Subdivision-Based Representations for Surface Styling and Design

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1 Introduction

Subdivision surfaces are emerging as a powerful representation for shape design. Their simplicity and potential to overcome difficulties associated with traditional spline-based modeling has made them a popular choice for several applications. Among these, the modeling of animated characters for movie production has, by far, received the most attention in the literature. In contrast, we focus our attention on the use of subdivision surfaces for the automotive, aerospace, and consumer product industrial sectors. Over the past few years we have developed a suite of modeling tools to facilitate a more efficient and smooth transition from the initial stages of design to class-A surfaces. These tools considerably improve the efficiency of certain design operations and, in some cases, enable tasks that are difficult or even impossible to perform using NURBS-based approaches.

Our presentation includes a brief review of multiresolution subdivision surfaces, followed by several interactive operations for shape modeling and their potential applications. We discuss the novel aspects of our algorithms and we illustrate them in the context of different design scenarios. We include results of integrating our technology into Dassault Systèmes' CATIA solid modeler.

2 Multiresolution Subdivision Surfaces

Subdivision defines a smooth surface recursively, as the limit of a sequence of meshes. A finer mesh is obtained from a coarse mesh by applying a set of fixed refinement rules (e.g., Loop [Loop 1987] or Catmull-Clark [Catmull and Clark 1978]). The initial, coarsest mesh serves as a base domain over which the resulting surface is naturally parameterized.

Multiresolution subdivision extends the concept of subdivision by introducing *details* at each level of the subdivision hierarchy. Each time a finer mesh is computed, detail offsets may be added to the subdivided coarse mesh. General shape deformations, as well as minute features can be easily captured through this representation.

3 Interactive Styling Operations

3.1 Free-Form Design

A common design paradigm is to allow designers to interactively deform an initial geometric shape to obtain a new one that satisfies certain requirements. A typical approach is to optimize a fairness measure representing physical parameters of a real object bearing the shape. It is often the case, however, that the input model has high frequency geometric detail across multiple resolutions that should be preserved during global deformations of its shape. Fairing techniques tend to smooth out not only the global shape of the object, but the high-frequency details as well (see Figure 2).

To address this problem we consider the deformations applied to the initial shape as a vector field defined over the input model. Instead of attempting to minimize the energy of the deformed shape, we minimize the energy of the deformations and we apply the resulting smooth vector field to the original shape to obtain the deformed one. Using this approach, the input model becomes the rest shape to which the optimization converges in the absence of constraints. We consider several types of constraints which can be imposed at different resolution levels.

3.2 Model Decorations

To support efficient exploration of alternatives in the initial stages of design, we consider the problem of interactive creation and placement of complex features. We have developed tools for surface cut-and-paste and for engraving and trimming of surfaces along user-defined curves.

Surface cut-and-paste operations [Biermann et al. 2002a] enable efficient modeling of complex shapes without having to design every detail from scratch. For instance, shapes obtained by 3D scanning can be transferred onto relatively simple objects creating a complex look with minimal effort (see Figures 1 (a) and (b)).

Transferring a selected feature between two surfaces requires separating them into base and detail parts. The goal is to replace the detail part of the target with the detail part of the source by means of parameterization and resampling. Our main contributions include methods to separate base from detail, to automatically identify an area on the target surface where the feature should be pasted, and to efficiently establish the necessary maps between the source and target surfaces for pasting at interactive rates.

Sharp features such as creases, corners, and trim boundaries characterize many real objects. Modeling them using subdivision is challenging as subdivision typically leads to smooth surfaces. The novel aspects of our research in this area [Biermann et al. 2002b] include: (a) an algorithm for creating sharp features along arbitrary curves on a multiresolution surface without remeshing, (b) an extended set of rules for the Catmull-Clark subdivision scheme for the creation of creases along quad diagonals, and (c) a unified framework for offsetting and trimming operations. Using our technique, a sharp crease with a user-defined profile may be created along a given curve. Alternatively, the portion of the surface delimited by the curve can be trimmed off (see Figures 1 (c) and (d)).

4 Conversion from Other Representations

As the set of tools for manipulating subdivision surfaces is growing, the main obstacle to their widespread use is having to convert existing models to this format. In our research, we have investigated the conversion of irregular triangulated meshes to multiresolution subdivision hierarchies. We have developed a quadrilateral remeshing technique for the purpose of generating multiresolution Catmull-Clark hierarchies. Figures 3 (a)-(d) show results obtained this method. For triangular remeshing and Loop mesh extraction we have developed an image-based approach [Boier-Martin 2003] (see Figures 3 (e) and (f)).

