DESIGN PRINCIPLES FOR DESKTOP 3D USER INTERFACES
Case Movie Plaza

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Abstract: 3D user interfaces in desktop applications are becoming more common and available to all users. However, not many guidelines are available to support desktop 3D user interface design. We derived a set of design principles from the practices of a company specialized to 3D graphics and user interfaces and made a prototype to evaluate these principles. The results of our evaluations show that some of the principles - on the structure of the space, navigation and interaction - helped users while some others did not have the desired impact. We conclude that design guidelines for 3D user interfaces can be derived from the designers' practices but research is needed to make principles more specific and to test their affect more precisely.

1 INTRODUCTION

In recent years the amount of digital information has increased. How to manage, browse, explore, and retrieve all this vast amount of information has become an important and challenging research topic.

One approach to solve this problem is to use three dimensional, 3D, desktop user interfaces instead of the 2D desktop, which has been the de facto standard in most operating systems and desktop applications during the past 20 years.

There are studies suggesting that the 3D metaphor would help users to remember the location of the information objects, because it utilizes natural human capabilities, such as spatial memory (Robertson et al. 1998; Robertson et al. 2000).

The 3D user interfaces are often associated with virtual reality systems utilizing head-mounted-displays (HMD) and data gloves (Barrilleaux, 2001). Desktop 3D user interfaces, however, require only one special device: a 3D-accelerated video card. These cards are common nowadays, but the use of the desktop 3D is still rare outside gaming and scientific communities (Chin, 2002).

Earlier 3D technology has been available only for specialists who have been using Computer Aided Design (CAD) or similar applications in their work, but today, after the web has made 3D applications popular amongst ordinary users, it is likely that the desktop 3D user interfaces will become more common (Barrilleaux, 2001). Thus, it is important to understand and pay attention to how to design usable 3D desktop interfaces (Poupyrev, 1995). However, not many guidelines are available to support desktop 3D user interface design (Herndon et al. 1994).

1.1 Usability Problems

The lack of guidelines and design principles has lead to poor design, which has caused usability problems in 3D user interfaces. Earlier, when 3D technologies were not so common, the problems related, among other things, to insufficient performance of the computers. Users did not get immediate feedback, so the interaction was difficult (Carey et al. 1994). Nowadays these problems are not relevant, because the development of 3D graphics standards, like Virtual Reality Modelling Language (VRML), and 3D-accelerated video cards has increased these performance related problems (Li & Ling, 2002). Nowadays the problems relate to users perceptive and cognitive skills. For example there have been difficulties in orientation in some 3D user interfaces

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(Chin, 2002) and users have experienced interfaces with 3D more cluttered and less efficient than their 2D counterparts (Cockburn & McKenzie, 2002). Designing navigation methods for 3D user interface is a challenge for designers. Many studies suggest that using the navigation methods provided by 3D virtual space is difficult for users (Elliot & Bruckman, 2002; Hendricks et al. 2003). Also moving virtual camera, view to the virtual space, can cause problems. The camera can "get stuck" in certain parts of the environment (Li & Ting, 2002) or user may feel that the environment moves towards him/her when user is supposed to feel that he/she is moving (Chin, 2002).

In summary, the typical problems in 3D user interfaces are related to orientation, incoherence, navigation and handling the virtual camera. Designers need design guidance that would address the challenge of creating 3D user interfaces that are easier to use.

1.2 Research setting

The guidelines for two-dimensional world do not take into account special characteristics of the three-dimensional world. A designer has to make decisions on elementary 3D design aspects such as how to organize the space, how to use light and textures on different surfaces and objects, and how to let the users orientate themselves in a 3D world.

Our hypothesis is that if users were able to perceive the structure of the virtual space better and if they would be provided with natural navigation methods they would orientate themselves better and the user interface would be easier to use. The purpose of this article is to preliminary evaluate a set of design principles that address the specific design challenges of the 3D user interfaces. We derived the design principles from the practices of a company specialized to 3D graphics and user interfaces. The designers of the company have knowledge also from architecture – designing real world spaces, and cultural philosophy – the cultural knowledge of how people interact with the environment. The experience of this company's designers is transformed for the first time to design principles. Material from the earlier studies that the company had performed, including interviews, discussions and written material was used during the development of the principles.

