論文の内容の要旨

VOLUMETRIC MODELING OF NATURAL OBJECTS WITH COMPACT AND CONSISTENT REPRESENTATIONS

(コンパクトかつ整合性のある表現形式による
自然物のボリューメトリックなモデリング)

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Modeling of 3D objects' internal structures and appearances, or volumetric modeling, is useful for various computer graphics applications. For example, volumetric information would enable a rich set of natural and intuitive interactions with 3D models such as cutting and peeling. Volumetric information would also be crucial for algorithms that perform volume rendering or soft body simulation on objects with heterogeneous internal material distributions. On the other hand, volumetric modeling is inherently difficult in many respects such as real-world data acquisition, from-scratch creation, editing, and visualization, which has hindered its wide adoption in the industry.

One popular approach to volumetric modeling is to synthesize solid textures representing specific materials (e.g., marble, asphalt), using procedural descriptions or 2D-to-3D texture synthesis algorithms. This approach alone is, however, not enough for representing more complex volumetric objects consisting of multiple materials. Another approach to modeling volumetric objects consisting of multiple materials is to partition the object volume into disjoint regions and to assign material types to individual regions procedurally. Not all volumetric objects can be, however, decomposed into disjoint regions with clear region boundaries. Besides, writing a script code is not necessarily an intuitive modeling interface for general users with limited programming skills. There are a few other different approaches aiming at volumetric modeling of complex objects, such as on-demand 2D texture synthesis on 3D models' cross-sections, morphing of 2D cross-sectional images positioned in 3D space, and direct painting interface for volumes. Unfortunately, each of them has its own limitations (e.g., volume inconsistency, limited expressivity).

In this thesis, our goal is to achieve volumetric modeling of complex natural objects (e.g., fruits, vegetables, and organs) while alleviating limitations of previous approaches. In particular, we aim at interactive creation of consistent volumetric color distributions using intuitive sketch-based interfaces, while requiring small storage and low computational cost.

After describing the background and related work in the first two chapters, we propose two user interfaces for efficiently designing volumetric orientation fields. We consider the design of volumetric orientation fields as a subproblem of volumetric modeling since orientation fields play an important role when synthesizing anisotropic solid textures within the volume. We make our design processes efficient by exploiting some domain-specific knowledge. In the first method for volumetric vector field design, we assume that the vectors at the boundary surface always align with the surface tangent planes. In the second method for volumetric frame field design, we assume that one of the three frame directions follows the gradient direction of a scalar field. To demonstrate the usefulness of our methods, we also present two applications for the designed orientation fields other than synthesizing solid textures: electrophysiological simulations of heart ventricles and active deformations of unarticulated characters such as jellyfish.

In the next chapter, we propose Lapped Solid Textures (LSTs), a method for representing solid objects with spatially-varying anisotropic textures by repeatedly pasting patches of solid textures. The underlying concept is to extend the 2D texture patch-pasting approach of Lapped Textures to 3D solids using a tetrahedral mesh and 3D texture patches. To represent oriented textures, the system places texture patches over the mesh according to a volumetric tensor field designed using the interfaces described in the previous chapter. We have also extended the original technique to handle nonhomogeneous textures for creating solid models whose textural patterns change gradually along scalar depth fields. We identify several texture types considering the amount of anisotropy and spatial variation and provide a tailored modeling interface for each. We show that realistic and consistent solid models can be created easily with little memory and computational cost using LSTs.

It remains still a challenge, even for LSTs, to model volumetric objects that have distinct global features such as long fiber-like structures and large boundaries with sharp color transitions typically seen in many vegetables and fruits such as tomatoes and apples. In the next chapter, we propose a representation called Diffusion Surfaces (DSs) to enable modeling such objects. DSs consist of 3D surfaces with colors defined on both sides, such that the interior colors in the volume are obtained by diffusing colors from nearby surfaces. A straightforward way to compute color diffusion is to solve a volumetric diffusion equation with the colors of the DSs as boundary conditions, but it requires expensive volumetric meshing which is not appropriate for interactive modeling. We therefore propose to interpolate colors only locally at user-defined cross-sections using a modified version of the Positive Mean Value Coordinates algorithm to avoid volumetric meshing. DSs is a resolution-independent vector representation of volumetric models with both smooth and sharp color transitions, and can be generally used to model many different kinds of objects with internal structures. As a case study, we present a simple sketch-based interface for modeling objects with rotational symmetries. We demonstrate the effectiveness of our approach by modeling various volumetric objects compactly using DSs, and applying simple non-photorealistic rendering techniques enabled by structural information encoded in DSs.

In closing, we summarize our approaches while comparing them with existing ones, followed by describing areas for future research. We hope that this dissertation will help volumetric modeling be adopted more widely by the industry and stimulate further developments.