Assignment 5
Class CS-6635
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Part 1: Multi-Field Visualization [20 pts]

Step by Step Explanation:

1. First I uploaded the hurricanekatrina.vts file into Paraview and apply QCLOUD volume rendering as shown in the figure 1. QCLOUD mostly have dense lower range values (1e-12 - 4e-4) with scattered higher values in the range of 1.5e-3.

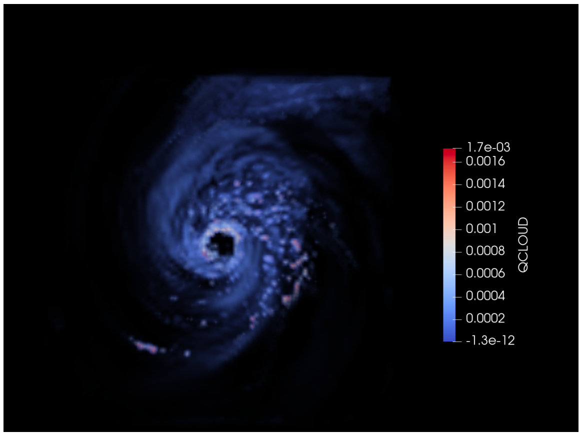

Fig 1. Volume rendering of QCLOUD.

2. Selected a contour filter with QCLOUD iso-surface value 2e-4 as shown in the figure 2 and optimized the transfer function for better view.

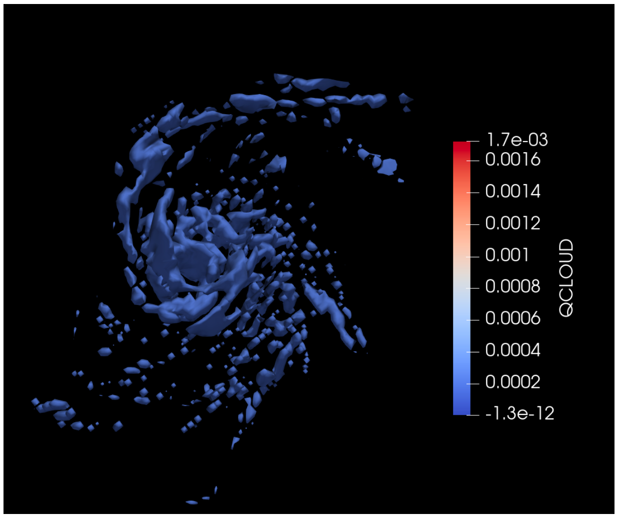

Fig 2. Iso surface using contour value 2e-4

3. Selected the stream tracer filter for wind flow visualization with seed type line, kept the resolution to 100 to have clear view of the stream lines, selected the coloring with wind magnitude with a different color map and transfer function as shown in figure 3.