Following the design principles, we built a 3D prototype called Movie Plaza. Then we carried out a set of qualitative usability evaluations, in which we studied how these principles worked and, in more general, how the users experienced 3D user interface.

In the next section, we describe the design principles. Then we describe shortly how those principles were used to build our prototype, the Movie Plaza. Thereafter, we draw conclusions on how well those principles worked according to the user evaluations.

2 DESIGN PRINCIPLES

The design principles (DP) fall into three categories: the structure of the space, lighting and textures, and navigation and interaction.

2.1 The Structure of the Space

The design of the structure of space aims at providing the user with a possibility to use spatial memory efficiently in memorizing the location of user interface objects and outline the boundaries of accessible space.

DP1: Four orthogonal main directions should be used in the basic spatial layout.

Vast majority of real world buildings are based on four orthogonal main directions. Orthogonal co-ordinate system is fast to perceive and easy to remember. Humans have a bodily co-ordinate system that has four directions: human body has clear front and back, and symmetric left and right directions. These directions are so obvious for us that we do not have to count them to be able to utilize them in our memory and decision making processes. Our hypothesis is that users would easily understand the four main directions and be able to know their orientation in space at all situations. Using symmetrical order and shapes of geometric primitives would enhance this. Utilizing this ability in 3D user interfaces would help users to understand the layout of the space and orientate themselves in the space with a small cognitive load.

DP2: If there is a lot of data to be visualized, the space should be divided into several elevations rather than only one.

Effective usage of computer screen requires effective use of z-axis in the spatial design. The idea behind this design solution is simply to imitate the idea of multi-floor spaces. The specific advantage of this principle would be the effective use of the screen area. Many of 3D user interface applications have only one level, a model probably adopted from the open landscapes. If lots of data must be visible, it means that objects are "far" and users may have difficulties in seeing them clearly. In addition, navigation and moving from one side of the space to the other with standard mouse and keyboard is time consuming (Elliot & Bruckman, 2002). Allocating the data on several elevations would mean more effective use of the screen space. Our hypothesis is that if the screen is used effectively for displaying the relevant data, there is less need for movement and navigation is more effective. Users also understand the structure of the space and thus they are able to orientate themselves.

2.2 Lighting and Textures

Lighting is used for drawing the attention of the user as well as giving information about the directions for the user. In real world, the same principles are used for marking pathways and to grab attention to important and relevant details.

DP3: There should be one main light source used throughout the space giving a sense of directions. The general lighting should be neutral, and the shadows of the general lighting should be used throughout the space.

Some people and many animals are known to use sunlight direction as a navigational tool in real world navigation. These light effects have an important meaning in orientation. The hypothesis is that in 3D user interfaces the use of light effects would also be important for orientation. Simulation of sunlight that comes from one direction and creates lights and shadows to the walls should be used to help orientation inside the space.

DP4: Spotlights should be used to highlight important and interesting places and landmarks.

Spotlights are used to emphasize points of interest. Several specific pointed lights should be used to highlight important and interesting places and to imply of warm and inviting atmosphere. Our hypothesis is that users are able to see where to pay attention with the help of the spotlights and thus, they are able to understand the structure of the space better.

DP5: The grids on surfaces should be used for emphasizing the structure.

In 3D user interfaces grids should be used for emphasizing the structure of space in order to give for the user a better understanding of distances and scales of the space. Grids are also one way to make more effective perspective impression. Our hypothesis is that the grids help user to better understand the structure of the space.

DP6: Textures of objects other than the ones containing the actual information should be simple and minimalist in detail.

Our hypothesis is that surfaces that surround the information should not divert user's attention from the actual information but to give an understanding of the space and structure in order for the user to find the information.

2.3 Navigation and Interaction

Navigation and interaction design principles are used for providing the user with the possibility to interact with the system using the metaphors of the three-dimensional worlds.

