Volume Visual Attention Maps (VVAM) in Ray-Casting Rendering

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Abstract. This paper presents an extension visual attention maps for volume data visualization, where eye fixation points become rays in the 3D space, and the visual attention map becomes a volume. This Volume Visual Attention Map (VVAM) is used to interactively enhance a ray-casting based direct volume rendering DVR visualization. The practical application of this idea into the biomedical image visualization field is explored for interactive visualization.

Keywords. Ray-casting, volume visual attention maps, eye-gaze tracking

Introduction

Dense volume data visualization on conventional 2D monitors is a complex task due to the superposition of many data layers in the view plane. Many different techniques have been proposed in order to enhance or select different regions or data value intervals in the image, such as direct volume rendering (DVR) techniques and the related transfer functions, but it is still an open problem. In the medical field, professionals have more patients and image data, but less time for analysis, so techniques which help them increase the image review quality and efficiency are becoming increasingly relevant.

Visual Attention Maps [1], VAM from now on, usually visualized as heat maps, depict the focus of the user's attention graphically using different values and colors for each location depending on the time the user spent looking at it. This structure is generally constrained to a plane, since the eye tracking process is usually related to the attention on a screen, and limited by the eye tracking system [2].

This paper presents an extension of VAM for volume data visualization, the Volume Visual Attention Map (VVAM), where VAM become 3D volumes (see Figure 1), as a process to support and enhance the online volume data visualization/analysis procedure in a ray-casting based DVR. A software prototype has been developed in order to test the feasibility of the approach, which is able to compute the VVAM, and use it to enhance a ray-casting based DVR method for medical volume image visualization, in real-time (~60 fps), without any noticeable delay.

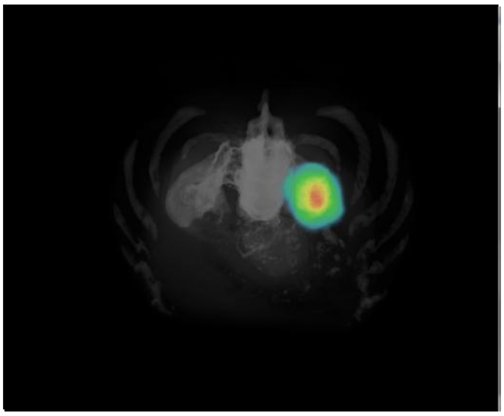

Figure 1. VVAM on medical image volume

1. Materials

Our prototype comprises several components:

- A commercial, point-of-regard based, non-intrusive eye tracker. For a technical understanding of the eye tracking techniques, the reader is referred to [2].
- A GPU based ray-casting DVR implementation previously presented in [3].
- The VVAM module implementation in GPU, integrated into the GPU ray-casting implementation, so that it performs in real time.

Our system allows using the eye tracking interface to interact with the volume visualization in two different ways: on one hand manipulating the virtual camera (zoom and rotate), and on the other hand by computing the volume visual attention map, which in turn guides the real-time DVR process to enhance the most salient regions.

2. Methods

When viewing a scene, the eyes perform two kinds of operations called saccades and fixations [2]. Fixations are relatively stable eye focus points and correspond to human cognitive processes where we extract visual information that we process. Saccades on the other hand are unconscious rapid eye motions with no relationship to any cognitive process, and usually correspond to the eye motion between consecutive fixations. Therefore, only fixations are considered for the VVAM computation. In a conventional VAM a fixation is defined by a 2D coordinate, *p(x, y)* and the time amount spent *t*, *Fix_2D(p, t)*.

In VVAM we define a fixation as a Gaussian cylinder that crosses the volume data using a projection of the 2D fixation coordinates onto the volume data perspective view. The value of each point inside the cylinder corresponds to a 1D Gaussian function on the distance to the cylinder centerline multiplied by the normalized fixation time.

