



# Interaction Techniques For A Highly Interactive 3D Geometric Modeling System

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## 1 Introduction

Three dimensional (3D) geometric modeling has been a challenging topic for computer graphics and computer-aided design (CAD) [Spro 90]. Though many 3D modeling systems have been developed, few systems penetrate into the early and creative stage of the designing process, that is, the *sketching* (or *conceptualization*) phase [Hatv 84]. This is mainly because of the long turn around time required to construct a 3D model. One important reason for this low efficiency in interaction is the disparity between (a) the high degrees of freedom nature of the 3D modeling task, and (b) the low degrees of freedom nature of traditional input devices and thus that of the interaction techniques associated with them. To reduce this discrepancy, we adopted a *bat* [Ware 88] as the main input device. It is a hand-held 3Space Isotrak (a six degrees of freedom tracker). Several novel interaction techniques have been developed based on the bat. They form a 3D direct manipulation interface for the modeling task, so the user can quickly "sketch" out a 3D model, and easily modify it. A kinetic 3D display scheme may also be used to enhance spatial perception in the design space [Lian 93]. A prototype system has been built on a Silicon Graphics VGX/310 workstation, to verify the effectiveness of various interaction techniques. Preliminary results showed that bat-based direct manipulation can reduce modeling time to about one-tenth of what is usually required.

## 2 Bat-Based Manipulations

The creation of a primitive shape can be easily accomplished by 3D rubber-banding, often in a matter of sec-

onds. The three independent translational degrees of freedom of the bat are mapped onto corresponding measurements of the primitive shape. When a primitive shape has more than three independent measurements, a fixed ratio is used to link the extra ones to those directly controlled by the bat.

Reshaping of an object often requires more flexibility, as the user may wish to modify a certain set of measurements while leaving the rest untouched. The handle-based metaphor does not work well in 3D, as the handles tend to clutter the scene, and it is also more difficult to grab a handle in 3D with limited depth perception. To cope with these problems, we expanded the handles to fill the vicinity of the object, and made them invisible. The 3D cursor takes over for visual feedback, by showing different shapes when in different regions. This region-based technique maintains the flexibility of the handle-based metaphor while relaxing the precision requirement and also avoiding the cluttering.

The intuitive orientation control provided by the bat can also facilitate specifying reference directions in space (as often required by alignment and conformation operations). In order to pick a direction from several candidates (e.g. directions along the three major axis), the user can simply point the bat at roughly the desired direction, and let the system identify the closest candidate. Using the orientation of the bat, a graphical dial tool was also implemented to help adjust quantities such as angles in a natural and intuitive way.

These modeling operations forms the core of the 3D direct manipulation interface that allows for quick sketching of a 3D model.

## 3 BSP Rendering

Constructive solid geometry (CSG) is an important tool in solid modeling. However, CSG operations (union, intersection, difference) present a special challenge for direct manipulation, for three reasons. First, due to the inherited complexity of these operations, it is very difficult to accomplish them in a real time manner (such

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as within one-tenth of a second) on today's workstations. Second, in addition to the resulting object, the user may also wish to view the spatial relationship of the operands and other objects in the vicinity. Third, the visualization method must accommodate, in real time, changes in object placement as well as changes of viewing parameters.

We developed a binary space partition (BSP) rendering technique to tackle this problem. The idea is to render solids as transparent (translucent) shells formed by non-penetrating polygons, so any intersection between solids can be visually identified. Since transparent rendering on the SGI workstation requires a correct ordering of the polygons, we use the binary space partition concept introduced in [Fuch 80]. However, since the solids are subject to direct manipulation, actually building a BSP-tree would not be of benefit. Instead, we perform rendering when no further splitting is necessary, and the ordering is available.

BSP rendering does not require the result of any set operations on the solids, and its execution is relatively faster. It provides a good preview of the CSG operations, and can also be used for interference detection among solids.

## 4 Hand-Held Cross Sectioning

In designing a complex model, one often needs to inspect the internal structure of a certain part (e.g. an assembled component). Cross sectioning is the traditional method for this purpose. We designed a bat-based clipping tool to further facilitate such operations.

Since the SGI VGX graphics workstation supports six additional clipping planes in rendering, we use them to form several cross sectioning tools that the user can dynamically place in space with the bat. So the user can "poke around" to examine internal structures and profiles of cavities.

In our current system, the user can view cross sections by dynamically clipping out a half space, a quarter space, or an octant. These tools would also be useful for interrogating a model under simulation, for example, collision checking for a mechanism.

## 5 Conclusions

Based on a hand-held tracker as the main input device, we have developed several interaction techniques for 3D geometric modeling. These techniques improve the efficiency of interaction by removing the bottleneck caused by traditional low degrees of freedom input devices (such as a mouse and a tablet). In our prototype modeling system it only takes about five minutes to sketch out the 3D model in figure 1, about one-tenth

the time usually required by traditional CAD systems (see, for example, [Hods 89]).

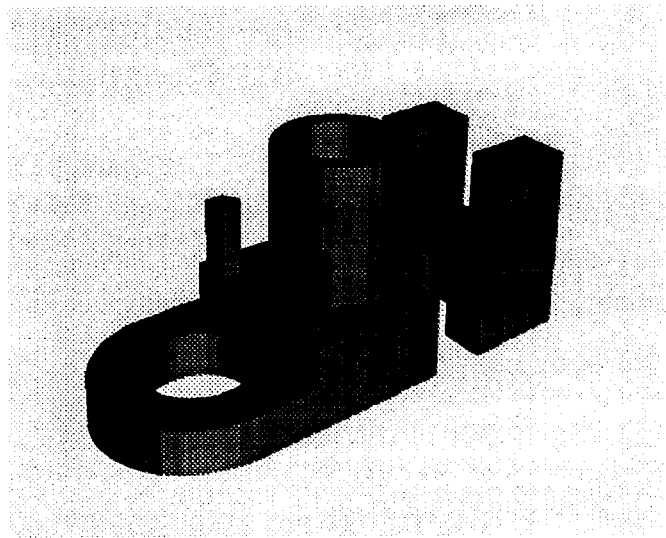


Figure 1: A sample mechanical component.

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