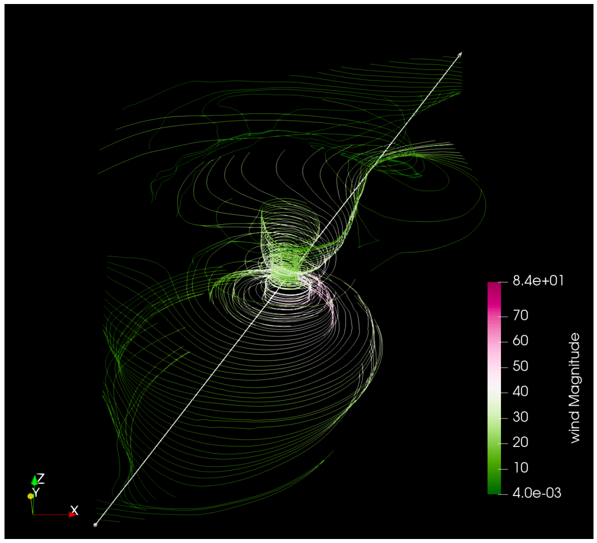

Fig 3. Stream lines of wind flow

4. Applied arrow glyphs with orientation as wind and scale as wind and adjusted the scale factor as shown in figure 4.

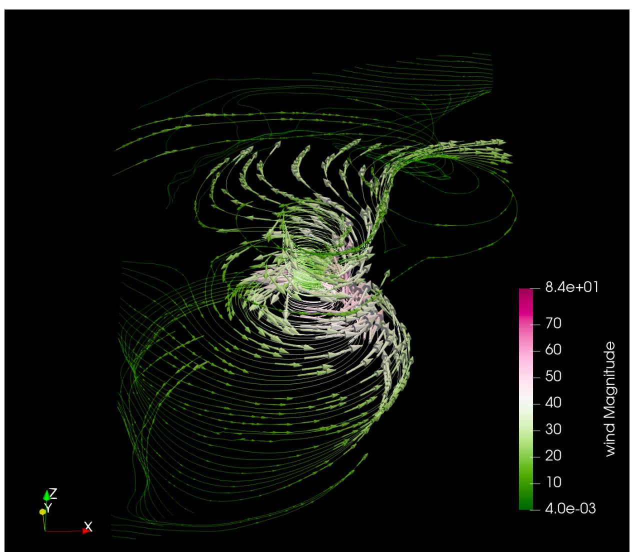

Fig 4. Stream lines of wind flow with arrow glyphs

5. Visualizing all at once as shown in Figure 5. Single visualization including QCLOUD volume rendering, QCLOUD iso-surface, wind flow streamlines with wind flow arrow glyphs.

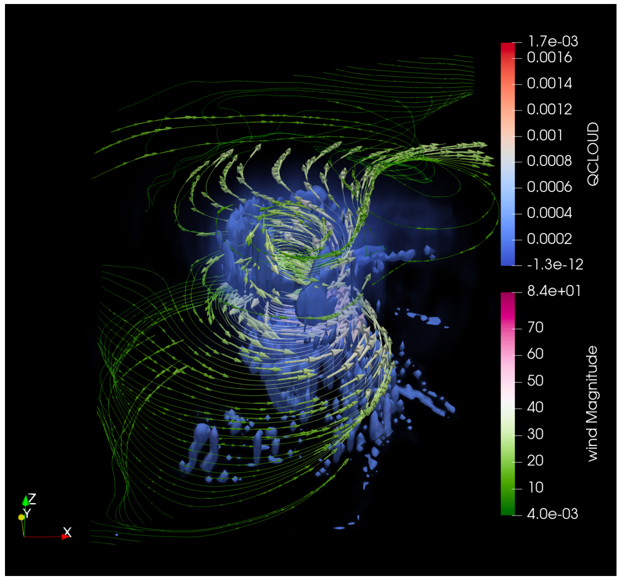

Fig 5. Single visualization QCLOUD volume rendering, QCLOUD iso-surface, wind flow streamlines with wind flow arrow glyphs.

Please explain what you can understand of the simulation data via your multi-field visualization.

1. Near the eye of the hurricane the wind velocity is maximum colored by pink and with bigger arrow size.
2. Top and bottom of the hurricane the wind velocity is low as seen by green color with small arrow size.
3. The direction of wind flow is in counterclockwise direction.
4. Cloud moisture mixing ratio denser at the center than the periphery and both the ends as seen in the QCLOUD rendering.

Part 2: Reading Questions (The visualization handbook) [20 pts]

1) What is diffusion tensor MRI imaging? State three types of diffusivities and describe each briefly. How a diffusion tensor can be represented mathematically? [Chapters 15,16]

DT MRI represents the anisotropic diffusion of water molecules in biological tissues. It works by application of magnetic field gradient results into the diffusion of water molecules. This technique provides the insight into microstructure of the tissues especially the brain. The diffusion rate of water molecule is different biological tissue depends on cell shape and cell membrane properties. DT MRI is useful for understanding the brain connectivity and any abnormality.

Three types of diffusivities

Axial Diffusivity: This represents the rate of diffusion along the principal axis of diffusion. For example, in the brain DT MRI, axial diffusivity is in the direction parallel to white matter fibers. It is associated with the largest eigenvalues of the diffusion tensor.

Radial Diffusivity: This represents the rate of diffusion perpendicular to the principal axis of diffusion. For example, in brain DT MRI, it represents the change in the myelin sheath.

Mean Diffusivity: Average rate of diffusion in all directions. It is calculated by taking the average of all three eigenvalues of the diffusion tensor and provides information on the general structure of the tissue.

A diffusion tensor can be represented mathematically as a symmetric 3 x 3 matrix showing how diffusion varies in the three-dimensional space. This tensor represents the diffusion process across each voxel in the tissue. By using the matrix decomposition technique, this tensor can be represented as eigenvalues and eigenvectors where eigenvalues represent the diffusivity, and the eigenvectors represent the principal diffusion direction.

