OBJECT SELECTION IN VIRTUAL ENVIRONMENTS WITH AN IMPROVED VIRTUAL POINTER METAPHOR

Frank Steinicke, Timo Ropinski, and Klaus Hinrichs
Institut für Informatik, Westfälische Wilhelms-Universität Münster, Germany

Abstract   In this paper we describe object selection techniques and metaphors for virtual environments (VEs). By combining and extending known techniques, we introduce an improved virtual pointer metaphor which enhances interactive object selection. The extension of the virtual pointer metaphor is based on a bendable ray, which is visualized by a quadratic beziér curve and points to the selectable object closest to the additionally visualized direction ray of the pointer. Strategies for determining this object are discussed and compared.

Keywords: Virtual Reality, Interaction Techniques, Selection Metaphors

1. Introduction

Virtual environments (VEs) have shown considerable potential as an intuitive and natural form of human-computer interaction. Improving the acceptance of virtual reality (VR) technology requires optimization of the most basic interaction techniques to maximize user performance and provide efficient virtual interfaces.

Before interacting with virtual objects, the user needs to specify the target for the desired interaction. This *selection* is generally considered as an interaction technique itself and its direct interaction metaphors are in the main focus of this paper. Object selection requires a set of *selectable* objects, a technique for identifying the object to be selected and a mechanism to indicate the time of selection. Furthermore, the user should get an adequate feedback, e.g. visible, audible or tactile, about a possible or an already performed object selection.

In this paper we describe a new interaction metaphor for object selection in VEs. Our approach improves selection techniques by combining the following advantages:

- possible selection of near as well as distant objects,

- prevention of accuracy errors and ambiguousness,

- sufficiency of 2 DoF for controlling the virtual input device in many applications,

- possible selection of occluded objects and

- a better understanding of the virtual world by getting adequate feedback.

In Section 2 we describe existing metaphors for object selection. Section 3 introduces our approach of an improved virtual pointer metaphor and discusses example configurations. Applications are presented in Section 4, and in Section 5 an overview about future work is given.

2. Related Work

Many basic approaches for interaction techniques in VEs have been proposed. In [Poupyrev et al., 1998] manipulation techniques in VEs are compared, among them the virtual hand and the virtual pointer metaphor. Both metaphors use a virtual tool controlled by a real input device, but differ in the way a selection is performed.

When using the virtual hand metaphor, a selection is possible if the virtual input device intersects a desired object. For the selection of distant objects outside the immediate reach of the user, alternative strategies must be used. The Go-Go ([Poupyrev et al., 1996]) and HOMER techniques ([Bowman and Hodges, 1997]) support distance selection by a non-linear mapping function to translate the measured distance from the user's head to hand into the controlled distance between real and virtual hand. In contrast to moving a virtual hand to the object, virtual pointer metaphors, e.g. ray-casting techniques ([Jacoby et al., 1994]), involve pointing a virtual ray to an object. Using this metaphor a selection can be performed when the ray hits the desired object. In [Poupyrev et al., 1998] a comparison of the Go-Go and a simple ray-casting technique shows comparable performance for local selection conditions, i.e. selection in the immediate reach of the user, independent of the virtual object's size. With increasing distance, especially when higher selection accuracy is required, the Go-Go technique has a significant performance advantage.

Other similar selection techniques, e.g. image plane based selection ([Pierce et al., 1997]), are based on an evaluation of a ray casted from the user's head through his hand onto the image plane.

By using a cone instead of a ray, as it is done in the spotlight technique [Liang and Green, 1994], accuracy errors in distance selection are reduced. But more than one object may fall into the light cone. In [Forsberg et al., 1996] a modification of the spotlight technique is described, which diminishes the ambiguities by providing aperture based and resizeable selection cones. However, using selection cones, ambiguities must be resolved if the cone intersects more than one object.

