Shape Modeling by Sketching using Convolution Surfaces

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Abstract

This paper proposes a user-friendly modeling system that interactively generates 3D organic-like shapes from user drawn sketches. A skeleton, in the form of a graph of branching polylines and polygons, is first extracted from the user's sketch. The 3D shape is then defined as a convolution surface generated by this skeleton. The skeleton's resolution is adapted according to the level of detail selected by the user. The subsequent 2D strokes are used to infer new object parts, which are combined with the existing shape using CSG operators. We propose an algorithm for computing a skeleton defined as a connected graph of polylines and polygons. To combine the primitives we propose precise CSG operators for a convolution surfaces blending hierarchy.

Our new formulation has the advantage of requiring no optimization step for fitting the 3D shape to the 2D contours. This yields interactive performances and avoids any non-desired oscillation of the reconstructed surface. As our results show, our system allows non-expert users to generate a wide variety of free form shapes with an easy to use sketch-based interface.

Keywords: sketch based modeling, implicit surfaces, convolution surfaces, CSG.

1. Introduction

The complexity of user interaction is the main obstacle to the use of standard modeling systems. This impacts both the user and the possibilities of expression this system provides. Achieving a simple and faithful translation of the user's idea without requiring sophisticated input and a long training process remains a challenge for the modeling software. One of the simplest and user-friendliest modeling metaphors is drawing. This kind of communication is useful in educational applications such as teaching, and already has industrial purposes such as story boarding. It is generally used in the early stages of design, because drawing a sketch is both much faster than creating a 3D model, and more convenient for expressing ideas. However, the obvious drawback of 2D sketches is their limitation to a single viewpoint. The user cannot move around the drawn object, nor view it from different angles, except in [4] where the sketch cannot be used for extracting a 3D shape. The aim of the sketch-based modeling is to combine the simplicity of 2D sketching with powerful 3D capabilities. Since the first sketch based interface [11] the concept has been largely developed and explored, from architectural design [5] to artistic design [8] and free form shapes [6, 7, 10]. The latter are difficult to model with sketches, though among the most interesting because of the large modeling possibilities they provide. The main difficulty in reconstructing a 3D model from a 2D contour is extrapolating lacking information. There are two main approaches for constructing smooth, rounded shapes from 2D contours. The first one consists in perspective projections of the contour point samples to reconstruct the 3D geometry. These points are then interpolated using variational implicit surfaces [7, 12, 5]. The second is to construct a skeleton from the 2D contour and use it to generate a 3D shape [6, 10, 1]. The main drawback for the first approach is that the surface has to be recalculated every time it is edited and the time taken to compute the coefficients for the variational implicit surfaces increases with the number of points. Also, small details are lost when blending the object parts because preserving them would require too many constraints and too much computation. Therefore we prefer the second approach. Previous research in this field has raised some difficulties. One of these is the necessity of an optimization step to adjust the implicit surface to the drawn contour. This leads to a better contour approximation in terms of error but the surface oscillates [10, 1]. Moreover it is time consuming and in the context of sketch based interface providing very accurate reconstruction is not necessary. Indeed, the user drawn contour is seldom noisy so we rather aim at getting a smooth shape with close appearance to the contour. Removing the optimization step saves time and reconstructs a smooth non-oscillating surface. Of course the contour approximation constraints have to remain satisfied. Another drawback of most of the previous approaches is that the shape thickness is automatically inferred so the result may differ from what the user wanted. For example if the user draws the shape of the palm of a hand, the fingers will be smoothly reconstructed as cylinders, whereas the palm will look like a sphere, far from the user’s expectation. In [10] the problem is addressed by asking the user to provide additional information about the cross section's profile.

This increases the complexity of the interface and for this reason the technique might not be intuitive enough for non-expert users.

Our contribution

We propose a representation that allows for a great variety of topological shapes, a richer collection of sketch-based operations, an adaptive level of detail for sketch modeling with precise control of the result up to small details, while keeping a very simple and friendly user interface. For this purpose we reconstruct the 3D shape using convolution surfaces [3] with both polylines and polygons skeletons. The primitives are composed with CSG blending in a blending hierarchy.

Section 2 presents our system from the user's point of view. Section 3 presents the application from the system's point of view, i.e. the algorithms and the techniques used. Section 4 shows and discusses some results and also draws the conclusions and perspectives of our work.

2. From the user viewpoint

The purpose of our system is to enlarge the possibilities offered by the paper-pencil 3D modeling metaphor, while keeping a simple and intuitive input interface. The modeling process iterates the following steps until modeling is complete:

1. The user draws one or several strokes
2. The strokes are interpreted to reconstruct a 3D object part
3. The part is added to the current object (or subtracted if carving)

As the user draws a stroke, its thickness and color intensity vary proportionally with the pressure on the digital pen, as to imitate the irregular density and thickness of the strokes produced by a real pen. Several strokes accumulated in the same pixel result in a darker color for that pixel. The other end of the pen is used as an eraser. As long as the stroke has not been reconstructed, the user is free to erase and modify it. This way the user's input is allowed to be noisy and irregular, as it is naturally on paper. To create a new shape, the user draws a contour on the graphic tablet using the digital pen. Once the contour has been completed the user presses the digital pen against the tablet. This produces the 3D reconstruction of the stroke (see Fig. 1 (a),(b)). To add part to an existing shape, the mechanism is the same as for creation. The first surface point hit by the user gives the depth of the shape to be constructed. When the stroke is complete, the user presses the stylus if he wishes to add the shape to the existing object, or the eraser (at the opposite pen's end) if he wishes to carve it into the object. The shape is reconstructed in such a manner that the projection of the shape on the screen fits the contour that has been drawn by the user (see Fig. 1 (c),(d),(e) and (f),(g),(h)). The user controls the thickness of the shape using the pen's bend (see Fig. 1 (i),(j),(k)). Small details can be modeled by zooming to get closer to the object. The large object parts will smoothly blend with each other, while the small details (e.g. eyes, nose of a character) will have a sharper blending. The user can paint directly on the objects or in space next to them. In this way additional information or annotation can be added to the model.

