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DigitalSculpture: a subdivision-based approach to interactive implicit surface modeling

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Abstract

This paper presents *DigitalSculpture*, an interactive sculpting framework founded upon iso-surfaces extracted from recursively subdivided, 3D irregular grids. Our unique implicit surface model arises from an interpolatory, volumetric subdivision scheme that is C^1 continuous across the domains defined by arbitrary 3D irregular grids. We assign scalar coefficients and color to each control vertex and allow these quantities to participate in the volumetric subdivision of irregular grids. In the subdivision limit, a virtual sculpture is obtained by extracting the zero-level from the volumetric, scalar field defined over the irregular grid. This novel shape geometry extends concepts from solid modeling, recursive subdivision, and implicit surfaces; facilitates many techniques for interactive sculpting; permits rapid, local evaluation of iso-surfaces; and affords level-of-detail control of the sculpted surfaces.

Keywords: Implicit surfaces; Interactive sculpting; Subdivision algorithms; Solid modeling

1. Introduction and motivation

This paper presents a new implicit surface modeling technique founded upon *implicit subdivision solids*, which define scalar fields over 3D irregular grids. We have

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developed an accompanying sculpting system called *DigitalSculpture* that employs implicit subdivision solids as the underlying shape primitive. In our new shape design approach, the boundary of an object is given by a level surface of a 3D function defined over an arbitrary, volumetric region (spanned by hexahedral meshes) of complex topology. The space is uniquely defined by our new interpolatory, solid subdivision algorithm [21]. (By *interpolatory* we mean that vertices are preserved or *interpolated* between subdivision levels.) Our subdivision scheme is founded upon the cubic, Lagrange interpolating polynomial and can be applied over arbitrary hexahedral meshes. The scalar field from which the iso-surface arises is constructed by first assigning a scalar coefficient to each vertex of the control mesh. Then the subdivision algorithm refines both the positions and the scalar coefficients of the control vertices with the same set of rules. After subdivision of these *control coefficients*, an iso-surface can be extracted from the subdivided scalar field. The surface can be modified by directly changing the control coefficients.

Our approach exhibits several capabilities in a *single, integrated framework* which, to our best knowledge, cannot be accommodated by other existing approaches. First, our framework supports sculpting of implicit surfaces over non-rectilinear working spaces (grids). Such flexibility can help to address the well-known blending problem as well as provide a control lattice appropriate for free-form deformation [35]. Second, blending is guaranteed to be at least C^1 throughout the volumetric domain, thereby permitting the definition of smooth shapes. Finer features like corners and cusps can be approximated by increasing the grid resolution. Third, our approach exhibits many of the desirable properties of subdivision-based schemes. For instance, the subdivision algorithm's continuity guarantees smoothness even when the working space is deformed, which can be manipulated in a global or local fashion using FFD-like techniques. It also affords local control, straightforward geometric manipulation, topological flexibility, and level-of-detail control. Fourth, our framework is very general and can be extended to other volumetric subdivision algorithms [2,6–8] or even volumetric spline-based approaches. It can be extended to accommodate newer volumetric models as they appear and also to sophisticated parametric approaches, such as simplex splines [16]. Last, our approach is not limited only to the representation of geometric quantities like position. Indeed, the *DigitalSculpture* framework can be generalized to support the specification of material and physical attributes [27,22] and thereby broaden the applications of our work even further.

2. Related work

This work is strongly motivated by a number of disparate areas of research, including volumetric sculpting [1,30,39], implicit and functional modeling [4,29], and volumetric subdivision schemes [2,6,20]. To our best knowledge, no one has yet proposed the idea of defining an implicit surface as the iso-level of a smooth scalar field defined by recursive *volumetric* subdivision algorithms. Cani and Hornus [5] proposed the idea of defining an implicit surface by a skeleton of subdivision curves. This reliance on skeletons limits the ranges of definable shapes and the types of inter-