IMPORTANCE-DRIVEN VOLUME RENDERING AND GRADIENT PEELING

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Keywords: Importance-driven, Volume rendering, Gradient peeling.

Abstract: Volume rendering is widely used in visualizing and exploring volume datasets. In volume visualization, it is challenging to obtain desired results, because different tissue types are represented in overlapping ranges of scalar values and interesting structures will be partly or completely occluded by surrounding tissue of less importance. This paper introduces importance-driven volume rendering and gradient peeling techniques to reveal inner structures of interest. The importance of clusters is specified interactively and composited into the opacity of voxels. Then gradient peeling is performed on the clusters whose importance is greater than the user-defined threshold. This semi-automatic approach provides users with the freedom to visualize clusters of interest and the ability to peel off surface layers of the material. Experiment results show that our approach has superior capability in revealing inner structures and removing surrounding tissue which occludes the tissue of interest.

1 INTRODUCTION

Volume rendering has become an important technique for various visualization applications such as medical imaging and scientific visualization. In volume rendering, there are two key factors that prevent us from obtaining desired results, especially for interior tissues. Firstly, different tissues are represented in similar or even overlapping ranges of scalar values in MRI and CT datasets. Secondly, interesting structures may be partly or completely occluded by surrounding tissue, which is common in visualizing inner structures.

In traditional volume rendering, these two problems are handled by transfer function specification. However, traditional transfer function approach, which assigns optical properties only based on scalar values, is inadequate to extract inner structures of interest from the volume data. For instance, there are skin and fat tissue around the brain, and their intensities lie in the same range as the brain. If we want to visualize the brain by setting the scalar value range of the brain to opaque, the surrounding skin and fat tissue will also be set to opaque. Then the brain will be occluded by these surrounding soft tissues. Common approaches to this problem are to introduce explicit segmentation of structures of interest before the volume rendering process (Rezk-Salama & Kolb, 2006).

The work in this paper focuses on visualizing inner structures in volume datasets. In traditional transfer function approaches, regions of interest are usually areas of relatively homogeneous material. If an organ is opaque in rendering, inner structures of the organ will be invisible from outside. To solve the occlusion problem, the volume dataset is classified into clusters, and weights of the clusters are specified interactively, and then rendering and peeling are performed on the clusters of interest.

2 RELATED WORKS

It is difficult to visualize complicated information of volume datasets, because the outer opaque layers always occlude the internal information. Rezk-Salama and Lolb (Rezk-Salama & Kolb, 2006) introduced opacity peeling, inspired by depth-peeling for volume rendering (Nagy & Klein, 2003), for the extraction of feature layers that allows the extraction of structures which are difficult to classify with conventional transfer functions.

Li X., Luo S., Wu J. and Ma X..
IMPORTANCE-DRIVEN VOLUME RENDERING AND GRADIENT PEELING.
DOI: 10.5220/0003368002110214
In *Proceedings of the International Conference on Computer Graphics Theory and Applications* (GRAPP-2011), pages 211-214
ISBN: 978-989-8425-45-4

Boundaries often cannot be distinguished by transfer functions based only on scalar values (Sereda et al., 2006). However, higher dimensional transfer function shows superior capability in distinguishing between different boundaries (Kindlmann & Durkin, 1998). For example, Figure 1 shows a nucleon dataset, and Figure 2 shows that boundaries in the nucleon dataset appear as arches in 2D histograms of the scalar value and the gradient magnitude. Kniss et al. introduced interactive widgets to manually select boundaries in these 2D histograms of arches (Kniss et al., 2001). Huang and Ma (Huang & Ma, 2003) used these histograms for partial region growing to select features in the volume. These semi-automatic approaches turned out to be effective on a small number of boundaries. However, it is inadequate to deal with an increasing number of boundaries since their separation becomes more difficult due to intersections and overlaps.

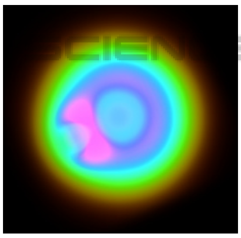

Figure 1: A nucleon dataset (The Voreen Team, n.d.).

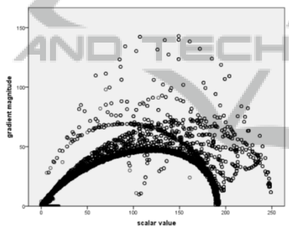

Figure 2: Boundaries in the nucleon appear as arches.

3 OUR APPROACH

There are three steps in our approach. First, voxels are classified into clusters automatically based on their scalar values (f), gradient magnitudes (f') and second derivative magnitudes (f''). Second, each cluster is assigned an importance I ($I \in [0,1]$) interactively. Voxels are considered to have the importance of the cluster that they belong to. Then the importance of a voxel is composited into its opacity during the volume ray-casting process. Third, gradient peeling is performed on clusters whose importance is greater than the user-defined threshold.

