Assigned: ***2-28-2024***
Due Date: ***3-20-2024 by Noon***

CS 6635/5635 Spring Semester 2024

Assignment 4 (Vector Field Visualization)

For **Part 1** of the assignment, we will use data from a simulation of air flow above a heated disk.

For **Part 2** of the assignment, we will use data that was created by the National Center for Atmospheric Research's Weather Research and Forecasting Model.
The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications:

https://www.mmm.ucar.edu/weather-research-and-forecasting-model

We are going to visualize both scalar and vector fields of WRF forecast simulations of Hurricane Katrina's path:

https://www.youtube.com/watch?v=dW3pErARlYc

We are going to use one time step in the forecast simulation, which you can download from the class website:

https://my.eng.utah.edu/~cs6635/hurricanekatrina.vts.gz

This has been converted from WRF format to a format ParaView can read. After loading the Hurricane Katrina data set and clicking Apply, you will see four data fields (T, QCLOUD, QVAPOR, and Wind). T is the Temperature, QCLOUD is the cloud water mixing ratio, QVAPOR is the Column Water Vapor Content, and Wind is Wind Speed.

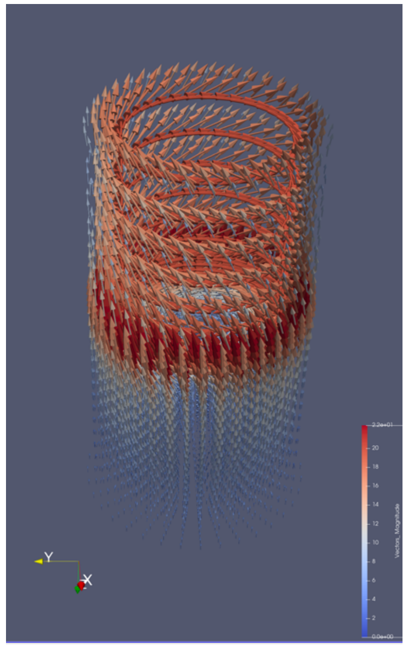
For **Part 3**, we will use simulation data of the air flow around a moving car.

You will use ParaView to visualize the vector field data in **Parts 1-3**.

Part 1: Streamline Visualization of Air Flow above Heated Disk using Glyphs [15 pts]

Load the dataset https://my.eng.utah.edu/~cs6635/Assignment4-output.vtu.gz

To start, add the “Glyph” filter. Set the "Scale Mode" to the vector magnitude. Turn down the scale factor to reduce clutter. Change the color to "Vectors." Then change the "Glyph Mode" to "All Points." This shows you the underlying vector field without any resampling.

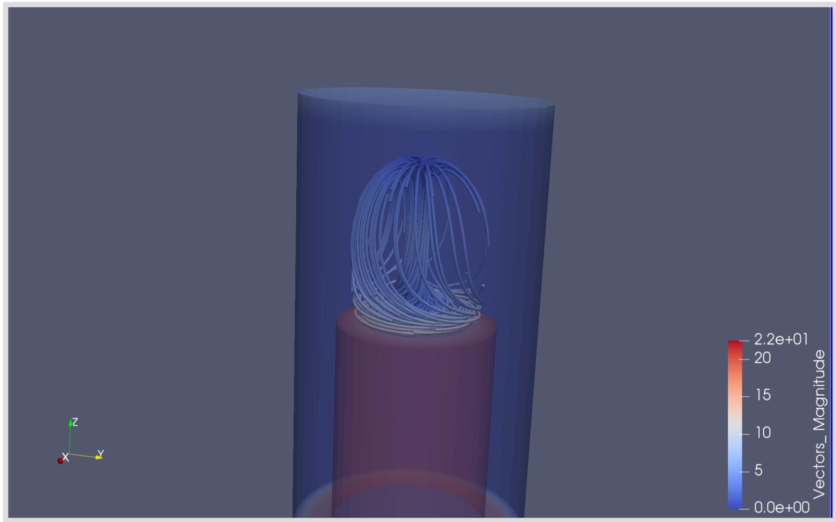


Find and apply the appropriate filter to:

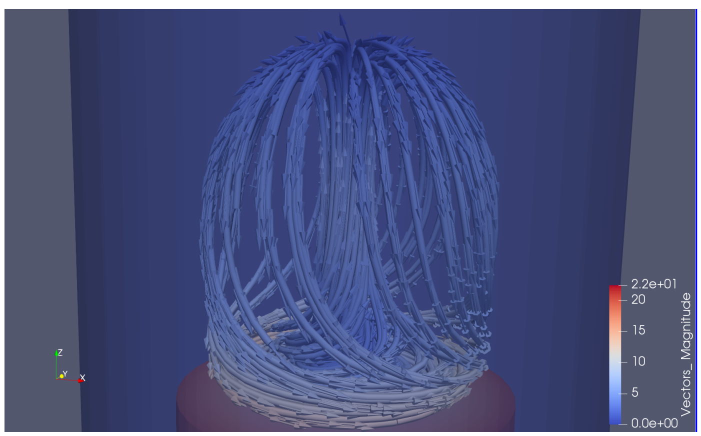
1. Extract streamlines using ‘Point Source” seed type.
2. Enhance the rendering by using tubular surfaces.