DP7: Interaction should be direct, which means that objects are manipulated by direct actions. Indirect user interface components such as menus and scroll bars should not be used.

The 3D user interface makes possible and understandable to use real world direct interaction, which means that operations can be done for example by pointing and clicking the objects directly. Our hypothesis is that direct interaction decreases users' cognitive load and makes the choices easier and more natural to the user. This should help users to navigate easily.

DP8: Browsing - i.e. looking the environment - and moving in it should be different operations.

Our hypothesis is that if natural ways to move from the real world are exploited in the 3D user interface by differentiating browsing and moving, it helps users to navigate in the environment. The hypothesis is based on assumption that users are able to utilize their real world experiences and thus, the user feels moving methods natural and easy. This should help users to navigate easily and also moving the virtual camera should be easy.

DP9: Moving should be restricted to natural movements.

In real world gravity restricts movements so that it is impossible to float in the air or sink down through the floor. In some virtual reality applications user is able to have six degrees of freedom (6dof), which makes them able to incline camera view in correlation to Z-axis or to turn around in horizontal or vertical direction. This may cause difficulties for users, because they may lose their orientation. Our hypothesis is that in 3D user interfaces moving should be restricted so that user easily understands the limitations and possibilities of the environment. This is best done by restricting users' moves so that free flying in the air is not possible and users' are not able to turn upside down. This principle should help users to navigate easily and also moving the virtual camera should become easy.

3 THE MOVIE PLAZA PROTOTYPE

The Movie Plaza environment was developed to demonstrate and evaluate the principles outlined in the previous section. The goal was to design a 3D user interface that would be easy to use and that would enable users to achieve their objectives in a natural and enjoyable way. This means utilizing natural human abilities, such as spatial memory.

The Movie Plaza is a gallery where a user can browse movie information. The user interface is illustrated in Figure 1.

Figure 1: The Movie Plaza.

3.1 Applying the design principles in the prototype

The Movie Plaza was designed using the preceding ten design principles. The usage of the principles is described in the following.

DP1: The virtual space in the Movie Plaza strongly emphasizes the four orthogonal main directions in the spatial layout. The space consists of four equally long and high walls, so the space is shaped like a cube. Four movie cylinders are symmetrically organized to these walls. Geometric primitives, cube and cylinder, are used to enhance the effect of the four main directions.

DP2: The virtual space of the Movie Plaza composes of three elevations, and so the whole screen is used effectively for displaying essential information: movie posters. There is, however, some empty space between categories so that user can separate the groups from each other and the visual image is clear.

DP3: General lighting that helps in orientation is implemented in the Movie Plaza by placing two windows on one wall for illuminating the space. With the help of this one main light source, users should have better understanding of their orientation. The windows are illustrated in Figure 1.

DP4: The contrast of cool-toned general lighting and warm-toned spotlights is used to illuminate the movie cylinders and draw the focus to the movies. Warm light spots are also used for providing user feedback: light is switched on when user points the cylinder and switched off when the user moves the cursor away from the cylinder. The tone of lighting used in the cylinders is warm so that cylinders would look inviting.

DP5: In the Movie Plaza walls, floor and roof are consistently covered with 3x3 grids. Colors of the grids are white and green. Thus, the visual image is simple.

DP6: Simple textures have been used on surfaces. Only the actual information items, i.e. movie posters, are rich in color and detail. All other surfaces are simple as they try not to draw user's attention.

Lighting is simple and light effects are not used in textures. This is done to avoid the assumption that the user interface provides the possibilities of real world interaction often available in computer games.

DP7: Only buttons used in the Movie Plaza are elevator buttons that can be used for taking the user up or down in the space. Otherwise functions such as getting information about movie or changing view or viewpoint is done by moving the mouse or pointing or clicking an object. Information window opens when the user clicks on the poster and closes when the user clicks on the information window.

Figure 2: The user browses the environment with the automatic view change.