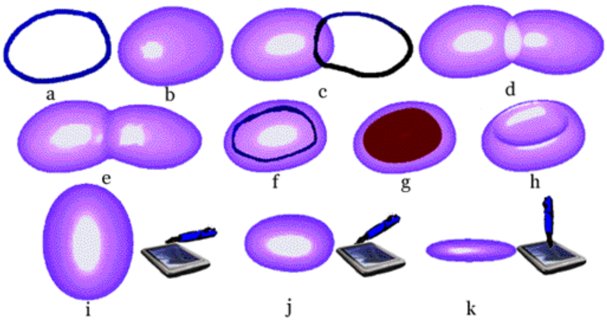

Figure 1: (a), (b) Creating a part. (c),(d),(e) Adding a part to an object. (f),(g),(h) Carving. (i),(j),(k) Thickness control (side view).

3. From the system viewpoint

A pressure threshold indicates that the drawing is finished. When the stylus pressure has reached this threshold, the strokes image is recovered as a 2D bitmap, then compressed and reduced in size using a pixel averaging technique. This also reduces the amount of computation for the skeleton. In order to perform the skeleton extraction we iteratively construct a connected pixels skeleton, which is then sampled in order to obtain a segments and triangles graph [13]. This will be used to define a convolution surface [3]. In order to obtain interactive modeling, we use the pseudo Cauchy [9] convolution kernel, which gives a closed form solution for the convolution integral for the primitives that we use (segments and triangles). See [13] for a full algorithm description.

The addition and subtraction operations are defined using CSG, for which we have adapted the composition model shown in [2] and rewrote the union and difference operators in order to allow hierarchical exact composition. The level of detail of the skeleton remains constant in the image space, but it is automatically adapted to the level of detail of the 3D shape, given by the distance between the object and the camera. The level of detail determines the blending parameters, the skeleton weights and the size of the polygonization cell for the shape to be reconstructed. The polygonization for the reconstructed stroke is computed and displayed immediately, while a process in the background computes the final surface polygonization. The final mesh is displayed as soon as it is available. This allows maintaining interactive rates and rapid application response during the modeling process so that the user feels free to pursue his modeling activity.

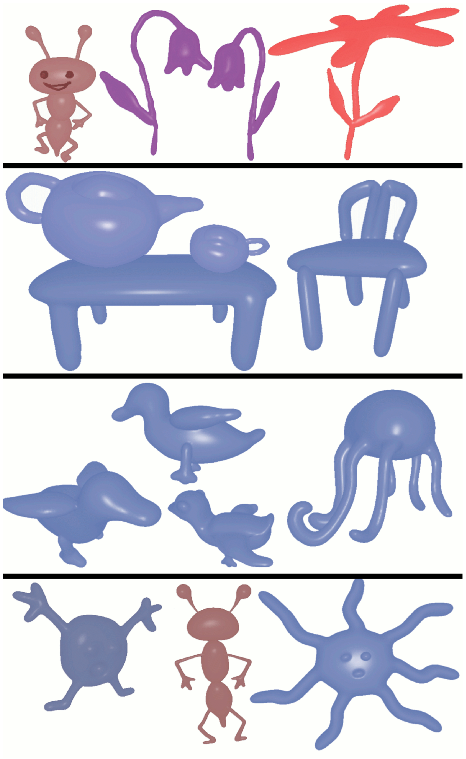

Figure 2: Objects modelled with our system. The user took 2 to 5 minutes overall modelling time and 3 to 9 strokes for each object.

5. Results and conclusions

Convolution surfaces allow much better shape representation than standard skeleton based implicit surfaces, due to their possibility to represent flat surfaces, as well as a large topological variety. Fig. 2 shows objects modeled with our system. The system provides a real simplicity for the non-expert user, for example three strokes only are necessary to create each one of the birds in Fig. 2 (with symmetry enabled for the wings and legs). The Fig. 2 also shows flat surfaces (table and chairs). The shapes have no oscillations and no bulges. The CSG composition is a generalized composition more flexible and accurate than the simple sum, allowing a better blending control, from smooth to sharp transitions. The small details of the objects are well preserved due to the parametrable CSG.

For example, the sun's eyes and mouth are small details compared to the face but they are well preserved by the blending. The shape may have various topologies (ex. chairs, teapot) and can be carved (teapot, mugs). The applications of our system are educational, but also story boarding for films making (ex. cartoons, see Fig. 2) where the scenarios writer is not necessary a 3D designer. The system could be extended to design the internal structure of organic shapes because the composition model is suitable for this.

In the future we would also like to focus on accelerating the polygonization time for generating the final implicit surface and investigate adaptive polygonization.

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