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Uncertainty Visualization for Multi-resolution Volume Data with Regular Grids Using Volume Ray Casting-based Iso-surface Rendering

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Abstract. With the continuous growth of computer hardware and software performance, and the increasing advance of high-speed bandwidth of computer networking, data acquired from complex simulation, experiment and internet continues to increase and outpace hardware advantages. Visualization and analysis of such large size of data sets remains a significant challenge to the visualization community. Over the past years, various data reduction techniques that deal with large data sets have been proposed to solve the problem. However, these proposed data reduction techniques lead to another issue with regard to integrity of the data. In this paper we address this issue by presenting two new uncertainty visualization methods using volume ray casting-based iso-surface rendering. We apply them to the multi-resolution (MR) data sets from the medical domain to visualize both the data and error information. The results have proved that our methods are promising.

Keywords: Scientific Visualization; Uncertainty Visualization; Multi-resolution Data; Direct Volume Rendering; Volume Ray Casting; Iso-surface Extraction

1. Introduction

With rapid and continuous growth of computer hardware and software performance, as well as the increasing advance of high-speed bandwidth of computer networks, data sets acquired from complex science simulations, engineering experiments and the internet continue to increase and outpace current storage capacity. It leads to many difficulties with regard to visualization e.g., visual clutter and non real-time interaction, which prevent scientists to visually explore and analyze the phenomenon behind the data. Over the past years, many scientists have made efforts and proposed variety of data reduction techniques to address this issue. However, errors might be introduced into the original data set by means of these techniques and are often ignored to be depicted by traditional visualization methods [1]. As a result, scientists might be mistrustful or unconscious of the integrity of the processed data and might thus make incorrect decisions. Therefore in this paper we focus on the research field of uncertainty visualization and aim to explore new uncertainty visualization methods to assist users to faithfully represent the integrity of data for their suitable decisions.

Uncertainty visualization research has gained momentum in the visualization community since its significance was emphasized by some leading researchers [1][2][3]. However, most of the works were done on uncertainty visualization of scalar fields over 2D surfaces [4]. In this paper therefore we aim to explore the new uncertainty visualization methods of scalar volume data using direct volume rendering (DVR). We extend the volume ray casting-based iso-surface rendering algorithm and combine it with MR data together into a hybrid approach to visualize the uncertainty incorporated within the MR volume data. We also apply the new visualization methods on a data set from the medical domain to demonstrate its usability.

The structure of this paper is organized as follows. Section 2 describes the related research and their significance to our work. Section 3 introduces the Haar wavelet transformation utilized to generate the MR data sets and the error model employed to quantify the errors. Section 4 describes the extended volume ray casting-based iso-surface rendering algorithm with error information. Section 5 presents two new uncertainty visualization techniques based on the extended algorithm. Section 6 discusses the experimental results after applying our methods to the data set from medical domain. Section 7 draws our conclusions and we discuss the future direction and work to be carried out.

2. Related Work

2.1. MR Volume Data

With the growing interest of visualization and analysis of large-scale data sets as well as the increasing user demands for real-time exploration and interaction, MR methods have been developed rapidly to reduce the size of data sets and therefore speed up the output of graphics during past decade. There has been a large number of different MR methods proposed, each one with its preferred application. Here we only discuss two methods that we are interested in. A more extensive summary can be found in [5]. The first method is called wavelet transformation. In this method, two filters are applied to the original data set. The low pass filter is used to capture the coarse approximations of the original data set while the high pass filter is used to capture the details. Since wavelet transformation has the firm mathematical basis and nice theoretical properties, many publications have proposed using it for data compression [6][7][8]. The second method we are interested in is called decimation. In this method, elements are iteratively removed from the data set and the information decimated from the data set is simply discarded. A number of papers have also been published to adopt this method to decrease the size of data sets [9][10]. In this paper, we only present how to utilize the wavelet transformation based methods, especially Haar wavelet transformation to acquire the MR hierarchy of original data. However, it is equally possible to utilize the decimation method to obtain the MR data sets.

2.2. Direct Volume Rendering

DVR is a technique that produces two-dimensional images from discrete, three-dimensional volume data directly. In other words, it projects the three-dimensional representation of volume data directly into a two-dimensional frame buffer. All data in the DVR is characterized by two properties: color and transparency. The color represents the color of the data, and the transparency represents the obscured relationship within the volume data. Both of them, together with the optical model, form the mechanism that allows DVR to depict the entire picture of the three-dimensional data set, including visualization of its internals.

