Homework 5

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Tuesday, April 2

1 Part 1: Multi-Field Visualization

- The goal is to effectively visualize multiple fields in the same view. Create a single visualization that includes an isosurface of QCLOUD, plus a volume rendering of QCLOUD, plus streamlines of the wind flow, plus arrow glyphs of the wind flow. You will need to make the isosurface semi-transparent and create a transfer function so that you can see the fields. You will want to show a few streamlines and a moderate number of arrow glyphs so you can get a good understanding of the flow, but not occlude the scalar field visualizations. Please include the figure in your report (5/20).

- Explain your solution step by step (5/20).

  First, I created an isosurface of QCLOUD using the contour filter and adjusting opacity to 0.25 for better view of future visualizations as seen on Figure 1. Second, I created the arrow glyph visualization of the wind flow using the glyph filter, adjusting its scaling factor to 65000 and using the maximum of 1000 sample points for better representation as seen on Figure 2. Next, I created the visualization of streamlines of the wind flow using the stream tracer filter, setting it to the axis and the resolution to 50, which gives us enough streamlines but does not make the visualization cluttered as seen on Figure 3. Lastly, I added the volume rendering of QCLOUD by adjusting the initial file and creating a transfer function for a better view of the data as seen on Figure 4. Lastly, we get a full image of all 4 visualizations as seen on Figures 5 and 6 (Figure 7 portrays the inability of software to process both contour and volume at the same time no matter the order of showing).

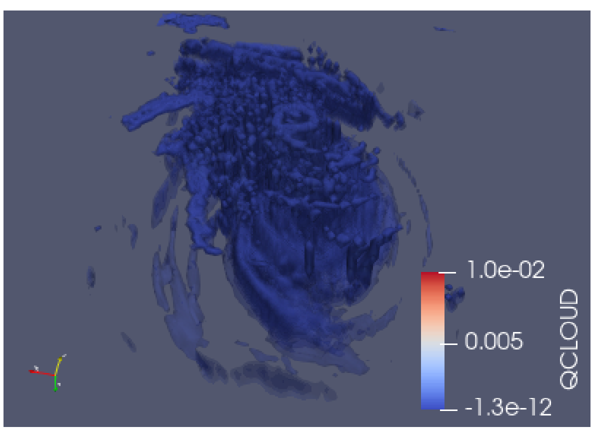

Figure 1: Part 1: isosurface of QCLOUD

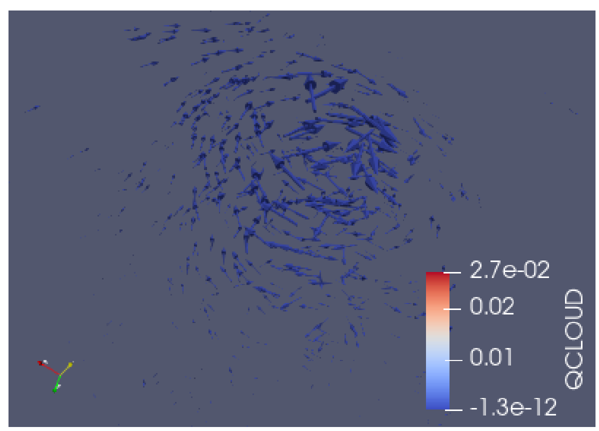

Figure 2: Part 1: arrow glyph visualization of the wind flow

- Please explain what you can understand of the simulation data via your multi-field visualization (10/20).

  We can understand the following from the created visualization:

  - Wind speed is higher towards the bottom of the hurricane formation.
  - Wind speed inside the hurricane is overall stronger towards the direction in which the wind is blowing.

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code: https://github.com/milenabel/CS6635-VisforScD

