Interactive Coarse Segmentation and Analysis of Volume Data with a Suite of 3D Interaction Tools

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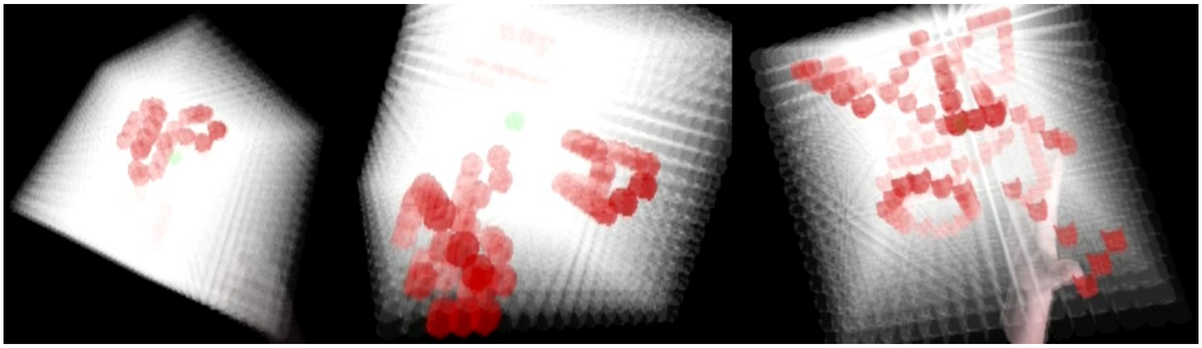

Figure 1: Simulated volume datasets with internal structures highlighted after interactive segmentation.

ABSTRACT

Manual and automatic segmentation of raw volumetric data is a very time consuming but important process for volume data analysis. We propose to create a suite of 3D interaction tools for interactive coarse segmentation of raw volumetric datasets, aimed at cutting down the time for initial segmentation drastically, to just a few minutes. We outline our plans to evaluate these different 3D interaction tools for the various tasks performed by scientists for analyzing volume datasets, by leveraging a generic task taxonomy mapping the tasks for volume data analysis from various scientific domains. Based on our research findings, we plan to design semi-immersive workstations packaged with our suite of 3D interaction tools for improving the effectiveness of volume data analysis.

Keywords: 3D interaction, 3D visualization, volume data analysis, segmentation, bimanual, two-handed interaction, virtual reality.

1 Suite of 3D Interaction Tools for Interactive Segmentation of Volume Data

Typical manual segmentation of a raw volume dataset involves marking the regions of interest (ROIs) in orthogonal slices through the entire length of a volume, along any of the orthogonal axes. This may take from a few hours to a few days of focused and hard work by an experienced researcher to complete to her satisfaction. An automated segmentation might be quicker, but often the extrapolation algorithms that segment surfaces through the volume do not live up to the users' expectations.

We propose to alter the way segmentation is done traditionally. We are designing a suite of 3D interaction techniques that will allow scientists to quickly perform a coarse and interactive segmentation of a raw volume dataset to look more closely at the ROI. The goal is to reduce hours or days worth of work to a few minutes, allowing more time to be spent on analysis and less on *preparing* for analysis.

The process will involve using one or more of the techniques from our suite to clear out unwanted voxels, and to break the remaining useful volume in connected or disconnected sub-volumes with ROIs that the scientists want to analyze closely. Further use of the removal tools will allow finer definition of the boundaries of the sub-volume, and isolation of the ROIs they want to analyze. Another method would be to interactively mark particular voxels, regions, or paths in 3D space (see Figure 1). The interactive segmentation will be rough, but will be enough to make correct judgments in many cases, and inform easier and faster selection of ROIs for a follow-up manual segmentation in other cases.

