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Graph-based interactive volume exploration

Daniel Ponciano, Marcos Seefelder, Ricardo Marroquim *

Cidade Universitária, Centro de Tecnologia, bloco H, sala 319, Rio de Janeiro - RJ CEP 21941-972, Brazil

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ABSTRACT

The exploration of volumetric datasets is a challenging task due to its three-dimensional nature. Segmenting or classifying the volume helps to reduce the dimensionality of the problem, but there remains the issue of searching through the feature space in order to find regions of interest. This problem is aggravated when the relation between scalar values and spatial features is unclear or unknown. To aid in the identification and selection of significant structures, interactive exploration methods are important, as they help to correlate the volumetric rendering with the scalar data domain. In this work, we present a semi-automatic method for exploring volumetric datasets using a graph-based approach. First, we automatically classify the volume from a 2D histogram, following ideas from previous proposals. Then, through a graph structure with dynamic edge weights, a hierarchy is generated to identify similar structures. The final hierarchy allows for an interactive and in-depth volume exploration by splitting, joining or removing regions in real-time.

1. Introduction

Volume visualization has grown to be an accepted and useful tool in many communities [1]. However, due to its volumetric nature, naively applying rendering techniques may lead to a poor inspection of the dataset's internal structures. In most situations, at least some effort must be placed into segmenting the volume or designing transfer functions to have a clear insight about the feature space.

By separating the volume into regions, internal structures can be better isolated and visualized. Nevertheless, volumetric segmentation and classification is a challenging task, and for the general case it still requires manual intervention [2,3]. Furthermore, the segmented regions must be presented in a meaningful way as their correlation with the volumetric rendering is important to provide an intuitive exploration of the dataset.

Transfer functions can further help the visualization by mapping ranges of scalar values to colors and opacities, but also imply in some, either manual or automatic, segmentation of the volume. Moreover, when going beyond one-dimensional transfer functions, their design becomes a complex task [4].

The issue is even more aggravated if there is no deep understanding of the dataset beforehand, for example, when one is exploring the data without previous knowledge about how its internal structures relate to the scalar values. Even for researchers in visualization, sometimes it is hard to extract meaningful images from volumetric data.

Motivated by the need to intuitively and interactively explore a volumetric dataset, we propose a method to navigate a graph-based hierarchy generated from a previous classification of the volume. The hierarchy generation only takes around one minute or less, and once ready, exploration can be performed interactively by hiding, splitting and joining regions. It may serve as an initial exploration of the feature space to quickly highlight the internal structures (Fig. 1), or as a first step in designing transfer functions. The main contribution of our proposal is twofold:

- our graph-based structure is compact and efficient, allowing for real-time exploration, and a natural correlation of regions in the 2D domain and the volumetric rendering;
- by fine controlling the hierarchy generation we are able to isolate noise regions and produce a balanced structure that keeps most relevant segments near the top of the hierarchy, avoiding loading the user with tedious tasks.

The paper is divided into the following manner. In Section 2 we review the most related works and those that inspired our approach. In Section 3 we briefly overview Wang's method for automatically segmenting the volume's 2D histogram. To achieve a balanced structure from the segmentation, we propose new criteria to join segments as described in Sections 4.1 and 4.2. In Section 5 we describe how the hierarchy can be interactively explored. Results are shown in Section 6, followed by conclusions and future research directions in Sections 7 and 8, respectively.

* Corresponding author. Fax: +55 21 3938 8676.

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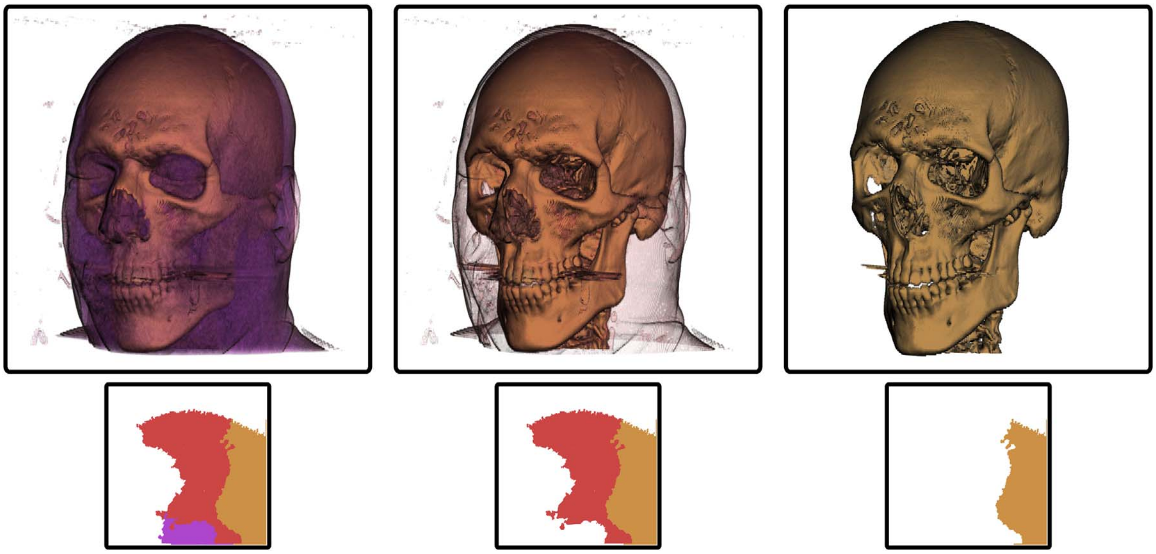

