3DM: A Three Dimensional Modeler Using a Head-Mounted Display

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Abstract

3dm is a three dimensional (3D) surface modeling program that draws techniques of model manipulation from both CAD and drawing programs and applies them to modeling in an intuitive way. 3dm uses a head-mounted display (HMD) to simplify the problem of 3D model manipulation and understanding. A HMD places the user in the modeling space, making three dimensional relationships more understandable. As a result, 3dm is easy to learn how to use and encourages experimentation with model shapes.

1 Introduction

The use of interactive 3D environments has increased the demand for complex 3D models.[9] The 3D environments that provide a sense of telepresence or "virtual reality" require a large number of models in order to give the user the illusion of being in a specific place. This demand for more models has highlighted the fact that most modeling systems are difficult to use for all but a small number of experts.[9] Through identification and removal of some of the fundamental obstacles to modeling we hope to make it accessible to more users.

Typical techniques used to select and display objects are a major hindrance to 3D modeling.[3] To place an object in 3D requires six parameters: the position (three) and the orientation (three). Most modeling systems (modelers) must settle for a 2D mouse augmented by a keyboard for this purpose. This mismatch results in difficult placement and picking of objects in modeling space. The display of models usually takes the form of a projection onto a 2D monitor. This has the effect of making spatial relationships unclear. Technological improvements to 3D model display and manipulation hardware can remove these barriers to model creation and understanding.

Current virtual reality technology provides one solution to more intuitive modeling. A HMD system gives the ability to understand complex spatial relationships of models by placing the user in the model's world. Within this type of system, a hand-held pointing device supplies users with the ability to specify 3D relationships through direct 3D manipulation. As a result, the user can build the virtual world from *within* the virtual world.

Our source of inspiration for designing a user interface for a HMD-based modeler is the current software used for 2D modeling. At one time, creating 2D models required cumbersome CAD programs. This software took a long time to learn and often did not provide real-time interaction. Now, however, 2D drawings can be manipulated by even the most casual users of personal computers. This revolution is in part the result of intuitive drawing programs like MacDraw. One of the keys to MacDraw's success is its inherent simplicity. Most work done with it requires no reading or use of the keyboard. Rather, it provides a palette of tools which is always available next to the model. To change modes, the user simply selects the tool from the palette using the mouse. The process of 3D modeling can become more accessible if some of the lessons learned from this evaluation of 2D modeling can be applied to 3D modeling systems.

This paper presents a HMD-based system called **3dm** which simplifies the task of 3D modeling by implementing the concepts introduced above. Basic techniques for working within 3dm's virtual world are described to show how users access the various features. The implementation of 3dm is described through a presentation of its most useful commands. Finally, the results of actually using 3dm are presented with an emphasis on new techniques that can be applied within other virtual worlds.

2 Prior Work

A large body of work has been done on 3D modeling. Although 3D *input* devices have been used to enhance modelers, very little modeling has been done with a HMD. Some examples of modeling with six degree-of-freedom input devices are [1] and [8], but both of those used traditional 2D displays. Previous uses of HMD systems have concentrated more on exploration of virtual worlds rather than creating or modifying them. Some examples of this work with HMD's can be found in [5].

Modeling using a HMD system has been explored by Clark.[4] Users of Clark's system created parametric surfaces by manipulating control points on a wire-frame grid. This system highlighted the utility of using a HMD for improved understanding and interaction with models. Like Clark's system, 3dm relies on a HMD to help simplify modeling, but 3dm's intuitive user interface design also makes it easy to learn and use.

3 Implementation

3dm was developed using a VPL eyephone as the display device and Polhemus trackers to track the head and hand. A 6D 2-button mouse, developed at UNC-CH, was the input device. The images were rendered using the Pixel-Planes 4 and Pixel-Planes 5 high-performance graphics engines developed at UNC-CH.[6][7] Currently, all models created with 3dm are made up of hierarchical groups of triangles.

3.1 User Interface

In addition to the model, the virtual world of 3dm contains the components of the user interface. The most important of these are the toolbox and the cursor. The cursor follows the position of the hand-held mouse, giving the user a sense of hand position in the modeling space. The toolbox is the means by which most actions are performed.

Some of the user interface components are simply helpful markers that can be turned off, unlike the toolbox and the cursor, which are always visible. The user stands on a "magic carpet" which marks the boundaries of where the tracking system operates. Remaining within tracker range is important because the virtual world will begin to tilt as the user moves farther out of range. Below the magic carpet lies a checkered ground plane, above which the model is usually created. Additional reference objects, such as coordinate axes, can be turned on by the user.

