Focal Region-Guided Feature-Based Volume Rendering

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Abstract

In this paper we advocate the use of a focal region-guided feature-based volume renderer that offers an alternative for visualization of internal structures of volumetric data. We describe this promising technique for communicating the first impression of object shape or contour while at the same time providing detailed information of volumetric data with the use of lens-like focal region. We designed a method for generating object contours and enhancing volumetric features to depict context information out of focal region based on gradient volume. In the focal region, we render interesting volume data using the direct volume rendering method. The rendering is guided by focal region through which we can specify what subset to render. The connection between the structure of inside and outside of focal region gives a better understanding of spatial relationship. This is to better communicate the existence, form, and location of underlying targets while minimally occluding them.

1: Introduction

Recent developments in image modalities, such as Multislice-Spiral CT in medical imaging, have led to a substantial increase in resolution in slice direction. Data sets with 300 or more slices will be the standard in the next years. On the other hand, the structure of interest (tumours, arterial structures, etc.) occupies a percentage of the voxels that is often below 10% of all voxels. In practical applications, the large number of slices per study require fast, versatile and efficient methods for reducing the data for information extraction. However, the analysis of such structures needs context information like locations within a specific organ or nearness to sensitive structures. All these require an alternative rendering approach which integrates both: on the one hand, focusing on a specific structure and, on the other hand, context information. Focal region-guided feature-based volume visualization, which aims at making the visualization process more efficient by focusing on the effects or events the user is interested in, is the best solution for this problem.

In this paper, we propose a new approach to volume rendering: *Focal Region-Guided Feature-Based Volume Rendering*. We use a geometry shape (e.g. sphere) to divide volumetric data into two parts: focal region and context region. We describe this technique for communicating the first impression of object shape or contour while at the same time providing detailed information of volume data using lens-like focal region. This gives the scientist detailed information and context information of volume at the same time. Inspired by the nonphotorealistic rendering (NPR) to define an object with just a few contour lines with less redundant information, we designed a method for generating and enhancing volumetric features like object contours of the volume data to depict context information out of focal region based on gradient volume. In the focal region, we render interesting volume data using a direct volume rendering method. We obtain different object in focal region through specifying object specific transfer function.

2: Related Work

Traditional volume rendering approaches like direct volume rendering (DVR), maximum intensity projection (MIP) and surface rendering have been widely used to extract information from volume data. In contrast to these photorealistic approaches, nonphotorealistic approaches allow to depict and enhance user-specified features, like surface curvatures and silhouettes. Recently, NPR has been proposed for volume rendering [1, 2] to extend the abilities for the investigation of 3D data. Rheingans [1] introduced the volume illustration approach, combining the familiarity of a physics-based illumination model with the ability to enhance important features (boundary enhancement, sketch lines, silhouettes, feature halos, etc.)

using nonphotorealistic rendering techniques. Csebfalvi [2] developed an NPR technique for volumetric data to visualize object contours depending on the magnitude of gradient information. This approach provided a fast interactive investigation of 3D data and let users quickly learn about internal structures. Although all these approaches can provide promising visualization results to some degree, they all lack in providing volume of details and context information at the same time and thus lack a flexible understanding of volumetric data.

3: Method

Since methods of NPR and volume rendering have been extensively studied, we felt these techniques would be a good starting point for our research. Our method is to investigate techniques of NPR and volume rendering and evaluate how to combine NPR techniques with volume rendering techniques effectively and make full use of respective advantages of each technique to visualize medical data.

4: Approach

After the discussion of previous research on volume rendering, we now present our focal region-guided feature-based volume rendering approach which combines nonphotorealistic rendering and volume rendering into one renderer to investigate volumetric data.

4.1: Outline of FRGFBVR

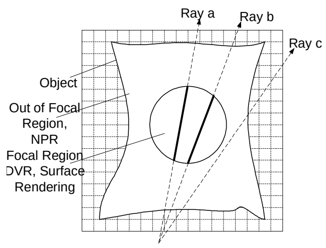

Figure 1. Outline of focal region-guided feature-based volume rendering

The *focal region-guided feature-based volume rendering (FRGFBVR)* approach uses a lens-like geometry to divide volumetric data into two parts: inside and outside of the focal region. Because the volumetric data in the focal region is the main area of interest, it is rendered with DVR or surface rendering. The area out of the focal region, which is rendered to show volume context information and enhance volumetric features, is rendered with NPR (e.g. contours, silhouettes). In our approach, we can change focal region interactively. In this way, the visualization is guided by focal region through which we can specify what subset is to be rendered. Figure 1 shows the main idea of FRGFBVR.

