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Specializing Interfaces for Citizen Science Segmentation of Volumetric Data

Authors: Michelle Vaughan, Cindy Grimm, Ruth Sowell, Robert Pless, and Stephen Kobourov

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Type of Report: Other

Specializing Interfaces for Citizen Science Segmentation of Volumetric Data

M. Vaughan¹, R. West², C. Grimm¹, R. Sowell¹, R. Pless², S. Kobourov³

¹Washington University in St. Louis, USA

²University of California, San Diego, USA

³University of Arizona

Abstract

Segmentation of 3D and time-varying volumetric (4D) image data is considered a time and resource intensive bottleneck in scientific endeavors. Automatic methods are becoming more reliable, but many data sets still require manual intervention. This can mainly be attributed to the characteristics of the image data not being amenable to automated methods, the existence of variations in or poor image quality, or the need for an expert to review and edit results from an automatic technique. Manually segmenting volumetric data is a challenge even for those more experienced. Understanding the 3D nature of the data and navigating through the 3D environment poses some of the main difficulties of the task. Understanding what it means to segment data, and what a contour and a set of contours portrays is key to producing meaningful and usable results. Our goal is to construct a system that will allow even novices to segment 3D data and produce results that experts and scientists can review and use. Through the use of features such as tutorials, contouring protocols, navigation aids, and other interface enhancements, we believe that we can create a workflow that will allow any level of user to work with and understand 3D data. We propose a guided segmentation system that (1) lets experts create data specific segmentation aids, (2) helps users create a meaningful segmentation using these aids, and (3) allows the experts to use the results to provide helpful information to scientists.

1. Introduction

Constructing surfaces from volumetric data is a way for doctors to better examine organs or other objects of interest from CT scans or MRI images. The ability to study the object in 3D versus a series of 2D images can greatly increase the quality and pace of research[ALS*10]. As an example, a scientist can study the dynamics of chicken embryo heart walls by using time varying 3D reconstructions of the heart strung into an animation [RSL*08] (Figure 1). This would be more difficult to study if she only had 2D images of each part of the heart over time to work from.

To make these models, a scientist must draw outlines (i.e. contours) on 2D images of the object from several layers or slices of the 3D image. A surface can then be constructed from these contours, which is called a segmentation. However, making all the necessary segmentations is a difficult process and it can be very time intensive, especially for just a few scientists. Semi-automatic segmentation methods are becoming more reliable, but they require strong image gradients or templates, and they are still susceptible to noise and poor image quality.

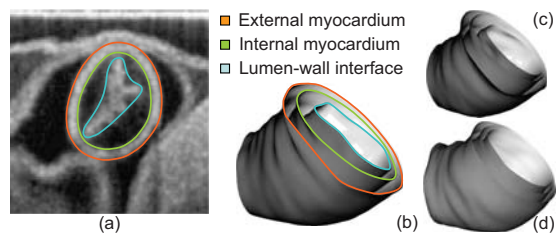


Figure 1: Surfaces reconstructed from chicken heart data: Original heart data with contours (a). Surfaces of the heart when it is fully closed (b), opening (c), and fully opened (d). [PKB*11]

A way to help speed up this process, is to allow volunteers to help scientists segment all their data. Citizen science is the term coined for involving the general public with scientific research regardless of their background and/or training. It has been shown that people generally like to be involved in science, especially if they have personal reasons or interests. If scientists had these volunteers at their disposal, we

could reduce the significant bottleneck that the 3D segmentation process employs, and allow scientists to get results faster. However, generating usable 3D segmentations is difficult even for those more experienced, so how can we make it easy and motivating for the general public?

In this paper we discuss a new process and interface for performing 3D segmentations. We focus on making volumetric data understandable and helping novices produce usable results. We employ the use of tutorials, contouring guidelines, navigation aids, and other interface enhancements to allow any level of user the ability to produce a 3D segmentation.

