Illustrative Visualization of Segmented Human Cardiac Anatomy Based on Context-Preserving Model

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Abstract

The layered structure of human heart is a challenging task for visualization. Conventional visualization method can hardly be used to provide satisfied rendering results due to the complex anatomical structure of human heart. In addition, it is very hard to find a balance between rendering the inner structure and the silhouettes of the heart. In this work we adopt the context-preserving volume rendering model which has been widely applied to layered medical data sets. We add new ingredient to the context-preserving model to fit the human heart volume data set and design an interactive tuning transfer function to enhance the tissue silhouettes. A transfer function is designed to map the gray scale in 3D cardiac data to the corresponding optical attribute according to the anatomical structure. To enhance rendering efficiency, we implement our method in a Graphic Processing Units (GPU) based framework.

1. Introduction

Heart is one of the most important organs of human beings. Due to the complexity of the cardiac anatomical structure, good visualization would be beneficial to no-invasive clinical approach, pathology research, pre-surgical planning, and medical training [1, 2]. Volume rendering is an effective method to generate 2D images from volume data, which has been applied in visualizing 3D medical data sets. Direct volume rendering [3, 4] (DVR) is one of the most important techniques developed to achieve direct perception of such volumetric data. It is a tough work for finding a balance between reveals the inner structures and shows the outline of the layered volumetric data. So in this paper we adopt the context-preserving volume rendering model [5] which has been widely applied to layered medical data sets to provide the human heart visualization.

The remainder of this paper is organized as follows. In Section 2, we first introduce the transfer function design scheme. Then we introduce the context-preserving model and our modulation. In Section 3, we evaluate the rendering speed of the proposed scheme. Finally, in Section 4 we provide our conclusion.

2. Methods

2.1. Transfer function design

A comprehensive review of existing transfer function design is beyond the scope of our paper. We focus on the transfer function design of pre-segmented data [6]. In the segmented 3D cardiac data set, each tissue is assigned with a specific gray level. We can determine which tissue is represented by a gray level. For demonstrating the anatomical structures of the heart, different colors are employed to represent different tissues according to the relative location of tissues in the cardiac anatomical model [7]. Opacity is another important factor in transfer function design [8]. Considering the spatial position of the tissues, the opacity of interior tissues is larger than that of exterior tissues, and the optical property of transition is different from that of the tissues.

2.2. The context-preserving model

In volume rendering, it is hard to visualize interesting interior structures and exterior structures simultaneously. Every single voxel does contribution to the final rendering results. So there are two kinds of problems we have to be addressed to and which will lead us to a dilemma. On the one hand, from figure 1a we can see if we enhance surface information interior objects will be occluded by other in the front. On the other hand, figure 1b shows that if we try to uncover the objects inside the rendering volume the silhouette of the whole will be lost. Furthermore, it is very hard and time-consuming to specify a proper transfer function.

In this work we adopt the context-preserving model which has been widely applied to layered medical data sets. Figure 2 shows two rendering results using the context-preserving model. In collaboration with the existing framework, we modified the model and design an interactively tuned transfer function to enhance the tissue silhouettes. Conventional volume rendering [9] method uses discrete approximation of integral along a viewing ray by the front to back formulation to compute opacity α_i and color c_i

$$\alpha_i = \alpha_{i-1} + \alpha(p) \cdot (1 - \alpha_{i-1}) \quad (1)$$

$$c_i = c_{i-1} + c(p) \cdot \alpha(p) \cdot (1 - \alpha_{i-1}) \quad (2)$$

where α_{i-1} and c_{i-1} are previous sum of opacity and color. $\alpha(p)$ and $c(p)$ are opacity and color of current sample point .

Traditionally, $\alpha(p)$ and $c(p)$ are defined as follows:

$$\alpha(p) = \alpha_{tf}(f) \quad (3)$$

$$c(p) = c_{tf}(f) \cdot s(p) \quad (4)$$

where $\alpha_{tf}(f)$ and $c_{tf}(f)$ are transfer function which map the scalar value of volumetric data to optical properties. $s(p)$ is the shading intensity at current voxel position, and is calculate as follows:

$$s(p) = (n \cdot l) \cdot c_d + c_s \cdot (n \cdot h)^{c_e} + c_a \quad (5)$$

where c_d, c_s and c_a are the diffuse, specular and ambient lighting coefficients and c_e is the specular exponent. n is the normal, l is the normalized light vector, and h is the normalized half-way vector. $s(p)$ is used for opacity performing the functionality as clipping plane.

$$\alpha(p) = \alpha_{tf}(f) \cdot m(p) \quad (6)$$

where $m(p)$ is described as follows:

$$m(p) = |g|^{(\kappa_t \cdot s(p) \cdot (1 - |p-e|) \cdot (1 - \alpha_{i-1}))^{\kappa_s}} \quad (7)$$

the $|g|$ is the gradient magnitude normalized to the range [0, 1] (Zero corresponds to the lowest and one to the highest gradient magnitude in the dataset), $s(p)$ is the shading intensity at the current sample position p, $|p-e|$ is the distance of the current sample position p to the eye point e. κ_t controls the basic slope, and the parameter κ_s is used to interactively tune the transfer function to view the curvature.

