Extended Cubical Marching Squares for Surface Extraction from Various Kinds of Volumetric Structure

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1 Introduction

To display volume data efficiently, such representations often need to be converted into polygonal meshes. A well-know method for this conversion is the marching cubes (MC) algorithm. Although effective, unfortunately, MC-style algorithms inherit the limitation of its cube based sampling structure. It partitions space into cubes, samples a single sample point on each sign-changed edge and triangulates samples by the pre-defined pattern in a look-up table. Such limitation could be illustrated as shown in Figure 1, extracting surface from a thin cylinder (left image) may cause problems using cube based structure (center image) because there is no edge encounter a sign change due to more than one intersection occured. Thus, surfaces extracted by MC-style algorithms tend to be sensitive to the structure which used to sample the space. Our previous work, cubical marching squares (CMS) [Ho et al. 2005], overcomes several known problems of MC-style algorithms, such as topological ambiguity, cracks in adaptive resolution, inability to preserve sharp features and inter-cell dependence simultaneously. CMS method solves the above problems by converting the cubes into squares. Instead of using the lookup table of marching cubes in 3D, CMS algorithm unfolds cubes into squares, determines the shape and the topology of each face dynamically in 2D and then folds them back into cubes. Currently, we address the problem of MC-style sampling structure (includes CMS) may cause defects if the cube based structure doesn't well fit the underlaying model. In this paper, we propose an extension of CMS to achieve adaptively adjusting the structure to fit the underlaying volumetric models.

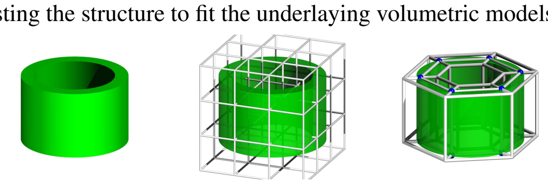

Figure 1 The problem of surface extraction using cube base structure and the solution using extended CMS (ECMS).

2 Algorithm

CMS can be briefly illustrated as following. Firstly, it constructs a cube based structure (adaptive octree). Then, it unfolds cubes to faces and generates line segments for each leaf face (red lines on the left image of Figure 2). After that, it folds faces back to original cubes and connects those line segments properly to form components (magenta and yellow cycles on the right image of Figure 2). Finally, it triangulates these components.

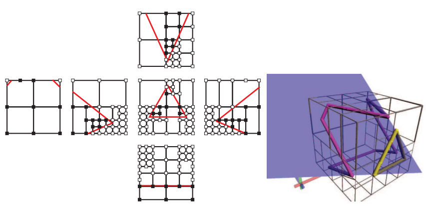

Figure 2 Unfolding and folding concept of CMS and handling adaptive resolution using sub-squares.

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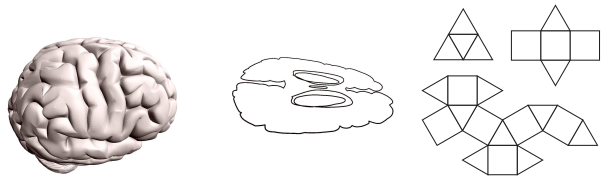

Figure 3 Tracking contours from graphical model and possible unfolded shapes of ECMS.

The unfolding/folding idea could be extended to use other shapes as well as cubes. In such condition, we can adaptively change the structure as shown in the right image of Figure 1 to overcome problems of sampling structure. Thus, we slightly change the steps of CMS to handle different shapes. We performed the following experiment to illustrate the algorithm of the extended CMS (ECMS). Firstly, we track contours slice by slice from segmentations of volume data or intersections of a graphics model and flat planes, as shown in the left and center images of Figure 3. Then, we build bounding frames along the tracked contours, and use quads and triangles to connect these bounding frames to form a bounding volume. At this step, the bounding volume consists several shapes, such as tetrahedron, triangular prism, cube, possibly cuboctahedron, etc. Some possible unfolded shapes are shown in right image of Figure 3. Then, we generate line segments for each leaf faces (quads and triangles). After that, we fold faces back to original shapes and connect those line segments properly to form components and triangulate these components as before. Although it is possible to resolve topological ambiguity when using polygons instead of squares, we prefer to use quads and triangles to compose cubical shapes, because this allows us to accelerate the execution using high level shading language (HLSL) which could potentially run much faster when programmable graphic hardware evolves.

3 Conclusion

	MC	TMC	DC	EMC	CMS	ECMS
adaptive resolution			√		√	√
topological correctness		√			√	√
sharp-feature preserving			√	√	√	√
inter-cell independence	√	√			√	√
adaptive structure						√

Table 1 The comparisons of ECMS with MC, topological MC(TMC), dual contour(DC), extended MC(EMC) and CMS. See reference for more detail.

Table 1 shows the comparisons among ECMS and others. In addition to CMS, ECMS augments the ability to adjust the sampling structure to fit various kinds of volumetric structure. Such ability will be useful if the regular structure wouldn't fit the requirements of application. From our experiments, ECMS also has a lower average geometry error compared to other state-of-art surface extraction methods.

Reference

HO, C.-C., WU, F.-C., CHEN, B.-Y., CHUANG, Y.-Y., AND OUHYOUNG, M. 2005. Cubical marching squares: Adaptive feature preserving surface extraction from volume data. *Computer Graphics Forum 24*, 3, 537–545.