To select fully or partially occluded objects Olwal and Feiner have described a flexible pointer ([Olwal and Feiner, 2003]) visualized as a curvature. This approach is based on a two handed control of the curve, whereas the vector formed by the hands determines the pointer's direction. The amount of curvature is determined by the orientation of each hand.

3.   The Improved Virtual Pointer Metaphor

We believe that virtual pointer metaphors are natural and require less effort for local and remote object selection. But improving the acceptance of raycasting techniques requires a simple way to aim at virtual objects. Therefore, we have developed an improved virtual pointer metaphor with the goal to avoid the disadvantages of current selection metaphors.

In our approach we combine the metaphors described in Section 2 and extend them to provide an intuitive mechanism for object selection. The main concept is based on enable a selection without the need of an exact hit by bending a virtual ray to the closest selectable object. This object, which would be chosen when a selection is performed, is called *active object*. The additional curved ray is visualized besides the direction vector of the input device, conventionally used in virtual pointer metaphors.

Distance Calculation

For an improved object selection the object with the minimal orthogonal distance to the virtual ray has to be determined. This minimal orthogonal distance may refer to different reference points of a desired object, e.g. the center of the object's bounding box, the nearest vertex, the nearest edge etc. ([De Amicis et al., 2001]). If more than one object have the same minimal distance to the virtual ray, different strategies may be considered, e.g. the object closest to the user becomes active. The minimal distance is calculated by dropping a perpendicular from the reference points of all considered objects to the virtual ray. Figure 1 clarifies this calculation. The distance vector d_i between the virtual ray and a reference point of an object obj_i is calculated using the ray direction, the vector from the virtual pointer position to the reference point of obj_i and the bending angle α_{obj_i} between them.

The calculation has to be performed for every scene object considered. But since nowadays most computer graphic systems use hierarchical scene structures, we avail of multiple scene passes used in scene graph based systems. All required distances are calculated during an anyway performed scene traversal and all considered selectable objects are stored in a list, ordered by the described distance metrics. Therefore, almost same frame rates are maintained as using classical virtual pointer metaphors and furthermore, the user can utilize

the ordered list to switch between selectable objects, e.g. to select an occluded object.

Region Examination

The number of considered objects depends on the scene configuration and the examined region. When the user moves the virtual pointer through the VE, the object closest to the virtual ray within an appropriate region has to be determined. The optimal choice for structure and size of this region depends on the scene's configuration and the arrangement of its selectable objects. We distinguish between two possible concepts: Constraining the number of considered objects depending on intersections with geometric shapes and considering all selectable objects.

In the first case only objects intersected by a predefined geometric shape are considered. Possible geometric shapes are cones, cylinders, spheres, boxes etc. which may be attached to the virtual input device or located somewhere in the scene. If one or more selectable objects intersect such a geometric shape, the object with the smallest distance to the ray will become the active object and will attract the ray. If no such intersecting object exists, the geometric shape will be enlarged and tested again for intersecting objects. The enlargement process is repeated until either an intersection is found or the complete scene has been examined without success, i.e. the scene does not contain any objects.
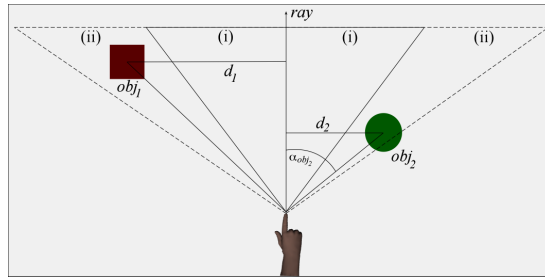

Figure 1. Example configuration with initial (i) and extended (ii) cone.

Figure 1 illustrates an example. Since the virtual ray does not hit any object, an initial cone-shaped region (i) is examined. Because no object is intersected by the initial cone a larger region is analyzed. Now that two objects are within the cone (ii) and due to $|d_2| < |d_1|$ obj_2 becomes the active object. This strategy is favorable for extremely densely populated scenes but the appropriate size of the region to be examined depends on the topology of the scene.