Therefore, it is defined by the 3D coordinates of its centerline ends, *pIn(x, y, z)* and *pOut(x, y, z)* the radius, *r*, the fixation time, *t*, and the 1D Gaussian function parameters, *G*, that is, *Fix_3D(pIn, pIut, r, G, t).*

3D attentional maps were previously introduced by [4]. Although, the authors use them for offline attention analysis, and their visualization method was not well suited for ray-casting DVR. As opposed to theirs, our definition naturally deals with the specific characteristics of ray-casting based volume data visualization. Ray-casting represents a blending of many layers, instead of depicting the closest layer only. We simulate this fact by using a volume crossing cylinder. The addition of a Gaussian function, not considered by [4], corrects minor accuracy errors in the eye tracking procedure. It also takes into account that eyes do not necessarily focus on only one point, but on a region, and that points closer to the center point have more relevance for the user.

The VVAM computation follows the next steps: identifying fixations in 2D, then obtaining the fixation cylinder input and output coordinates, and finally adding the fixation cylinder contribution to the VVAM.

There are many different kinds of VVAM. For our system we chose the time normalized version, without a forgetting factor. This method allows time varying region selection, and it is more convenient to avoid implementation value overflows and to reduce the computation cost of the fixation cylinder values. After adding each fixation, time measures are normalized, and the whole VVAM values are updated. Both, the fixation cylinder computation and VVAM update procedures are time consuming, so taking advantage of our GPU based ray-casting implementation, we have implemented the VVAM computation into an OpenGL fragment shader.

The VVAM is provided to the ray-casting fragment shader so that the volume visualization is adapted to the user's attention focus, modifying the values provided by the original opacity and color transfer functions. Volume regions with higher VVAM values look more opaque and more color saturated, while lower valued regions have a reduced opacity, and are less saturated are represented with higher detail level, using a denser sampling of the volume set along the ray-casting ray (see Figure 2). Alternative enhancements are also possible.

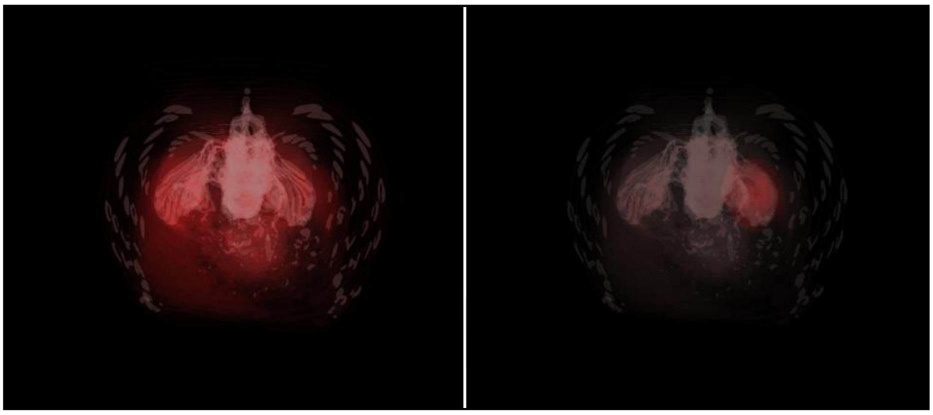

Figure 2. Left: No VVAM based enhancement. Right: VVAM enhanced visualization.

Figure 2 on the left depicts a low detail level DVR, where the VVAM is still empty, while the picture on the right shows the same perspective of the volume, where the user has focused on a region, forming an ellipsoidal shape. The low quality of the non-focused region has been exaggerated, so that the difference is clearly noticeable in the pictures. Nevertheless, the difference is clearly perceptible on any conventional computer monitor. And Figure 1 shows a heat map based VVAM representation which corresponds to the VVAM in Figure 2, right.

Eye tracking is also used to modify the model viewing perspective. The virtual camera can orbit around the volume data and zoom in/out. Currently, the keyboard is used to set the specific camera action to perform, while eye-gaze is used to set the action location (context) and to trigger it.

The interaction sequence consists of using the rotation and zoom controls to look at the regions of interest for the medical professional from different perspectives, so that as time goes by, those volume regions of interest are highlighted and the surrounding data fades away progressively.