Over the past years a number of DVR algorithms have been proposed for visualizing the characteristics of volume data e.g. volume ray casting, splatting, shear warp and texture mapping. In particular, due to the high quality rendering results, volume ray casting has become the most frequently used algorithm in DVR and has been extended for displaying iso-surface as well [11][12]. Unlike traditional marching cubes-based iso-surface rendering, which involves approximating a surface contained within the data using geometric primitives, there are no inter-mediate geometric primitives constructed during volume ray casting-based iso-surface rendering. This method generates rays from the viewpoint through each screen pixel into volume space, and it finds the intersection point of the ray and the iso-surface. The intersection point can be found by an analytic method [13] or an interpolation method [14]. The intensity value of the pixel is calculated at the intersection point. As a result, we can now visualize the iso-surface of volume data without going through an inter-mediate surface extraction and the concern about generating an excessive amount of geometric primitives can be dispelled. In this paper, we utilize the volume ray casting-based iso-surface rendering method to render the iso-surface incorporated within the volume data.

2.3. Uncertainty Visualization

Some of the earliest work of uncertainty visualization was carried out by the geographic information systems (GIS) community. Their work is mainly to represent the uncertainty and error for terrain models. Later, Pang and his colleagues made some significant contributions to the uncertainty visualization [15][16].

Their work summarized various forms of uncertainty that is often introduced during the process of data acquisition, transformation and visualization. They also present a variety of techniques suitable for the introduced uncertainty. These techniques ranged from adding or modifying the model's geometry to using textures. However, these techniques are not applicable for visualizing volume data with uncertainty. Uncertainty visualization research started to receive more attention in the visualization community since its significance was emphasized by some leading researchers [1][2][3]. And visualizing the uncertainty within volume data started to become a hot topic. However, few papers have been published to study the uncertainty visualization of MR volume data. P. J. Phodes et al. [17] proposed to utilize hue and opacity of textures to convey errors incorporated in low resolution approximations of original data. These two methods have been proved to be effective and meaningful for uncertainty visualization. Their future work expects to incorporate uncertainty into more complex direct volume visualization. In this paper, we exploited volume ray casting-based iso-surface rendering to visualize uncertainty in MR volume data.

3. MR Data Generation and Error Model

3.1. Haar Wavelet Transformation

Haar wavelet transformation is one of the simplest wavelet-based algorithms. It can be used effectively to generate MR data models. Application of the Haar wavelet on discrete data will yield both a summary as well as detail information [18]. The size of the summary and detail information will depend on the concrete dimensions of the data set used. For a one dimensional data set with s values, the 1D Haar wavelet will be used to transform it into a s/2 summary and a s/2 detail coefficient. For a two dimensional data set with m x n values, the 1D Haar wavelet algorithm will be applied firstly along its each row, and then along its each column. This process is normally called 2D Haar wavelet transformation which results in a summary with 1/4 size of original data (m/2 x n/2), and 3 quadrants of detail data. Similarly, for a three dimensional data set with m x n x l, the 1D Haar wavelet algorithm will be applied on it firstly along each row, then along each column, and finally along each slice. This process is normally called 3D Haar wavelet transformation and a summary with 1/8 size of original data (m/2 x n/2 x l/2), and 7 octants of various detail coefficients will be generated.

In order to obtain the MR hierarchy of an original data set, multiple passes of Haar wavelet transformation have to be applied on the data set. Figure 1 shows a 2D example of MR data sets with regular grids. Each black dot in the figure represents a unique sampling point where an attribute value resides. The dimensions of the original data set are 8 x 8 (Figure 1(a)). After one 2D Haar wavelet transformation, the dimension of the first low resolution representation of the original data set is 4 x 4 (Figure 1(b)). After applying two passes of the 2D Haar wavelet transformation, the dimension of the second low resolution representation of the original data set is 2 x 2 (figure 1 (c)). As a result, we obtain a MR hierarchy with 3 different resolutions.

3.2. Error Model

Quantification of the uncertainties that were introduced into the low resolution approximations of the original data set is an essential step to implementing uncertainty visualization. In our case, we use the Standard Deviation Model (SDM) to measure the local information of error, as illustrated in equation 1:

$$e = \sqrt{\frac{1}{n}[(V_1 - \bar{V})^2 + (V_2 - \bar{V})^2 + \cdots + (V_n - \bar{V})^2]} \quad (1)$$

Where e represents a local measurement of the error based on n grids points; n represents the number of grids points used to calculate a weighted average of $\bar{V}$; V_1, V_2,…, V_n represent the attribute values resident on those grid points; $\bar{V}$ represents the weighted average value based on V_1, V_2,…, V_n.

