

Virtual Clay Modeling Using Adaptive Distance Fields

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Abstract

In this paper we describe an approach for the parameterization and modeling of objects represented by adaptive distance fields (ADFs). ADFs allow the construction of powerful solid modeling tools. They can represent surfaces of arbitrary and even changing topology, while providing a more intuitive modeling interface than control point based structures such as splines. Using the octree structure of ADFs, we build an adaptively refined quadrilateral mesh that is topologically equivalent to the object's surface. We then project the mesh onto the object using multiple projection and smoothing steps. The resulting mesh serves as the user interface for modeling operations and is used for high quality rendering of the resulting shape.

Keywords: Virtual Reality, Modeling, Shrink Wrapping, Adaptive Distance Field

1 Introduction

In recent years the industrial design process moved more and more towards computer aided virtual reality based design. Using computer aided geometric design techniques prototyping of new products can be sped up significantly. However, due to several factors the design process is still not purely virtual. Creating intricate spline models from scratch turns out to be very complicated. Therefore, designers often create a model prototype out of clay or a similar material and scan and convert the object into its analytical form afterwards. ADFs as described by Frisken et al. [5] could change this process. Using them, one could imagine a very powerful virtual toolkit that could model, for example clay, quite accurately. Compared to other volumetric modeling techniques such as a voxel or CSG (constructive solid geometry) representation, ADFs also provide superior image quality. However, this kind of volume modeling will only be useful if it can be performed interactively while supporting direct conversion to traditional model representations.

We describe a fast and simple algorithm to create a quadrilateral mesh on the surface of any object in ADF representation. This mesh can then be used to render the object and later to approximate the object's surface using splines.

2 Related Work

ADFs were first proposed by Frisken et al. [5] and were based on earlier work by Gibson [2]. They use distance maps to represent surfaces. A distance map is a volumetric data set, where each sample point contains the minimal signed

distance to the surface of the model. This approach has the same flexibility as a voxel based representation, but needs, especially in the refined adaptive version, much less storage space.

Traditionally, computer aided geometric modeling is divided into solid modeling and surface modeling. The former method is mostly based on a direct voxel representation [1]. The modeling space is divided into voxels that are segmented into two categories: inside and outside of the model. The advantage of this method is its flexibility. One can represent objects of arbitrary topology and the modeling of topological changes requires no extra work. However, since the manageable data-size and resolution are limited, model quality does not satisfy the precision demands of industrial design.

Surface based modeling techniques on the other hand are used extensively in industry already. There has been plenty of work describing virtual modeling using surface deformation [7, 3, 4]. However, all of these approaches share two basic problems: (1) Since surface models are control point based, the modeling process is in its nature indirect. Even though there has been work on direct free-form deformations (FDDs) [6], these methods still modify control points and therefore parts of the surface the user did not directly change. (2) Another limitation for control point based structures is the topology of their starting mesh. For all practical purposes it cannot be changed and therefore the topology of the model itself cannot change.

Our work will combine the advantages of these two approaches. We will use the ADFs to model objects without any restraints. Furthermore, we will provide a fast and simple method to generate a surface mesh to any given object. This allows interactive rendering rates as well as high image quality. As a side effect, the resulting mesh can also be used to convert any ADF model into a surface representation.

3 Modeling

One of the major advantages of ADFs lies in their flexibility. This is especially true in the straight forward implementation of boolean operations. For example, the difference between the distance field of an object d_O and the distance field of a tool d_T can be computed by $\min(d_O, -d_T)$. All other boolean operations and ADF tools can be computed in the same way. For a more detailed description of tools and techniques to model with ADFs we refer the reader to [5]. We achieve interactive frame rates by using a novel approach to render ADFs. Instead of using a direct volume rendering approach as Frisken et al. or a standard marching cubes algorithm we build a quadrilateral surface mesh directly from the ADF octree.