Contributions

1. Presentation of volumetric data to both experts and novices
2. Guided segmentation tool with tutorials, contouring instructions, and example contours and segmentations
3. New 3D environment tools

2. Previous work

2.1. Semi-Automatic Methods

(Discussion of current automatic methods and their fall-backs...)

2.2. Interactive Methods

(Discussion of other interactive methods / interfaces...) [MO10], [CSS08].

This work is a continuation of the VolumeViewer project [SLJ*09].

2.3. 3D Environment Navigation

(Different approaches to 3D environment navigation and other 3D cues. No work looks at navigation through volumetric data like CT scans...) [KMF*08], [GBK*01], [SCP95], [WHB06], [FMM*08], [KNBP06], [BK99], [ZF99], [BKFK06].

3. Background on 3D Segmentation Difficulty

Segmentation of 3D objects is the most widely used method for studying volumetric data today. However there are many difficulties and fallbacks to the process normally used that must be considered when designing a system to be used by novices.

3.1. Contouring

First, we can delve into the contouring process itself. Traditionally, scientist would draw contours on each slice of the

3D data down the sampling direction. This usually results in needing on average 20-30 contours for a given object (Figure 2a). This is obviously very cumbersome and time consuming if you need to make models for several datasets. However, with recent advancements, we have been able to greatly reduce the number of contours needed by allowing contours to be drawn on any arbitrary / oblique plane and not just the sampling direction [BTS04] (Figure 2b). Now surfaces can be generated with as little as 3 contours, and on average a maximum of 10. This alone already puts the segmentation task in an achievable scope for volunteer novice users.

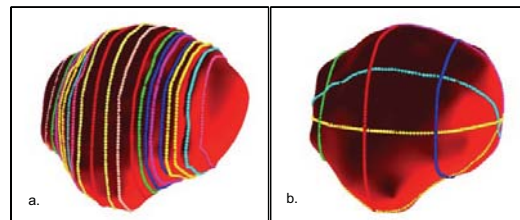


Figure 2: (a) Surface constructed from parallel contours (b) Surface constructed from oblique contours.

The major difficulty with contouring, however, is noise and clarity. Depending on the object of interest, CT scans often have noise or the data itself is not very clear. It is usually very difficult to even know what to look at in a given 2D image slice of the volume. This makes contouring a challenge since the user may not be able to determine where to draw or what to outline.

3.2. Segmentation

Producing a usable segmentation itself also has its challenges. Firstly, is contour consistency. The contours drawn by the user need to work together to be able to construct a surface from them. This wasn't as much a problem with parallel contouring, but with oblique contouring, contour inconsistency mainly comes up from inaccurate intersection points. Another challenge is making sure the reconstructed surface captures features to be studied. Many times there is a small bump or tumor on the surface, and that small bump can only be captured if a contour is specifically drawn around it.

4. System Design

In order to have a system usable by novices, we needed to take all of these challenges into account. We, therefore, devised a specific work flow that would allow the experts to provide tools and guidelines to novices which would be presented in our proposed interface.

First, the expert sets up the basic guidelines for the given

dataset. This entails a contouring protocol (more details in Section 4.1), a set of example contours and segmentations, and any tips/annotations. The examples would be made by the expert using the protocol they initialized.

Then the novice user will run this protocol package which guides them step-by-step towards creating a usable segmentation. Once enough users run the protocol the scientist will then have several results to use in their research.

4.1. Contouring Protocol

The contouring protocol is simply step-by-step instructions for drawing contours and constructing the 3D surface. The motivation behind this is that it is very easy to get lost in volumetric data if you allow free 3D navigation. So to alleviate this, the expert predetermines a set of planes on which to draw contours. Then they provide a set of instructions for each contour along with their generated examples as stated above.