Acknowledgments

The methods described have been developed in collaboration with Dassault Systèmes. The core multiresolution subdivision technology, as well as all tools pertaining to model decoration have been developed together with Henning Biermann and Denis Zorin from New York University and were published in the ACM Transactions on Graphics / Siggraph Conference Proceedings, the IEEE Pacific Graphics Conference, and the Journal of Graphical Models. The variational design work was performed jointly with Remi Ronfard, while on visiting assignment with IBM. Our Loop remeshing procedure appeared in the Eurographics / Siggraph Symposium on Geometry Processing.

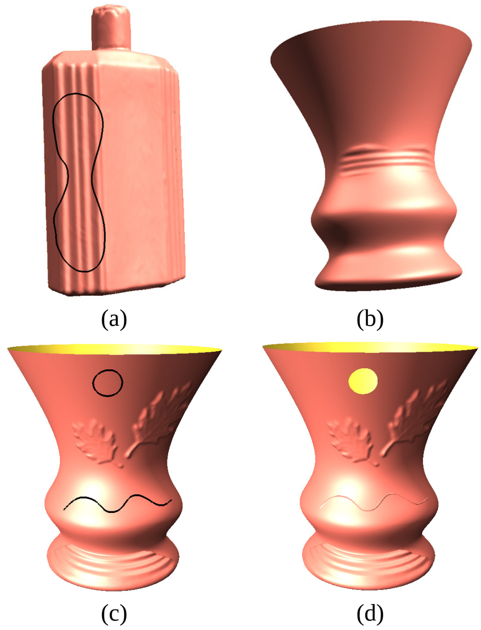

Figure 1: Model decoration: (a) Scanned perfume bottle. Curve indicates user-selected detail to be cut and pasted onto the vase shown in (b). (b) Result of surface pasting. (c) User-selected curves define the location of sharp features. (d) Sharp embossing and trimmed region created along the curves defined in (c).

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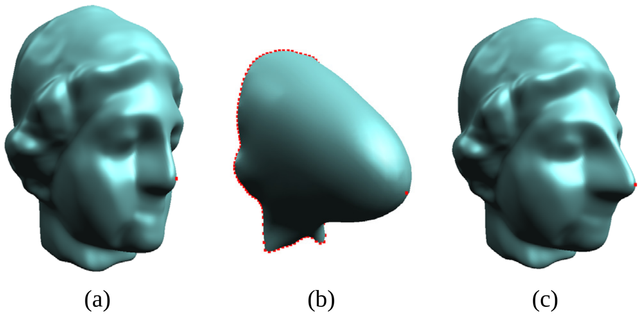

Figure 2: Interactive free-form editing: (a) Input model with geometric details at various resolutions. (b) Shape deformation using thin-plate energy optimization. Boundary constraints are needed to prevent the collapse of the model. (c) Details are preserved using our variational approach and no boundary constraints are necessary.

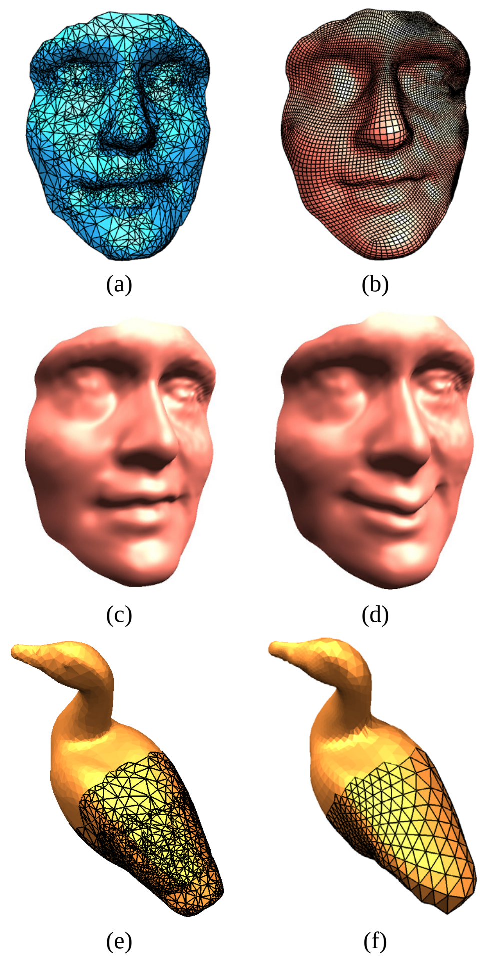

Figure 3: (a)-(b) Quadrilateral remeshing. (c)-(d) Multiresolution editing performed on the semi-regular mesh. (e)-(f) Triangular remeshing.