We perform the calculations of local errors on the entire volume data iteratively, using the attribute values of the data points from the original data set and the corresponding attribute value of the data point from the low resolution data set. Consequently we get error values, each one being associated with a data point of the low resolution data set. Based on the availability of the MR data sets as well as the error information, we can now explore the new uncertainty visualization methods for depicting the errors.

4. Extended Volume Ray Casting-based Iso-surface Rendering with Error Information

The traditional volume ray casting-based iso-surface rendering usually only renders data without error information. In order to take advantage of this algorithm to explore new uncertainty visualization techniques, we have to extend it. The process is repeated and can be divided into three steps. The first step is to find each sampling point's 8 nearest bounding points that consist of one voxel. The second step is to get the error values of the 8 bounding points. The third step is to get the error value of the sampling point by means of tri-linear interpolating the error values of those 8 bounding points.

After performing such three steps at every sampling point, we can have a collection of local error measurement of the iso-surface, along with its data values. Now we can explore different visualization methods to depict the errors.

5. Uncertainty Visualization Using Volume Ray Casting-based Iso-surface Rendering

5.1. Uncertainty Visualization Using Hue

Mapping the error to hue is a good choice and it is generally agreed that we are more visually sensitive to changes of hue rather than changes of saturation. P. J. Rhodes and his colleagues [17] carried out an experiment to map the error to hue for depicting the uncertainty and their result has been proved to be effective. Therefore we reference their idea into our experiment and apply it into a more complex rendering technique.

The idea itself is quite simple. As we know, HSL (Hue, Saturation, and Lightness) is a cylindrical-coordinate representation of points in an RGB color model which rearranges the geometry of RGB in an attempt to be more intuitive and perceptually relevant than the Cartesian representation. In this idea, we keep the components of saturation and lightness within the HSL model unchanged, and we only depend on the values of errors to change the values of hue. Consequently users can express and distinguish the values of errors according to different visual effect of hue.

In this experiment, we select the angle range of hue from 0° to 60°, which corresponds to red and yellow in the RGB color model. We utilize pure yellow to render the error-free data set and we exploit red to render the errors. The more reddish the color is, the bigger the error is and vice versa. Figure 3 illustrates the results of the experiment.

5.2. Uncertainty Visualization Using Transparency

Mapping errors to transparency is another straightforward and feasible choice for volume ray casting-based iso-surface rendering. In this experiment, we map the errors with large values to less transparency and map the errors with small values to high transparency. In this way, we enable users to evaluate and distinguish the errors of the MR data sets by observing the different levels of transparency.

6. Experimental Results

The data set we utilized to test our program is a Computed tomography (CT) scan of a cadaver head, available at [19]. The original dimensions of the data set are 256 x 256 x 113, with 2 bytes per voxel. For the convenience of the 3D Haar wavelet transformation, we appended 143 extra slices at the end of the original data set to obtain a 256 x 256 x 256 data set (figure 2(a)). We then applied two successive 3D Haar wavelet transformations on the data set to get two coarse resolutions, as shown in figure 2(b) and figure 2(c), respectively.

6.1. Results of Uncertainty Visualization Using Hue

Figure 3(a), (b) and (c) show the MR data sets' results after we utilize hue to depict the errors that exist in the extracted iso-surface. Figure 3(a) presents the original data set. Since there is no error in the data set, the iso-surface shown in figure 3(a) appears pure yellow. Figure 3(b) presents the data set to which one pass of 3D Haar wavelet transformation has been applied. Since certain errors were introduced during the transformation, the appearance of the iso-surface shown in figure 3(b) is slightly reddish. In particular, it is clear that the color around the mouth of the skull is redder. That means in such an area the error values are larger. Figure 3(c) presents the data set to which two passes of 3D Haar wavelet transformation has been applied. It is clear that more reddish appears in the iso-surface. Clearly, more errors have been introduced during the process of two passes of 3D Haar wavelet transformation and a substantial amount of data accuracy has been lost.

6.2. Results of Uncertainty Visualization Using Transparency

Figure 4(a) and (b) show the corresponding results for MR data sets after we exploit transparency to depict the errors. Here, we did not present a figure for the original data set, as what we did for figure 3(a). Since errors in this method are visualized by increased opacity (reduced transparency), the original, error-free data will be completed transparency. Therefore, we only need to render the figures for the two coarse approximations of the original data. Figure 4(a) presents the data set that is reduced by one pass of 3D Haar wavelet transformation. It is clear that in the areas around mouth, left eye and the left lower jaw of the skull the transparency of the iso-surface is low. That corresponds to relatively high error values. On the contrary, in certain areas like the chin, the transparency of the iso-surface is high, which refers to the relatively low error values. Figure 4(b) presents the data set that is reduced by two passes of 3D Haar wavelet transformation. From this figure it is clear that it is perceptually difficult to distinguish the different levels of opacity based on this data set, since more errors are introduced and the appearance of the iso-surface tends to be more opaque. In order to reflect the values of errors using transparency effectively, we performed further improvement of our experiment to enhance its effectiveness. Section 6.3 presents the details.