3.1 Clustering Voxels in Multidimensional Space

We adopt clustering techniques to automatically classify voxels into clusters based on the scalar value, gradient magnitude and second derivative magnitude. The voxels are projected into a 3D space which is made up of the scalar value, gradient magnitude and second derivative magnitude. To measure the difference D between two voxels (voxel A and voxel B) in this space, we apply the following formula which is similar to the Euclidean distance:

$$D_0 = f_A - f_B \quad (1)$$

$$D_1 = f_A' - f_B' \quad (2)$$

$$D_2 = f_A'' - f_B'' \quad (3)$$

$$D = \sqrt{(w_0 D_0)^2 + (w_1 D_1)^2 + (w_2 D_2)^2} \quad (4)$$

where f_A, f_A', and f_A'' denote the scalar value, the gradient magnitude and the second derivative magnitude of voxel A respectively. Similarly, f_B, f_B', and f_B'' denote those of voxel B. w_0, w_1, and w_2 are scale factors depending on the ranges of the scalar, the gradient magnitude, and the second derivative magnitude.

3.2 Rendering with Importance

After clustering, clusters are rendered in different colors, then the user can interactively select each cluster and assign an importance I to it. The importance I of a cluster will be composited into opacity of voxels belong to that cluster during the volume ray-casting process.

In volume ray-casting, there are two methods to calculate this rendering equation by iteration along the ray, the back-to-front compositing and the front-to-back compositing. The front-to-back compositing is used in our implementation. It starts with zero radiance at the eye position and proceeds in the direction away from the eye. The radiance and the opacity are composited with the following equations:

$$L_{i-1} = L_i + (1 - A_i) q_i \quad (5)$$

$$A_{i-1} = A_i + (1 - A_i) \alpha_i \quad (6)$$

where L_i is the radiance and A_i is the opacity accumulated along the ray so far, and q_i and α_i is the source term and the opacity of the i-th ray segment. In our approach, the importance of clusters I are incorporated into the opacity equation:

$$A_{i-1} = A_i + (1 - A_i) \alpha_i I \quad (7)$$

3.3 Gradient Peeling with Importance

The initial idea behind the peeling techniques for direct volume rendering is quite simple. That is to peel off parts of the volume when certain criterions are met. The aim of boundary peeling is to reveal boundaries of inner structures in volume data sets which are not easy to visualize without explicit segmentation of structures of interest.

The importance of clusters is utilized in gradient peeling with importance. In other words, gradient peeling with importance will only be triggered on clusters with importance factors greater than the user-defined threshold.

Instead of peeling off opaque material, gradient peeling is design to peel off translucent material and boundary regions. This is based on an observation that the boundaries in a volume data set contribute most to the accumulated value of gradients. Hence gradient peeling which accumulates and measures the gradients will has better performance on peeling off boundary regions than opacity peeling which accumulates and measures opacity values.

The mechanism of gradient peeling is very similar to that of opacity peeling. That is to peel off layers of material with certain accumulated gradient magnitude and only to start new layers in blank regions. Two thresholds are used for peeling, the accumulated threshold and the current sampled threshold. When the accumulated value reaches the accumulated threshold and the sampled value of current voxel is less than the sample threshold, a layer will be peeled off.

4 RESULTS AND DISCUSSION

For the convenience of comparison, we implemented our importance-driven techniques with a simple scalar value (1D) transfer function, and put the rendering results with and without the importance-driven techniques in this section.

The importance-driven techniques allow users to visualize the clusters of their interests. Figure 3 and Figure 4 are rendered from the same nucleon dataset in Figure 1. In Figure 3, the exterior of the nucleon is removed, because the importance of the exterior of the nucleon is set to zero. On the contrary, in Figure 4, the importance of interior of the nucleon is set to zero, so that it is invisible in the image. These two images show the ability of the importance-driven techniques to rendered specific parts of the dataset by assigning importance to clusters.

The importance-driven techniques are capable to reveal inner structures. Figure 5 is a foot dataset rendered with the 1D transfer function, and Figure 6 is the same dataset rendered with the 1D transfer function and the importance-driven techniques. In Figure 6, the exterior of the foot (skin and muscles) are completely removed, and the articulations and the phalanges are exposed entirely. Similarly, in the result of the VisMale dataset (Roettger, 2006) rendered with the 1D transfer function (Figure 7), the outside clusters are nearly opaque so that the visibility of the skull inside is very limited. By contrast, in the result with importance-driven techniques (Figure 8), the outside clusters, i.e. skin and muscles, are transparent, and the inside clusters, i.e. the skull, is clearly visible.

