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A Survey of Volumetric Visualization Techniques for Medical Images

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Abstract: *Medical Image Visualization provides a better visualization for doctors in clinical diagnosis, surgery operation, leading treatment and so on. It aims at a visual representation of the full dataset, of all images at the same time. The main issue is to select the most appropriate image rendering method, based on the acquired data and the medical relevance. The paper presents a review of some significant work in the area of volumetric visualization. An overview of various algorithms and analysis are provided with their assumptions, advantages and limitations, so that the user can choose the better technique to detect particular defects in any small region of the body parts which helps the doctors for more accurate and proper diagnosis of different medical ailments.*

Keywords: *Medical Imaging, Volume Visualization, Isosurface, Surface Extraction, Direct Volume Rendering.*

1. Introduction

Visualization in medicine or medical visualization [1] is a special area of scientific visualization that established itself as a research area in the late 1980s. Medical visualization [1,9] is based on computer graphics, which provide representations to store 3D geometry and efficient algorithms to render such representations. Additional influence comes from image processing, which basically defined the field of medical image analysis (MIA). MIA, however, is originally the processing of 2D images, while its 3D extension was traditionally credited to medical visualization.

Medical Visualization deals primarily with the visualization, exploration, and analysis of datasets arising from measurements or simulation of real world phenomena. The underlying data of medical visualizations are often very large, which makes it necessary to consider the efficiency and hence the time and space complexity of algorithms [1].The Goals of Medical Visualization is 1)To explore data (undirected search without a specific hypothesis). 2)To test a hypothesis based on measurements or simulations and their visualization and 3)The presentation of results.

2. Volume Visualization

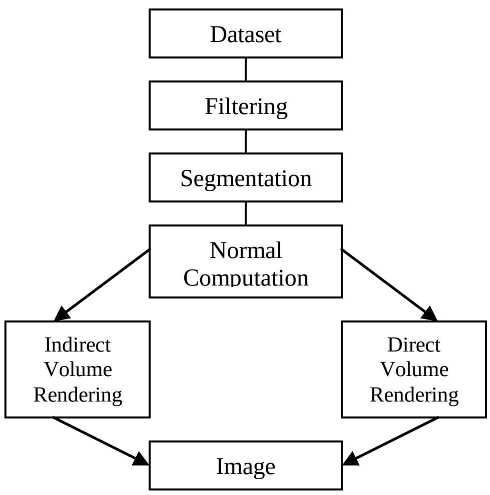

Fig 1. *Volume Visualization Pipeline*

Volume visualization [1] is concerned with the generation of a visual representation of volumetric data. Volume Visualization is becoming an important tool in engineering, medicine, and many areas of science. Medical volumetric data can be considered as a stack of aligned images or slices of the same resolution and adjacent position in z.

The volume visualization pipeline shown in Fig.1 describes about the different steps and avenues of volume visualization fit together. After the data acquisition, the dataset may be filtered (e.g., to enhance the data quality) and objects are segmented. After the possible selection of a sub range of the voxels the normals of the voxels are computed. Finally, the voxels are projected onto or rendered into an image by either indirect or direct volume rendering.

The fundamental volume visualization algorithms are divided into two categories as Surface Extraction algorithms and Direct Volume Rendering (DVR) algorithms shown in Fig.2. Surface Extraction Technique is also

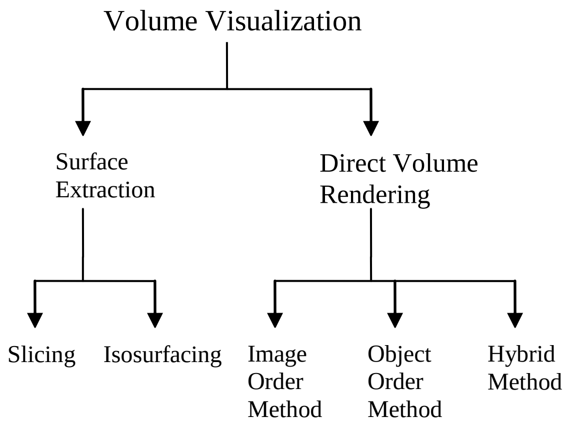

Fig. 2: *Classification of Volume Visualization Methods*

known as Indirect Volume Rendering. Surface extraction algorithms show only the interested surface information of the objects. DVR algorithms show both inner and outer information of objects. Surface Extraction methods are faster than DVR methods as they only traverse the volume once to extract surfaces.

Surface Extraction Algorithms further classified into Slicing and Isosurfacing. DVR Algorithms are classified into three types: Image Order Methods, Object Order Methods and Hybrid Methods.

3. SURFACE EXTRACTION

Surface Extraction algorithms fit (usually planar) surface primitives such as polygons to constant-value contour surfaces in volumetric datasets. The user selects a threshold value and then geometric primitives are automatically fit in the volume that matches the threshold. Cells whose corner values are all above or all below the threshold are discarded and have no effect on the final image. Surface Extraction Methods are categorized into two types:

3.1 Slicing

The acquired medical data image is divided into slices and the surface is formed by the connection of data points within the volume of different value or density.

