Flythrough data exploration using multi-level classification driven focus and context

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Abstract

Non-invasive imaging of the coronary arteries has attracted growing interest in the past few years. In conjunction with recent development of desktop-based hardware-accelerated volume rendering techniques, the analysis and visualization of data has become more complex with larger datasets. The objective of this paper is to leverage advancements in hardware acceleration for the categorization and visualization of calcium depositions through a multi-layered focus and context flythrough approach. The three pronged approach provides relative positioning (context), high resolution focal point (focus / region of interest) and refined precision on specific objects (object of interest) to assist with the identification and categorization of abnormal structures through classification, segmentation and application of transfer functions.

1 Introduction

The correlation between calcium depositions within vessels and cardiovascular disease was first described in the 19th century. Individuals at risk for coronary heart disease increase with aortic arch calcification, as with the risk of stroke. The process of vascular calcification is heterogeneous, occurring in different parts of the vessel and causing damage in varying ways [1].

Clinicians typically visualize vessels through individual slices or mono-colour flythrough. In the former, the overall structural size of the calcification cannot be easily determined while in the latter, the calcification cannot be clearly identified without applying transfer functions to isolate the calcium to enhance the visual aspects.

This paper describes a novel approach to data analysis allowing individuals to view, classify and enhance the visualization of select data through a "Three Level" Focus and Context technique. Coupled with the flexibility in defining the rendering type and transfer functions at each layer, the visualization of calcification is possible within vessels.

2 Related Work

Common obstacles across existing medical visualization applications include the problem of viewing internal structures where data between the "region of interest" is obscured by structures that share the same range of data values and the problem of potential loss of context during interaction. Visualization techniques such as Opacity Peeling [2], Feature Pealing [3] have been considered to offer a solution to these problems. However,

uniformly applying these concepts to large datasets, results in the loss/removal of relevant viewer information. Beyer et al. proposed the use of multimodal data [4] to represent the different tissues for pre-surgical planning however the technique requires the use of many methods such as skull peeling and prior segmentation to work in unison to be effective, leaving little to no room for exploration of novel data.

With the focus and context approach, visualization methods can be applied to a specific "region of interest" instead of the entire view. Many techniques have been developed using this approach. Zhou et al. [5] devised focus-region based volume rendering for volume feature enhancement. Volume data inside and outside the focus region are rendered in different styles and the distance to the focal point is further included to control the optical properties of volume features in the context region. Gaze-directed volume rendering [6] takes the observer's viewing focus into account to increase the rendering performance. The volume dataset is rendered at different resolutions, with the focal region represented at high resolution and the other parts at a lower resolution. Importance-driven volume rendering [7] is a view-dependent model for automatic focus + context volume visualization. With the Magic Lens [8], the object importance is added as a new dimension to the traditional volume rendering pipeline in order to maximize the visual information. With pre-processed segmentation, this technique removes or suppresses less important parts of a scene to reveal more important underlying information.

In this paper, a more practical and novel approach is proposed for a flexible and intuitive interface that combines the application of transfer functions and focus+context with an emphasis on the "object of interest" within the focus region, also referred to as "region of interest".

3 Method

Using a flexible framework [9], the solution extends the concept of focus and context by introducing the ability to intuitively segment and classify data within a tubular focus region to overcome the obstacle of data obscurity in real-time. Further exploration of the data surrounding the classified "object of interest" is then possible by modifying parameters associated to the region through the interactive properties of a priority based multi volume OpenGL Shading Language (GLSL) raycaster with extended flythrough capabilities. Once the objects of interest are identified within the vessel, segmenting the desired data captures an instance of the relevant data for categorization and / or further investigation. The overall workflow associated with the visualization of calcification in vessels is captured in figure 1.
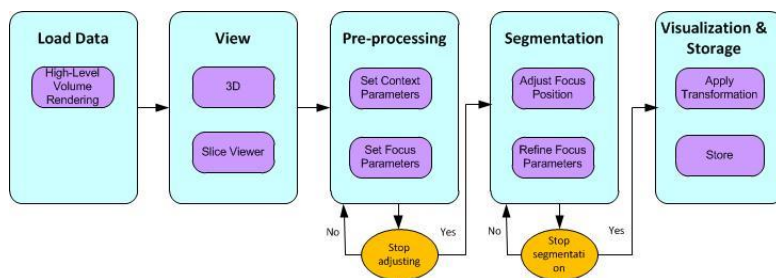

Fig. 1. Application workflow for calcification detection in Vessels

With abdominal aortic aneurysm CT data loaded into the workspace, focus and context is enabled to enhance visual aspects of specific regions. Moreover, a 2D cross-sectional

planar view of the 3D focal point is also available as an alternative approach for initial 2D slice investigation of calcium deposits (Figure 2). Although the slice helps in identifying calcification, the 2D view isn't able to depict the magnitude of the 3D structure.