4.2: NPR for Volumetric Data

For a full depiction of 3D objects, often volumetric features like iso-surfaces are used as a visual representation of the objects [2]. Contour lines are particularly important in the perception of surface shape and have been utilized in surface illustration and surface visualization rendering. Similarly, contour lines in volumetric data which we call contour volume increase the perception of volumetric features. Our approach sets up an NPR model which is used to render the contours of the objects to enhance volumetric features within the volumetric data set out of the focal region.

4.2.1. Model for Contour Volumes. The non-photorealistic rendering model for contour volumes can be expressed as:

$$I(P,V) = WF(\nabla(P)) \cdot W(P,V) \cdot DepthW(P) \qquad (1)$$

where *P* is voxel position, *V* is viewing direction, *I(P,V)* is the intensity at the voxel position *P*, *WF(∇(P)* is the windowing function for the gradient at the position *P*, *W(P,V)* is the viewing-dependent weighting function which we presented on hybrid volume rendering for analysing 3-d data sets (for details see [4]), and *DepthW(P)* is the depth-weighted coefficient of intensity at the position *P*.

The windowing function *WF(∇(P)* is used to determine the range of interest in the domain of gradient magnitude. The weighting function *W(P,V)* is used to introduce the viewing direction into the model and gives higher weights to the voxels which belong to an object contour [4]. The depth-weighted coefficient *DepthW(P)* is introduced to overcome the limitation of MIP, which can not depict depth cueing of objects and is used later for compositing the image.

4.2.2. Windowing Function. The windowing function *WF(∇(P)* is used to determine the range of interest in the domain of gradient magnitude. Our model provided several windowing function styles to get different ranges of interest as indicated in Figure 2. In this way, we can control what features are to be visualized and enhanced.

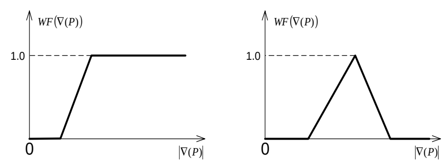

Figure 2. Different windowing functions

4.2.3. Depth Weight. Depth-weighted coefficient *DepthW(P)* of intensity approach is originated as an intuitive view of the natural visual characteristics that are evident when envisioning sight as a group of progressive planes. These planes are layered one after another, as if along a plane's normal or along the path of an ideal X-ray. This scenario gives the front visual plane the greatest intensity. Also, this scenario gives diminishing intensity to planes as they go into the distance. The base plane, the first plane in the line of vision, retains its full intensity. Thus, values from the base plane are given the heaviest weighting. Depth weighting is decreased with increasing distance from the base plane, and thus it is modeled as the loss of intensity. Depth-weighted coefficient *DepthW(P)* of intensity can be modelled as:

$$DepthW(P) = \frac{d_{\max} - d_i}{d_{\max}} \tag{3}$$

where d_{max} is the distance from the first plane to last plane, d_i is the distance between the first plane and the i plane. This approach produces the depth perspective scene in the final result (see Figure 3 left).

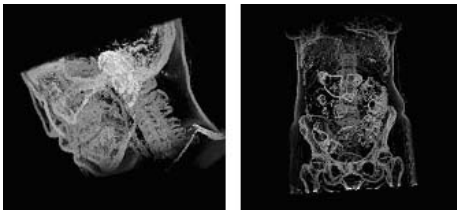

Figure 3. (left) Using depth-based MIP to show depth cue: the ear is clearly seen because it is close to the viewer; (right) using MIP to composite contour volume to show contour lines.

4.2.4. MIP Composition. After creating the intensity of each sample position along a viewing ray, an image is produced in a compositing step by maximum intensity projection (MIP) or alpha blending. The effect obtained thereby is a sketch figure of contour lines of the surrounding structures. The outer contours are then particularly emphasized. A useful characteristic of such a representation method is the recognizability of structures, which read from the focal region into the context region. In such a case, the focal region can be emphasized. Figure 3 right shows a result of using MIP to composite our contour volume.

4.3: Gradient Estimation

Since gradient information plays a very important role in our approach, it is necessary to get a precise gradient estimation. The traditional approaches of gradient estimation for visualization lead to undesirable image artifacts. Traditional approaches to gradient computation include 6-neighbour, 3D Sobel operator and others. These estimates are based on the inherent gray-scale variation in the image data, which for our data is discontinuous and results are aliasing. In our approach, the Zucker-Hummel (ZH) gradient [3] computation method was used. The ZH gradient is a three-dimensional edge operator that incorporates information from a 3×3×3 adjacent voxels for a better approximation of the edge.

4.4: Ray-Bounded DVR

After we create the nonphotorealistic rendering for context information out of the focal region, we use direct volume rendering to represent objects in the focal region. For efficient rendering and providing more information, we present a method of volume ray bounding during ray casting in our focal region rendering. The rays in ray casting are bounded by a user defined geometric shape (e.g. sphere, ellipsoid, cube) according to the volume of interest. The volumetric features can also be enhanced in this way and the rendering can be accelerated by avoiding unnecessary volume traversals.