2) Briefly describe box, ellipsoid, and superquadric glyphs for visualization of tensors field. Compare and contrast the benefits and disadvantages for these glyphs. [Chapter 16]

Box, Ellipsoids, and Superquadric glyphs are the geometric representations used in the local visualization of tensor fields. These glyphs visually encode the properties of each tensor, such as its shape and orientation.

Box Glyphs: In Box Glyphs tensors are represented as box-like shapes where edges of the box represent the eigen values of the tensor and orientation is corresponding to the eigen vector.

Benefits: Box glyphs can distinguish between tensors of different shapes and orientation by edges and corners, useful for areas of high anisotropy. The anisotropy regions can be well distinguished from the isotropic and planar anisotropy by using box glyphs.

Limitation: Box glyphs are misleading for planar anisotropy and isotropy as the eigen vectors are not numerically well defined. Also, occlusion / clutters arise due to solid box glyphs for densely packed tensors results difficulty in data interpretation.

Ellipsoid Glyphs: Uses ellipsoids to represent the tensor fields where the axis of the ellipsoids is aligned with the eigen vectors of the tensor, and the axis lengths are proportional to the eigen values.

Benefits: Ellipsoid glyphs provide smooth continuous representation of tensor fields and reduces visual clutter suitable for dense tensor field visualization.

Limitation: Challenging to distinguish between slightly anisotropy and isotropy tensor fields

Superquadric glyphs: Provides most flexible representation of tensor fields. Smooth transition between spherical, cylindrical and cuboid shapes and provides a versatile and clear representation between isotropic, planar and linear diffusion profiles.

Benefits: Superquadric glyphs combine the best of the box and ellipsoid methods reduced ambiguity by varying the shape based on diffusion anisotropy.

Limitations: Increased complexity and computationally challenging affecting the speed in real time applications.

Part 3: Brain DTI Tractography Visualization [30 pts]

Loaded the data 'brain_dti', It contains diff_5k.nii, a brain DTI scan; bvals_5k.txt, the b-values for each voxel; and bvecs_5k.txt, the b-vectors for each voxel.

1) Performed the steps T1 and T2 to compute fiber tracking data. I kept the diffusion sampling length ratio at 0.8 and applied the reconstruction to generate the FIB file.

2) In step T3, I opened the FIB file and created a tensor field visualization of two different choices of MRI slice. Figure 6 represents the diffusivity pattern of one of the sub regions of the MRI slice.

In this figure we can see most of the lines are parallel and uniform following certain direction which indicates strong anisotropy region in the white matter of brain where water diffuses faster along the axis of the neurons. Some of the regions have very small lines or spheres showing isotropic diffusion where there is no dominant eigen vector and water diffuses with same speed in all direction. At some tensor includes multiple direction indicating complicated fiber structure of brain and some region does not show any tensor indicating region with no diffusion of water.

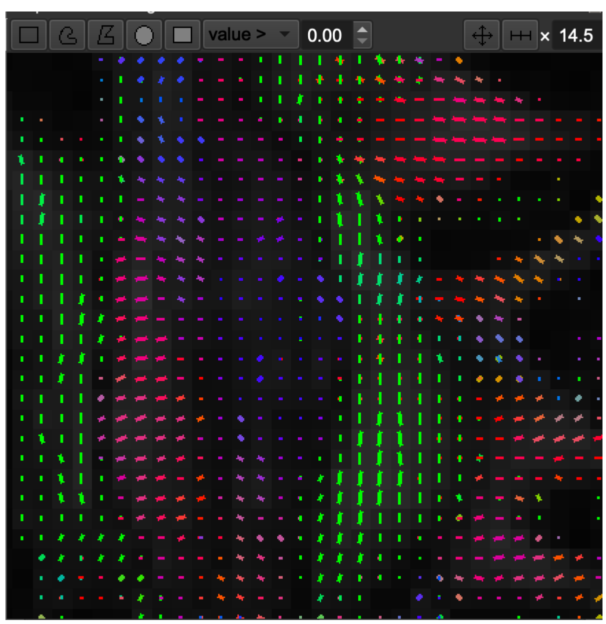

Figure 6. Diffusivity pattern of one sub region of DT- MRI slice

3) I Performed the fiber tracking and visualize the tractography for the whole brain. I adjusted the tracking parameters and track rendering to obtain the below images. Figure 7, 8, and 9 represents the whole brain fiber tractography in axial, sagittal and coronal view. These images show primary direction of water diffusion in brain tissue. It can be seen that the fibers are color-coded identifying the orientation of white matter tracts within the brain. Red indicates the diffusion that primarily from left to right, green represents diffusion from anterior to posterior (front-back) and blue indicates diffusion from superior to inferior (up-down). This shows the complex microstructure of brain and helps in identifying brain connectivity and any kind of abnormalities.