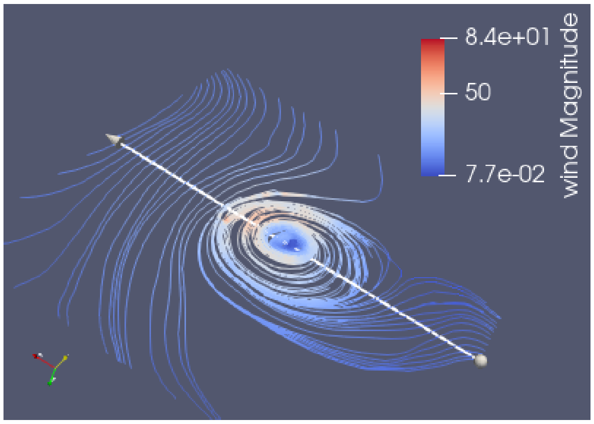

Figure 3: Part 1: streamlines visualization of the wind flow

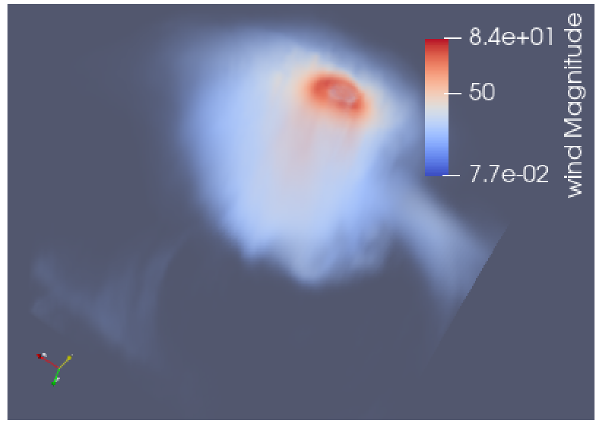

Figure 4: Part 1: volume rendering of QCLOUD

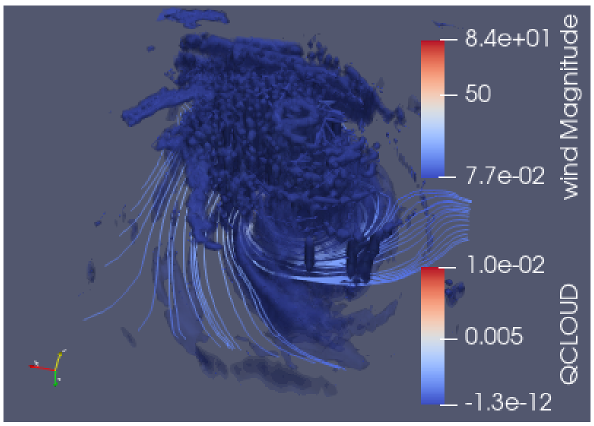

Figure 5: Part 1: multiview (no volume)

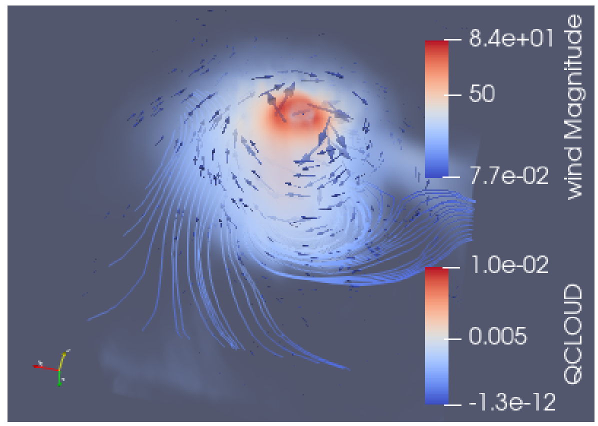

Figure 6: Part 1: multiview (no contour)

- The cloud water mixing ratio is much more dense inside the hurricane rather than towards the sides of it.

2 Part 2: Reading Questions (The visualization handbook)

- 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]

  Diffusion Tensor MRI (DT-MRI) imaging is a technique that captures the anisotropic diffusion properties of water molecules within biological tissues. It provides invaluable insights into the microstructure of tissues, particularly useful for brain imaging to assess the white matter fiber tracts' integrity and architecture. In DT-MRI, water molecule diffusion is not uniform and varies in different directions, influenced by the tissue's microstructural properties, such as cell membranes and fiber orientations. This anisotropy in diffusion is pivotal in diagnosing and understanding various neurological conditions.

  Three types of diffusivities characterized from DT-MRI data are:

  - Linear or Axial Diffusivity: Reflects water diffusion along the principal direction, often associated with the axonal integrity within fiber tracts.

code: https://github.com/milenabel/CS6635-VisforScD

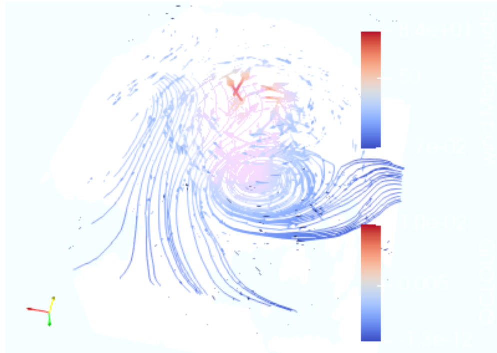

Figure 7: Part 1: multiview glitch

  - Radial Diffusivity: Indicates diffusion perpendicular to the principal direction, relevant to demyelination studies as it's sensitive to the myelin sheath condition around axons.
  - Mean Diffusivity: Averages the diffusion rates in all directions, offering a general sense of water molecule mobility in the tissue, indicative of various pathological conditions.

