MODELING FROM WITHIN

A Proposal for the Investigation of Modeling Within the Immersive Environment

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Thesis Statement:

Immersive modeling enables a user to design three-dimensional spaces more easily than modeling through-the-window by avoiding the accidental difficulties that result from the limitations of a two-dimensional interface.

1. Introduction

Creating three-dimensional models for use in computer graphics and virtual environments is a challenging and time-consuming task. Limitations in current modeling systems make it difficult to realize envisioned three-dimensional shapes and complex models can take a considerable amount of time to generate (approximately 1/2 a year for a 30K element model [Brooks 90]).

I propose to investigate the use of virtual environments for the creation of three-dimensional models. In particular, I will compare the effectiveness of immersive modeling with conventional through-the-window modeling. I feel that a virtual environment is an ideal medium for the creation of complex, computer graphics models. My research will consist of the following areas:

1) *The systematic analysis of existing techniques used for the generation of computer graphics models.* I will concentrate on the analysis of through-the-window computer-aided modeling systems in which a user can create models "from scratch" (as distinguished from scanning technologies used to create models of existing objects). The goal of my analysis is to identify the strengths and weaknesses of current modeling techniques. In particular, I will attempt to determine the impact of the use of two-dimensional (2D) displays and input devices on modeling and interaction techniques.

2) *The exploration of the new power of modeling from within.* I will explore the implications of the liberation from a 2D interface. A major component of this research will be the development of techniques and interaction paradigms that can be used for modeling within a virtual environment. Key areas of consideration are the specification of positions, orientations and extents within a 3D environment and the types of assists and constraints needed to support interaction in a virtual environment.

3) *The investigation of interface-independent modeling techniques.* I will investigate modeling techniques not exclusive to the immersive domain that nonetheless will greatly enhance an immersive modeling system. Of particular

interest are multi-view systems in which a user can view multiple representations of the same model simultaneously. The different views may be at different scales, different levels of detail, or present different types of information. Though not specific to the immersive domain, these techniques are particularly well suited to implementation in an immersive environment.

4) *The design and implementation of an immersive modeling testbed.* I will design the system based upon the findings of the research in items 1-3. I have chosen architectural design as a driving problem to motivate and guide the modeling system development. During implementation, I will give special consideration to algorithms and techniques that can enhance system performance and help maintain real-time interaction.

5) *The evaluation of the immersive modeling system.* I will evaluate the effectiveness of immersive modeling as a modeling paradigm and compare immersive modeling with through-the-window modeling techniques.

I discuss each of these objectives in greater detail in the sections below.

2. Evaluation of Through-the-Window Modeling Systems

In preparation for the development of an immersive modeling system, I am evaluating existing techniques used in the generation of three-dimensional computer graphics models. My goals are to categorize how people create three-dimensional shapes in current systems, and to determine where and why it is difficult to create models using these techniques. As a final product I will produce a taxonomy of modeling system interaction techniques and primitives.

I am focusing my analysis on through-the-window computer-aided modeling applications due to their direct relationship to the immersive modeling task. Other modeling techniques such as algorithmic methods and 3D scanners, though useful for creating models of natural phenomena (such as trees) or complex models of existing objects (such as the human head), do not bear as close a relationship to my proposed immersive modeling system. This is especially true in the case of synthetic modeling (i.e., the creation of a model "from scratch").

One of the most important things I consider in my review of through-the-window modeling systems is the significance of using a two-dimensional interface (both input devices and displays) for the three-dimensional modeling task. I am interested in how the use of a 2D interface complicates interaction with the modeling environment and results in ambiguity in the interpretation of the displayed information.

The Limitations of Two-Dimensional Input

Two-dimensional input devices such as the mouse or the data tablet, for example, preclude the direct specification of three-dimensional positions, orientations and extents. Specification of these parameters requires at least two separate inputs when using these two-dimensional input devices. I found many different alternatives used for the mapping of a three-dimensional task to a two-dimensional input device in the modeling systems I reviewed.

In many cases, for example, the current elevation of the modeling cursor (the point in the three-dimensional modeling space at which all modeling actions occur) must be prespecified. During subsequent modeling actions this component is held constant and movements of the input device are mapped directly onto the remaining two components of the cursor position. In many modeling systems this prespecified component is what is known as the *current working plane*. All movements of the input device are mapped directly onto the current working plane. The elevation of the current working plane remains fixed until it is reset using some separate form of specification such as numeric input, the movement of a slider, or through movement of the input device that is differentiated from normal device movements by the simultaneous pressing of a modifier key.