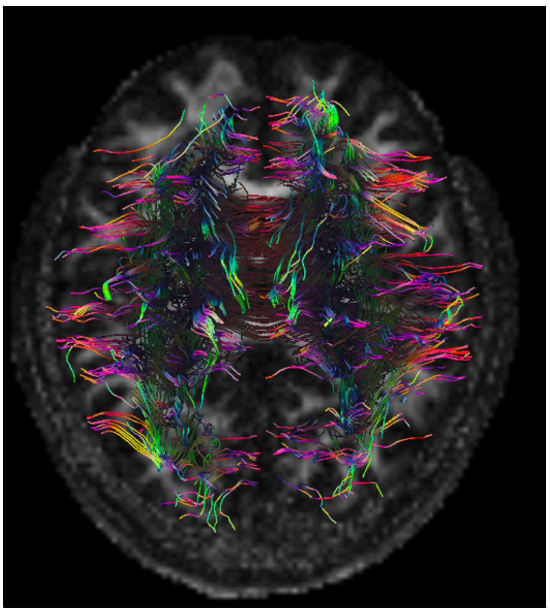

Figure 7. Whole brain fiber tractography Axial view

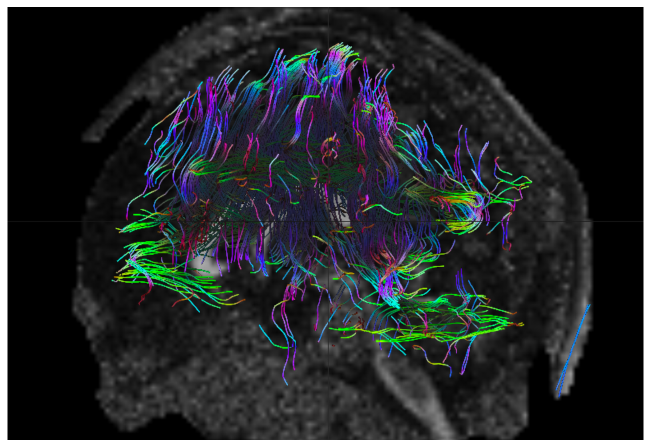

Figure 8. Whole brain fiber tractography sagittal view

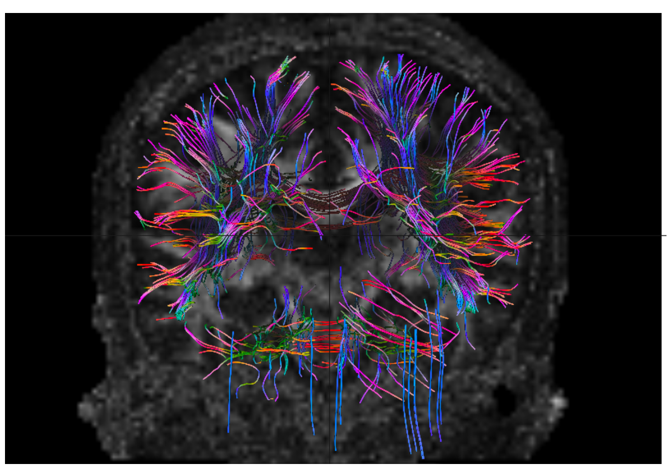

Figure 9. Whole brain fiber tractography Coronal view

4) I kept the sagittal view and drew a region corresponding to the brain stem. Set this region as the seed and compute the tractography. Figure 10. shows the image of the brain stem region tractography. In this figure we can see the brain stem, which is the important part to transfer the information from brain to spinal cord has connected to the brain neurons. The fibers show the connectivity between brain stem and the brain neurons.