In [5] an alternative way to use eye-gaze for enhanced ray-casting based DVR is proposed. In that paper the volume data is constantly rotating around its center and the user is asked to keep the focus of attention on the region of interest while this rotation takes place. Afterwards, the visualization parameters are automatically tuned to highlight the regions which were the focus of attention. We consider that our system has several advantages over that one. First of all, our process is completely interactive and online as opposed to theirs, because the user perceives a real-time feedback with the enhancement of the current selection. In addition, we consider that focusing on a 3D region while the volume is rotating is much more difficult than making the user select several view planes, using eye interaction too, and focusing on each of these static views, and even more difficult if the user wants to select several non-connected regions simultaneously.

3. Conclusions & Discussion

We have presented an adaptation of the Visual Attention Maps to the interactive ray-casting DVR visualization, which includes the definition of the VAM for 3D volumes, denoted as Volume Visual Attention Maps (VVAM), and its online usage to enhance or highlight the volume data regions of interest. We have also implemented a prototype to test the feasibility of the approach and its suitability in the medical image visualization field.

We consider that this new technique can increase the effectiveness and efficiency of ray-casting DVR visualization, especially in the medical image visualization field. Effectiveness can be improved in two ways: firstly because VVAM can be used to track which image regions have been reviewed by the medical professional, and which remain unexplored, to avoid skipping any detail; and secondly because it has a didactic potential, to teach future medical professionals the right way to review images. Efficiency comes in terms of time, as eye based virtual camera manipulation can be quicker and more natural than using a mouse, and because this natural way to enhance complex regions automatically permits focusing in what is really important for the professional. There is a final benefit in the usability and naturalness of the approach. Our approach is intuitive, since it is grounded in the common behavior of humans when looking at a scene, which is to focus on what it is really important to the user. In addition, our approach provides the user with real-time feedback of the focus region, which helps in the selection refinement. These two characteristics make the interface natural, in the sense that it has a flat learning curve and a low cognitive load.

Currently the eye based camera interaction requires the use of the keyboard, but we are working on using voice commands for this control. In the same sense, even although this system has been designed for eye based interaction, it could also be used with conventional keyboard and mouse interaction, if the eye tracking device is not available. In this particular case, the concept of VVAM would be more related to a complex shape 3D selection technique guided by the mouse cursor position.

Finally, we are considering the migration of this system to a web based application, following the current trend in cloud computing and thin client based solutions for medical image visualization as it is part of our roadmap [6].

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5. References

[1] A. Bojko, "Informative or Misleading? Heatmaps Deconstructed," Human-Computer Interaction. New Trends, Berlin, Heidelberg: Springer Berlin Heidelberg, 2009, pp. 30-39.

[2] A. Poole and L.J. Ball, "Eye Tracking in Human-Computer Interaction and Usability Research : Current Status and Future Prospects," Encyclopedia of Human Computer Interaction, C. Ghaoui, ed., Idea Group, 2006.

[3] R. Marques, L.P. Santos, P. Leškovskv Y, and C. Paloc, "GPU Ray Casting," 17º Encontro Português de Computaçao Gráfica, A. Coelho, A.P. Cláudio, F. Silva, and A. Gomes, eds., En Anexo, 2009, pp. 83-91.

[4] S. Stellmach, L. Nacke, and R. Dachselt, "3D attentional maps," Proceedings of the International Conference on Advanced Visual Interfaces - AVI '10, New York, New York, USA: ACM Press, 2010, p. 345.

[5] A. Lu, R. Maciejewski, and D.S. Ebert, "Volume Composition Using Eye Tracking Data," ACM Transactions on Applied Perception, New York, NY, USA: ACM, 2010, pp. 1-20.

[6] J. Congote, L. Kabongo, Á. Segura, A. Moreno, J. Posada, and O. Ruiz, "Interactive visualization of volumetric data with WebGL in real-time," Web3D '11: Proceedings of the 16th International Conference on 3D Web Technology, Paris, France: 2011, pp. 137-146.