In order to help the user to obtain their satisfied picture, we design and implement an interactively tuning method which restricts the user adjusting the parameter within a small range. The rendering results are shown in figure 3 and figure 4. With the increasing of κ_t, the tissues far from the viewing position in figure 3 are uncovered gradually by fixing κ_s. From figure 4 we can observe that when κ_t kept unchanged the user can enhance the curvature of the heart by enlarging the value of κ_s. In order to enhance the silhouette and boundary between different tissues we use the Blinn-Phong [10] model to rewrite the color formulation.

$$c_w(p) = c(p) + weight \cdot (LBPShading) \quad (8)$$

where *weight* is in the range of [0, 1] and *LBPShading* is the Blinn-Phong shading model. The modified formulation is described as below.

$$c_i = c_{i-1} + c_w(p) \cdot \alpha(p) \cdot (1 - \alpha_{i-1}) \quad (9)$$

Figure 5 shows the rendering results with local shading.

3. Results

Our method can clearly reveal the interior structure of heart while preserving the silhouette of the whole heart. By means of the proposed interactive method for tuning transfer function parameters, one can focus the attention to an interested part and observe the detailed structures without losing global information. In addition, our approach has been implemented in OpenGL and Cg 3.0, and tested on a system equipped with an Intel(R) Core(TM) 2 Duo CPU and NVidia GeForce 9600 GPU. The rendering performance is 25 frames per second and meets the requirement of a real time system. The results show that the proposed method is well-suited for the layered 3D cardiac anatomical data.

4. Discussion and conclusions

In this paper, we applied the context-preserving model to visualize the segmented heart data obtained from the cross-sectional data from the Visible Human Project. We further proposed a local illumination ingredient to enhance the boundary information. To achieve satisfactory visualization quality on the shape and boundary of cardiac tissues, we designed the transfer function according to the anatomical structure of the heart. We also provide the interactive rendering method to help users get proper rendering results.

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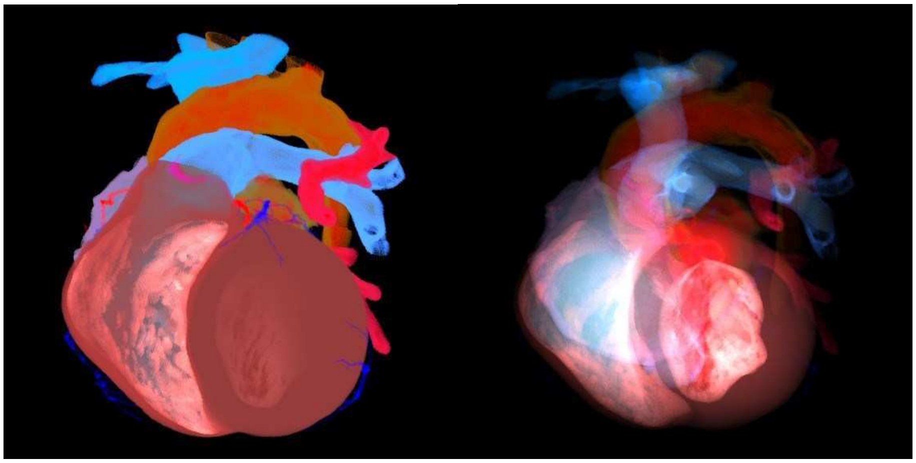
(a) (b)

Figure 1. Rendering results of ray casting method to show contour information and interior structures with different opacity setup. (a) is used to show the contour of the human heart but the interior information is missing. (b) is used to reveal the interior tissues, while the exterior tissues becomes semitransparent and hard to exhibit the surface curvature.

