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Comparative Study of Marching Cubes Algorithms for the Conversion of 2D image to 3D

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Abstract

Nowadays, in most clinical places three-dimensional images are routinely produced. To produce these images anatomic structures are segmented and identified as a stack of intersections along with some parallel planes which corresponds to 3-dimensional image slices. This is achieved with the help of marching cubes algorithm. When it comes to surface rendering, marching cubes is proved to be one of the greatest methods for surface extraction by using surface configuration of a cube. This algorithm is basically used for extracting a polygonal mesh from a volumetric data. The paper provides a survey for the development of the algorithm that helps in isosurfacing and its properties, extensions, and limitations. The main algorithm is marching cubes and we see its other variants. One of the major problems is to reduce the number of triangles (or polygons) generated during isosurface extraction from volumetric datasets. In this paper, presents algorithms and a comparative study that can considerably reduce the number of triangles generated by Marching Cubes and similar algorithms without increasing the overall complexity of the algorithm.

Keywords: Isosurface; Medical imaging; trilinear interpolation; ambiguity

INTRODUCTION

As days are passing, new technologies are coming to hospitals and also medical schools which helps doctors not only to see 3D pictures but also allows the doctors to interact with the picture whether its heart or brain like it's in real. There are new virtual reality techniques coming up which can pull in data and images from multiple sources. They have potential to affect patient's outcomes more dramatically. Some virtual reality simulators have decreased the surgery planning time and increased the accuracy of the surgery. One of the most important application of virtual reality is medical training. Many Universities and colleges cannot afford to store cadavers for training but they can adapt to virtual reality techniques. Virtual reality will provide a 3D body which the doctors can see and also practice on them. With the help of virtual reality, medical imaging capabilities have increased as well as there is increase in dimensions and resolution. 3D and 4D images produced by modern imaging techniques are becoming very common.

Medical Imaging has been playing a great role in the past few years. With the evolution of Magnetic Resonance Imaging(MRI), radiological diagnosis is becoming less harmful. It is getting used often in medical field these days. 3-dimensional image with high resolution data is of prime concern in medicine. Various Image processing techniques plays a vital role when image diagnosis comes into picture. Along with 3D visualization, image navigation is helping surgeons for clinical purposes. Image guided surgeries have become a common thing and it also helps doctors to serve better outcomes. In spite of these advancements, there are limitations where 3D visualization of data is restricted to flat screens. techniques, 3D(three dimensional) image visualization has become an important method in diagnosing medical images. There are various methods through which a 2D MRI image can be converted to 3D. This paper mostly deals with marching cubes and other efficient algorithms which can be used to convert. It is important to convert a 2D MRI image to 3D to detect if there are any problems or irregularities. The brain image obtained from MRI consists wide range of gray scales and irregular boundaries so it is difficult to classify different tissues using current methods.

Medical imaging creates a visual look of the interior parts of the human body which is used for medical intervention and analysis of complex diseases in short amount of time. The medical imaging market is going to put a big difference in the medical field in the coming five years as medical providers continue to search for new and innovative approaches to improve patient diagnosis techniques. In 2012, medical care was worth $24.39 billion and it is estimated to increase to $35.35 billion by 2019.

Previously, imaging techniques applied to medical field used to produce only 2D visualization of organs of the human body but now we can create both 2D and 3D visualizations of the human body parts with the help of digital imaging systems like X-rays. Systems that can generate 3D visualizations covers only a small area in the medical field but it has grown a lot over the last two years and expanding its use to various fields like dentistry, orthopedics, oncology, cardiology and gynecology.

Any device that provides either 2D/3D visualizations are very essential in medical imaging systems. Currently, the display devices that are available provides visual representation of 2D data or simulated 3D data on 2D.

As advancements are applied to 3D display systems, the resulting applications are unending and very useful.

RELATED WORK

An algorithm was proposed by C. Montani, R. Scateni, R. Scopigno [1] in which voxels with constant value directly returns the voxel faces. It consists of cell interpolation approach of Marching Cubes. Two considerations were made which could relate to visualization requirements and data characteristics, and their solution helps in reducing output fragmentation by using a simple filtering approach. Isosurfaces without topological inconsistency can be obtained with the help of triangulation scheme which is proved to be unambiguous.