3.2 Isosurfacing

Isosurfacing is an approach where a surface is formed from a cross connection of data points, within a volume, of equal value or density. Isosurface methods typically approximate an isosurface with a polygon mesh and shade the mesh in standard graphics pipeline. Since the polygon mesh is constructed in the object space, the graphics display can response rather quickly to a change of the view point. This makes isosurface approach well suited for an interactive environment [2].Isosuracing methods reduce the data to store. A popular method of constructing an isosurface from a data volume is the marching cubes algorithm [11].

The following techniques are some of the Isosurface techniques which are used to render the 3D image.

3.2.1 Contour Connecting

One of the first-invented methods for generating volume visualization images was called contour-connecting.The basic idea of tracing one closed contour in each slice of data and then connecting contours in adjacent slices of data was suggested by Keppel.E, and refined by Fuchs.H, et.al. [4, 5].

Contour connecting begins by operating on each slice of data individually. After the user has specified a threshold value, a closed curve contour at this value is found for each data slice. Image processing techniques now provide methods for automatically generating the contours, but human intervention is sometimes still required for low contrast data.

Once the slice contours are found, optimal tessellation is found, usually of triangles, connecting the curves in each two adjacent slices. The last step is to select viewing, lighting, and rendering parameters, and to pass the strips of triangles to a surface renderer. Advantages of this approach include the simplicity of the algorithm. The surface fitting portion of the algorithm is parallelizable since no two adjacent slices are dependent on the result of another pair.

3.2.2 Marching Cubes

William E.Lorensen, Harvey E. Cline, has presented a basic algorithm for surface extraction known as *Marching Cubes.* It uses the surface configurations of a cube for surface rendering of the volume data. In the marching cubes method, a volume data is first partitioned into cubes. Each cube consists of eight voxels. Then it decides the surface configuration of each cube according to 15 surface configurations as shown in Fig.3. After determining the surface configuration of cube, the surfaces of every two adjacent neighbor cubes are combined to form the surface of an object. The surface of an object is then projected to a plane to form the final image.

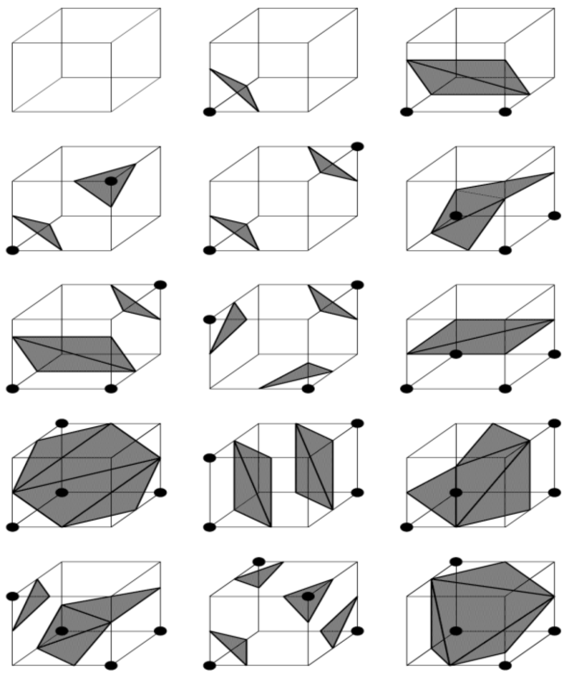

Fig 3. *Triangulated Cubes*

While generating triangles, Marching cubes sometimes results in false positive and negative triangles in the iso-surface.

3.2.3 Vertex Merging Algorithm

The marching cubes algorithm (MC) generates enormous number of triangles which is not suitable for interactive manipulation in terms of both space and time. Hence, reducing the numbers of triangles while minimizing the loss of object details and saving the space of storage is important.In order to reduce the number of triangles, Kwang Man Oh and Kyu Ho Park proposed a new surface modeling approach, called the Vertex Merging Algorithm [6], which merges the vertices of triangles generated by the MC at a surface generation step.

For merging, the angle between two vertex normals of triangles is used and if the angle is less than the angle threshold (AT)**,** two vertices are merged. Using vertex merging method, a variable resolution isosurface generation is available if we specify a various value of the AT.

4. Direct Volume Rendering

DVR methods display the entire volume V= {(x, f(x))| x belongs to R} as a 3D RGBA (color and opacity) cloud [2].Direct Volume Rendering [2, 3, 4] process the volume without generating any intermediate representation assigning optical properties directly to the volume elements (voxels).Transfer functions are used to assign optical properties, such as color, opacity and shading, to original values of the data set being visualized. In order to generate an image of the volume a viewing ray is cast from the virtual camera location through each pixel (picture element) of the image plane.Finding appropriate transfer functions for direct volume rendering is difficult because of large amount of user experimentation involved[8].