Please include screenshots with appropriate title or caption, and a PSVM file.

If you got it right, you should be visualizing something like this:



Find and apply the appropriate filters to provide visual insights about the orientation and magnitude of the vector field in this region of space. This could be similar as follows:



Discuss what patterns you see in the data and compare the visualization methods used.

Part 2: Hurricane Visualization [25 pts]

Step 1:

1. Create streamlines of the wind flow within the hurricane. Seed the streamlines so as to get a good overview of the flow.
2. Create stream tubes of the wind flow within the hurricane.
3. Add cone glyphs to the stream tubes so you can see direction of the flow (see pages 35-36 of the ParaView Tutorial).

Do this with two types of seeds (i.e. cloud vs. line) and describe the different trends you can identity in the data with different seed types such as rotation of flow or how the air travels into and out of the center of the hurricane.

Step 2:

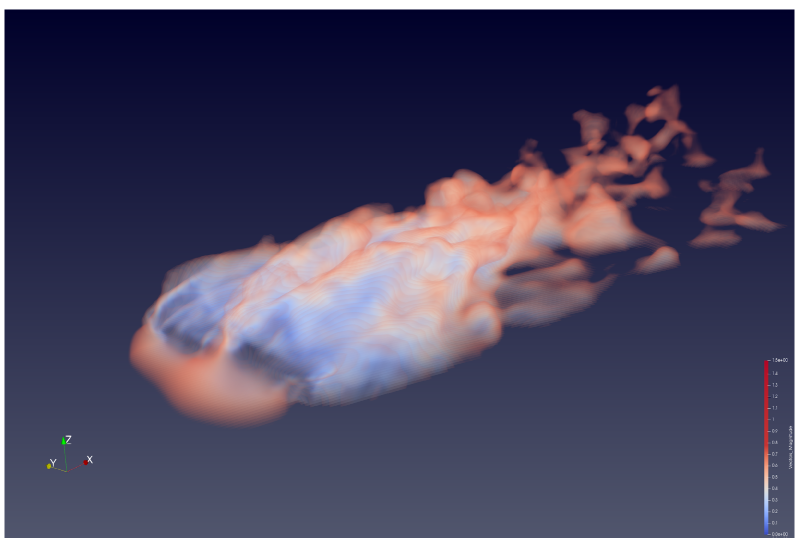
4. To see a big picture of the direction of the wind flow within the hurricane, create a visualization using arrow glyphs at randomly sampled places throughout the volume. You should use enough arrow glyphs to get a good overview, but not so many arrow glyphs that the view is cluttered.
5. Now scale the vectors proportional to their speed and add a colormap for the speed. What happens, why should we do this? Explain the flow in this visualization and compare to any trends you observed in Step 1.

<u>Please include screenshots with appropriate title or caption, and a PSVM file</u>

Part 3: Visualization of Air Flow around a Moving Car [25 pts]

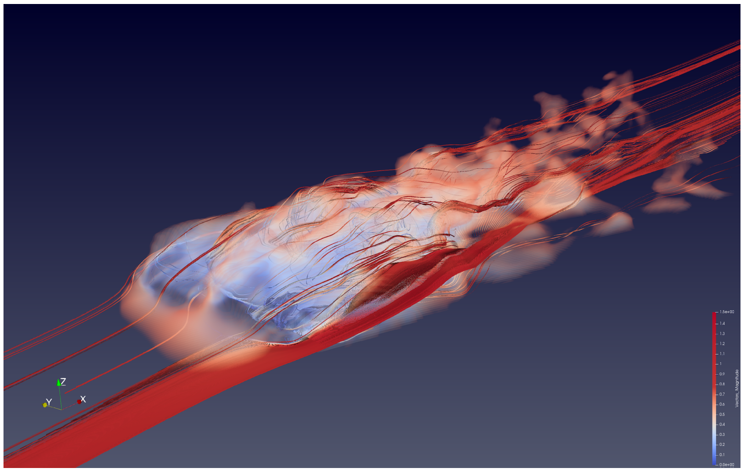
1. Load the dataset: https://my.eng.utah.edu/~cs6635/Assignment4-output.vti.gz

2. Design a transfer function for direct volume rendering of flow velocity magnitudes to create a visualization similar to the following (Red: relatively high magnitudes, Blue: relatively low magnitudes)