Similarly for extents, all movements of the input device are used to specify the extents of an object in two dimensions only. The third dimension must be specified separately, again using techniques such as numeric input, sliders, and modified input-device motions.

In systems using this form of input device mapping, objects are created by drawing a two-dimensional profile in the current working plane that is then extruded to the specified extrusion height. All objects are at the same elevation (the current working plane) and have the same height (the extrusion depth). To create an object at a different elevation (a shelf four feet above the ground, for example), the user must reset the working plane to the new desired elevation. To create an object with a different height, he must reset the extrusion depth.

Some systems, such as the Upfront program from Alias Research, allow the user to quickly position the working plane relative to existing objects by snapping the working plane to be coincident with any indicated face. This makes it easy to quickly create a vase on top of a table for example. It also makes it necessary, however, to create *construction surfaces,* objects whose sole purpose is to assist in the construction process. Thus to create a shelf four feet off the ground you would first create an object that is 4 feet high, snap the working plane to the top of the object, and then create the shelf at that height.

Arbitrary rotations are difficult to specify using a 2D input device; most rotations are generally limited to rotations about the normal of the current working plane. More complex rotations often require the use of numeric input (via separate dialog boxes) to be fully specified.

As an alternative to the use of working planes, some systems allow the direct specification of all three components of the current cursor position. This typically requires the specification of cursor position in two separate windows each showing an orthogonal view into the modeling space. The combination of the two inputs is required to specify the three-dimensional position in modeling space fully (with one axis specified redundantly in both windows).

Experiments by J.D. Liang of the University of Alberta have shown that the use of a 6 Degree-of-freedom (DOF) input device greatly facilitates the modeling task [Liang 93].

The Ambiguity of Two-Dimensional Output

The use of two-dimensional displays inherently injects ambiguity in the interpretation of the displayed information [Gregory 73]. It is difficult to infer three-dimensional shapes based only on orthogonal views or perspective projections of three-dimensional space. Furthermore, most through-the-window modeling systems lack interactive visualizations. Users must rely on static visualizations that require the repeated specification of viewpoint and focus point for each new view of the model. One of the key advantages of the Virtus Walkthrough program [Virtus 93] is that it provides an interactive *walkthrough,* a separate visualization window in which the user can move through the model in near real-time. This provides a better understanding of the shapes being created.

Another important consideration is whether the visualization is separate or integrated from the modeling environment. Some systems provide separate modeling views (in which the user performs all modeling actions) and visualization views (in which the user views a rendering of the modeled objects). This results in additional work for the user to mentally integrate the two views. The choice of an integrated or separate visualization also has an impact on input interaction. Perspective projections, for example, make it difficult to specify positions and extents unambiguously; equal lengths have different projections depending upon their distance from the viewer. This increases the need for construction aids such as cursor snaps and constrained cursor motion and complicates the modeling task.

A factor that I did not consider to be as important in my review of modeling systems was the type and extent of primitives available for performing the modeling task. This is because the choice of modeling primitives is not specific to the type of interface (2D or 3D) used for the system; any modeling primitive available in a 2D modeling system can be adapted to a 3D immersive system. My hope is that the direct interaction and visualization provided by the immersive system may simplify the interaction with these elements, as is discussed in the next section.

Presented in "A Review and Analysis of Through-the-Window Computer-Aided Modeling Systems", by Mark Mine (attached as an appendix) are the preliminary results of my review of through-the-window modeling systems.

3. Investigation of the Virtual Environment as a Modeling Medium

I will analyze the advantages and disadvantages of working in an immersive environment and develop new interaction techniques for modeling from within.

Benefits of the Immersive Domain

The primary benefits of modeling in a virtual environment are: direct interaction in three-space with the virtual world, direct perception of three-dimensional virtual objects, and immersion within the virtual space.

Through direct interaction, a user can specify positions, orientations and extents more efficiently and gain proprioceptive information that can help in the development of mental models of the shapes and spaces being created.

Direct perception through immersion provides better spatial perception cues which aid in the understanding of the modeling environment. The use of head tracking allows for the decoupling of viewpoint specification from modeling interaction. This leads to better understanding of the environment through head-motion parallax (the kinetic depth effect).