When the user runs this protocol, they start at the first plane and as they progress, they are shown animated transitions through the 3D volume to each plane (see the protocol animation example video). At each step they are presented with the example contours to base off of, and instructions for what to look for and outline. They are also shown intersection points with previously drawn contours that they must pass through to ensure consistency. They have the ability to move these intersection points to adjust the previous contours.

5. Interface Design

Now that we have our work flow set up, we need a way to present everything to the user in an easy and manageable way. There are a few challenges that we focused on in our interface design that would ideally keep the user oriented and up-to-date with what they are actually doing and how far along in the protocol they are.

3D data by nature is very difficult to portray in a 2D environment. We wanted to be able to show the data to the user such that they understand the 3D position of the current 2D slice they are viewing. We also wanted the user to understand the relationship between the contours they draw and the segmentation they produce.

To confront these challenges, we devised our new 3D environment tools, and after iterating through several design ideas and mock-ups, we came up with the interface shown in Figure 3 and Figure 4.

The VolumeViewer interface [SLJ*09] consists of four main areas. The main window shows a slice through the volume, and contains traditional in-screen viewpoint controls. The three areas on the right serve to following purposes, from top to bottom: Localization within the volume, instructions on how to segment the current view, and visualization

of the navigation path. The interface's primary design principal is to expose all of the interface's functionality visually through interactive, in-screen elements, rather than menus. Secondary design principals are: 1) Maintain maximum context so the user is always clear what they are suppose to do next, and 2) Minimize mouse clicks. We next describe each area in detail.

5.1. Main Window

This window shows the current slice, along with the contour the user is currently drawing and, if desired, contours the user has already drawn. The free-form navigation controls are in this window, positioned to indicate their function.

5.2. Upper Right, Localization - also known as the You are Here (YAH) cube

This is a pair of linked views, controlled by absolute turntable scrollbars on the left and bottom. Both views show the outline of the current view volume as a cube. The left view indicates where the current view is located with respect to the volume and animates as one navigates through the volume. The right view shows any segmentation contours and the resulting constructed surface, with the current contour highlighted. The YAH cube allows the user to visualize where the current view is with respect to the volume and the existing segmentation. The limited viewpoint control (left-right, up-down) provides enough freedom to find a good view on the volume without the problem of getting lost.

These cubes were devised out of the previous works of: [KMF*08], [KNBP06], and [SCP95].

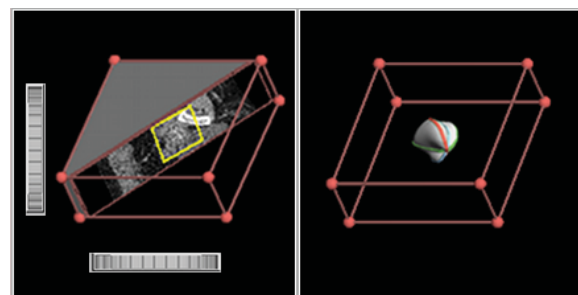


Figure 5: *The You-Are-Here Cube on the left, and the Contour/Surface Cube on the right*

5.3. Middle Right, Instructions

This window has space for text instructions plus mouse-over icons that show example images overlaid on the main window when the mouse is over them. The combination supports both image-based and text-based information to the user. The idea behind the mouse over sample images was

