of rhythmically repeated formal elements, “frames”, was also applied along its length, in addition to the dynamic texture.

These results were also confirmed by spontaneous observations made by subjects during the experiment which were transcribed from the videotape. Indeed, many subjects reported that they felt an enhanced impression of movement in path2 and an even more enhanced impression in path3 and they attributed this to:

- the existence of a texture mapped on the surface of path2
- the existence of rhythmically repeated frames in path3, which provided an indication of the velocity of each subject’s movement, by how quickly these frames passed by the subject.
4. Investigating the impact of the volumetric proportions of an enclosure on movement

4.1 Experiment design

The distinction between a path and a place has been described by Thiel (1961, p.41) as the dichotomy between spaces of a “longitudinal” and a “centralised” character. Similarly Kepes (1956, as quoted in Thiel, 1961, p.41) has distinguished, in terms of spatial form quality, between dynamic, expansive spaces which induce movement and those of a centralised, ordered character. This distinction can be made on the basis of considering an implicit spatial quality that these spaces have in terms of their intrinsic dynamics. This implicit quality, along with all other qualities of the space, which are also determined by the properties of the enclosure (Ching, 1979, p.175), affect the spatial experience.

The difference between the spatial form of a path and a place can be described in terms of their formal configuration and consequent volumetric proportions. Accordingly, the hypothesis that this experiment attempted to evaluate was that the volumetric proportions of a space may affect the behaviour of a subject within the boundaries of this space, by inducing a certain kind of movement. It was speculated that:

• Being inside a path induces movement along the path’s main axis.
• Being inside a place induces movement which focuses on the centre or the boundaries of the space, since a place is a space which is mainly defined in terms of a centre and its boundaries.

Since these speculations were somehow arbitrary, it would be wrong to consider these two kinds of navigational behaviour as the only possible ways of moving within these spaces. It was therefore essential to identify the possible ways that subjects would move within the experimental spaces, during a pilot experimental study. Three groups of subjects took part in this study and the ways that they navigated in each type of space were recorded. These subjects either:

i. moved to the centre and looked around from there,
ii. moved along the main axis of the space towards its extents or
iii. moved along the boundaries of the space and observed space from there.

Accordingly, the dependent variable investigated in this experiment was the response of subjects in terms of how they moved within each of the spaces. The values for this variable corresponded to the three identified ways of moving within space.

To achieve the objectives of this experiment, a VE comprising a central hall, 4 differently shaped spaces and 4 identical small paths, which connected the central hall with each space, was built. The three-dimensional shape of each space, which is described by its volumetric proportions and is accordingly determined by the length, width and height of its boundaries was the independent variable in this experiment. This variable was set at specific levels of interest and its effect on the dependent variable was studied. Each of these levels corresponded to each of the four differently shaped spaces. These spaces were two instances of a path and two instances of a place; they were all parallelepiped and had equal width but they differed in their length/height ratio:

i. space1 had the form of a vertical path, similar to a “lift shaft” and had a length/height ratio of 1/10,
ii. space2 looked more like a “normal room” and had a length/height ratio of 2,
iii. space3 had the form of a horizontal path and a length/height ratio of 10 and
iv. space4 had a cubic form and a length/height ratio of 1.

**Figure 4:** The experimental domain comprising the central hall and the 4 spaces in experiment 2.

**Figure 5:** Interior views of the 4 experimental spaces. From left to right: looking down from the entrance towards the floor in space1, view form the corner towards the entrance in space2, view from one end towards the other in space3 and view from corner towards the entrance in space4.

32 subjects (11 female and 21 male) were asked to enter each one of the 4 spaces and after staying there for as long as the they wanted, they were asked to exit the space and wait for the next prompt. No restrictions were given to subjects in terms of how they would move within each space; they were only requested not to exit immediately. In order to avoid biasing the way that subjects moved within each space, no questions were asked but their navigational behaviour was merely interpreted and recorded after each trial. The order of the spaces entered was randomised.

### 4.2 Results

As no comparison between responses in each of the experimental spaces was required a table of frequencies for each type of response for each space was sufficient for the analysis. The results for the vertical longitudinal space (space1) showed that:

- 15 subjects (46.9%) moved along the space’s axis towards its extents.
- 14 subjects (43.8%) first moved to the centre and looked around before moving to its extents
- 3 subjects did something else

The results for the horizontal longitudinal space (space3) were:

- 16 subjects (50%) moved along the spaces axis towards its extents.
12 subjects (37.5%) moved to the centre, looked around, then moved along the axis to the extents.
2 subjects moved along the axis and then returned to the centre
2 subjects did something else

The results for space2, which had the volumetric proportions of a real room, showed that:
20 subjects (62.5%) moved to the boundaries of the space and followed the “wall” around the space.
8 subjects (25%) moved to the centre, looked around, and then moved to the boundary.
2 moved to the boundary first and then to the centre.
2 did something else

The results for the cubic space (space4) were:
21 subjects (65.6%) moved along the boundaries of the space.
9 subjects (28.1%) moved to the centre before going to the boundaries.
1 subject followed the boundaries and then moved to the centre.
1 moved around in the space and then followed the boundaries.

In summary, therefore, analysis of the results for the way that subjects navigated in each place provided evidence in support of the hypothesis and led to the following conclusions:
Both the vertical and horizontal longitudinal spaces, space1 and space3 respectively, induced movement along the main axis of the space towards its extents;
Both centralised spaces induced movement along the boundaries of the space from where subjects observed the space;

Additionally the significance of the centre of a space, as a strategic point from where a considerable number subjects preferred to observe the interior of all four spaces, was also identified.

When inside each of the spaces, subjects were not able to see any cues which would inform them of their orientation in relation to a global reference system, due to the opacity of these spaces boundaries. In the absence of such cues and due to the overall symmetrical spatial arrangement, most subjects did not understand that space1 was vertical and space3 was horizontal. In fact, since the environment was undifferentiated, orientation did not seem important to them and they seemed more occupied with:
finding out the shape of the space, by reaching its extents and relating their position to the other extents of the space;
identifying where the exit from the space was in relation to their position at each time.

Subjects generally seemed to explore these unknown spaces by moving to a corner of the space and then trying to observe the space from there. This could be attributed to the facts that
The corner may provide the best possible view in an enclosed space.
In the context of a space, a subject may feel more secure in there because the corner could be considered as a subset of the space or because the subject may feel that his back is protected.

Finally, it is interesting to mention that although space4 was twice the size of space2, the latter actually seemed bigger than the former to many of the subjects; indeed three subjects reported that they felt more comfortable moving around in space2 than in space4. The apparent size of space4 felt smaller and 4 subjects felt more claustrophobic and less comfortable to be in there and wanted to come out of this space as quickly as possible. This phenomenon could be attributed to the absence of a human body representation which would help subjects to compare their avatar with perceived space at all times. This phenomenon could also be considered, however, as an indication that the sense of scale in a place is more related to the place’s volumetric proportions than to its actual size. This suggestion may have significant implications for the design of enclosed spaces in VEs and has to be investigated by experimental methods of research in the future.
5. Conclusions

The first experiment showed that the experience of movement in a VE was significantly enhanced by the use of dynamic textures and a sense of speed and distance travelled was induced by the use of repetitive rhythmically repeated elements in addition to the textures. The second experiment confirmed that the proportions of a “path” could induce movement along that path’s main axis, whilst the proportion of a “place” may be designed to induce movement which focuses on the centre or the boundary of that place.

6. References