  Mathematically, a diffusion tensor can be represented by a symmetric second-order 3x3 matrix, describing the diffusion coefficient in three orthogonal directions. This matrix captures the complete diffusion process at each voxel of the scanned tissue, offering insights into the microstructural orientation and integrity of the tissue. The eigenvalues and eigenvectors of this matrix provide a detailed description of the diffusion's magnitude and direction, respectively, at each voxel point.

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

  For the visualization of tensor fields, glyphs are visual representations that encode data through their geometric properties, such as shape and orientation. Three common types of glyphs used for tensor field visualization are:

  - Box Glyphs: Represent tensors through box-like shapes where the dimensions of the box correspond to the magnitude of the tensor's eigenvalues. They are particularly effective in distinguishing between different magnitudes of anisotropy but can sometimes be misleading in areas of isotropy or planar anisotropy due to their defined edges.

    Advantages:

    * Directionality Clarity: Box glyphs offer clear visual cues about the primary diffusion directions due to their sharp edges and flat faces, making it easier to discern the tensor's orientation at a glance.
    * Visual Distinction: The defined edges and corners of boxes can make tensors in highly anisotropic regions stand out distinctly from those in isotropic or less anisotropic regions, enhancing the visualization of complex tissue structures.

    Limitations:

    * Misleading in Isotropic Regions: In regions of isotropic diffusion, where diffusion is uniform in all directions, the orientation of a box glyph can be misleading, as there is no preferred direction of diffusion.
    * Occlusion and Clutter: Due to their solid and blocky nature, box glyphs can cause visual clutter and occlusion when densely packed, obscuring details and making it difficult to interpret the underlying data.

    * Limited Shape Representation: Box glyphs do not smoothly represent the transition between different types of anisotropy (linear, planar, isotropic), potentially oversimplifying the complexity of diffusion patterns.

- Ellipsoid Glyphs: Use ellipsoids to depict tensors, where the length of each axis of the ellipsoid is proportional to the corresponding eigenvalue. This representation naturally illustrates the anisotropy and directionality of diffusion, providing a clear indication of the principal diffusion direction through the ellipsoid's elongation. Ellipsoid glyphs are widely used due to their intuitive representation of diffusion properties.

  Advantages:

    * Intuitive Representation: Ellipsoids naturally represent the diffusion tensor's anisotropic properties, with the axes of the ellipsoid aligned with the tensor's eigenvectors and their lengths proportional to the eigenvalues, providing an intuitive understanding of diffusion directions and magnitude.
    * Reduced Visual Clutter: Compared to box glyphs, ellipsoids offer a smoother appearance that can reduce visual clutter, making them suitable for dense tensor fields and enhancing the overall readability of the visualization.
    * Versatility: Ellipsoid glyphs can represent various degrees of anisotropy, including isotropic diffusion, by adjusting the ellipsoid's shape, making them versatile across different regions of the tensor field.

  Limitations:

    * Subtlety in Shape Differences: The differences in shape between slightly anisotropic and isotropic tensors may be subtle, potentially making it challenging to distinguish between these conditions based solely on ellipsoid shape.
    * Ambiguity in Orientation: In regions of planar anisotropy, determining the principal direction of diffusion from the ellipsoid shape alone may be ambiguous, as the orientation of the ellipsoid's major axis might not be immediately apparent.

- Superquadric Glyphs: Are a more flexible representation that can smoothly transition between shapes that represent linear, planar, and spherical anisotropy, making them highly informative for visualizing the nature of diffusion across a continuum of anisotropic conditions. Superquadric glyphs offer a compromise between the specificity of box glyphs and the generality of ellipsoid glyphs, effectively conveying the diffusion tensor's properties in a visually coherent manner.

  Advantages:

    * Comprehensive Shape Representation: Superquadric glyphs offer a more comprehensive representation of tensor shapes, smoothly transitioning between linear, planar, and spherical anisotropy. This versatility allows for a detailed visualization of the tensor field's complexity.
    * Clarity in Anisotropy Types: The ability of superquadric glyphs to morph between different shapes provides clear visual cues about the nature of anisotropy (linear, planar, isotropic) at each tensor location, enhancing the interpretability of the DTI data.
    * Reduced Ambiguity: By varying the shape to represent different types of diffusion anisotropy, superquadric glyphs reduce the ambiguity seen with other glyph types, offering a clearer understanding of the underlying tissue structure.

