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Sketch based 3D modeling with curvature classification ☆

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ABSTRACT

In this paper, we introduce a simple method for sketching 3D models in arbitrary topology. Using this method, we have developed a system to convert silhouette sketches to 3D meshes that mostly consists of quadrilaterals and 4-valent vertices. Because of their regular structures, these 3D meshes can effectively be smoothed using Catmull–Clark subdivision. Our method is based on the identification of corresponding points on a set of input curves. Using the structure of correspondences on the curves, we partition curves into junction, cap and tubular regions and construct mostly quadrilateral meshes using this partitioning.

1. Introduction

Sketch based interfaces for modeling started almost 20 years ago with the pioneering work by Tanaka et al. [1] and it gained significant attention with revolutionary work by Igarashi et al. [2]. Since then a wide variety of methods have been introduced [3,4]. In this paper, we present a curvature based curve partitioning approach for sketch based modeling of free-form 3D shapes. For partitioning curves we have developed the 2D-correspondence function as an extension of the shape diameter function [5]. 2D-correspondence function is used to identify corresponding points on the curves and to robustly classify junction, cap and tubular regions of the curves (see Fig. 2). Based on this classification, it is easy to construct 3D meshes with mostly quadrilateral faces and 4-valent vertices. These meshes can effectively be smoothed by Catmull–Clark subdivision [6] since they have only a few extra-ordinary vertices (see Fig. 1). We have also implemented the method to demonstrate the effectiveness of the new approach. Our current implementation can construct 3D models only from silhouette curves. We do not allow T-junctions (occluded curves), which can provide additional information about the shapes [7,8].

Our process for 3D sketching consists of three steps: curve construction, curve partitioning and mesh construction.

(1) *Curve construction*: This is a 1-manifold curve construction from a given set of arbitrary strokes. Section 3 briefly describes this process.
(2) *Curve partitioning*: This is the process of partitioning the curves into positive, negative and zero curvature regions using 2D-correspondence function. This is main contribution of our paper and it is described in Section 4 in detail.
(3) *Mesh construction*: This is the final process that converts the 2D curves to 3D models. Section 5 provides a description of this process.

In the next section, we briefly discuss previous work on sketch based shape modeling.

2. Related work

Sketch based modeling has been influential in creating many exciting products and software. For instance, the ideas developed in papers [9,10] provided the conceptual basis of SketchUp software [11], which is widely used for modeling simple architectural geometrical shapes. There also exist methods for modeling trees [12], modeling garments [13], modeling using symmetries [14], modeling with 3D curve networks [15,16], designing highways [17] and terrains [18].

In this paper, we are interested in sketching free form smooth 3D shapes like Teddy [2], which is probably one of the most influential works in sketch based modeling. Teddy is based on the centroidal distance transformation which is closely related to the medial axis transformation [19]. The distance from a point on the boundary to the medial axis is the radius of the maximal ball, whose center lies on the medial axis, touches the boundary at the point, and is completely contained in the object. This ball is called the medial-ball, and its radius can be seen as a form of local shape-radius connecting the boundary to the medial axis. The problem with medial axis transformation is that the definition and extraction of the medial axis or even of discrete approximations using skeletons

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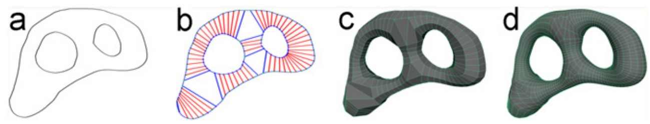

Fig. 1. A Genus-2 Mesh created by our system. Our method can partition user drawn sketches shown in (a) into a set of junctions, tubes and caps regions using a correspondence shown in (b). Using this partitioning it is easy to construct 3D models as shown in (c). These models can effectively be smoothed since they consists of mostly quadrilaterals as shown in (d). (a) input stroke data, (b) correspondence function applied, (c) generated mesh and (d) smoothed mesh.

are complex and often error prone [5]. Another problem using medial axis transformation in 3D mesh generation is that the resulting meshes are usually triangulated, which may require a beautification step [20]. Our corresponding function approach, which is inspired by the 3D shape diameter function [5], is also related to medial axis transform but is relatively robust and guarantees to construct meshes with mostly quadrilaterals and 4-valent vertices.

Our work is also related to sketch-based subdivision method [21], which presents a sketch-based interface to design subdivision models. By taking the profile surface curves as an input, it generates a coarse and quad dominant control mesh with few extraordinary vertices or faces. The corresponding limit surface interpolates the profile curves with the capability of local control across these curves and of the model in general. However, this approach creates models that are basically extrusions of the profile curves along z-axis which results in a flat looking model. Our approach can be seen as a combination of the organic look of [2] and smoothness achieved by subdivision surfaces suggested by Nasri et al. [21] (see Fig. 8).