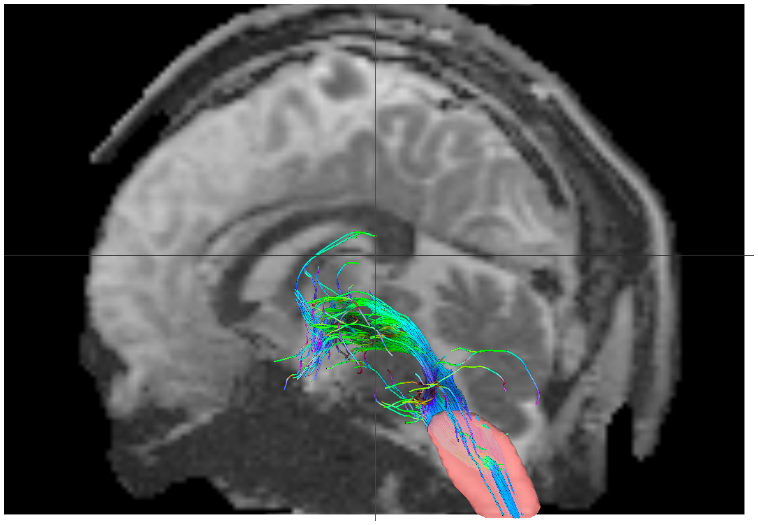

Figure 10. Brain stem region fiber tractography sagittal view

5) I used the cubic region selector, made two new regions where each roughly cover each brain hemisphere, as shown in the image below in figure 11. I added multiple cuboids for each region to achieve this. I set left hemisphere region as the seed and the right hemisphere region as ROI (Region of Interest). I adjusted the tracking parameters to obtain the fiber tractography for the selected regions. Figures 12 and 13 visualize the tracts that start in seed region and connect to the region of interest. Figure 12 shows axial view and figure 13 shows the coronal view of the fiber's tracts. Here we can see dense tracts at the central region connecting the left hemisphere with the right hemisphere. This image provides the more detailed view of the tracts connecting both hemispheres.

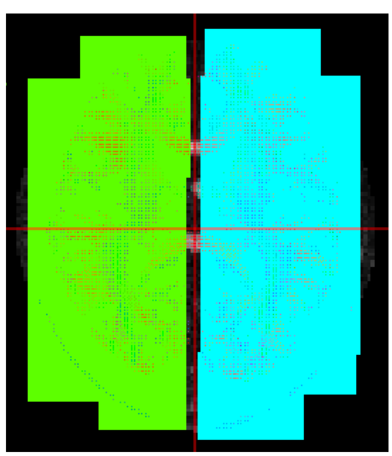

Figure 11. Selected regions to cover each brain's hemisphere (green – seed and blue -ROI)

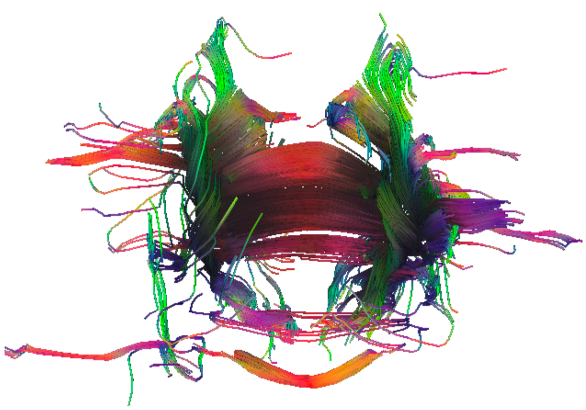

Figure 12. Hemispheres Tracts Axial View.

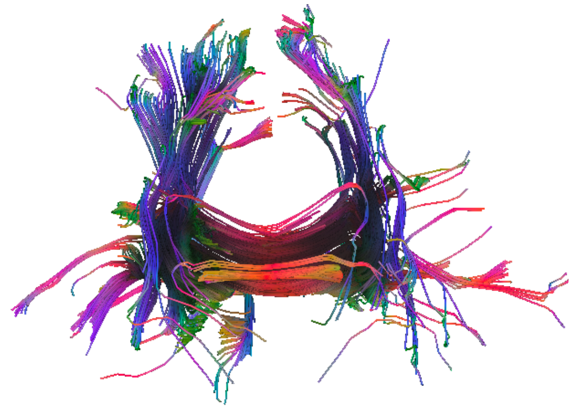

Figure 13. Hemispheres Tracts Coronal View.

Part 4: Tensor Glyph Visualization in ParaView [20 pts]

1) Loaded the dataset in Paraview and visualized the tensor using different glyphs.