3.1 Mesh Creation

Throughout the modeling process each octree node updates a dataFlag. This flag is true iff the node or one of its children contains or touches parts of the object's surface. An octree node is said to "touch" a surface if the distance values at each of its corners all have the same sign but one or more distance values are zero (within a certain error tolerance). A node contains parts of a surface if at least two of the distance values at each corner have a different sign. All leaves that contain or touch the surface are called data-leaves.

The union of all data-leaves build a structure that is topologically equivalent to the surface, within a user defined error bound. The outside faces of all data-leaves build a quadrilateral mesh that is topologically equivalent to the object's surface. We project all vertices of this mesh onto the object using the distance field. We smooth the resulting mesh and obtain a surface mesh for the object.

4 Results

Figures 1 and 2 show the results of drilling a hole through a sphere. Our implementation, in its current unoptimized form, allows for modeling at about one frame every two to three seconds. However, the geometry itself can be rendered at interactive frame rates. The most interesting result is the topology change of the sphere.

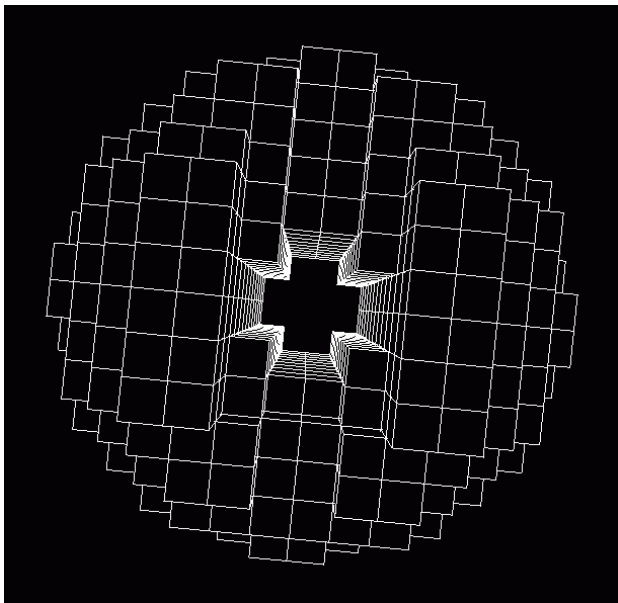


Figure 1: Drilled hole.

5 Conclusion

We have described an algorithm that converts any object in ADF representation into a surface mesh representation. Within a user defined error bound this quadrilateral mesh is topologically equivalent to the object's surface. It is numerically robust and fast enough to be used as a rendering method for ADFs. This combines the modeling techniques provided by ADFs with fast polygonal based rendering hardware. We are able to model any topology. More important,

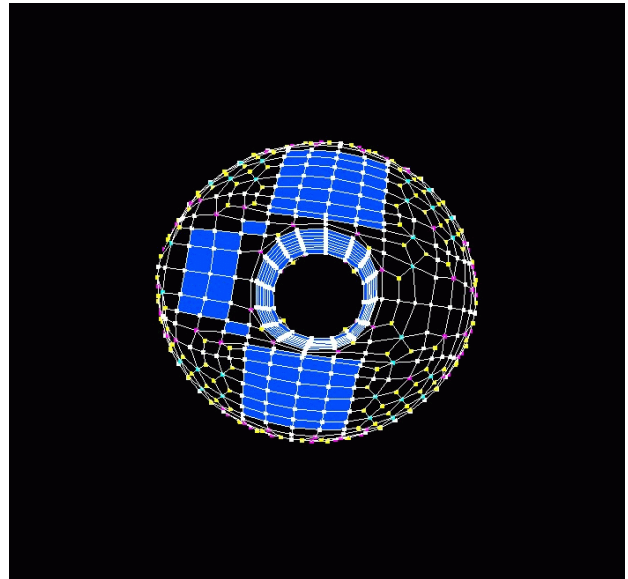


Figure 2: Drilled hole.

changes in topology require no additional operations or computer power. The new approach provides the high image quality common in polygonal rendering today.

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