Immersion within the virtual environment means that model data may be distributed about the user instead of being concentrated into a window filling only a small subset of the user's field-of-view (FOV). This makes it easier to register information (such as positions or dimensions) in space with the model. In addition, the modeling space's orientation can remain fixed relative to the user. This avoids actions, such as panning the screen about the environment, that complicate the formation of mental maps.

Complications of the Immersive Domain

The transition to the immersive domain is not without obstacles. Current virtual environment systems suffer from problems such as low-resolution displays, inaccurate tracking, and perceptible delays in image update. In addition, difficulties inherent in three-dimensional interaction combine with these technological limitations to further complicate the immersive modeling task.

One of the most significant problems in a 3D environment is the lack of constraints. The freedom of a three-dimensional interface is a double-edged sword: it allows for direct interaction and proprioceptive feedback but complicates certain positioning and construction tasks. I will explore the development of overridable constraints with resets that can assist in the immersive modeling task. Note that these constraints and assists may take the form of physical devices (such as the flat-sided pool ball [Brooks 86]) or software techniques (such as cursor snaps).

A significant portion of my work will be the development of interaction techniques that take advantage of the benefits of the virtual environment while compensating for its limitations. This will include the development of three-dimensional widgets (objects with affordances) to aid in the modeling task (see for example [Conner 92]). I will pay particular attention to techniques such as orbital mode [Chung 94] and action-at-a-distance that help to compensate for people's tendency to conserve energy whether working in virtual worlds or the real world.

I will also consider ways of specifying precise values within the virtual environment. The lack of a keyboard for alphanumeric input makes it difficult to specify numerical values (for example the exact dimensions of a door). Existing attempts to implement virtual keyboards have proven difficult to use. Voice input or the selection from likely-value sets are two possible alternatives to consider.

My objectives are to explore the nature of interaction in a virtual world and to concentrate on implementing a few techniques well. I am not interested in attempting to recreate all of the modeling primitives identified in my modeling system review. The specific set of primitives I choose to implement is adaptable.

4. Exploration of Interface-Independent Modeling Techniques

I will explore modeling techniques that are independent of the type of interface used that, nonetheless, are particularly well suited to the immersive domain.

Multi-view systems

The immersion of a user within a virtual environment facilitates the simultaneous presentations of multiple representations of the same data in *multi-view* systems. Models may be shown at different scales, different levels of detail or with different types of information presented in each view.

For example, the user could perform certain modeling and positioning tasks on a doll-house sized version of the model floating before him while he was simultaneously immersed within a life sized version of the same model. This would enable the designer to get an accurate sense of the size and shape of the spaces being created while providing him a manageable object with which he can interact.

Alternately it may be desirable to interact with different representations of a model; each presented at a different level of detail. The user would perform high level changes in a model on the most abstract representation of the model, small changes in detail on the most detailed representation. The challenge in such a system is the maintenance of consistent representations across all levels of representation.

The two multi-view systems discussed above could be combined in a system where level-of-detail is linked to model scale, with the smallest versions of the model presented at the lowest level of detail. This makes sense in terms of rendering efficiency and reflects the tendency of designers to work initially on small, simple drawings that grow in size as the designer adds more information [Tesar 93]. In such a system a user would work on a small abstract version of the model initially, specifying a minimum amount of information, and then slowly transition to a more detailed, more precise version of the model.

Object and User Defaults

The effectiveness of a modeling system can be greatly enhanced through the incorporation of mechanisms for the specification and application of defaults. The use of defaults speeds up the creation of complex models by allowing the user to avoid having to repeatedly specify information about objects being created. In an architectural design system, for example, defaults could be in the form of architectural style sheets that would define characteristics like color, texture (wallpaper), and molding style for objects such as walls or doors. Similarly, libraries of default objects could also help speed up the construction of complex environments.

A default and configurable interface could also aid in the development of powerful, special purpose modeling tools. Possible enhancements include user preference profiles and customizable menu sets.