2) Applied different glyphs and adjusted the glyph parameters and shading to visualize the tensor field. The images are shown below. Sphere glyphs (fig 14 and 15), box glyphs (figure 16), cylindrical glyphs (figure 17), and superquadric glyphs (fig 18).

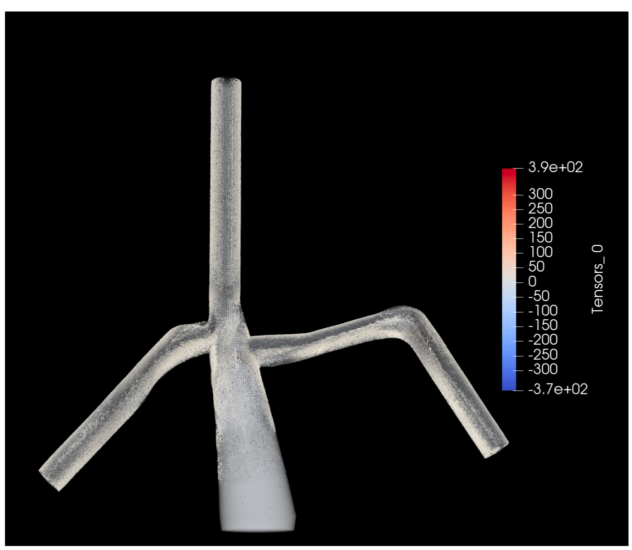

Figure 14. Tensor Field representation using sphere glyphs

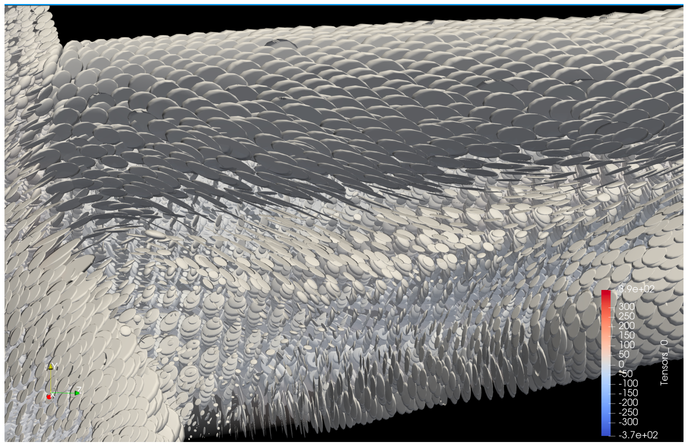

Figure 15. Tensor Field representation using sphere glyphs (zoomed view)