We will also explore whether the interactive segmentation can be combined with automatic approaches in a semi-supervised learning method to take advantage of both the processing power of the computer and the intuition and domain knowledge of the user. For example, the user may interactively mark some portion of a structure as an ROI, and the system may learn from this example what sorts of voxels and structures are of interest in the remainder of the dataset, segmenting them automatically. This approach holds great potential to reduce the time spent in segmentation, while producing high-quality results.

2 Design of 3D Interaction Techniques

In this section we outline the various 3D interaction techniques that we are designing for analysis of raw volume datasets.

Volume Cracker (VC): We have designed and tested the first 3D interaction technique called the Volume Cracker (VC) [3], which allows users to recursively crack open a volume like a book to reveal the internal structures. Based on participant feedback and our observations from the evaluation study, we are planning to extend the design of VC by adding an asymmetric bimanual interface, in which the non-dominant hand will provide the frame of reference, and the dominant hand will be able to make finer manipulations on the data, based on Guiard's bimanual framework. This design will leverage a magnet metaphor, in which, as the dominant hand hovers around the volume, different voxels cling to it (like pieces of iron cling to a magnet), based on the position of the hand relative to the volume. The separation between the hands will determine how many voxels are attracted towards the dominant hand, and from what depth inside the volume the voxels come. The relative positions of the hands will determine from which face of the volume the voxels get attracted towards the dominant hand.

Based on the contours created by the dominant hand's palm and fingers, we can modify the shape of the surface separating the two sub-volumes, along which the volume will crack. We are currently brainstorming different shapes of the cutting surface. We also want to consider how many of these shapes can be intuitively created by

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the user, without feeling the need to keep the shapes in their active memory. This will help reduce mental load on the user.

Volume Scooper (VS): This is very similar to the VC extension discussed above, except that the 3D surface created by the dominant hand is used here to clear out the voxels surrounding the surface, exposing the inner layers (or scooping out the ROI). When the user closes the fist of the dominant hand, we can either confirm the removal of the voxels, which are clipped already, or we can define the outline of a portion of the remaining volume, which will be separated out and grabbed by the dominant hand.

Volume Expander (VX): This design will involve making a hole in the volume, passing through to the center of the ROI, and then "blowing air" through it to blow up the volume internally, so that we can see the ROI and the associated structures from inside. This design is inspired by the sphere expander tool of McGuffin et al. [6], and the exploded views by Bruckner et al. [1].

Volume Peeler (VP): The design involves peeling off the voxels on top of any face or edge to expose the ones lying beneath. We can peel off geometric layers that are axis-aligned or oriented about any arbitrary axis.

Volume Grater (VG): This design will consist of grabbing the volume with the non-dominant hand and holding a grater or chisel with the dominant hand. The user will use the grater to remove the voxels from the volume, from any side of it, to expose inner structures. We can have different shapes of chisels offering various affordances for grating, more arbitrarily shaped than the regular geometries offered earlier by Huff et al. [2].

VS, VP, and VG suffer from the problem of losing context through removal of some voxels, but we believe these techniques would be useful in situations where users analyze ROIs in isolation, and removal of unwanted voxels will only speed up their analysis. The utility of such techniques may be realized in tasks such as pattern recognition (see section 3), where the researcher wants to separate or isolate structures or ROIs for closer analysis.

We may, however, choose to preserve the voxels by displacement, like the tools in McGuffin et al. [6], but we will need to verify for what task types (section 3) the preservation of voxels/context is really essential, and for which it could be detrimental, due to increased mental workload from any extra information not required for the task at hand.

3 Volume Visualization Task Taxonomy

In order to meet the needs of domain experts for volume data analysis tools, we are performing a requirements analysis, including surveys, interviews, and observation of laboratory work. We will gather requirements from scientists to understand their current and anticipated use of volume data in research, and to describe important current problems hindering the effective use of volume visualization.