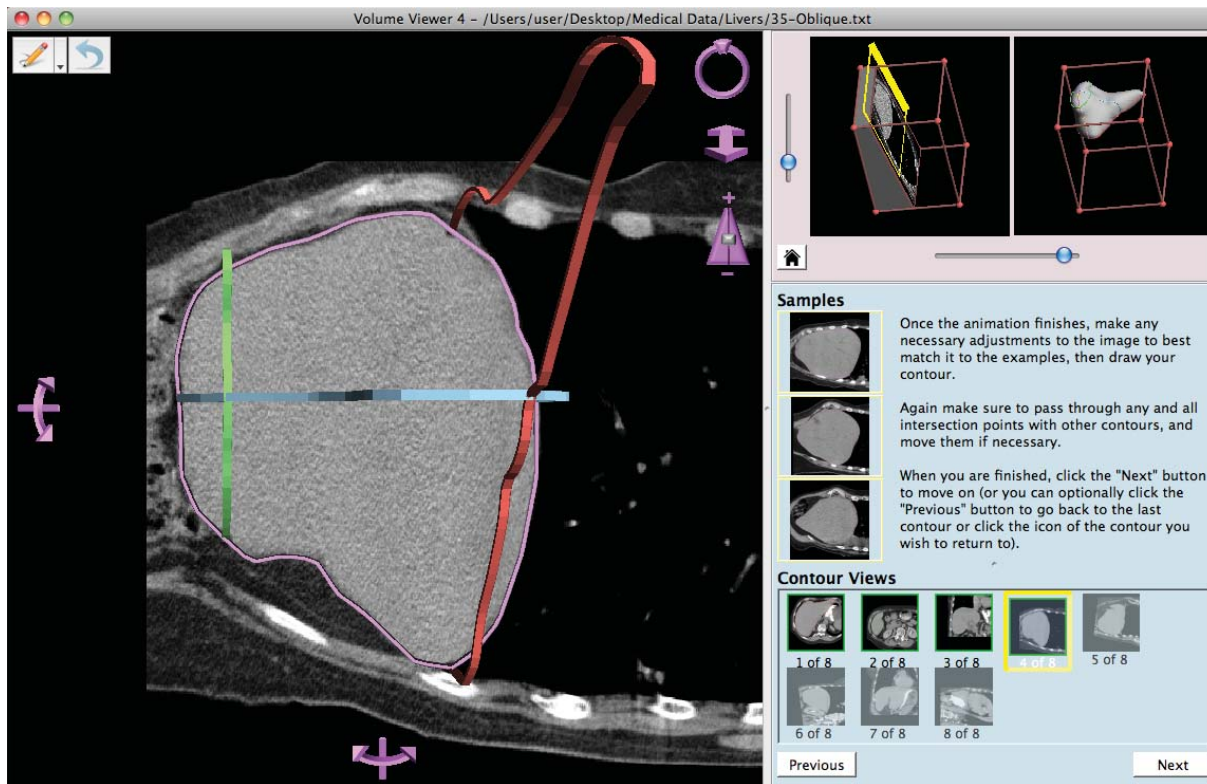


Figure 3: Screen Shot of Interface, Example 1

to let users be able to toggle an example on/off of the data they're working on to help them locate the shape they should be looking for.

5.4. Bottom Right, Navigation Path

The navigation path is visualized as a sequence of thumbnails, with the current view highlighted in yellow. The user can navigate through the path using either the previous and next buttons or by clicking on a thumbnail to go directly to that view. Mousing over a thumbnail overlays that view on the main window. Thumbnails corresponding to completed contours show the actual image and contour and the icon is outlined in green; uncompleted contours are grayed out and filled with an example image from another data set. All navigations between points on the path are smoothly animated, with the YAH cube mirroring the change in view as it happens. This helps to maintain the user's sense of orientation within the volume, and also provides a simple method for "scanning" through the volume. It also serves to show the user not only their progression through the protocol, but also the contours they've completed, the contour they are current on, and how many more there are left to do.

6. User Studies

After settling on a interface design, we wanted to test our new UI design on users that have some experience with segmenting volumetric data. This way we could determine if the interface is understandable and intuitive without it yet being interactive.

6.1. Formative User Study

For our formative study, we used an image mock-up of the interface, and we developed a broad set of questions that aimed to simply see what the user understands and doesn't understand with their first impression.

We found that users responded highly to the 3D cube views, however they couldn't quite grasp what it did since they could not interact with it. They understood that the first view shows them what slice in the volume they are viewing. They were also able to make the relation between the contour icons shown and the surface shown in the cube. These were our two big goals for the new interface, so these were promising results.