Marching Cubes(MC) is evolved as Discretized Marching Cubes(DiscMC) on the basis of midpoint selection. With the help of midpoint selection technique, a finite set of planes are generated along with their facets. A facet can lie only onto 13 different plane incidences.

There are 256 combinations of cell vertices in MC. And for each combination, a lookup table(lut) is generated which specifies the number of triangles that can be produced along with the cell edges where those vertices lie. The Discrete MC lookup table is slightly more organized than the standardized MC lookup table. The number of facets generated by Discrete Marching Cubes remains fixed with the help of midpoint selection, and the output primitives for each plane also remains fixed and it consists of only triangles.

Discrete Marching Cubes does not involve in maintaining geo- topological representation of each polygonal mesh. This is one of the features that differentiates this algorithm from other approaches. The methods and techniques used by Discretized Marching Cubes results in good quality images. And DiscMC acts as a tool which can construct images at a faster rate and can display the isosurface at a high resolution which is very useful to view 3D datasets.

Integer arithmetic is adequate for Discretized Marching Cubes algorithm, which is the most important feature of this algorithm and the use of floating point computations is restricted to normal only. This feature improves the efficiency and overall process of the algorithm.

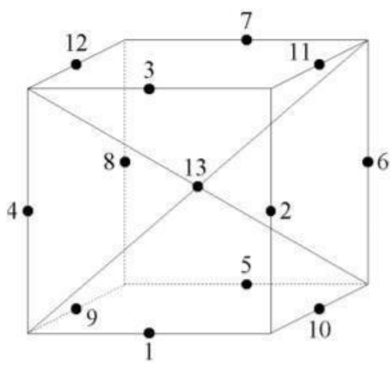

Figure 1: Vertex locations produced by discrete Marching Cubes

G.M. Treece, R.W. Prager and A.H. Gee [2] proposed the idea of combining of two fastest and simplest algorithms and came up with Marching Tetrahedrons (MT) for vertex clustering which helps in mesh simplification and for iso-surface extraction. Both of these methods enhance the performance of the algorithm. Vertex clustering is a method that can be used to create a regularized triangle set from Marching Tetrahedron algorithm, and it permits in preserving the original topology of the structure with the help of clustering around the tetrahedral lattice. Clustering techniques are generally hard to accomplish. The outcome of Marching Tetrahedrons is a surface in triangle form which comprises of normal triangles which are created at the same time as the surface.

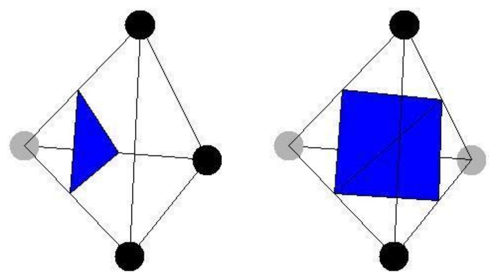

Figure 1: Marching tetrahedra. Triangulation is needed in both the cases. Case (b) can be considered as a quadrilateral rather than two triangles, as the surface appears to be planar.

Regularized Marching Tetrahedra is quite effective and fast when compared to other iso-surface extraction method and appropriate for distinct or implicit data. Marching Tetrahedrons reduces triangle generation by 70% and the surface and volume errors are less when compared to other algorithms. In MT, shading of the surface has vastly improved with the help of better aspect ratio of the triangles. The topology formed is consistent unlike other clustering methods.

For applications where the resolution can be decreased, the tetrahedral grid can be formed from a sub-set of the original orthogonal grid. For applications which already require inter- polation of the original data, there is no disadvantage in using a tetrahedral lattice for the interpolated data. Iso-surface extraction at the highest resolution of the original data is only possible if additional points are interpolated from this data.