Fig. 1. The images show the Head dataset at three different moments during exploration. The bottom figures are the corresponding histogram cells that are being rendered. The red and purple regions had their opacity values manually reduced. Between the first and second images the purple region is deleted. In the sequence, the red region is also deleted, remaining only the region representing the skull. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

2. Related work

Several proposals seek to segment the volume or design transfer functions in a semi-automatic or automatic fashion. Other researchers have focused on how to interactively explore the feature domain. Among these, we cite the most relevant methods in regard to our work. For a recent and more in depth state of the art report on the topic, we refer the reader to [5].

Huang and Ma [6] propose the RGVis, an interactive region-growing method to segment the volume and generate transfer functions. Correa and Ma [7] propose a size-based criterion to classify the volume. In another work, they further propose ambient occlusion as a classification criterion [8], and later introduce the idea of visibility histograms as a way to design transfer functions [9].

Kniss et al. [10] propose a collection of widgets to interactively design multidimensional transfer functions. Park and Bajaj [11] describe a method that specifically alleviates the issue of overlapping features in the 2D histogram space. Pinto and Freitas [12] propose a method for designing multi-dimensional transfer functions by reducing the dimensionality, where the exploration occurs on a reduced two-dimensional space.

Wu and Qu [13] propose a system to manipulate transfer functions from the direct volume rendering, using an optimization approach. Users can fuse and delete regions directly from the 3D view. In a similar direction, Guo et al. [14] introduce a What You See Is What You Get system for volume visualization, where the user explores the volume through sketches: operations such as coloring, changing opacity, erasing, and visual enhancements are directly applied on the volume. In a more recent work, Soundararajan and Schultz [4] also propose an approach to directly interact in the spatial domain, and discuss several classification techniques to aid in this task. Guo et al. [15] represent different transfer functions from the same dataset in a multi-dimensional scaling map, the transfer function map. This 2D space can be navigated to explore features in the volume data.

Tzeng et al. [16] use high-dimensional classification methods, such as neural networks and support vector machines, to build transfer functions. They employ a painting interface to segment regions and train the system to classify the rest of the volume. Maciejewski et al. [17] build 2D transfer functions using a non-parametric kernel density estimation to group similar voxels. After generating the function the user can further join, inflate or shrink regions. Praßni et al. [2] describe an uncertainty-aware volume segmentation, where a guided probabilistic approach is employed to alert the user about possible misclassifications. Lindholm et al. [18] describe a boundary aware reconstruction. Their method aims at reconstructing precise boundaries for each feature with a piecewise continuous model. However, they are only able to visualize 2D slices or small regions using their method due to performance issues, and rely on manually setting the transfer functions via widgets to classify the regions. Karimov et al. [3] describe an editing method to correct volumetric segmentation. Their system identifies possible segmentation defects and guides the user during an editing session. Shen et al. [19] propose a model-driven method, where a semantic model is used to label the volume's components.

Ip et al. [20] generate multilevel segmentation based on an intensity-gradient histogram. They use a hierarchy of normalized-cuts to segment the volume. From the automatic segmentation it is possible to interact with the transfer function to further explore the volume by subdividing or hiding segments.

Jönsson et al. [1] take a different route in exploring volumetric datasets, and propose a tool that should be intuitive enough for novice users. Their system is based on the automatic generation of design galleries to guide the user's choices.

Fujishiro et al. [21] propose the automation of transfer functions based on the analysis of 3D field topology. In a more recent topology based approach, Wang et al. [22] automatically generate a 2D transfer function by segmenting the histogram based on the Morse–Smale theory [23], and using the topological hierarchy from the work of Bremer and Edelsbrunner et al. [24,25]. They introduce the notion of persistence as a metric for joining regions and generating an automatic segmentation. They also build a limited hierarchy to allow the user to further explore the volume.

3. Histogram generation

We follow the approach by Wang et al. [22] to classify the volume by segmenting a 2D histogram generated from the voxel data. We refer to cells as the elements created by the histogram

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