Visualization of Multiple Anatomical Structures with Explicit Isosurface Manipulation

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Abstract—In medical image analysis and surgical planning, it is an essential task to visualize and differentiate multiple anatomical structures. The traditional approaches require expensive 3D segmentation steps during pre-processing stage, which defeats the purpose of real-time interaction with the data. In this paper, we propose an interactive method for visualization of multiple anatomical structures. In our results, we show that the new method is a promising technique for visual analysis of medical datasets and a helpful tool for surgical planning. It can be very efficient for a wide range of visualization and analysis tasks.

I. INTRODUCTION

In medical image analysis and surgical planning, it is an essential task to visualize and differentiate multiple anatomical structures, so that their spatial relationship can be intuitively observed. Normally, this requires a pre-segmentation of the input data. However, segmentation of structures can be a very expensive and tedious task. Usually, a specialized segmentation procedure has to be designed for each of the structures of interest to be extracted. There are some existing multi-structure segmentation methods available such as [1] [2] [3]. However, these methods are still restricted to a small set of segmentation tasks. In addition, direct visualization of the segmented results is likely to produce some visual artifact, such as the stair-case effect, since the segmentation results are usually represented with a binary mask.

In this work, we propose a new method which integrates the segmentation and visualization together. Using this method, the input requirement of segmentation can be done in 3D instead of 2D slices and corresponding segmentation results can be efficiently and smoothly integrated back into the 3D view. This method works in a way similar to a mesh segmentation [4], but they are different in the following two ways. First, the isosurface is rendered directly using ray-casting technique, which does not require the generation of a triangle mesh. Second, the segmentation tasks are highly integrated with the visualization task, which makes the whole procedure very interactive. As such, the surgeons can use this intuitive approach to explore the multiple structures. Also, since it directly works on the isosurface and do not generate a binary mask, the stair-case artifacts can be avoided. In this work, we apply the new method to different medical image analysis tasks. We will describe our approach and the results in the following sections.

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order to locate the feature of interest.

B. Structure Extracting

After the feature locating phase, we make sure that a feature of interest is visible to the user. However, it is likely that the feature is not completely isolated from the nearby structures. In order to extract the structure of interest, an interactive segmentation procedure is employed. The segmentation is performed on the isosurface instead of the original volume, which has two advantages. First, the segmentation task can directly use an intuitive explicit surface manipulation interface. Second, the segmentation result can be seamlessly integrated with the isosurface rendering framework. In isosurface rendering, the isosurface consists of many surface pieces. Each piece is contained in a cubic cell. The segmentation considers these pieces as the basic organization units of a isosurface. The segmentation requires the foreground selection seeds as well as the background selection seeds on the isosurface, which are directly picked from the 3D-View. As is shown in Fig. 2, the seeds can be picked from different viewing angles and with different peeling setups.

For picking seeds from 3D-View, a unique ID is firstly assigned to each voxel, as shown in Fig. 3 (a). Then, a voxel ID buffer is used to store the intersecting voxel IDs of each ray, which can be used for picking voxel seeds after the rendering. When user clicks or drags the mouse on the image plane, the corresponding voxel ID can be collected and organized. Fig. 3 (b) illustrates a voxel ID buffer. This figure is generated by assigning different colors according to the values collected in the voxel ID buffer.

According to the seeds, a min-cut based optimization procedure is performed to decide a geometrically shortest cut that divides the two sets of seeds. The segmentation separates the structure of interest from the nearby structures on the same isosurface, as is shown in Fig. 4.

C. Structure Recombining

By now, we have been focusing on a single feature of interest. The feature locating and structure extracting procedure can be applied to each structure of interest one by one. The extracted structures are then recombined to generate a multi-valued mask volume in an accumulative manner. Then, the mask volume, together with the original volume can be rendered to provide a multi-structure visualization with different color settings for different structures of interest. As is shown in Fig. 5, the internal structures and the lung boundaries are combined into the same scene, while other structures are removed.

III. Results

In many applications, the explicit isosurface manipulation method can be used as a useful tool to generate meaningful visualization results of multiple anatomical structures. Actually, more contents can be extracted from the thorax CTA
dataset which we used as an example in the previous section. As is shown in Fig. 6, it is easy to extract the kidneys and the heart from the dataset, which are meaningful for the surgery planning. In another experiment, we visualized an ear CT dataset. In this visualization, the surgeon is interested in a couple of different structures, i.e. the cochlea, the facial nerve, the chorda, which involves complicated segmentation techniques if full volume segmentation is required. As shown in the 2D slice of the dataset (Fig. 7), the facial nerve and the chorda are tiny structures which are difficult to track. However, just for a visualization, we find that the explicit isosurface manipulation method is also capable of handling that dataset.

The primary structures of interest in the ear CT dataset are: the external auditory canal, which is used as a landmark, the facial nerve, the chorda, and the cochlea. The external auditory canal is relatively easy to locate and extract. As shown in Fig. 9, it is part of the skin boundary, so a small isovalue should be used. In this example, only the inner part of the external auditory canal is of interest, so only that part is extracted. The facial nerve and the chorda are tiny structures, they can be located from the view shown in left picture of Fig. 8. Then as shown in Fig. 10 and Fig. 11, the seed points are selected and the structures are extracted. Similarly, the cochlea are located from the view shown in right picture of Fig. 8, and extracted as shown in Fig. 12. The recombined result is shown in Fig. 13.

<table>
<thead>
<tr>
<th>Content</th>
<th>Time (in seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left lung Boundary and Internal Structures</td>
<td>5.67</td>
</tr>
<tr>
<td>Right lung Boundary and Internal Structures</td>
<td>5.26</td>
</tr>
<tr>
<td>Left Kidney</td>
<td>2.46</td>
</tr>
<tr>
<td>Right Kidney</td>
<td>1.41</td>
</tr>
<tr>
<td>Heart</td>
<td>13.41</td>
</tr>
<tr>
<td>External Auditory Canal</td>
<td>0.98</td>
</tr>
<tr>
<td>Facial Nerve</td>
<td>0.21</td>
</tr>
<tr>
<td>Chorda</td>
<td>0.07</td>
</tr>
<tr>
<td>Cochlea</td>
<td>1.34</td>
</tr>
</tbody>
</table>

The displaying of the results of each stage is performed in real-time with GPU-accelerated ray-casting. However, it takes a few seconds to decide the min-cuts after the seeds are picked. According to the complexity of structures, the time of each segmentation varies, as shown in Table I.

IV. CONCLUSION

In this paper we presented an explicit isosurface manipulation method to visualize multiple anatomical structures from medical image datasets. The results show that the explicit isosurface manipulation is a promising technique for the visual analysis of medical datasets and the surgical planning. It is proven to be a very effective approach for a wide range of interactive segmentation applications.

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Fig. 8. Feature Locating: the facial nerve, the chorda and the cochlea (a) Locating the facial nerve and the chorda (b) Locating the cochlea

Fig. 9. Extraction of the external auditory canal from the ear CT dataset (a) External auditory canal labeling (b) External auditory canal segmentation

Fig. 10. Extraction of the facial nerve from the ear CT dataset (a) Facial nerve labeling (b) Facial nerve segmentation

Fig. 11. Extraction of the chorda from the ear CT dataset (a) Chorda labeling (b) Chorda segmentation

Fig. 12. Extraction of the cochlea from the ear CT dataset (a) Cochlea labeling (b) Cochlea segmentation

Fig. 13. Visualization of multiple anatomical structures extracted from the ear CT dataset

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