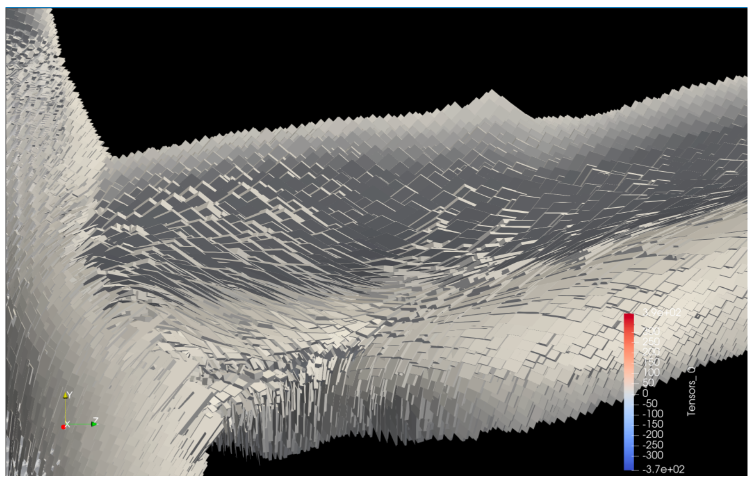

Figure 16. Tensor Field representation using box glyphs

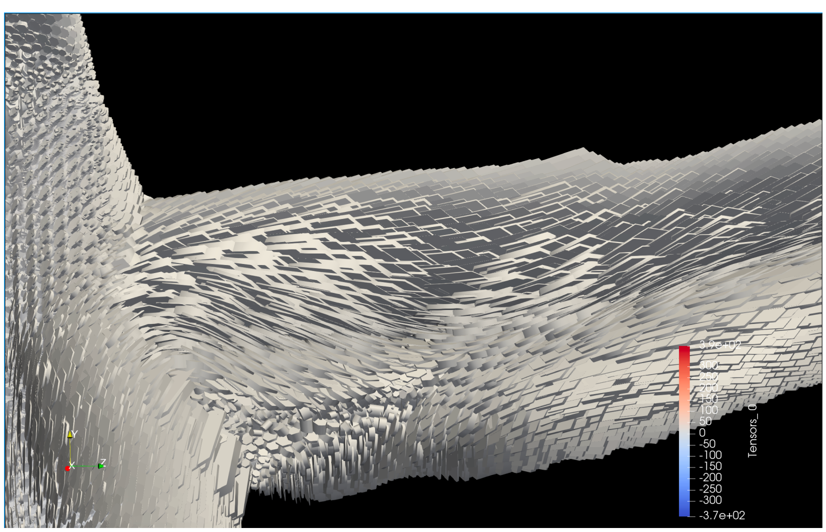

Figure 17. Tensor Field representation using cylindrical glyphs

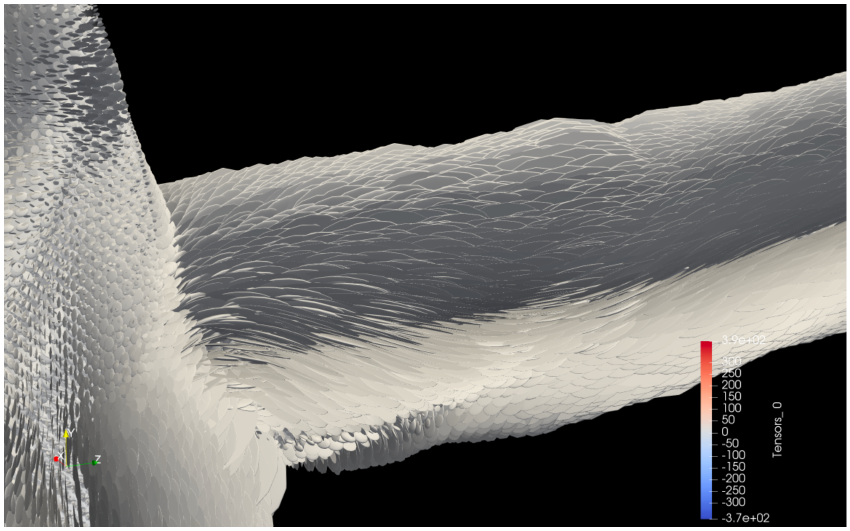

Figure 18. Tensor Field representation using superquadric glyphs

3) Which glyphs did you find the most informative for gaining insight into the tensor field data? Why?

I found the superquadric glyphs provide most information, as it clearly captures the dense tensor fields without any kind of clutter and able to represent the linear, planar anisotropy and isotropy tensors fields by varying the shapes.

Part 5: Reading Question on Multi-field Data Visualization (only for CS6635 students) [20 pts]

I read the 1st paper: J. Kniss, S. Premoze, M. Ikits, A. Lefohn, C. Hansen, and E. Praun; Gaussian Transfer Functions for Multi-Field Volume Visualization; In Proceedings of the 14th IEEE Visualization 2003, 2003.

- What is the new innovation described in the paper?

The paper focuses on Gaussian Transfer Functions (GTF) for volume rendering in the case of multi-variate datasets and highlights several key aspects.

1. **Direct evaluation of Transfer function without look up table reducing the need for a large amount of memory storage:** Contrary to traditional volume rendering techniques, where to visualize multi-valued data, the data values are converted to observable quantity such as color and opacity based on the transfer function and the precomputed lookup tables are used for volume rendering, GTF offers a compact and effective mean of volume rendering by direct evaluation of transfer function without use of lookup tables. Thus, GTF does not need a large amount of memory

storage like traditional volume rendering techniques and offers a concise and effective method for rendering volumes.

2. **Efficient use of graphics hardware:** The major innovation is the use of graphics hardware to achieve real-time high-quality interactive volume rendering for multi-variate data.

3. **Analytical integration of Transfer function:** This paper presents a method for analytical integration of GTF along line segments assuming linearly varying data between sample points. This technique improves the quality of volume rendering, specifically in identifying the narrow boundary in the dataset. Using this, common artifacts resulted because of under-sampling is mitigated by the traditional numerical integration method.

