Stair-Stepped Removal via Automatic Linearization for Marching Cubes Formulations

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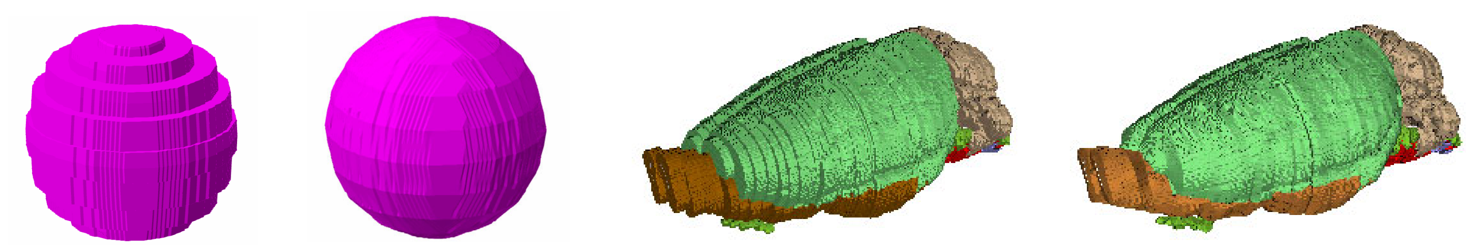
Introduction: The Marching Cubes algorithm is one of the most widely adopted methods for reconstructing single material surface models from images.[1] A multiple material marching cubes algorithm (M3C) has been reported recently.[2] It sweeps through a segmented image stack only once to faithfully create triangular surface platelets between as many tissues as specified. This robust tool eliminates numerous, and at time insurmountable, problems associated with blending single material image reconstructions into a unified model. However, the routine shares the same stair-stepped behavior as the single material marching cubes algorithm due to the common interpolation mechanism. Numerous post-processing smoothing efforts have been and are being made but they either cause volume shrinkage, geometry alterations or are computationally expensive. Herein, a linearization algorithm is presented that completely eliminates the stair-stepped outcome for both marching cube routines. This process increases the accuracy of the model by an order of magnitude while preserving the volume and geometry integrity.

Method: All marching cube routines process a single layer between two medical image slices completely before moving to the next layer. Consequently, the linearization algorithm was developed to work within this layer processing level. At each level a unique set of triangles connects the two slices forming a belt or collar within the layer. Only edges exist directly on each slice. In the M3C case each triangle has the two materials it separates identified. For the single material code, the triangle separates the desired material from any other material. A single sweep through the triangles created within the layer identifies a finite number of triangles that establish the surface separating a specific material combination. This subset of triangles can form an open or closed loop situation. This contiguous subset of triangles has termination edges on both slices (Slices A and B), no triangles exist on either slice. Beginning at the edges on slice A (by default) each node in the contiguous subset of triangles is tagged with two attributes M and N. N is the minimum number of steps required to reach slice B in an edge path containing the node, and M is the step location for this node on that path. With this information, the new z-coordinate (direction from slice to slice) of each node can be calculated by $z = (1\text{-}M/N)z_A + (M/N)z_B$, where z_A and z_B are the z coordinates of level A and B, respectively. This edge-path creation strategy eliminates a variety of problems associated with other mathematical strategies; problems such as indeterminate path directions, multi-valued functions, and capping situations whenever a specific material is not encountered within an adjacent slice. This linearization algorithm is applied to the z direction only so each triangular facet retains its integrity.



Results: A sphere, due to its utility for round-robin testing, and a rat-brain atlas were selected to demonstrate the effectiveness of the algorithm. Each example displays the results of the marching cube routine with and without the linearization enhancement. No post-processing was performed. The stair-stepped behavior and its complete removal are evident. Naturally, slope changes do exist as one spans the layers.

Conclusions: A linearization routine has been developed that operates within the marching cube formulations for either single or multiple material situations. It is extremely robust and computationally efficient. Linearization within layers increases the accuracy of the geometry by an order of magnitude. It preserves both shape and geometry of the original medical image objects with fidelity.

References: [1] W. E. Lorensen and H. E. Cline, "Marching Cubes: a high resolution 3D surface construction algorithm", Computer Graphics, V 21, pp. 163-169, (1987).

[2] Wu, Z. and J.M. Sullivan, Jr., "Multiple material marching cubes algorithm", Int J Num Meth Eng, V58, pg 189-207, (2003).

Acknowledgement: This work was supported, in part, with funding from NCI P01-CA80139