A critical piece of this research is to understand what questions domain experts are trying to answer when analyzing volume datasets, and what tasks they must complete to answer those questions. We hypothesize that there is a relatively small set of fundamental abstract tasks that are used by scientists in volume data analysis, regardless of domain. Thus, we propose to develop a *task taxonomy* as part of our requirements analysis. Based on our preliminary work, we have a draft framework, including six task categories (search, pattern recognition, spatial understanding, path following, quantitative estimation, and shape description).

We are planning to refine the taxonomy by interviewing and talking to more domain scientists and researchers, by running a survey targeting a wider population of domain experts from archaeology, geology, geophysics, paleontology, medical biology, biomechanics, cell biology, engineering (CAD/CAM), molecular biology and biophysics, through online listservs (like CHI, IEEEVR, IEEEVis, 3DUI, etc.), personal and professional contacts, and also by matching the task categories with those suggested through guidelines created by a recent DICOM consortium.

4 Evaluation of the 3D Interaction Techniques

To determine the effectiveness of the designs of the 3D interaction techniques, we need to evaluate their performance for tasks in the different task categories of the task taxonomy. We will run several short user studies comparing these various techniques with standard techniques for analyzing volume data [3], and among themselves. Each study will pick one or two of these techniques, and the task categories in which they promise to show benefits of task performance, and evaluate them for tasks in those categories of the task taxonomy. Each study will inform the design of the subsequent studies, and might also generate new ideas for volume interactions.

Currently we have a set of preliminary hypotheses based on anecdotal and perceived evidence of the benefits of these various techniques to the different task categories in our task taxonomy, considering each technique is used in isolation. Table 1 below summarizes our hypotheses. A tick mark (√) in a box indicates a possible benefit of using the technique shown in the corresponding column, for the task type shown in the corresponding row.

Table 1: Hypotheses about the proposed 3D interaction techniques for the tasks in our task taxonomy

Task Types	VC	VX	VS	VP	VG
Search	√	√	√	√	√
Pattern Recognition	√		√	√	
Spatial Understanding	√		√		√
Path Following			√	√	√
Quantitative Estimation	√	√		√	√
Shape Description	√	√	√		√

5 Conclusion

We have presented a research agenda to design and evaluate novel 3D interaction techniques for interactive coarse segmentation and analysis of volume datasets. We plan to use the suite of 3D interaction techniques we develop along with display systems with empirically verified display characteristics [4, 5]. Our research is aimed at contributing a deeper understanding for designing effective semi-immersive workstations for improving volume data analysis.

References

[1] S. Bruckner, M.E. Groller, "Exploded Views for Volume Data," *IEEE Transactions on Visualization and Computer Graphics,* vol. 12, pp. 1077 -1084, 2006.

[2] R. Huff, C.A. Dietrich, L.P.Nedel, C.M.D.S.Freitas, J.L.D.Comba, and S.D.Olabarriaga, "Erasing, digging and clipping in volumetric datasets with one or two hands," in *ACM international conference on Virtual reality continuum and its applications*, NY, USA, 2006, pp. 271–278.

[3] B. Laha, and D. A. Bowman, "Volume Cracker: A Bimanual 3D Interaction Technique for Analysis of Raw Volumetric Data," presented at the IEEE Symposium of 3D User Interfaces (POSTER), FL, 2013.

[4] B. Laha, D. A. Bowman, J. D. Schiffbauer, "Validation of the MR Simulation Approach for Evaluating the Effects of Immersion on Visual Analysis of Volume Data," *IEEE Transactions of Visualization and Computer Graphics,* vol. 19, April, 2013.

[5] B. Laha, K. Sensharma, J. D. Schiffbauer, D. Bowman, "Effects of Immersion on Visual Analysis of Volume Data," *IEEE Transactions on Visualization and Computer Graphics,* vol. 18, pp. 597-606, 2012.

[6] M. J. McGuffin, L. Tancau, R. Balakrishnan, "Using deformations for browsing volumetric data," in *IEEE Visualization, 2003. VIS 2003*, ed, 2003, pp. 401 -408.