  Limitations:

    * Complexity: The increased complexity of superquadric glyphs, due to their variable shape characteristics, might make them more challenging to interpret without prior knowledge or experience, potentially hindering their effectiveness for novice users.

* Computational Demand: Rendering superquadric glyphs, especially in dense tensor fields, can be computationally more demanding than simpler glyphs like ellipsoids, potentially affecting performance in real-time visualization applications.

In summary, the choice of glyph for DTI visualization depends on the specific requirements of the analysis, including the need for clarity in representing diffusion anisotropy, the desire to minimize visual clutter, and the computational resources available. Each glyph type offers a unique balance of these factors, catering to different aspects of DTI data visualization.

3 Part 3: Brain DTI Tractography Visualization

- Load the data 'brain.dti' located in the directory data.assignment5 of Assignment5-Data.zip (link near the beginning of this document). 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.

- Following the DSI Studio Manual, perform steps T1 and T2 to compute fiber tracking data. Note that the diffusion sampling length ratio in T2 will have an effect on step T3. Look at the Reconstruction page in the manual. Try some different values to find a good fit.

  After playing around with editing the mask, I have chosen to use the smoothing and defragmenting options for further visualizations due to other editor functions being less useful with our data as well as picking diffusion sampling length ratio as 0.75.

- In step T3, create a tensor field visualization similar to the following for any choice of MRI slice. If you choose a poor diffusion sampling length ratio in the previous step, you will have too many fiber directions per pixel in this image. Describe the diffusivity patterns for a few subregions of the image. Include an image in your report.

  The result of this step can be seen on Figure 8.

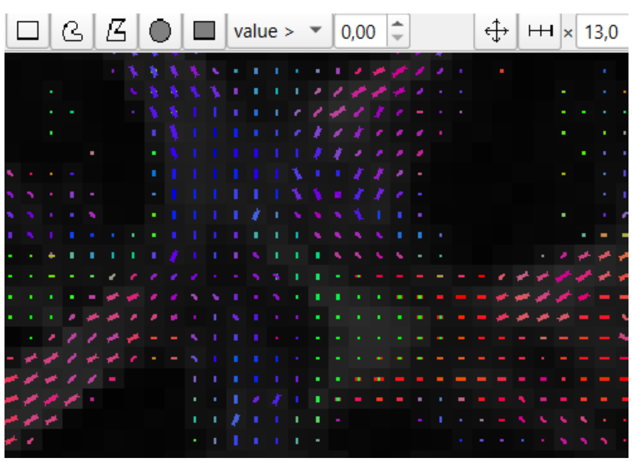

Figure 8: Part 3: subregion image

Diffusivity patterns:

  – High Anisotropy Regions: we can see some lines that are parallel and uniformly aligned. These regions indicate strong directional diffusion in white matter tracts. These tracts are likely to be major pathways for neural signals.

- Mixed Anisotropy Regions: we can see a mixture of directions in the underlying fiber architecture. This could indicate areas where tracts cross or where there is more complexity in the brain's fiber organization.
- Isotropic Regions: we can also see some areas where the lines appear as dots or regions where lines are very short, which represents regions of isotropic diffusion, which is typical of gray matter or cerebrospinal fluid where the diffusion is more uniform in all directions.

- Perform fiber tracking and visualize tractography for the whole brain. The links under "Conventional Tractography" are the most relevant, though you may also want to look under "General Topics" and "Visualization". In the step T3c window, you will find Tracking Parameters, Slice Rendering, and Tract Rendering to be useful. Attach your results as images in your report and describe what you see.

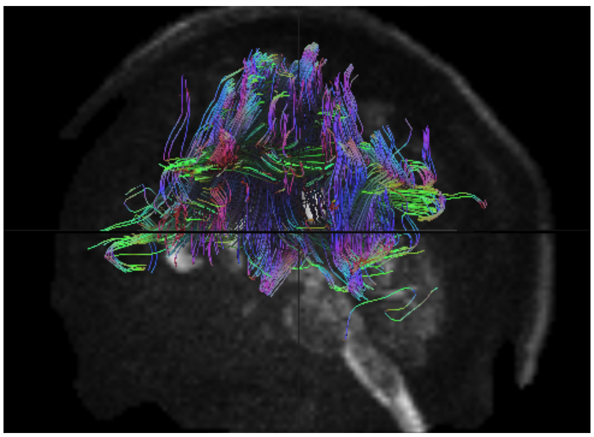

Figure 9: Part 1: whole brain (sagittal view)