DP8: The Movie Plaza offers two different ways to move in the space. User can move between different elevations by using an elevator, which works by clicking the elevator buttons. Another way to move is restricted flying between the categories, which works by clicking the destination category with a mouse. There is also two ways to browse the environment. User can keep the left mouse button in the bottom and move the mouse, when the view changes in relation to mouse movements. Another way is to move mouse to the other side of the screen which makes the view to change automatically. With these navigation methods users should be able to move fluently and efficiently. View change is illustrated in Figure 2.

DP9: In the Movie Plaza moving is limited so that view's Z-axis is always kept inline with the world's Z-axis. Also, looking up and down is natural so that it is not possible for the user to turn up side down and look what is behind him without turning around. Also navigation routes are restricted so that users are able to move only between three central points and categories and from category to category. Restricted flying in the air is one way to move, but flying freely in the air is not possible.

4 EVALUATION

The evaluation of our design principles using Movie Plaza prototype was based on qualitative usability testing as depicted in (Dumas & Redish, 1993), i.e. we observed how subjects were able to perform given tasks with the prototype. We were interested in the performance of the subjects and their subjective experience evoked by the system. We evaluated how the subjects liked to use the system, what cognitive responses did the user interface evoke, and how the design principles affected these.

Analysis was qualitative and it was based on user comments and researchers' observations, interviews and video analysis. Evaluation must be considered to be only preliminary, as we had only six users.

Users found the test interesting. Design principles seemed to have effect to usability, because only few of the typical usability problems appeared. The evaluation results are summarized in Table 1.

User evaluation showed that most of the users perceived the space well during the first task and they were able to move there smoothly and efficiently. Vertical orientation was experienced easy. Users considered the space simple and according to their opinion they were able to find movies easily, although some users would have wanted to use text-based search in search tasks.

Table 1: Summary of design principles and results.

Design principle	Result
DP1	Positive results. Users did not get lost and perceived the space easily.
DP2	Positive results. Users were able to remember if a certain movie or category was above or below them.
DP3	Negative results. Light did not help in orientation and users lost their orientation.
DP4	Neutral results. Lights made categories look inviting, but did not help in giving feedback to user.
DP5	Results suggest that simple grids helped understanding the structure of the space and did not draw users' attention from more important issues.
DP6	Results suggest that textures could be even simpler so that users do not confuse 3D user interfaces with games.
DP7	Positive results. Users were able move smoothly and getting more information about a movie was self-explanatory.
DP8	Positive results. Users understood immediately that moving mouse moves their view. Most of the users found navigation easy.
DP9	Positive results. Navigation methods guided users to the right actions.

Horizontal orientation was experienced to be hard, because light did not help users in orientation. The users thought that a clear landmark for helping in horizontal orientation would be needed, for example a compass on the floor, windows that would provide a view to outside world or some object inside the space that calls users' attention. Some users had problems related to navigational controls, partly because they did not get any guidance at the beginning. Especially two older users had difficulties in navigation tasks that may have been derived from the fact that they had less experience of different types of computer applications.

Evaluation showed that users find 3D desktop metaphor useful and also exciting. In general users' experiences were positive and most of them said that 3D user interface could be useful in their every day life.

5 DISCUSSION

We created a set of design principles for 3D user interfaces. The user evaluations showed that some of these principles would be beneficial in designing 3D user interfaces and that these principles are a good start for developing the design of 3D interfaces. Although the results are preliminary, we find this work as an important contribution. More and more 3D user interfaces are being designed but no guidelines for designing desktop 3D user interfaces exist.

Our research has limitations that need to be understood. First, the study was done based on a single prototype. The principles were implemented in the prototype but the details of user interface design impact on the usability, too. Thereby, the isolation of the impact of principles from the other design solutions is not easy.

Second, our tests were preliminary ones and of qualitative nature. In qualitative research results are always subjective despite that the results are based on thorough analysis of video and written material.

The results suggest paths for further research. The principles could cover better horizontal orientation and logical ways of starting and ending using the application. Standard moving methods could be developed so that users could use different applications after they have learned one. Another interesting question is whether 3D user interfaces could be an answer to the problems small 2D screens of mobile devices.

Our research suggests, that design principles can be derived from the existing 3D user interface design practices, and this can result in 3D interfaces that are easy and effective to use.

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