The Direct Volume Rendering is classified into three methods:

4.1 Image Order Method

Image-order volume rendering techniques represent a *backward-mapping* scheme. The image is generated pixel-by-pixel casting rays from the view-point through each pixel of the image plane resampling the volume along the viewing rays.Early methods cast parallel or perspective rays from the pixels of the image plane and determine only the first intersection points with a surface contained in the volume.

4.1.1 Ray Casting

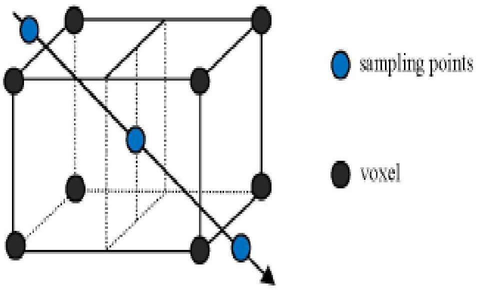

Fig 4. *The Model of Sampling*

Ray Casting is an image order method and the most used algorithm in medical volume visualization in the recent past. It was proposed by Levoy. In an image order algorithm all pixels of the image plane are traversed. In volume rendering, the arithmetic of Ray-Casting [2, 7] is used. The basic principle of the arithmetic is as follows. First, a ray is shot out based on the setting viewing direction from a specific point in the screen, and this ray is intersected with the three dimensional data fields. Then select several equidistant sampling points on the line, the model is illustrated in Fig. 4.

The RGB value and the opacity at every sampling point are obtained by using the arithmetic of tri linear interpolation with its nearest eight point values. At last, 3D medical image visualization can be implemented by synthesizing the RGB value and the opacity of every sampling point in the ray.

Ray casting can produce very high quality images but the calculation time can be very high with a small sample distance. There is always a compromise between the image quality and the rendering speed. Ray casting can be parallelized at the pixel level since rays from all of the pixels in the image plane can be cast independently.

4.2 The Object Order Method

Object Order Method [2] process the volume voxel-by-voxel projecting them onto the image plane. Object-order volume rendering techniques apply a *forward-mapping* scheme. The samples are projected in *back-to-front* order to ensure correct visibility. If two voxels are projected onto the same pixel, the first processed voxel must be farther away from the image plane. This can be accomplished by traversing the data plane-by-plane, and row-by-row inside each plane.

4.2.1 Splatting

One of the first object-order algorithms is called splatting. It was introduced by Westover. It performs a front to back traversal of all voxels in the volumetric data set. The method is called splatting because it can be compared to throwing a snowball from each voxel position on the screen. Like a snowball after being thrown on a wall also the voxel is spread around the center of the projection. This distribution on the image plane is called footprint. The form and the size of the footprint is dependent on the used function. Mostly a Gaussian distribution function is used .For all pixels affected by the footprint a color and opacity is calculated depending on the underlying distribution function. If a color and opacity for a pixel is already set from previous voxel footprints then a resulting color and opacity is calculated by compositing the new and the old optical properties. The advantage of splatting technique over ray casting is the user can watch the image grow more refined one slice at a time instead of one pixel at a time.

4.2.2 Shear Warp Factorization

Another object-order volume rendering is called shear warp factorization. It was first introduced by Lacroute and Levoy. The algorithm consists of two steps. In the first step a 3D shear of the slices is being done along the stack of slices. The shear has the effect to change the direction of the viewing rays through the volume. After the shear all rays should pass the sheared stack of slices perpendicular to the first one in the stack. When this is done the slices are blended together from front to back with the blended result from the slices before into a result image. This image is still distorted because in general the first slice will not be parallel to the image plane. For this reason as second algorithm step a 2D warp is applied to produce an undistorted image on the image plane.

The shear warp factorization is a very fast algorithm but the result is not that good compared to other volume rendering methods. The stack for the main direction with the highest dot product value should be used. The penalty of these view dependent stacks is a higher memory need.

4.3 Hybrid Method

Hybrid Method [2] is the combination of both Image Order Method and Object Order Method.

5. CONCLUSIONS

Many of the fundamental concepts of Volume Visualization has been explained along with some of the pioneering algorithms. Surface Rendering can be much quicker than Volume Rendering as only the vertices need to be recomputed following a rotation, while in volume rendering every voxel must be recomputed.The data structures representing the surfaces have far fewer elements and require typically an order of magnitude less storage than those used to represent the 3-D data set in volume rendering.

Once preprocessing is completed, typically much less computational work needs to be done by a (special-purpose) surface renderer than by a (more general-purpose) volume renderer. The image rendering step in surface extraction takes only seconds, neither requires large memory.The volumetric method requires large memory to process the entire data set efficiently.Surface Extraction methods suffer from problems such as occasional false positive and negative surface pieces.

The future of 3-D medical imaging depends on our ability to handle and to improve the many stages involved in patient management.

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