A Smoothing Operator for Boolean Operations on Surfel-Bounded Solids

Bart Adams
Philip Dutré

Report CW 359, April 2003

Katholieke Universiteit Leuven
Department of Computer Science
Celestijnenlaan 200A – B-3001 Heverlee (Belgium)

A Smoothing Operator for Boolean Operations on Surfel-Bounded Solids

Bart Adams
Philip Dutré

Report CW 359, April 2003

Department of Computer Science, K.U.Leuven

Abstract

We present a simple smoothing operator for surfel-bounded solids obtained by adding two solids together using boolean operations. When adding two surfel-bounded solids together with the union operator, it is sometimes desirable to smooth out the sharp creases in the surface of the resulting solid. This report presents a simple local smoothing operator for this purpose. We illustrate that this operator enables us to obtain a more natural integration of the two solids added together.

Keywords : free-form modeling, boolean operations, surfels, point-based geometry, smoothing.
CR Subject Classification : I.3.5, I.3.6, I.3.4

A Smoothing Operator for Boolean Operations on Surfel-Bounded Solids

Bart Adams* Philip Dutré*

April 29, 2003

Abstract

We present a simple smoothing operator for surfel-bounded solids obtained by adding two solids together using boolean operations. When adding two surfel-bounded solids together with the union operator, it is sometimes desirable to smooth out the sharp creases in the surface of the resulting solid. This report presents a simple local smoothing operator for this purpose. We illustrate that this operator enables us to obtain a more natural integration of the two solids added together.

1 Introduction

In [1] Adams and Dutré presented a technique to perform boolean operations on surfel-bounded solids. This report is an addendum to this work and presents the local smoothing operator used to eliminate sharp creases.

The technique presented by Adams and Dutré is based on a fast inside-outside test. The test classifies the surfels of two solids A and B as being completely inside or outside the other solid or as intersecting with the surface of the other solid. Surfels are considered as being disks with center $\mathbf{x}_s$, a radius of influence r_s and a normal $\mathbf{n}_s$. Each surfel thus represents a small area of the surface of the solid it belongs to. Only a small number of these disks intersect with the surface of the other solid. These surfels are classified as *intersecting* by the inside-outside test. In this report we present a local smoothing operator that smooths out the region in the neighborhood of the surfels classified as *intersecting*. The operator enables us, if desired, to obtain a more natural integration of the two solids added together with the union operator.

In section 2 we present the mathematics of the smoothing operator. In section 3 examples are given and possible difficulties are discussed. We conclude in section 4.

2 Smoothing Operator

When adding two surfel-bounded solids A and B together with the union operator, we use the inside-outside test to decide which surfels of A and B are part of the surface of

*email:{barta,phil}@cs.kuleuven.ac.be

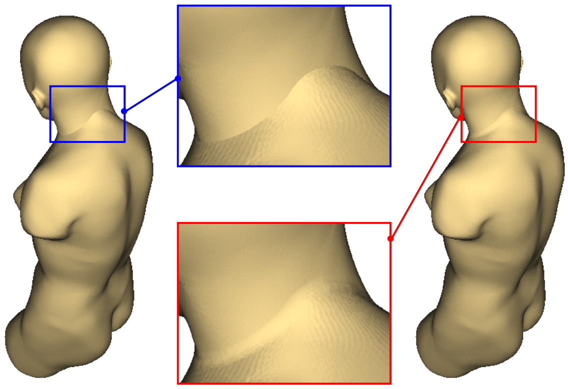

Figure 1: Union of head and body. Left: no smoothing. Right: smoothing of surfels in the neighborhood of the surface-surface intersection gives a more natural integration of the head and the body.

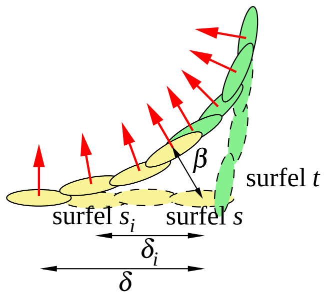

Figure 2: Smoothing operator. The dashed surfels are rotated and translated to their new position. Sharp creases are eliminated.

the resulting solid. The resulting solid consists of the surfels of the surface of A outside solid B and vice versa. The surfels classified as intersecting with the surface of the other solid are also added to the resulting solid. Figure 1, left shows the result of the union of head and body. A sharp crease can be seen in the region of the surface-surface intersection.

In this section we propose a local smoothing operator that works well in most practical cases and results in a more natural integration of the two solids added together with the union operator.