As part of the pre-processing, a tubular shaped focus filters out vascular blood by using a high resolution isosurface (ISO) rendering type to provide an initial rendering of the calcification. The low resolution context region allows realistic Direct Volume Rendering (DVR) representation of the captured data as well as identifying external structures for reference during the flythrough.
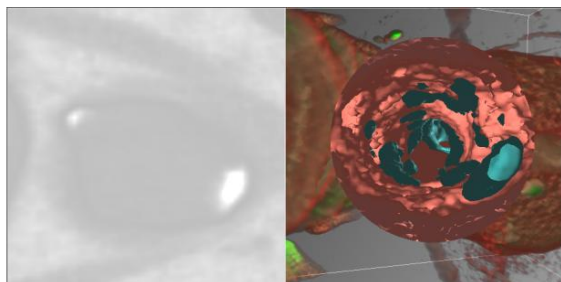

Fig. 2. Single slice (left) at the focus point of the 3D focus region (right)

Two forms of visualization are available to the end user. The first method is the multi-level tubular focus and context through a single magic lens. Additionally, to account for multiple regions of interest, a classification driven visualization method is incorporated into the framework to provide overall visibility of structures with similar characteristics. It is through this mechanism the extent of calcification throughout the aorta is determined.

Focus + Context	Depth Perception	Fly Through	Geometric Primitive	Magnification	Multiple Resolution	Multiple Compositions	Priority-Driven	Transfer Function	3 Level F+C
Spherical		•	•	•	•	•		•	•
Tubular	•	•	•	•	•	•		•	•
Classification				•	•	•	•	•	

Table 1. Comparison: focus+context types

Table 1 illustrates the variances of the different focus+context methods discussed within this paper. One of the primary differences between the methods is that spherical and tubular use geometric primitives to define the focus region whereas the classification method relies on data generated through a transfer function which enables priority driven rendering of important data.
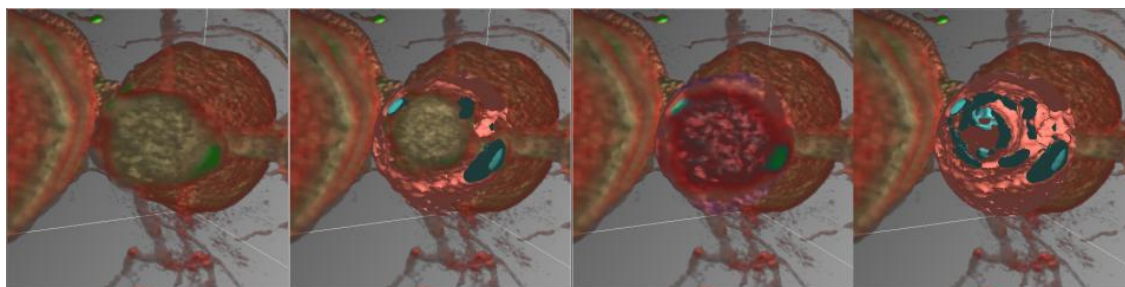
3.1 Spherical vs. Tubular Focus and Context

Fig. 3. a) DVR depiction of aorta without focus + context; b) Spherical ISO focus + DVR context; c) Tubular DVR focus + DVR context; d) Tubular ISO focus + DVR context

Figure 3 depicts the cross section of the aorta with the spine for relational context. Figure 3a uses DVR of the aorta without the application of focus and context. The remaining images in the figure use variances of focus+context to visualize the vessel. In figure 3b, a spherical focus + context approach is applied with ISO focus representing the region of interest to enhance the visualization of the calcium depositions coupled with a DVR context to help with relative details in the surrounding region. In this case the spherical focus region and the surrounding contextual region supply adequate visualization but lack the desired depth (beyond the focus region) to provide guidance and additional visual cues for fly-through such as forthcoming calcium depositions. A pure DVR solution is presented in figure 3c where the focus region is obstructed by the renders' inability to filter out the vascular blood without impacting the lining of the vessels. The tubular focus + context method, in figure 3d, mimics the approach of figure 3b and adds a greater level of depth perception to support flythrough; rendering the results of underlying data in z-order that are difficult to view and in some cases missed when using existing techniques.