Gradient peeling is better at peeling translucent material and thin structures than the opacity. Compare to the results of opacity peeling (Figure 9 and Figure 10), the results of gradient peeling (Figure 11 and Figure 12) have more details of the surface of the skull. It is more obvious in the second layer than in the first layer. In Figure 10, parts of the surface of the skull are peeled away entirely, and the skull can be seen through. This difference is derived from the thresholds setting in opacity peeling and gradient peeling. When peeling translucent boundaries of soft tissues or thin structures, it is difficult to set an appropriate threshold in opacity peeling, and a slight adjustment to the thresholds will reflect in a rapid change in the resulting image. Since the thresholds in opacity peeling are set on accumulated opacity, it is more capable in peeling opaque materials than translucent boundaries, which are of little opacity. On the other hand, since the thresholds in gradient peeling are set on accumulated gradients, gradient peeling is sensitive to the changes of opacity even if that is translucent, which is usually happen in the boundaries of soft tissues and thin structures.

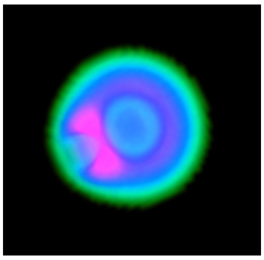

Figure 3: The exterior of the nucleon is removed.

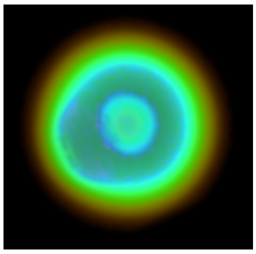

Figure 4: The interior of the nucleon is removed.

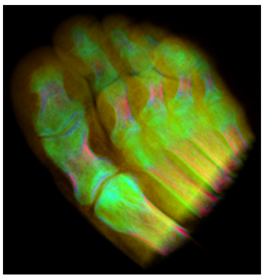

Figure 5: 1D transfer function.

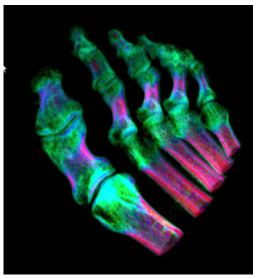

Figure 6: 1D transfer function with importance.

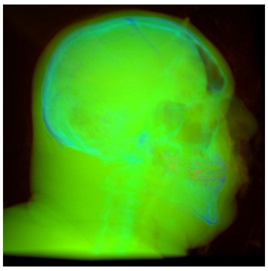

Figure 7: 1D transfer function.

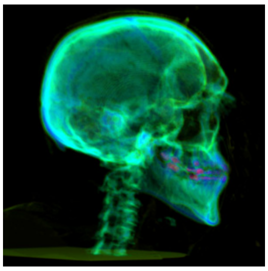

Figure 8: 1D transfer function with importance.

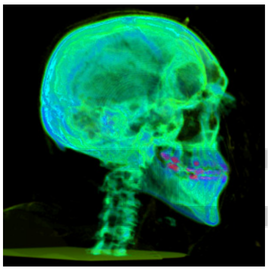

Figure 9: The first layer by opacity peeling with importance.

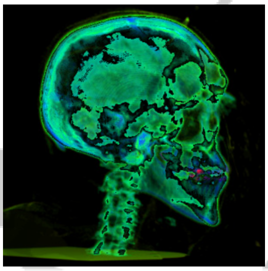

Figure 10: The second layer by opacity peeling with importance.

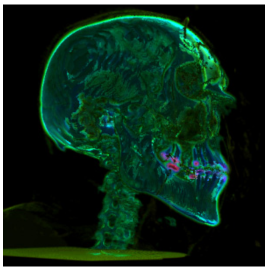

Figure 11: The first layer by gradient peeling with importance.

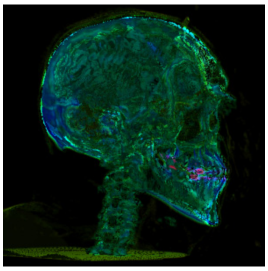

Figure 12: The second layer by gradient peeling with importance.

5 CONCLUSIONS

In this paper, we presented the importance-driven techniques and its application in volume rendering. We also proposed the gradient peeling with importance. The importance-driven volume rendering and gradient peeling techniques provide useful tools to reveal inner structures and peel off translucent material and thin structures. The importance of clusters is assigned interactively and composited into the opacity of voxels in the GPU volume ray-casting process. With this semi-automatic approach, users can choose the clusters of interest to visualize and peel off surface layers of the material.

The work presented in this paper exploits the clustering technique for volume classification in multidimensional space. Statistic properties can be taken into account to improve the understanding of volume datasets. The gradient peeling technique in this paper focuses only on heterogeneous regions. This method is flexible and can be extended to other properties of volume datasets.

ACKNOWLEDGEMENTS

The work presented in this paper was supported by National Natural Science Foundation of China (Grant No.60803108, No.30700165).

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