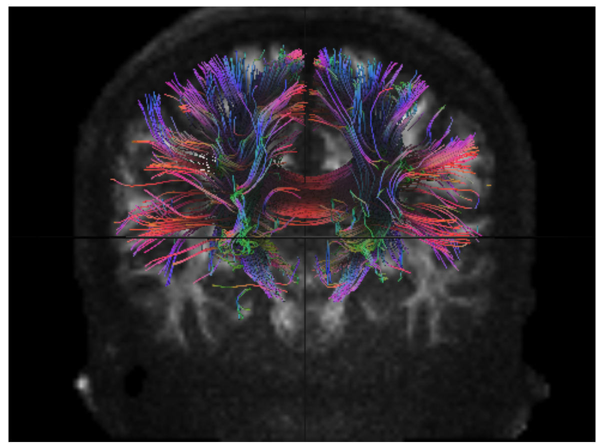

Figure 10: Part 1: whole brain (coronal view)

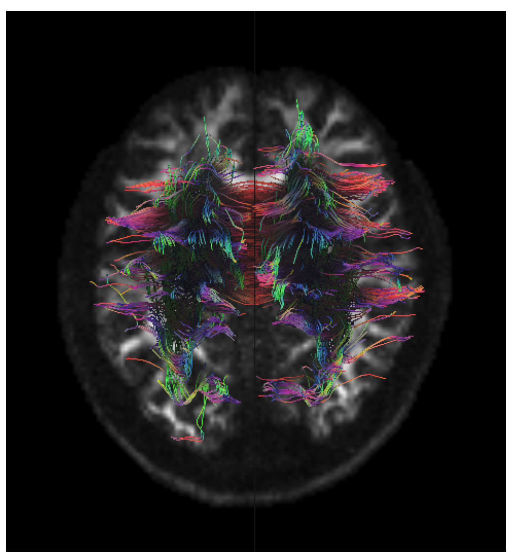

Figure 11: Part 1: whole brain (axial view)

The visualizations in Figures 9-11 collectively showcase a detailed tractography visualization of the brain's white matter pathways. They depict the complex architecture of neural tracts from different perspectives—sagittal, axial, and coronal. The colorful representation signifies the orientation of the

code: https://github.com/milenabel/CS6635-VisforScD

fibers: red indicates left-right, green shows anterior-posterior, and blue marks superior-inferior directional diffusion. Central tracts, corresponding to the corpus callosum, are visible across the images, suggesting a strong connectivity between the brain's hemispheres. The tracts emanate out towards the cortex, indicating communication paths essential for sensory and motor function integration. Overall, the visualization demonstrate the brain's intricate internal structure with a high degree of anisotropy, indicating healthy and directional white matter integrity. Such visualizations are critical for understanding brain anatomy, assessing neurological health, and planning neurosurgical interventions.

- Remove or hide the previous tracts. Now draw a region roughly corresponding to the brain stem. You can see this in the middle of the brain in the sagittal view. You can change your slice image to help you find it. Set this region as the Seed and compute tractography again. Show a image of your tractography in the 3D view. Describe what you see.

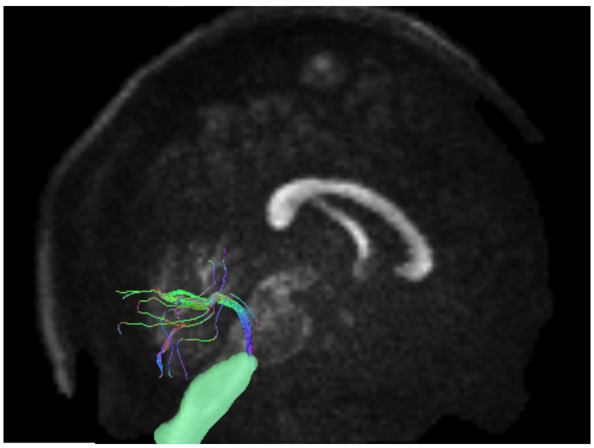

Figure 12: Part 1: brain steam region (right side)