3.2 Classification driven Focus and Context

Through the application of classification, sparse calcium depositions can be grouped and viewed during the vessel flythrough. Following the steps presented in Figure 1, this classification procedure is achieved by using a integrated Level Set General-purpose Graphics Processing Unit (GPGPU) segmentation algorithm to identify data in real-time.
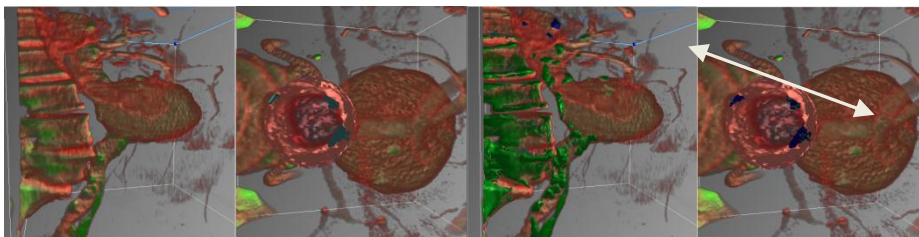

Fig. 4. a) Visualization of aorta without classification-driven focus+context, sagittal view; b) ISO Focus + DVR context with enhanced focus imaging through transfer functions, axial view; c) Classification driven focus+context, sagittal view with blue segmented data in the descending aorta to represent the third more granular level of focus and context; d) Three level focus+context, axial view with blue classified calcium deposits

Figure 4a represents a rudimentary view of calcification within the vessel. Focus and Context is applied to figure 4b and figure 4c allowing for different rendering methods (ISO Focus + DVR Context) and separate viewing capabilities (transfer function, resolution, magnification, etc) to highlight relevant data or occlude unimportant information such as calcium and blood respectively. In contrast, Figure 4c and d depicts classification based calcification in the descending aorta with a navy blue colour. The visual characteristics of the "object(s) of interest" can be further refined through similar customization capabilities provided to the region of interest.

4 Focus and Context Flythrough

Focus+context provide greater perspective when applied to flythrough. By adjusting the rendering mode and the transfer functions to both the focus and context regions, internal and external analysis occurs in parallel without impacting each other. For example, a significant variation in the diameter within the vessel may imply an aneurysm as depicted

in figure 5 where it is faster to identify the anomaly through the context than by loading and analyzing multiple 2D image slices.

Additionally, figure 5 makes use of a perpendicular contextual cutting plane that aligns with the focus. Here, the camera position is moved with the focus and contextual cutting plane to provide contextual perspective as the focus manoeuvres through the vessel. Figure 5b depicts the location of the focus region in sagittal view.
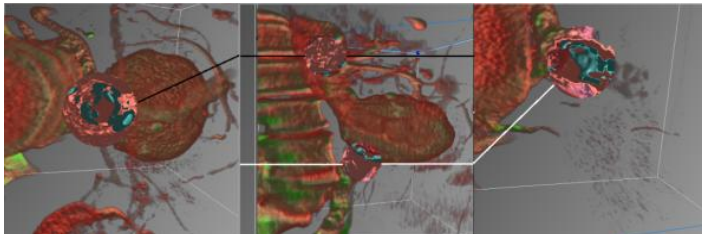

Fig. 5. Black and white lines cross reference focus positions in sagittal and axial view. The contextual cutting plane is aligned to the focus position to provide perspective (between the focus region and the surrounding). a) Axial view with focal point coordinates at (.48, .27, .87); and cutting plane at z = .87 (aneurysm is clearly visible) b) Sagittal view of both focal points descending aorta and abdominal aorta c) Axial view with focal point at coordinates (.48, .44, .40) with a cutting plane at z = .40 (aneurysm no longer visible)

5 Conclusions

This paper describes a novel approach to visualization using multiple levels of focus + context in conjunction with two distinct variances of focus + context (Tubular and Classification driven) to improve visualization. Data visualization is enhanced by including segmentation, classification, and enhanced flythrough capabilities into the workflow. Once the initial data is segmented, refinement is possible by applying three distinct transfer functions for each level resulting in an enhanced visualization of each selection. In addition, all relevant data can be viewed collectively through flythrough or priority driven visualization.

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