6.3. Results of Enhanced Uncertainty Visualization Using Transparency

We draw grids as the background of the image to reveal the transparent degree of the data set. Figure 5(a) presents the corresponding result of the design based on the same data set as utilized in figure 4(b). We place the position of the grids at the back of the data set so that the ray casted from every pixel of the screen will go through the data set first, and then pass through the grids. In figure 5(a) it is clear that in many areas of the skull e.g., at the top of the head, the data is more opaque and that implies the values of errors in those areas are relatively big. On the contrast, in some areas like in the middle of the skull, the data is more transparent and that implies the values of the errors in those areas are relatively small. As a result, the obscuring relationship of the grids reflects the transparency of the data set.

In addition to the method of drawing grids, we can also design suitable transfer functions to enhance the contrast of the transparency. Here we only present a very simple step function for the purpose of demonstration. The transfer function can be expressed as the following formula:

$$tranparency = f(error) = \begin{cases} 0.1, & error < 0.4; \\ 1.0, & error \geq 0.4. \end{cases} \quad (2)$$

Where *error* is the independent variable and its range is between *0.0* to *1.0*; *transparency* is the dependent variable and its range is between *0.0* to *1.0*.

Figure 5(b) illustrates the corresponding result based on the simple step function for data set after one pass of wavelet transformation. It is clear that the opacity in the area of mouth is high, and it means the high values of errors (*error* >= 0.4). On the contrast, the opacity in other areas is low, and it means the low values of errors (*error* < 0.4).

7. Conclusion and Future Work

In this paper we present two useful methods to depict the errors of MR volume data sets through volume ray casting-based iso-surface rendering. We map the errors to the hue and transparency respectively to evaluate their effects for uncertainty visualization. In summary, using hue to reflect the error values is a very effective approach for volume ray casting-based iso-surface rendering since the human visual system is quite sensitive to the changes of hue. Alternatively, using transparency to express the errors is another useful method for volume ray casting-based iso-surface rendering. However, in order to perceptually distinguish the different levels of transparency or opacity easily, it is very important to apply good strategy e.g., drawing grids as background or design suitable transfer functions.

In the near future we are planning to explore more new methods to express the uncertainty within volume data and apply these techniques to different application domains based on different formats of data.

8. References

[1] C. R. Johnson, A. R. Sanderson, 2003. A Nex Step: Visualizing Errors and Uncertainty. IEEE Computer Graphics and Applications. No. 5, Vol. 23. Pp.6 -10.

[2] C. R. Johnson, 2004. Top Scientific Visualization Research Problems. IEEE Computer Graphics and Applications. No. 4, Vol. 24. Pp. 13 -17.

[3] C. M. Chen, 2004. Top 10 Unsolved Information Visualization Problems. IEEE Computer Graphics and Applications. No.4, Vol. 25. Pp. 12 -16.

[4] V. Dinesha, N. Adabala, V. Natarajan, 2011. Uncertainty Visualization using HDR Volume Rendering. The Visual Computer. Pp. 1 -14.

[5] E. Puppo, R. Scopigno, 1997. Simplification, LOD and Multi-resolution Principles and Applications. Eurographics Tutorial. Blackwell Publishers.

[6] P. C. Wong, R. D. Bergeron, 1995. Authenticity Analysis of Wavelet Approximations in Visualization. In Proceedings of IEEE Visualization '95. IEEE Computer Society Press. pp. 184 – 191.

[7] P. C. Wong, R. D. Bergeron, 1997. Performance Evaluation of Multi-resolution Iso-surface Rendering. In Proceedings of Scientific Visualization '1997. pp. 322 – 331.

[8] A. Foulks, R. D. Bergeron, J. P. McHugh, 2005. STARview: A Multi-resolution Time Series Data Visualizer. Visualization and Data Analysis. pp. 187 – 198.

[9] R. Klein, G. Liebich, W. Strasser, 1996. Mesh Reduction with Error Control. In Proceedings of Visualization '96. pp. 311 – 318.