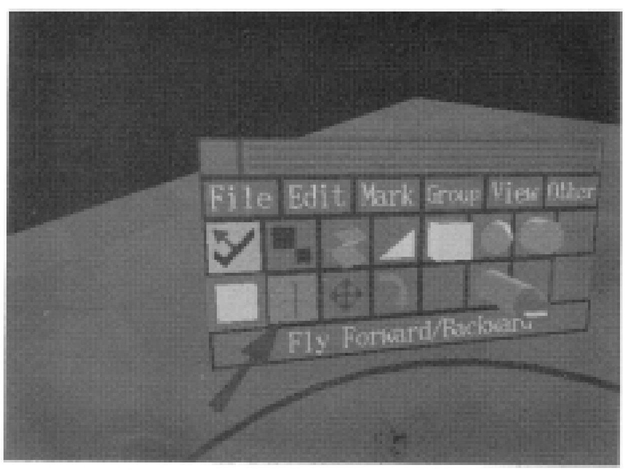

Figure 1: The toolbox as seen by the user.

The toolbox initially appears suspended in space near the user's waist, but it can be moved to a more convenient location. The toolbox remains attached to the user as he or she moves around the modeling space, or it can be disconnected and left anywhere above the magic carpet. The toolbox is organized into cells containing 3D icons. Each icon represents either a tool, a command, or a toggle. Many of these icons can optionally appear in pulldown menus at the top of the toolbox in order to reduce clutter.

Icons perform actions when they are selected with the cursor. Tools change the current mode of operation as reflected in the shape of the cursor. For instance, when the user reaches into the toolbox and selects the flying tool, the cursor takes the form of an airplane. Selecting a command performs a single task without changing the current mode of operation. Toggles change some global aspect of 3dm. An example is the snap-to grid toggle, which restricts cursor movement to a 3D grid when it is on.

Exploring the model provides understanding of its 3D shape, so 3dm supports multiple methods of navigating in the modeling space. The HMD system used for 3dm allows the user to walk through the model space a few paces in any direction. Walking simply does not provide the range of movement needed for most models, so 3dm supports "flying," a commonly used method of traveling through virtual worlds.[2] Flying consists of translating the user through model space in the direction that the cursor is pointing. Flying moves the magic carpet, which carries the user and the toolbox along. A method of navigation that is the complement of flying is "grabbing" the world. Grabbing the world allows the user to attach the modeling space to the cursor and then drag and rotate it. Grabbing can be used to bring a feature of the world to the user rather than forcing the user to walk or fly to the feature.

Models often require manipulation at vastly different scales. To facilitate this type of work, the user can be scaled using a process called *growing* and *shrinking*. This scaling does not affect the model: it changes the user's relative size with respect to the model. The user could shrink down to bird size in order to add eyelashes to a model of an elephant and then grow to the size of a house to alter the same model's legs. Since the user can become disoriented by all of these methods of movement, there is a command that immediately returns the user to the initial viewpoint in the middle of the modeling space.

The user receives continuous feedback in a variety of ways. The HMD system provides all visual input to the user, so the display must be updated between 15 and 30 times per second. Even during file loading and other slow operations, the screen is updated and the head is tracked. Rubber banding is implemented in many situations: when defining a new triangle, scaling or moving an object, and extruding. Predictive highlighting shows the user what *would* be selected if a mouse button were pressed. This highlighting is used in the toolbox, and even more importantly, when marking vertices. Whenever the cursor is near a model, the nearest vertex is highlighted, giving the user an indication of which vertex would be operated on before actually attempting the operation.

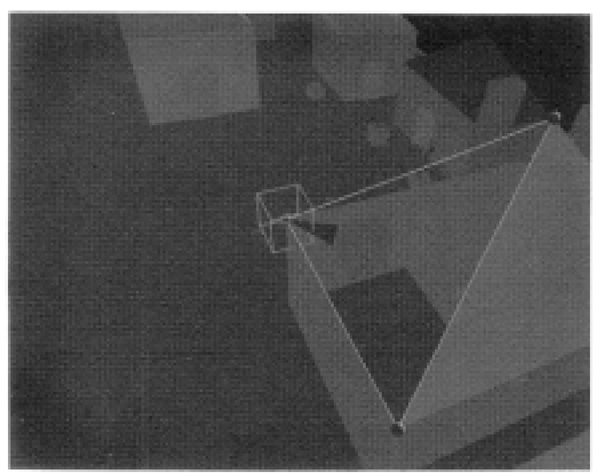

Figure 2: A triangle being added to a model. Demonstrates rubber banding and snapping to nearby vertices.