Implicit surfaces provide an alternative for sketching free form smooth surfaces which includes convolution surfaces [22], variational Hermite-RBF implicits [23], Shapeshop [24] and others [25–29]. Since implicit surfaces can provide exact and approximate set operations, they are particularly attractive to model complicated surfaces. In this work, we do not use an implicit based approach.

3. Curve construction

We assume that the initial silhouette is drawn as a set of unorganized strokes with no self-intersections and/or T-junctions. Curve construction process combine, resample and reorder these strokes in a way such that at the end of the process we obtain 1-manifold with well-defined inside and outside. In practice, we allow 1-manifold with boundaries and we can still obtain consistent normals.

Each stroke is represented as a poly-line in our system. We first take the individual poly-lines (strokes) whose end points are within a distance threshold and combine them into longer parameterized curves. We then resample each curve C equidistantly in high density to eliminate the variance in sketching speed. Besides the position, we also record normal N_i and tangent T_i for each sample point $C_i \in C$. Finally, we adjust rotation order each curve so that the right side always indicates the inside. This is done by using the classical inside–outside test. At the end of this process, we obtain a set of points connected by single-links in a consistent rotation direction. We call the resulting set of curves 1-manifold since they can define a closed shape in 2D.

4. Curve partitioning with point classification

We have developed the 2D correspondence function to partition 1-manifold curves. The corresponding function uses the mesh partitioning property of the shape diameter function to identify the parts of the curve as tubular, junction and cap regions to construct 3D models. These regions are categorized based on their total Gaussian curvature (TGC). A tubular region is any region with zero TGC. An obvious example of tubular region is a cylinder. A donut is also classified as a tubular region since its TGC is zero, although local Gaussian curvatures are non-zero [30]. Junctions are regions that connect tubular regions and their TGC is negative. Finally, caps are the regions with positive TGC. This classification is the key for obtaining a good quality quad-mesh since each region can easily be converted to a 3D shape as shown in Fig. 2(d).

The process of curve partitioning using 2D-correspondence function is simple and efficient. Let $\mathbb{C}$ be a 1-manifold, which includes all C_i's, and $\mathcal{C} \subset \mathbb{C}$. We define 2D correspondence function (2DCF) as a one-to-one function $f : \mathcal{C} \rightarrow \mathcal{C}$ that corresponds every point $\mathcal{C}$ to another point $\mathcal{C}$ using the neighborhood-diameter at each point $C_i \in \mathcal{C}$. The computation of 2D correspondences consists of two steps: computation of initial correspondences and correspondence processing.

4.1. Computation of initial correspondences

Initial corresponding points are computed using a variant of the procedure that is used in shape diameter function. In our computation instead of the diameter, we look for the minimum circles that can be enclosed between two curve pieces (see Fig. 4). For every curve point $C_i \in \mathcal{C}$, we define five 2D-cones (field-of-views) as shown in Fig. 3(a). We search for corresponding points C_j's checking all curve points that lies inside of these five 2D-cones. A point C_j is labeled as a corresponding point to C_i if the approximate radius of the circle that passes from C_i and C_j with normal vectors N_i and N_j is the smallest among all points that lies inside of these five 2D-cones. During the search, we ignore a C_j, if the line segment $\overline{C_iC_j}$ would intersect a neighboring connector line segment for either of the points. Fig. 4 illustrates how we identify enclosed circle for any two given points C_i and C_j. Note that if we do not find any enclosed shape that is reasonably close to circle, then we chose C_j and we compute the estimation of the

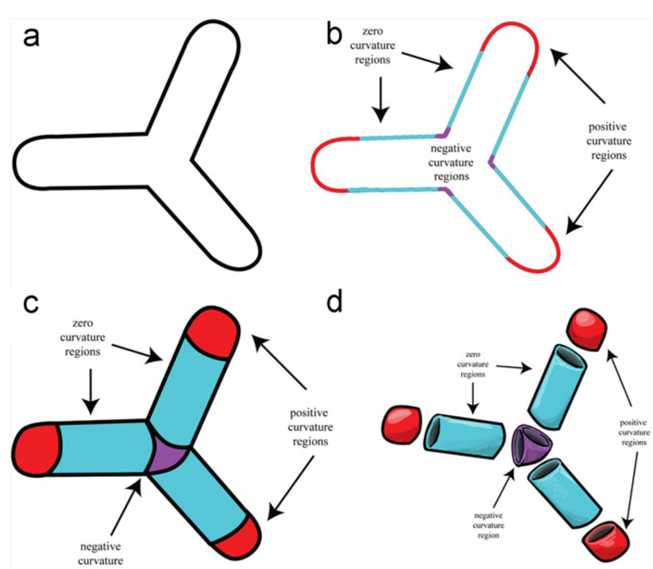

Fig. 2. Our correspondence function allows us to robustly classify the portions of curves as junctions, caps and tubes. These regions correspond to zero, negative and positive total Gaussian curvature regions. After this classification, it is easy to construct 3D meshes that consist of mostly quadrilateral faces. (a) Input curves, (b) curve region, (c) surface regions, (d) 3D regions.