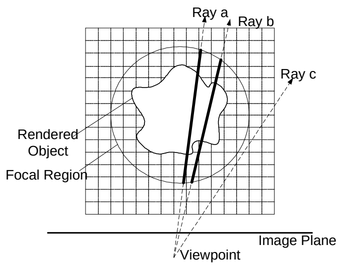

Figure 4. A 2D example of ray bounding during ray casting

Ray-bounding clips viewing rays against the user-defined polygon. This is done by projecting the polygon twice — first capturing a near Z buffer, then capturing a far Z buffer. The values from the Z buffers are decoded according to the current viewing transformation, and the decoded pairs of values (*near, far*) are returned as distance from the view point for perspective viewing, or distance from the view plane for parallel viewing. The idea is shown in Figure 4. As shown in Figure 4, only the bounded thick parts of rays are traversed during ray casting, and thus we only render the volumetric data in the focal region, instead of all of the volumetric data.

4.5: Combining NPR with DVR

After the NPR contour lines are rendered as context for focal region, here the user may specify a focal region on the rendition to get a new depiction of the data. We guide the rendering by clicking an area as focal region and combine focal region rendering with context of focal region. In this step, we have a rendering mixture of NPR and DVR. The use of a Z-buffer algorithm to solve this mixture problem is straightforward. In our approach, the contour lines for context region are rendered first. Subsequently, the focal region is rendered with direct volume rendering. The depth values of the volume samples in focal region are checked to make them contribute to the final image. This is rendered in front-to-back order. In this way the correct depth ordering of all contributing entities is preserved and the use of the over operator to composite them creates correct colors in the final image pixels.

5: Results and Discussion

We applied our method to CT data of the head for the representation of bones and their surrounding tissue sketches at the same time and also enhanced the volume features of the context of the focal region (Figure 5 left). This gave a good understanding of tissues in the focal region. In this case, the connection information between focal region and out of focal region was very important. The results have shown that such a focal region-guided feature-based volume rendering can differentiate the feature-based view of medical volume data for representing volume of interest. Figure 6 left shows the result of direct volume rendering of liver with tumours inside. Figure 6 right shows the result of rendering of liver for its focal region and out of focal region. In the focal region, we mainly show the tumours. The comparison of figure 6 shows that our presented approach can give more detailed information about the volume of interest. Rendered images are rich in densitometric information as well as in geometric information concerning local shapes and the spatial interrelations of structures.

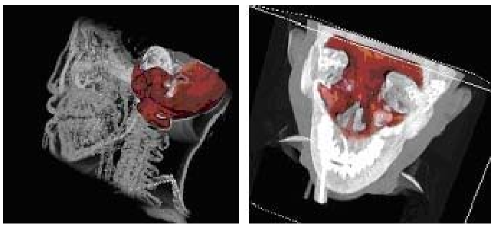

Figure 5. (left) Focal region-guided feature-based rendering of head, (right) gradient volume rendering

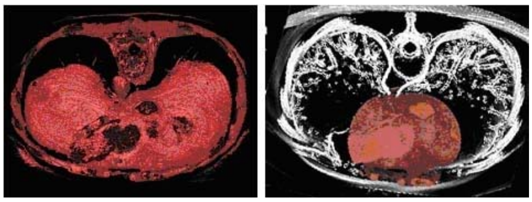

Figure 6. Direct volume rendering (left) and focal region-guided feature-based rendering (right) of liver with tumours inside

In addition to using NPR to enhance volumetric features of the context out of focal region, we use other rendering methods (e.g. surface rendering, etc.) to show context information. Figure 5 right presents an alternative approach to provide a good representation of volume context. We name this approach as *gradient volume rendering*, which is based on gradient information. In this approach, firstly we get the gradient for each sample position, which is interpreted as intensity for this sample position, and then we use MIP to composite the final image. In this figure, we can see large object contours (e.g. ears) clearly and can differentiate the high gradient objects easily. The red area is our focal region and it shows the head bone using direct volume rendering.

6: Conclusions and Future Work

In this paper, we have presented the approach of focal region-guided feature-based volume rendering for visualizing medical image data. This technique first divides volumetric data into focal region and out of focal region, then uses different rendering methods for different regions to show more details. The renderings, which we generated, provide a good representation of volume data features. We have shown that combining NPR with volume rendering produces more information and provides to the viewer a better understanding about volumetric data. This approach increases the comprehension about information in the volume data and provides a maximum comprehension of structures, and significantly reduces the time of visualization by offering a more controlled feature selection in the direct volume rendering process.

Our future work will focus on exploring other possibilities for rendering algorithms capable of showing more details of volume of interest and enhancing volume features for more context information. We will introduce segmentation information into our approach to enhance our algorithm.

7: References

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