The smoothing operator works on all surfels s classified as intersecting by the inside-outside test and all surfels s_i within a distance δ of s. Recall [1] that during the inside-outside test we stored the nearest neighbor t for all surfels s that intersect with the surface of the other solid. Our operator works as follows (figure 2). First, surfel s is rotated so that it points in the direction:

$$\mathbf{n}_s \leftarrow \frac{\mathbf{n}_s + \mathbf{n}_t}{\|\mathbf{n}_s + \mathbf{n}_t\|} \tag{1}$$

Next we translate s in the direction of its new normal over a distance β:

$$\mathbf{x}_s \leftarrow \mathbf{x}_s + \beta \cdot \mathbf{n}_s \tag{2}$$

In a second step we modify all the surfels s_i within a distance δ of a surfel s. The distance between s_i and s is δ_i with $\delta_i \leq \delta$. We replace the normal of s_i by blending between the normal $\mathbf{n}_{s_i}$ of s_i and the (new) normal $\mathbf{n}_s$ of s:

$$\mathbf{n}_{s_i} \leftarrow \frac{\alpha_i \cdot \mathbf{n}_{s_i} + (1-\alpha_i) \cdot \mathbf{n}_s}{\|\alpha_i \cdot \mathbf{n}_{s_i} + (1-\alpha_i) \cdot \mathbf{n}_s\|} \tag{3}$$

with $\alpha_i = \delta_i/\delta$. Next we translate the surfel s_i over a distance $(1-\alpha_i) \cdot \beta$ in the direction of its new normal:

$$\mathbf{x}_{s_i} \leftarrow \mathbf{x}_{s_i} + (1-\alpha_i) \cdot \beta \cdot \mathbf{n}_{s_i} \tag{4}$$

The parameters δ and β are user-chosen and influence the region and the amount of smoothing.

3 Discussion

The smoothing operator is not necessary to be able to perform boolean operations. When sharp creases are wanted, one does not apply the smoothing operation. Figures 1 and 3, however, show two examples where the smoothing operator is appropriate. The example in figure 3 is taken from [1].

One drawback of this smoothing operator is that it is possible to have surfels within a distance δ that belong to a different surface (see figure 4) and which should not be smoothed. A possible solution to this problem is given in figure 5: instead of searching for the surfels within a sphere of radius δ, one might search for nearest surfels within two ellipsoids with major axis of length δ and aligned as indicated in the figure. However, we did not encounter this problem in the practical examples given in this paper, and we did not implement the suggested solution.

If smoothing is desired, the resampling operator [1] is disabled and smoothing is applied as a post-process (after the resulting geometry is constructed). As smoothing is not performed during interaction, we did not optimize it for speed. Typical timings are in the order of one second.

4 Conclusion

This paper shows how sharp creases resulting from the union operator in [1] can be eliminated by a simple smoothing operator. Smoothing is only applied when desired as illustrated in the examples. As discussed, the smoothing operator will not always yield correct results. However, we did not encounter this problem in the practical examples given in this paper.

Acknowledgments The dragon model is from the Stanford Computer Graphics Laboratory. The horse model is provided by Cyberware Inc. The head model is provided

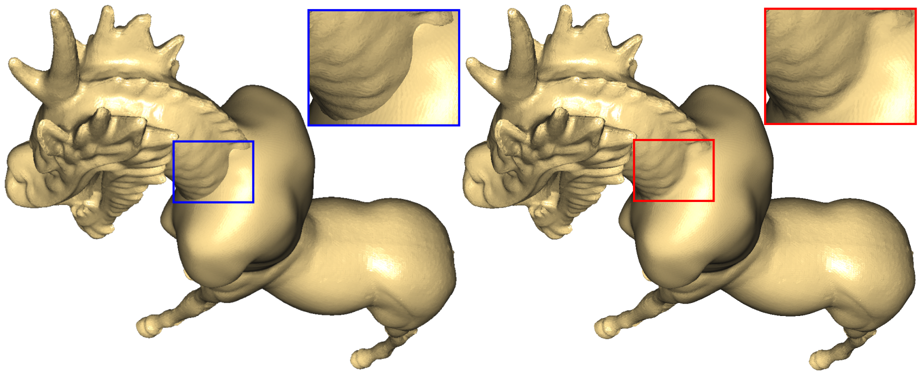

Figure 3: Mythical centaur. Left: no smoothing. Right: local smoothing in the neighborhood of the surface-surface intersections.

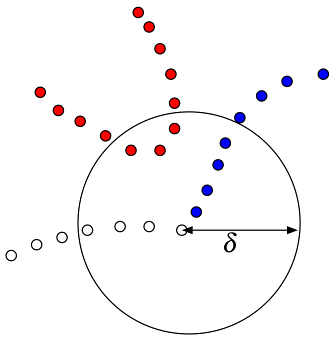

Figure 4: Surfels of a different surface (red) within a distance δ of the intersection curve. These surfels will be wrongly smoothed by the smoothing operator.

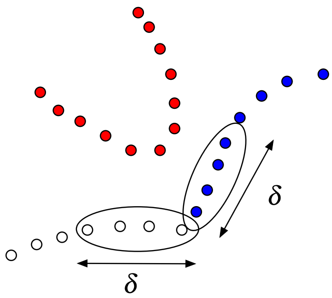

Figure 5: Possible solution to the problem of figure 4. Using ellipsoids to locate the surfels in the neighborhood of the surface-surface intersections.

by the Graphics and Imaging Laboratory, University of Washington. The first author is funded as a Research Assistant by the Fund for Scientific Research - Flanders, Belgium (F.W.O.-Vlaanderen).

References

[1] Bart Adams and Philip Dutré. Interactive boolean operations on surfel-bounded solids. In *Proceedings of ACM SIGGRAPH 2003 (to appear)*, Computer Graphics Proceedings, Annual Conference Series. ACM Press / ACM SIGGRAPH, July 2003.