3.2 Tools and Commands

Although many tools are available in the 3dm toolbox, it is more useful to understand the general classes of tools supplied to the user than to enumerate all of the specific tools. Most of these tools were chosen because of their proven utility in pre-existing modelers.

3.2.1 Surface Creation

Surface creation is the central purpose of most 3D modeling, so 3dm provides more than one method for creating surfaces. A triangle creation tool exists for generating both single triangles and triangle strips. The corners of these triangles are specified by pointing and clicking the mouse, so the triangles are created in their desired locations rather than appearing in a "building" area and then being moved into the model space. Pre-existing vertices may be used during triangle creation to allow triangles to share corners or entire edges, making seamless connections easy.

The extrusion tool supplies a more powerful and more specialized method of triangle creation. This tool allows the user to either draw a poly-line or select one from edges already in the model and stretch it out into an extruded surface. The extrusion is performed by dragging the leading edge of the surface with the mouse. Because the mouse can be twisted and translated arbitrarily during the extrusion, it becomes easy to create complex surfaces with this tool. In addition, the leading edge of this new surface can be scaled and then extruded again as many times as necessary. This form of extrusion can rapidly create such objects as walls, legs, tree trunks, and leaves.

The last surface creation tools facilitate creation of standard surface shapes. Currently box, sphere, and cylinder tools exist. They each allow the user to interactively stretch out an arbitrarily proportioned wireframe representation of a standard shape. When the wireframe representation has the desired proportions, it is turned into a triangulated surface.

3.2.2 Editing

Since surfaces are rarely in exactly the desired shape upon creation, it is important that surface editing be an easy operation. The most commonly used editing tool is the mark/move tool. This tool provides a method of grasping and moving arbitrary portions of the model. Not only can entire objects be grabbed and moved with the mouse, but selected groups of vertices can be moved in order to distort part of an object. Scaling can also be performed on either entire objects or groups of vertices. During both movement and scaling, the user sees the model changing in real time. This interaction decreases the number of edits needed to make a desired change. The marking aspects of this tool are used to mark arbitrary portions of the model for operations with other tools.

Familiar editing operations from drawing programs are a group of 3dm commands that facilitate rapid experimental changes. An arbitrary number of triangles or entire objects can be cut, copied, pasted and deleted. These commands provide easy reuse of existing objects.

An undo/redo stack is provided for reversing any number of operations from any tool or command. As operations are performed, the changes they cause to the model are stored in the undo/redo stack. The undo command can then be used to pop changes off of this stack to undo as many operations as necessary. These undo operations can themselves be undone with the redo command. The undo/redo commands encourage experimental changes to the model because no operation can cause permanent damage.

3.2.3 Hierarchy

The hierarchical features of 3dm provide methods for organizing complex models. "Grouping" can be used to associate triangles and possibly other groups to more easily manipulate them as a whole. These groups can be *instanced.* An instance is similar to a copy of a group that can be arbitrarily translated, rotated, and scaled. However, the difference between an instance and a copy is that the instances of a group are all linked to the same basic shape. If this shape is changed, then the change is reflected in all instances at once. An example where instancing would be useful is in a model of a large building. Suppose that hundreds of chairs were in this building. If one model of a chair were instanced many times to make these chairs, then a change to a single chair would be reflected in hundreds of places throughout the building.

Groups can be organized into a hierarchy represented by a directed acyclic graph. This type of hierarchy is particularly well-suited to modeling articulated figures. The ability to instance groups and impose a hierarchy on them helps to organize models.

4 Results

Actual modeling sessions have shown that 3dm is efficient for rapidly prototyping models. Organic shapes, like rocks and trees, have proven to be particularly good subjects for 3dm. These shapes are easily created in 3dm because it provides a good sense for spatial relationships. Users of 3dm have commented that they feel a sense of control, because they can reach out and grab any part of the model with ease. The ability to make these quick modifications encourages the user to experiment with shapes until they are satisfactory. However, 3dm has shown weakness in the area of constraints and models that traditional CAD and drawing programs create well. For instance, 3dm has no way of keeping two polygons parallel, causing some models to appear irregular.