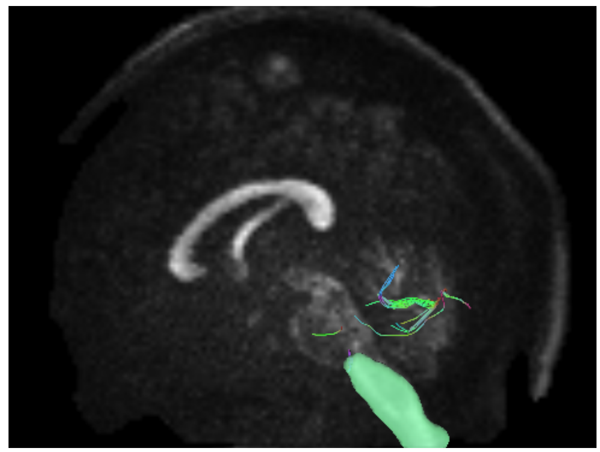

Figure 13: Part 1: brain steam region (left side)

The tractography visualizations in Figures 12 and 13 demonstrate the neural pathways associated with the brain stem, captured in the sagittal plane. The seed region has successfully initiated tractography to highlight the trajectory of the fibers connecting the brain stem with various cerebral regions. These images are crucial for understanding the brain stem's connectivity, which plays a vital role in relaying information between the brain and spinal cord and in controlling vital functions. The visualized tracts in these images could represent major pathways.

- Remove or hide the previous tracts and regions. Now using the cubic region(not the rectangular) selector, make 2 new regions where each roughly cover each brain hemisphere, as shown in the image below. You can add multiple cuboids for each region to achieve this. Set one of the regions as the Seed and set the other as ROI (Region of Interest). This will visualize tracts that start in one region and connect to the other. Remember that you can edit the tracking parameters. Show an image of your tracts in the 3D view with the region rendering and slice rendering disabled. Describe what you see.

The tractography visualizations in Figures 14 and 15 highlight the rich and complex network of neural connections between the brain's two hemispheres. The tracts' density and distribution suggest robust interhemispheric connectivity, providing insights into the structural integrity of the brain's communication pathways. The images capture the essential aspects of the neural architecture, from the dense, central pathways that might be associated with the corpus callosum to the more dispersed peripheral tracts. Such visualizations are particularly important in various studies, where hemisphere connectivity plays a critical role.

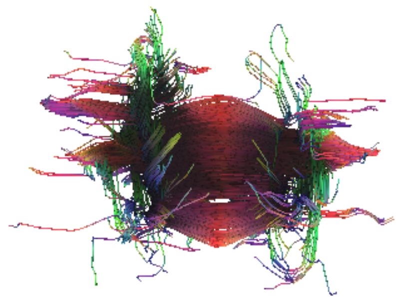

Figure 14: Part 1: hemisphere tracts (axial view)

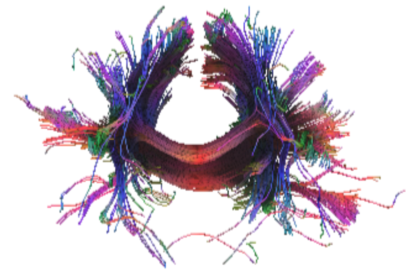

Figure 15: Part 1: hemisphere tracts region (coronal view)

4 Part 4: Tensor Glyph Visualization in ParaView

- Load the dataset.

- Visualize the tensor field using box, sphere, cylindrical, and superquadric glyphs. Turn off the toroidal shape setting for superquadrics. Create images that have a pleasing appearance by playing with the glyph parameters, such as glyph size, shading etc. and include them in your report.