Chien-Chang Ho, Fu-Che Wu, Bing-Yu Chen, Yung-Yu Chuang, Ming Ouhyoung [3] proposes a technique for surface extraction from volumetric data that helps in preserving sharp features, also handles crack patching and maintains consistent topology. It is similar to marching cubes algorithm. Marching cubes is the basic method to convert volume data into polygonal meshes.

The original algorithm (MC) has drawbacks like inconsistency in topological, inability to protect sharp features and appearance of cracks in the structure. Most of MC variants solve only one or few of these issues. Though these methods can combine and give a general solution to all the problems but it won't be fruitful enough. And some of these methods or variants can give rise to various other issues. But their method is comparatively easy and provides simple solution to all the problems by converting marching cubes into cubical marching squares, which helps solving ambiguity in topology with sharp features and eliminates inter-cell dependency. Cubical Marching Square algorithm is compared with various other MC variants and displays the comparative result along with their effectiveness.

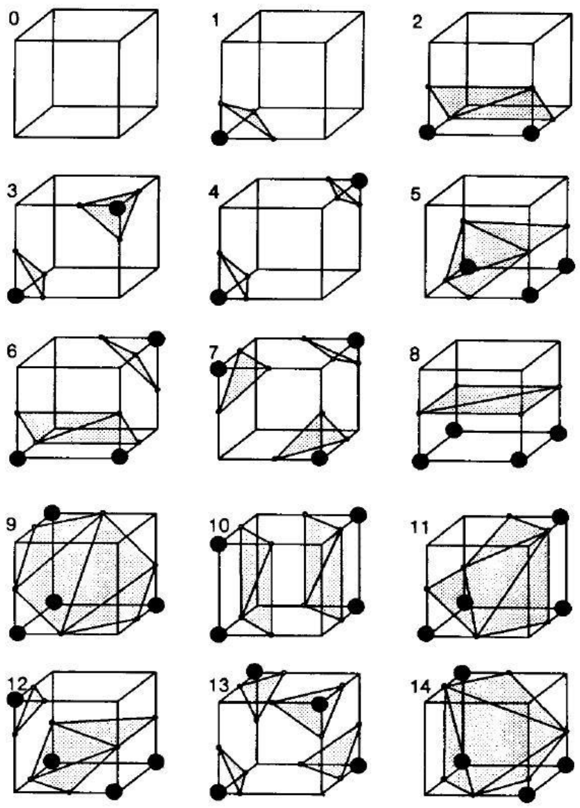

Figure 3: Triangulation of cubes

COMPARISON WITH OTHER METHODS

Parameters	**Marching cubes**	**Marching tetrahedra**	**Marching squares**	**Cubical Marching Squares**
Number of edges formed	12	19	4	12
Vertices involved	8	4	4	8
Look up table	15 cases	59 cases	16 possible configurations	16 cases simplified to 4 cases
ambiguity	Suffers from face ambiguity	Unambiguous	face ambiguity.	resolving internal ambiguity
Number of cubes involved	1 cube	6 tetrahedra	1 square	1 cube, the main contributions of the CMS algorithm is that it decomposes a Marching Cubes cell into six Marching Squares faces
Interpolation	Linear	Trilinear	Linear	
Sharp edge detection	does not preserve sharp features			Preserves sharp edges
Triangulation		Triangles reduced by 70%		Triangles reduced
Review about existing system	The algorithm basically describes the intersection of the surface of the cube. This process is carried out from one cube to another. Triangulating these 256 cases is possible but it is slow and causes errors.	Ambiguity is removed totally in this algorithm by using tetrahedra in place of cubes.	MS is a special case of the MC algorithm, restricted to two- dimensional space. Therefore, it is used for the extraction of isocurves and isolines	In this paper, the cubical marching squares algorithm is proposed for surface extraction from volumetric data which helps in preserving sharp features, maintaining consistency in topology, generating surface adaptively without any crack patches and eliminating inter-cell dependency.