Alternatively, all selectable objects can be considered. Because a complete scene traversal is needed for each additional examination step, in some VEs it may be advantageous to avoid the examination of regions and just use distance metrics to find the active object. This approach is especially favorable in VEs in which the initial examined region usually does not contain any objects. But this means, that the distance to the ray must be calculated in one scene traversal for all selectable objects. However, using the described distance metrics is actually not very complex, such that this approach is sufficient in most VEs.

The "Sticky-Ray" Metaphor

In a densely populated VE with large objects and small gaps between them, a different strategy may be advantageously. As in other techniques a ray is casted through the VE and the first object to be hit becomes the active object. It remains active until the virtual ray hits another selectable object. Therefore, selection is simplified because only a singular hit of a desired object with the selection ray is needed to afford a selection. This hysteresis-approach leads to a "sticky-ray" metaphor as illustrated in Figure 2. In the beginning the ray
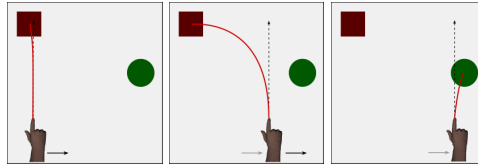

Figure 2.   "Sticky-ray" example during a translation of a virtual input device from left to right.

intersects the red box leading to a feasible selection (left). After moving to the right, the red box is still active (indicated by the red curve) although the green sphere is closer to the virtual ray (middle). Moving further to the right, the ray hits the green sphere which then becomes the active object (right). In contrast to the concepts described in the previous section the "sticky-ray" metaphor needs no distance calculation at all.

Visualization of the Virtual Ray

To get an adequate visual feedback of the possible selection, we visualize the ray direction vector as well as the position of the active object. Visualization of both aspects is ensured by visualizing, additional to the ray direction vector, a beziér curve graph

$$B(x) = \sum_{i=0}^{2} p_i \cdot \left(\begin{array}{c} 2 \\ i \end{array} \right) x^i (1-x)^{2-i}, \tag{1}$$

with $x \in \mathbb{R}^3$ and three points $p_i \in \mathbb{R}^3$, $i = 0, ..., 2$ defining the curve. The anchor points p_0 and p_2 are defined by the position of the virtual input device and the active object's reference point, e.g. the center of its bounding box. Between these start and end points the control point p_1 is located on the ray direction vector and determines the bend of the beziér curve. Our tests have indicated
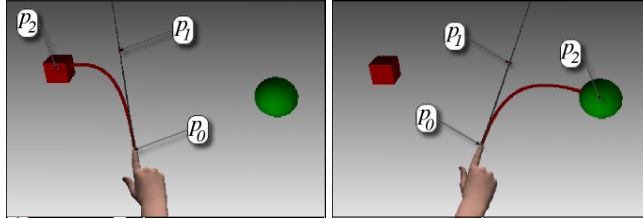

Figure 3.   The red box is active although it is not hit by the virtual ray (left). After a small rotation the green sphere is located closer to the ray and becomes the active object (right).

that $0 < |p_0 - p_1| < |p_0 - p_2|$ has to be satisfied, otherwise the attraction is too low or appears to be unnatural. Figure 3 shows a virtual scene illustrating the attraction for two selectable objects with p_1 chosen such that $|p_0 - p_1| = \frac{4}{5} \cdot |p_0 - p_2|$.

4.   Applications

Because of its natural and intuitive usability virtual pointer metaphors are applied in many VR applications. Especially VR systems, in which distant selection is essential, use ray-casting techniques for object selection and benefit from our approach. We present two application areas in which we use our improved virtual pointer metaphor and observe an advanced interaction for VR novices and VR experts. Both applications are used in a responsive workbench environment, combined with an optical tracking system, as well as in desktop environments and the user controls the virtual pointer by either an optical tracked input device or a 6 DoF spatial mouse.