They didn't quite understand what the three sample images were so we moved them closer to the image plane, and also highlighted them yellow to try to make the correlation

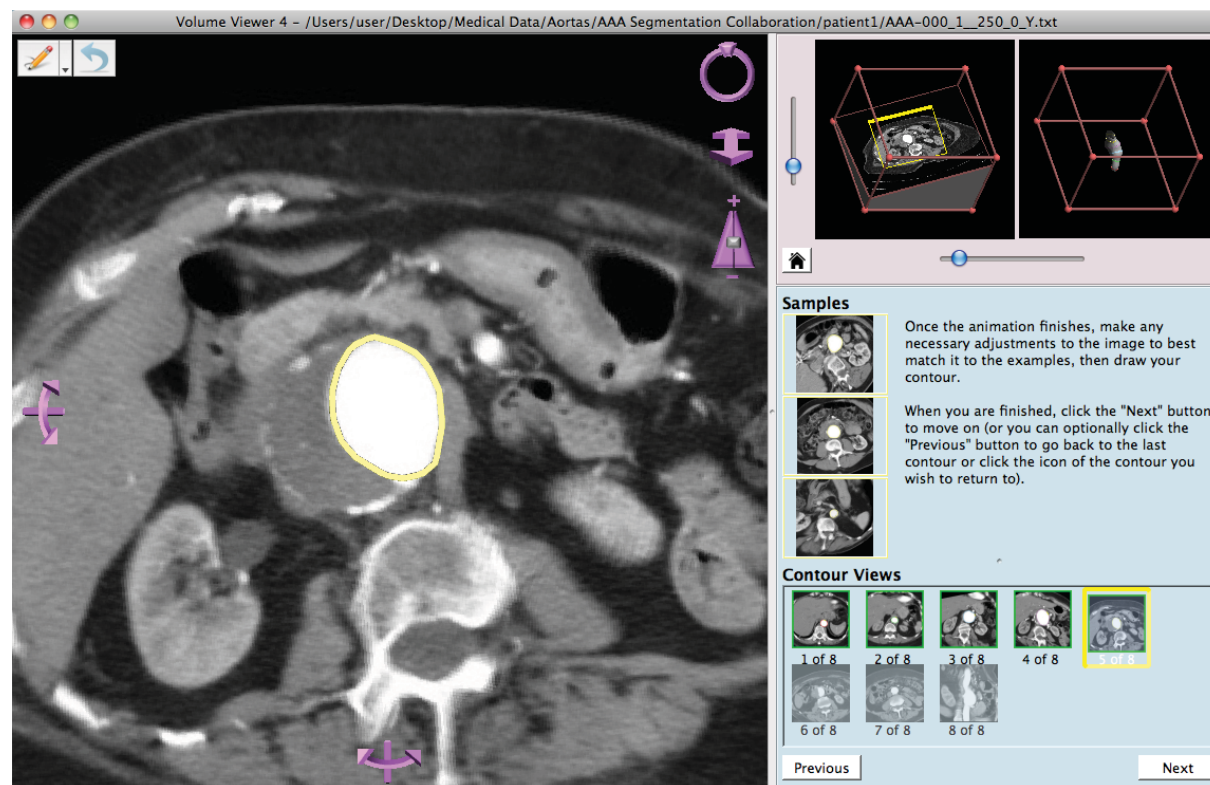


Figure 4: Screen Shot of Interface, Example 2

to the current contour in the contour progressor. They also didn't understand why there were contours under the "To do" labels, so we are going to try removing them and graying the image data out. They had no idea what the arrows on the next and previous buttons were, so we will try using the same arrows on the navigation tools to try and make the navigation correlation, or we may delete them altogether. Also, in order to tie all the elements together into 2 distinct groups, we colored background boxes to hold the cube elements and the instruction elements as well as reorganizing some of the element's positions within these boxes.

6.2. Formal User Study

7. Conclusions

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