RESULTS AND ANALYSIS FROM DIFFERENT METHODS

To show the volumetric data in an efficient manner, marching cubes and its other variants gives an efficient and convenient method to convert the volumetric data into polygonal meshes. These methods permit to provide accurate representation of geometric objects as volumetric data, make certain changes to them, and display them after converting from volumetric data to polygonal mesh. Though marching cubes algorithm is quite useful in nature, still there are few problems like inconsistency in topology, appearance of cracks in resolution and difficulty in preserving sharp features.

The first issue with MC (marching cubes) is topological irregularity which is caused due to ambiguities in topology. Such problems take place when more than one convenient assignments are detected for cases in the lookup table generated by the Marching Cubes algorithm. For such cases, the triangulation method needs to pick which intersections pairs to connect or to conclude if two components are joined or separated. It results in holes within the structure due to the inconsistency in ambiguity resolution.

The second issue that was detected is cracks in adaptive resolution. Various adaptive techniques that are applied on marching cubes, helps it to decrease the number of triangles that are generated. But, it can produce cracks at different resolution within the interfaces of grid cells. Such problems are solved by crack patching. Though crack patching helps to solve the problem, but at times it extends the edges which has high- resolution so that it matches with edges that has low resolution and therefore it doesn’t make full use of finer-resolution data.

The third problem is to protect sharp features. MC estimates that the surface produced do not contain any sharp corners or edges and is smooth enough. Therefore, a flat surface can result into wavy surface. The fundamental concept for fixing this issue is to locate the correct point of intersection of tangent planes. The scalar field and the tangent planes can be defined with the help of sharp feature preserving algorithms. This can be done if proper data of normals for zero crossing points of the tangent planes are provided.

As displayed in Figure 4, a cube has six faces. For each and every face, the isocurve or the isosurface is generated using MC. The isocurve generated from the algorithm consists of several segments for each face. When these segments of each face are connected properly and folded back to original cube, same components like MC (marching cubes algorithm) is obtained. In the end, the isosurface is generated with the help of triangulation. The triangulation method to generate the isosurface is chosen arbitrarily if it’s consistent. Therefore, a lookup table of marching cubes can be turned into six marching square lookup tables. Therefore, this method is called as cubical marching squares. Marching squares is a slow algorithm when compared to marching cubes. However, inter-cell dependency can be eliminated by sampling sharp features on the faces of the cube.

Internal ambiguity can be overcome with the help of 3D sharp features. When it becomes difficult to figure out if two components are separated or joined based on the signs of the vertices of the grid, it causes internal ambiguity. Internal ambiguity is similar like face ambiguity which can be resolved if two components can overlap. Two components are said to be joined if their volumes overlap with each other. Otherwise, the components are separated. A triangle fan is generated for each component which are found to be separate. The resulting surface is cylindrical in shape when two components are joined. For such cases, algorithm that uses dynamic programming becomes very useful to triangulate and connect the components to build the surface.

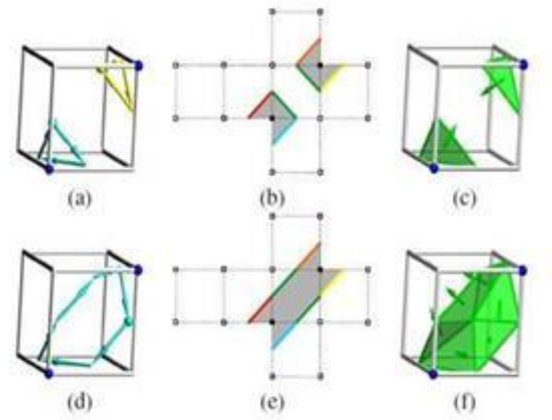

Figure 4: Cubical marching squares. A marching cube (a, d) is being unfolded into six marching squares (b, e). Each square is processed independently. The generated segments on these faces are put back to 3D to form components (a, d). By doing so, we can achieve the goal of being adaptive without performing crack patching. In addition, face ambiguities can be resolved in 2D by resolving the ambiguous faces (the middle faces in (b, e)). Finally, the resulting components are triangulated to generate the isosurface (c, f).