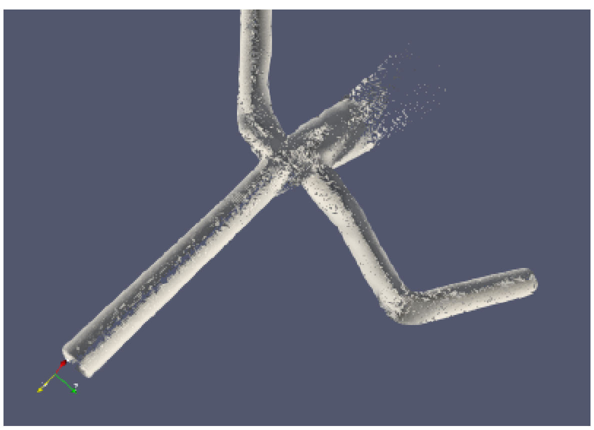

Figure 16: Part 4: box glyph representation

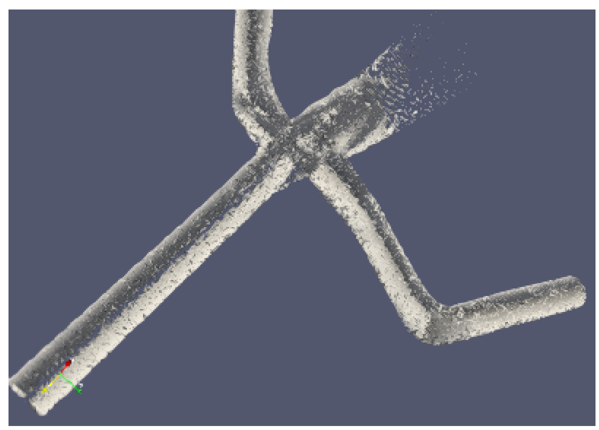

Figure 17: Part 4: sphere glyph representation

  The result of all of the glyph representations can be seen in Figure 14. All the parameter adjustments can be seen in the psvm file as well.

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

  I found superquadric glyphs to be the most informative since they provide the most comprehensive insights into tensor field data due to their ability to represent a wide range of tensor behaviors—from isotropic to linear and planar anisotropy—through shape variation.

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

- Choose one of the following papers and write a review of it:

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code: https://github.com/milenabel/CS6635-VisforScD

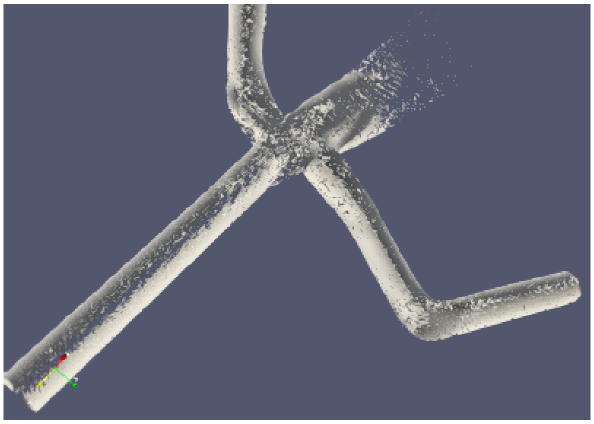

Figure 18: Part 4: cylinder glyph representation

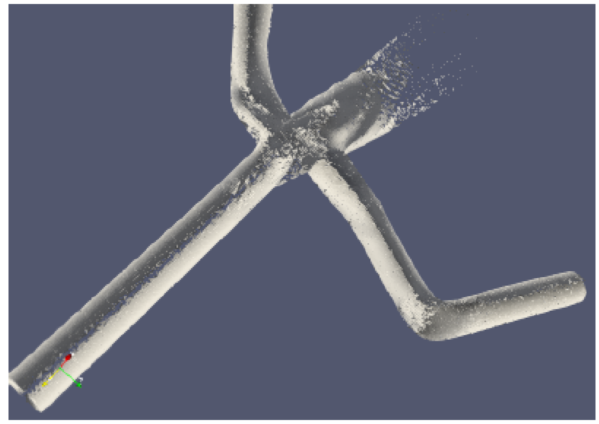

Figure 19: Part 4: superquadric glyph representation

- **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.**
- R. Fuchs and H. Hauser; Visualization of Multi-Variate Scientific Data; Computer Graphics Forum, 2009.
- S. Nagaraj, V. Natarajan, and R. S. Nanjundiah; A Gradient-Based Comparison Measure for Visual Analysis of Multifield Data, In Proceedings of the 13th Eurographics / IEEE - VGTC conference, 2011.

- Please answer the following questions when writing your review:
  - What is the new innovation described in the paper?
  - What did you learn by reading the paper?
  - 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?
  - Is what the paper presents useful, or is it just a curiosity?
  - What did you want to know more details about?
  - 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 by Kniss et al., titled ”Gaussian Transfer Functions for Multi-Field Volume Visualization,” introduces a novel approach to volume rendering, a technique critical for visualizing dense 3D volumetric datasets in fields such as medical imaging and meteorology. This review addresses the questions posed based on the insights gleaned from the paper.

New Innovation

The core innovation presented in this paper is the use of Gaussian Transfer Functions (GTFs) for the visualization of multivariate datasets. Unlike traditional methods that rely on precomputed lookup tables for transfer functions, which become impractically large for multivariate data, GTFs allow for the direct evaluation of transfer functions as true functions of the sampled data. This approach significantly reduces the need for extensive storage while providing a flexible and efficient means to classify and render multi-field datasets. The GTFs are particularly adept at classifying features within multidimensional domains, making them well-suited for datasets that are challenging to classify and render interactively using traditional methods.