In Figure 4 (left) the virtual pointer metaphor is used in a spatial planning environment for an improved selection and manipulation of virtual buildings. Figure 4 (right) shows the usage of the metaphor in a menu-based VE offering the user to experiment with platonic solids. In addition to the solids the virtual ray is attracted by all menu entries allowing an easy access to each menu item.

5.   Summary

In this paper we have introduced an improved interaction metaphor for selection tasks in VEs. We have described its advantages and gave some sample
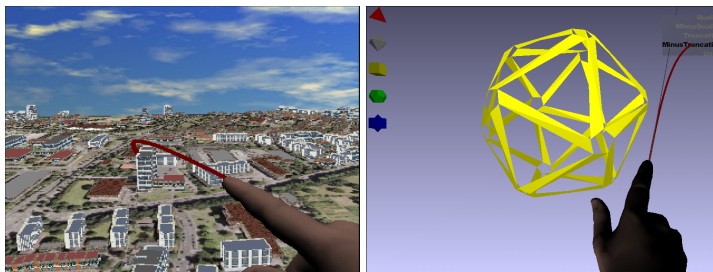
Figure 4. Interaction with a spatial planning environment by using a widget, without visualizing a straight ray (left). Improved virtual pointer metaphor used in menu-based VE (right).

applications. The proposed metaphors promise advanced usability and more intuitive interaction with VEs. To enhance further performance appropriate combinations of the approaches described in section 3 can be used. Currently we are setting up a user study to evaluate our improved virtual pointer metaphor. In this study we are going to compare different strategies used to simplify the selection of occluded objects, e.g. enable *tabbing* through all objects intersected by the ray. Furthermore, we will evaluate the use of different positions for the curve's control point p_1 and how omitting visualization of the straight ray, indicating the direction of the input device, affects user interaction.

References

[Bowman and Hodges, 1997] Bowman, D. and Hodges, L. (1997). An evaluation of techniques for grabbing and manipulating remote objects in immersive virtual environments. In *ACM Symposium on Interactive 3D Graphics*, pages 35–38.

[De Amicis et al., 2001] De Amicis, R., Fiorentino, M., and Stork, A. (2001). Parametric interaction for CAD application in virtual reality environment. In *XII ADM INTERNATIONAL CONFERENCE on Design Tools and Methods in Industrial Engineering*, pages D3/43–D3/52.

[Forsberg et al., 1996] Forsberg, A., Herndorn, K., and Zeleznik, R. (1996). Aperture based selection for immersive virtual environments. In *ACM Symposium on User Interface Software and Technology*, pages 95–96.

[Jacoby et al., 1994] Jacoby, R., Ferneau, M., and Humphries, J. (1994). Gestural interaction in a virtual environment. In *Stereoscopic Displays and Virtual Reality Systems: The Engineering of Virtual Reality*, pages 355–364. SPIE.

[Liang and Green, 1994] Liang, J. and Green, M. (1994). JDCAD: A highly interactive 3D modeling system. *Computers & Graphics*, 18(4):499–506.

[Olwal and Feiner, 2003] Olwal, A. and Feiner, S. (2003). The flexible pointer: An interaction technique for selection in augmented and virtual reality. In *ACM Symposium on User Interface Software and Technology (UIST Conference Supplement)*, pages 81–82.

[Pierce et al., 1997] Pierce, J., Forsberg, A., Conway, M., S. Hong, R. Zeleznik, and Mine, M. (1997). Image plane interaction techniques in 3D immersive environments. In *ACM Symposium on Interactive 3D Graphics*, pages 39–44.

[Poupyrev et al., 1996] Poupyrev, I., Billinghurst, M., Weghorst, S., and Ichikawa, T. (1996). The Go-Go interaction technique: Non-linear mapping for direct manipulation in VR. In *ACM Symposium on User Interface Software and Technology*, pages 79–80.

[Poupyrev et al., 1998] Poupyrev, I., Weghorst, S., Billinghurst, M., and Ichikawa, T. (1998). Egocentric object manipulation in virtual environments: Empirical evaluation of interaction techniques. *Computer Graphics Forum*, 17(3):41–52.