2D sharp features is spotted with the help of intersection points within 2 tangent lines. The tangent lines can be described by the normals and their sample points. Face ambiguity is resolved if sharp features are found to overlap. Figure 5 displays the segment assignments, Figure 5(a) overlaps the sharp features. This assignment is not acceptable cause the input data defines a volume which does not intersect itself. So, the other assignment is chosen where feature is not overlapped, figure 5(b) gives a solution to face ambiguity. Though the results obtained are not the same when compared to results generated by asymptotic deciders, but it’s very useful to resolve the face ambiguity by checking if sharp features can overlap.

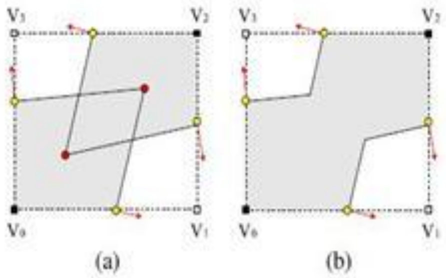

Figure 5: Face ambiguity. This is resolved by checking if sharp features overlap. While the input data specifies a volume, it should not intersect with itself. Therefore, the segment assignment with feature overlapping (a) is not valid. We choose the assignment (b) to form two segments and resolve the ambiguity.

As mentioned earlier, marching cubes has some drawbacks that are resulted due to the configurations in the algorithm which are made to the cube. MC do not differentiate the vertices of the cube in a proper manner, so vertices which are in and on the surface, are considered to be internal vertices. So, while calculating the interpolated points of the surface area of the edges of the cube, the approximate points are generated. This step will result in some repeated and separate triangles, which further gives rise to holes within the cubes. A new configuration scheme is proposed considering the relations of the internal vertices of the cube, which is either in or on the surface.

The first step is same like marching cubes algorithm in which the volume data is divided into cubes. A logical cube occurs repeatedly while dividing the internal and external vertices. Every logical cube depends on different cases of configuration. The number of configurations cannot be more than 15 patterns due to symmetric properties of cube.

In the next step, the configurations are specified again for the 15 cases. A second index is created by considering the inside vertices of a cube which is used to search the configurations that are produced by the cube. For the inside vertices, one is assigned to the vertices that are on the surface and zero to the vertices that are in the surface. This is the second index. After this step, the algorithm searches for configurations which are changed based on the second index. With the help of this method, the number of separate surfaces is reduced which results in reduction of hole appearance in the cube.

Based on each and every case of configuration that is provided by marching cubes, we can conclude that each cube consists of four vertices which are inside the surface. Therefore, when the second index configurations are re-defined, we get $2^4 = 16$ patterns. The number of configuration cases can be decreased when symmetry of the cube is considered. The mapping of the vertices is showed in Figure 6. The number sequence of the vertices of the cube is in vector form. For example, if we take vertices v0, v5 and v7, we represent them in vector form i.e. [0 1 0] to show that v5 lies on the surface so it is denoted by 1 and v0 and v7 lies in the surface so it is denoted by 0.

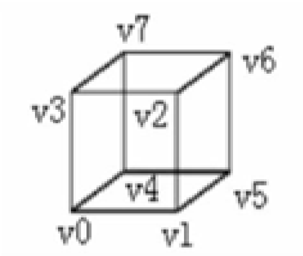

Figure 6: The vertices mapped in a cube.

CONCLUSION

Marching Cubes algorithm is one of the most popular methods for volume rendering and isosurface extraction. Since Marching Cubes came into existence, it has faced many challenges and researches have tried to extend the algorithm to solve the ambiguities and improve the performance. In this paper, a survey is presented to show the development of MC along with its extensions. We look into methods like cubical marching squares and marching tetrahedrons which uses the basic concept of cubes to generate 3D data and eliminates the problems faced by the original marching cubes. These methods took various types of data and compared their results in the end to come out with the most effective results.

In the future, many more methods will be coming up which will improve the ambiguities in a bigger scale. The Marching Cubes Algorithm is getting used in various fields for newer problems, and such applications will come up with new challenges faced in the algorithm.

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