Learning Outcomes

Reading the paper highlights several key learnings:

- The limitations of traditional volume rendering techniques, especially in handling multivariate datasets, due to the prohibitive size of lookup tables for transfer functions.
- The mathematical foundation and implementation details of Gaussian Transfer Functions, including their extension to handle gradient magnitudes for enhanced feature classification.
- The efficiency of GTFs in utilizing modern graphics hardware for real-time, interactive volume rendering without the need for precomputed lookup tables.
- The potential of GTFs to analytically integrate transfer functions over line segments, offering a method to render high-quality images with fewer samples and reduced artifacts.

Weaknesses

The paper is well-written and presents a compelling case for the use of GTFs in volume rendering. However, a few areas could be considered weaknesses or areas for further clarification:

- The paper could benefit from a more detailed discussion on the performance trade-offs when implementing GTFs, especially in comparison to traditional lookup table-based methods across various hardware configurations.
- While the paper mentions the intuitive control of GTF parameters, the complexity of tuning these parameters for non-expert users could be better addressed, possibly including user interface considerations.
- The evaluation primarily focuses on the technical and performance aspects. A more comprehensive assessment involving user studies could further validate the practical benefits and usability of the proposed method.

Usefulness

The Gaussian Transfer Functions described in the paper present a significant advancement in volume rendering, offering both theoretical and practical benefits. This method is not merely a curiosity but provides a valuable tool for fields that rely heavily on volume visualization, such as medical imaging, geosciences, and engineering. Its ability to efficiently handle multivariate datasets with reduced computational and storage requirements makes it a potentially transformative approach in volume visualization.

Desired Details

After reading the paper, a desire for more details emerges in several areas:

- Examples of real-world applications and case studies where GTFs have been applied would provide deeper insights into their practical benefits and limitations.
- Additional technical details on the implementation of GTFs on different hardware platforms could help assess the portability and scalability of this approach.
- A broader comparison with other state-of-the-art volume rendering techniques, including recent advancements not covered in the paper, would contextualize the significance of GTFs within the field.

Implementation Feasibility

The paper provides a solid foundation for understanding and implementing Gaussian Transfer Functions, including mathematical formulations and pseudo-code for key algorithms. However, for a practitioner aiming to implement GTFs from scratch, certain aspects could use further elaboration, especially regarding the handling of edge cases in data classification and integration steps. A more detailed discussion on these topics, alongside source code or pseudocode for the complete rendering pipeline, would enhance the paper's utility for developers and researchers aiming to adopt GTFs in their work.

6 Conclusion

In this assignment, I embarked on an insightful exploration into the realm of multi-field and tensor field visualizations. The key highlights of this exploration included:

Multi-Field Visualization: By synthesizing isosurfaces, volume rendering, streamline visualization, and glyph representation of the wind flow, I was able to construct a multifaceted view of meteorological phenomena. This multifaceted visualization approach offered a comprehensive understanding of the data, highlighting intricate flow patterns and the density distribution within a hurricane system.

Diffusion Tensor MRI Imaging and Tractography Visualization: DTI tractography visualization provided a window into the complex structure of the brain, allowing to observe the intricacy of neural pathways and the brain's white matter integrity. This was particularly evident in the visualization of the brain stem and the connectivity between the hemispheres, where the use of different diffusion sampling length ratios and the application of various tensor glyphs afforded a clear depiction of neural tracts and their orientations.

Tensor Glyph Visualization: The application of box, sphere, ellipsoid, and superquadric glyphs enabled a nuanced analysis of tensor field data. Superquadric glyphs proved to be most informative due to their flexibility in representing various types of diffusion anisotropy, which was crucial for capturing the complexity of the tensor field.

Reading and Application of Visualization Techniques: The critical evaluation of literature on Gaussian Transfer Functions for Multi-Field Volume Visualization informed my practical work, leading to a better understanding of the challenges in representing multivariate data. The insights gained underscored the paper's relevance in the context of contemporary visualization needs.

The collective experience from each part of the assignment has profoundly augmented my knowledge in the visualization of complex data. The successful fusion of visual elements across multiple fields demonstrated the potential of advanced visualization techniques in elucidating complex structures and phenomena. Moreover, the tasks prompted a deeper appreciation for the interplay between numerical methods, theoretical concepts, and practical visualization tools.

Throughout this assignment, the combination of practical application, critical reading, and methodical implementation honed my skills and expanded my perspective on the significance of data visualization in scientific discovery. I leave this assignment with an enhanced toolkit of visualization strategies, a richer comprehension of complex data, and an invigorated curiosity about the future of scientific visualization.