4. **Triangular GTF:** The adaptation of triangular GTF to include the gradient magnitude information improves the classification of the boundaries and interfaces by adjusting the width of Gaussian based on gradient magnitude.

- What did you learn by reading the paper?

After reading this paper, I have learned these key aspects:

- Gaussian Transfer functions are simple in parameterization, making them suitable for real-time rendering on modern graphics hardware.

- GTF overcomes the limitation of traditional volume rendering methods. Traditional volume rendering methods rely on the precomputed look-up table, requiring a large amount of memory storage. In contrast, GTF calculations are done by direct evaluation without any look-up table addressing the challenges related to storage concerns and the dynamic range of the multivariate data.

- Analytical gradient provides high-quality visualization with fewer samples, reducing artifacts that typically arise from under-sampling.

- Improvement in the classification of boundaries by using triangular GTF leveraging the gradient magnitudes.

- The innovations presented in the paper suggest future research direction in visualization.

What are the weaknesses in the paper? E.g. What claims are not convincing, and why? Are there claims made without adequate evidence? Are there weaknesses in how the authors evaluate the performance/effectiveness of their proposed technique?

The authors have highlighted the weakness of GTF in the paper and also mentioned where GTF could be beneficial, for example:

- If speed is the primary concern, then the separable transfer function with the look-up table is sufficient for volume rendering.

- The cost of analytical integration of GTF is high, but it is more effective for the classification of thin materials boundaries.

I found some areas for improvement in the paper which are not addressed in the paper.

- There should be a more detailed comparison of GTF with other traditional volume rendering methods concerning relative performance and quality improvements.

- The performance of GTF across a wide variety of datasets and a wide variety of hardware should have been discussed.

- The paper does not discuss the user interface and how users can design and adjust the GTF parameters for specific visualization tasks.

- The paper does not mention evaluations based on memory requirement, rendering speed, and image quality assessment under varying data sizes and dimensions.

- The analytical integration assumes linearly varying data between sample points; however, this paper does not discuss the implication of this assumption, in which cases this assumption fails to get accurate volume rendering.

-Is what the paper presents useful, or is it just a curiosity?

This paper highlights Gaussian Transfer Functions for significant advancement in volume rendering technique compared to the traditional volume rendering method, which is not curiosity-driven but offers substantial scientific contribution in the visualization field.

The authors have addressed the challenges in the existing volume rendering methods, offer practical solutions for real-world applications, and provide a foundation for future research.

-What did you want to know more details about?

1. User Interface Tool: The paper needs to provide more detail on the user interface and how a user can select and adjust the parameters of GTF for complex multivariate datasets.

2. Versality of the GTF techniques in various fields of science and engineering, such as application in the biological, fluid dynamic, and geological dataset

3. Limitations and challenges where GTF does not provide significant advantages over traditional volume rendering methods.

4. Automatic feature detection capability by optimizing the parameters of GTF.

-Does the paper provide enough detail to allow you to implement the proposed technique yourself? If not, which part is not detailed enough?

The paper provides a comprehensive overview of the GTF and its variants, such as triangular GTF and analytical gradients; however, additional details are required to implement the proposal myself.

1. The paper has explained the mathematical details of the GTF; however, it has not provided any code repository, making it difficult to implement.

2. A working example with a multivariate dataset could have been beneficial in understanding the complexity.

3. Guidance on GTF parameters selection and adjustment could have been beneficial to implement the complex multivariate data visualization.

Conclusions:

This assignment has helped me understand below highlighted point:

- Multifield Visualization: I could visualize multiple fields in one image by implementing volume rendering, iso-surface rendering, streamline visualization, and glyphs.

- DT MRI analysis using DSI Studio: I learned a new tool DSI studio and understood about Diffusion tensor MRI, which leverages the diffusion of water molecules under a magnetic field to visualize the integrity of the brain. I could understand the fiber tracking of the brain for different slices with different views, such as axial, coronal, and sagittal. I could visualize the brain stem and the fibers joining the brain stem with the brain neurons, and I could also analyze connectivity between the hemispheres.

- Tensor Glyph: I learned about different types of glyphs, such as boxes, spheres, ellipsoids, cylinders, and super quadric, and I applied these glyphs to tensor field visualization.

- Gaussian Transfer Function: From the reading assignment, I understood the concept of the gaussian transfer function and how it can be used to overcome the challenges involved in the current volume rendering methods in terms of memory storage requirement and dynamic range of multivariate data.