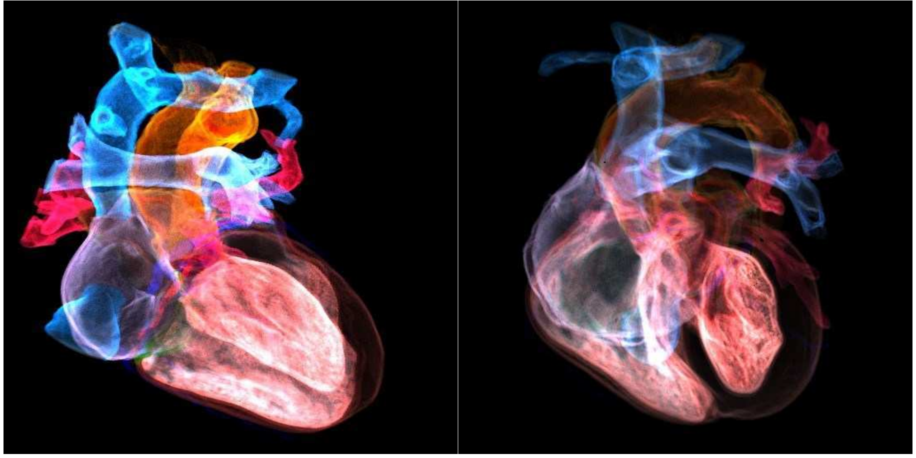
(a) (b)

Figure 2. Rendering results from two viewing directions.

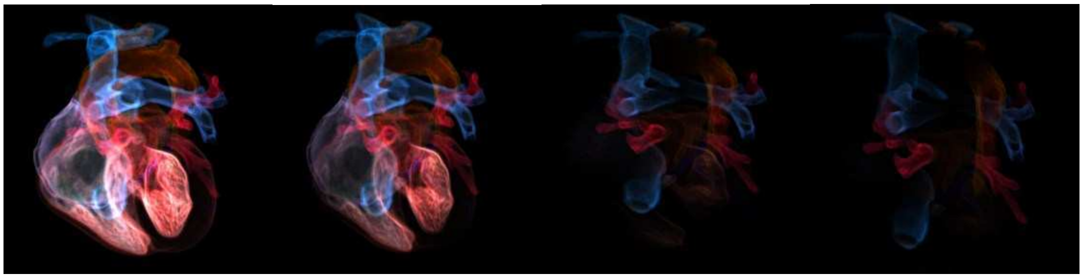
(a) (b) (c) (d)

Figure 3. Rendering results of different κ_t values. From (a) to (d) κ_t=0.1，0.3，1.0，1.5 and κ_s=1.5.

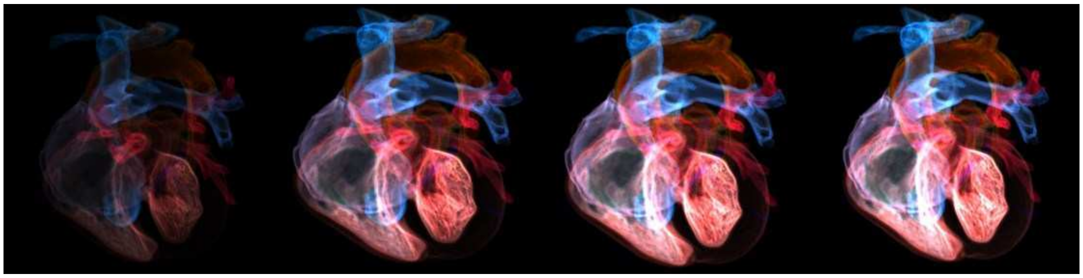
(a) (b) (c) (d)

Figure 4. Rendering results of different κ_s values. From (a) to (d) κ_s=0.5，1.0，1.5，2.0 and $\kappa_t = 0.1$.

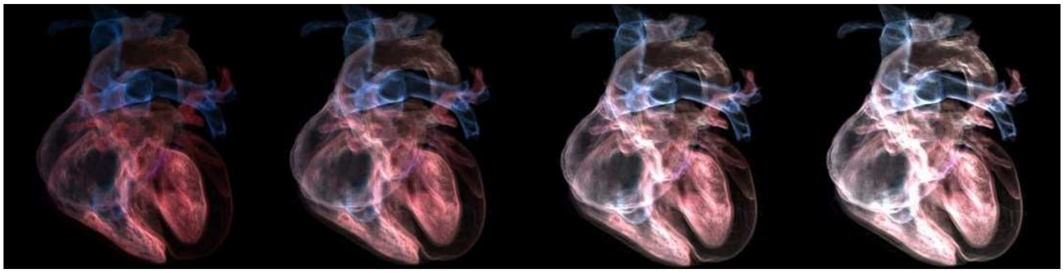
(a) (b) (c) (d)

Figure 5. Rendering results with four different of local illumination. From (a) to (d) weight = 0.0 ，0.1，0.4，0.6 and $\kappa_s = 2.5$, $\kappa_t = 0.2$.