5. Development and Evaluation of an Immersive Modeling System

Selection of a Driving Problem

To motivate my development of an immersive modeling system I have chosen the driving problem of architectural design. I made this choice for several reasons. First, architectural models are complex models that are difficult to build. Second, architectural models, more than mechanical models, are likely to benefit from being constructed in an immersive environment; the shapes and spaces inside the architectural model are just as important as its external form. Third, I can draw on the many years of experience in the area of architectural visualization here at UNC. Finally, the existence of a collaborative agreement with North Carolina State University's School of Design, Department of Architecture, gives me access to considerable experience and expertise in the area of architectural design.

To familiarize myself with the concepts of architectural design I have undertaken a program of study and research with members of the Design School at NC State. This includes classes in two-dimensional and three-dimensional design, observations of architectural design studios, interviews with professional designers and reviews of relevant literature. My goal is to obtain a better understanding of the architectural design process and to acquire knowledge that will help me determine the limitations and extra requirements imposed on my system due to the choice of architectural design as a driving problem.

It is important to emphasize that I am not trying to prove that computer modeling is a superior method for architectural design, I am trying to show that modeling from within is a powerful alternative to through-the-window model generation. The choice of architectural design as a driving problem, however, will give me real world issues that will help guide the development of my system. I will have to consider issues such as ergonomics that prevent the virtual environment from being used for anything more than toy design problems. I will have to explore enhancements such as architectural style sheets that will improve the efficiency of the modeling task and encourage design exploration. I will have to examine problems such as hard-copy generation for an immersive design.

Evaluation of the Thesis

To evaluate my thesis I will consider the benefits offered by immersive modeling over conventional through-the-window modeling systems. I will weigh the advantages of direct interaction and perception against the complications of immersive interaction. I will base my evaluation of the system upon the anecdotal experience of test subjects performing similar modeling tasks in immersive and through-the-window modeling systems. The projected test subjects will include architectural design students and professionals who can evaluate the effectiveness of the system as an immersive design tool.

6. Conclusions

This is a systems thesis. I am determining the required components for an immersive modeling system and evaluating what must be done to make it an effective system that can overcome some of the limitations of existing through-the-window modeling packages. The primary contributions of this research will include:

- The systematic analysis of the modeling task.
- The comparison of immersive and through-the-window modeling.
- The enhancement and adaptation to the immersive domain of interface-independent modeling techniques (such as the multi-view system).
- The development of immersive interaction techniques.
- The development and implementation of algorithmic techniques to better support real-time interaction in an immersive modeling system.

Though the immersive modeling techniques I will develop will not be exclusive to architectural design, it is my hope that immersive design will be superior to the current through-the-window modeling techniques used by architects. Immersive design would represent a new form of model-mediated design [Jones 81] in which the model under construction would be virtual rather than physical. It is my belief that this combines positive aspects of the existing design-by-drawing and model-mediated design techniques. My goal is to develop immersive modeling techniques that begin to approach the power and ease of use of traditional pencil and paper design techniques.

7. References

Alias (1993). *Alias Upfront*. Alias Research Inc., Toronto, Canada.

Brooks, F. P. (1986). Walkthrough - A Dynamic Graphics System for Simulating Virtual Buildings, *Proc. 1986 Workshop on Interactive 3D Graphics,* Chapel Hill, NC, 9-22

Brooks, F. P. (1990). *Modeling - Today's Biggest Graphics Problem*, Presentation.

Butterworth, J., A. Davidson, S. Hench, and T. M. Olano (1992). 3DM: A Three Dimensional Modeler Using a Head-Mounted Display. *Proc. 1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 135-138

Chung, J. (1994). *Intuitive Navigation in the Targeting of Radiation Therapy Treatment Beams*. Ph.D. Thesis, University of North Carolina, Chapel Hill, NC.

Conner, D., S. Snibbe, K. Herndon, D. Robbins, R. Zeleznik, A. van Dam (1992). Three-Dimensional Widgets, *Proc. 1992 Symposium on Interactive 3D Graphics*, Cambridge, MA, 197-208.

Gregory, R. L. (1973). *Eye and Brain: the Psychology of Seeing.* World University Library, London England. 131-163

Jones, C. J. (1981). *Design Methods - Seeds of Human Futures.* John Wiley & Sons, New York.

Liang, J.D., M. Green (1993). Geometric Modeling Using Six Degrees of Freedom. *CAD/Graphics Beijing* 1993.

Tesar, P., (1993). Personal conversation.

Virtus (1993). *Virtus Walkthrough: 3D Drawing and Visualization.* Virtus Corporation, Cary, NC.