The extrusion tool is an example of a traditional modeling tool that has become even more powerful because of its use in a HMD framework. In most modeling systems, extrusion is performed by moving one or two spatial parameters at a time. 3dm users often alter many parameters at once during an extrusion by twisting *and* translating the new surface. Extrusion in 3dm often consists of many short extrusions. In between these short operations the leading edge of the extruded surface is often scaled and twisted. The result is that complex surfaces can be rapidly created with an easy to use tool.

Some initial solutions to 3dm's lack of constraints have been to add toggles in the toolbox for a snap-to grid and a snap-to plane. The snap-to grid constrains the position of the cursor to the nodes of a regular 3D grid. The resolution of the snap-to grid is dynamically modified to be appropriate to the user's current "grown" or "shrunk" size. The snap-to plane gives the ability to constrain cursor movement to 2 dimensions. The snap-to constraints help in making regular objects, such as mechanical parts.

5 Conclusion

3dm draws techniques of model manipulation from both CAD and drawing programs and applies them to modeling in an intuitive way. A HMD modeling system uses these tools to simplify the problem of 3D model manipulation and understanding.

3dm is a step toward making 3D modeling accessible to unsophisticated users. It supports users' natural forms of interaction with objects to give them better understanding of the shapes of their models. Even a novice user can understand how to manipulate a model by reaching out and grasping it. Users are encouraged to experiment with model shape because 3dm facilitates making rapid changes. The effects of a change to a model can be clearly understood because the user can explore the model using a variety of intuitive navigation techniques.

Advanced users are also empowered by 3dm. Many of the tools borrowed from existing modeling systems become more powerful when used with a HMD. One source of increased utility is the fact that complex operations can involve simultaneous modification of many spatial parameters. Examples of tools that take advantage of this are object placement and extrusion, which both allow combinations of rotation and translation in a single step. By concentrating more functionality into each operation, fewer operations are needed to perform a task and models can be created faster.

6 Acknowledgements

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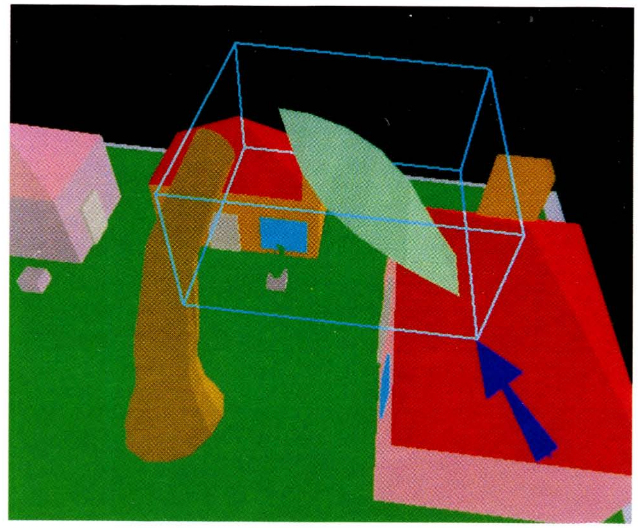
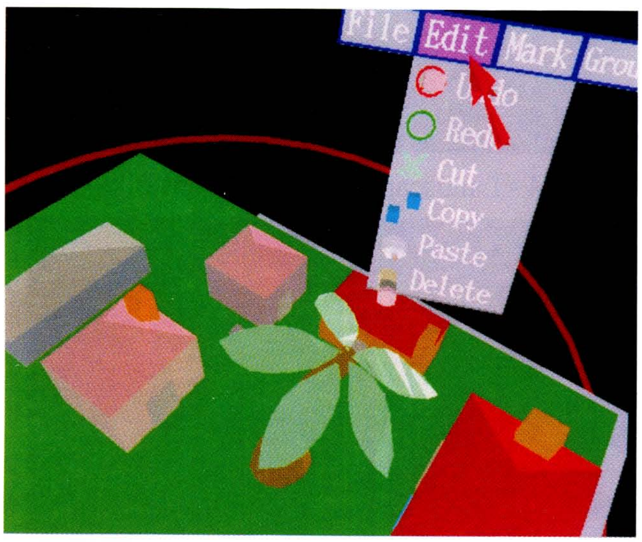
Color Plate 1
A tree trunk being extruded.
The user is roughly five times
taller than the houses.



Color Plate 2
A palm branch is being marked for
copying using a rubber banding box.



Color Plate 3
The branch has been copied four times.
Part of a toolbox menu is visible.
The red ring is the “magic carpet”,
showing the tracker range.

Color Plate 4
The user is now normal size.
The airplane is the cursor, which indicates
that the “flying” tool is being used.

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