[10] P. Lindstrom, D. Koller, W. Ribarsky, L. F. Hodges, N. Faust, G. A. Turner, 1996. Real-time, Continuous Level of Detail Rendering of Height Fields. In Proceedings of the 23rd Annual Conference on Computer Graphics and Interactive Techniques. Georgia Institute of Technology.

[11] J. J. Choi, B. S. Shin, Y. G. Shin, K. Cleary, 2000. Efficient Volumetric Ray Casting for Iso-surface Rendering. Computer and Graphics, No. 5, Vol. 24, pp. 661 – 670.

[12] S. Parker, S. Shirley, Y. Livnat, C. Hansen, P. Sloan, 1998. Interactive Ray Tracing for Iso-surface Ray Casting. IEEE Visualization, pp.233 – 238.

[13] C. Lin, Y. Ching, 1996. An Efficient Volume-Rendering Algorithm with An Analytic Approach. The Visual Computer. Pp 515 – 526.

[14] U. Tiede, T. Schiemann, K. Hohne, 1998. High Quality Rendering of Attributed Volume Data. IEEEVisualization 98. Pp 255 – 262.

[15] A. T. Pang, C. Wittenbrink, S. Lodha, 1997. Approaches to Uncertainty Visualization. The Visual Computer. Pp 70 – 90.

[16] S. K. Lodha, B. Sheehan, A. T. Pang, C. M. Wittenbrink, 1996. Visualizing Geometric Uncertainty of Surface Interpolantes. In GI '96 Proceedings of the Conference on Graphics Interface, pp. 238 – 245.

[17] P. J. Rhodes, R. S. Laremee, R. D. Bergeron, T. M. Sparr, 2003. Uncertainty Visualization Methods in Iso-surface Volume Rendering. Eurographics 2003. Pp. 83 – 88.

[18] A. Foulks, R. D. Bergeron, 2009. Uncertainty Visualization in the VisIt Visualization Environment. In Proceedings of Visualization and Data Analysis 2009. Vol, 7243.

[19] M. Levoy, 2000. CT scanner of a cadaver head volume data set [Internet]. Available at http://graphics.stanford.edu/data/voldata/

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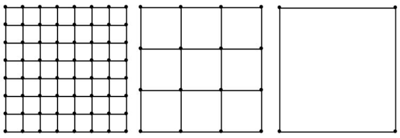
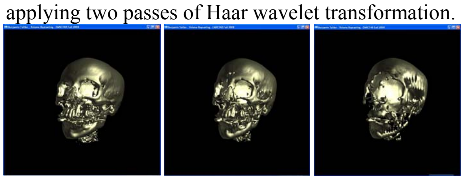


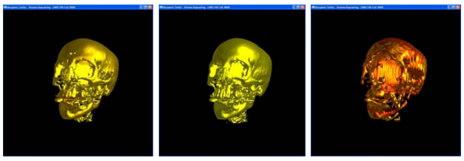
(a) (b) (c)

Figure 1. MR data hierarchy: (a) original data set. (b) first low resolution representation after applying one pass of Haar wavelet transformation. (c) second low resolution representation after applying two passes of Haar wavelet transformation.



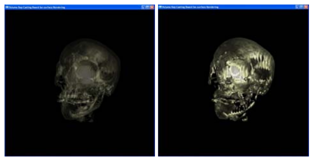
(a) (b) (c)

Figure 2. the MR data hierarchy of a cadaver head with iso-surface value of 128: (a) original data set with dimensions of 256^3. (b) after one pass of 3D Haar wavelet transformation with dimensions 128^3. (c) after two passes of 3D Haar wavelet transformation with dimensions 64^3.



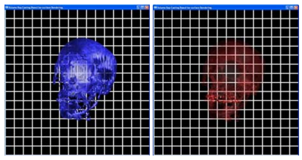
(a) (b) (c)

Figure 3. the MR data hierarchy of a cadaver head with iso-surface value of 128, after mapping the errors to hue: (a) the original data set with dimensions of 256^3. (b) after one pass of 3D Haar wavelet transformation with dimension 128^3. (c) after two passes of 3D Haar wavelet transformation with dimensions 64^3.



(a) (b)

Figure 4. the two coarse approximations of the original data set with iso-surface value of 128, after mapping the errors to transparency: (a) after one pass of 3D Haar wavelet transformation with dimensions 128^3. (b) after two passes of 3D Haar wavelet transformation with dimensions 64^3.



(a) (b)

Figure 5. (a) use grids as the background to enhance the effectiveness of data's transparency. The data set is 64^3, after two passes of 3D Haar wavelet transformation. (b) use transfer function to enhance the contrast of the data's transparency. The data set is 128^3, after one pass of 3D Haar wavelet transformation