3. Apply the Stream Tracer filter to output.vti. Please orient a seed line orthogonal to the moving direction and keep it horizontal **before applying the filter.**

4. Apply the ribbon filter to stream lines. Set ribbon width parameter such that the resulting visualization has a pleasing appearance. Note the ribbons, in contrast to tubes, enable to better illustrate small-scale helicoidal trajectories (in turbulent areas). The image looks similar to the following:

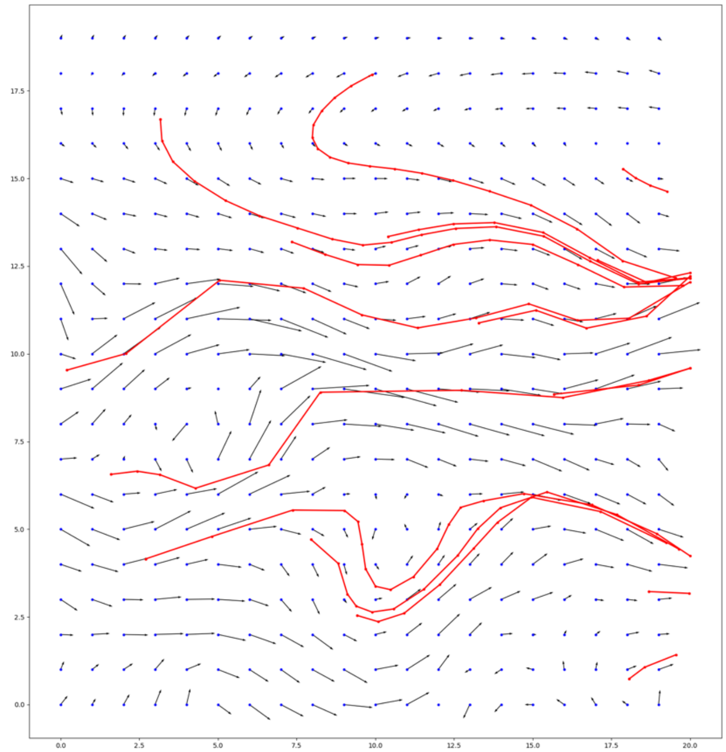


5. Create visualizations similar to image in question 4 for **two more** seed configurations of your choice. Please include screenshots with brief description, and a PSVM file.

6. Note any interesting observations for flow visualizations.

Part 4: Euler's Method[35 pts]
You are given some wind data as a 2D vector field of size 20x20. Compute and visualize seed points and streamlines on this dataset using Euler's Method(en.wikipedia.org/wiki/Euler_method).

Download the files: https://my.eng.utah.edu/~cs6635/wind_handout.zip which contains the wind data vectors (wind_vectors.raw) and also boilerplate python code (wind.py).



1. Use random sampling to generate 15 seed points within the range [0,19] in both dimensions. Also, set the random seed manually to an arbitrary number. This will give you consistent seed points which will be helpful for comparison. Show an image of your plot.

2. Trace a streamline from each point. Use a time step value of 0.3 and perform 8 steps for each streamline. You will need to write a function that will calculate the bilinear interpolation(wikipedia.org/wiki/Bilinear_interpolation) of the 4 neighboring vectors. Bound your points to the data range [0,20] along both dimensions. You can stop tracing early if you reach the image boundary. Show an image of your plot.

3. Trace streamlines again from the same seed points as the previous part. Make 3 more figures with the following parameters:
   - Step size 0.15, steps 16
   - Step size 0.075, steps 32
   - Step size 0.0375, steps 64
4. Describe differences you see between the figures. Explain what divergence is. How does this relate to your results?*(Tip:Read section 1.3.4 in the book)*

Extra Credit: Runge-Kutta Method[10 pts]

1. Implement the Runge-Kutta Method(RK4)(wikipedia.org/wiki/Runge–Kutta_methods) for the integration in part 4. Recreate the 4 figures from that question. When some of your sample points for interpolation are outside of the image bounds, only use the valid samples.
2. Compare the results from RK4 with Euler.

Part 5: The Reading Questions [Chapter 12, visualization handbook] [20 pts] (Only for CS 6635 students)

Please answer succinctly in YOUR OWN words:

- DO NOT write the same thing as in the source material with only slight changes in phrasing.
- DO NOT simply rewrite the same sentences as in the source material.
- You should be aiming to *summarize*, maybe with a little bit of *paraphrasing*, and you can also use some *quotations*. But even if you are paraphrasing, it cannot be too similar to the source material. You should be able to write your answer without simultaneously looking at the original text. E.g., see this guide on appropriate paraphrasing/summarizing:

  https://owl.purdue.edu/owl/research_and_citation/using_research/quoting_paraphrasing_and_summarizing/paraphrasing.html

1. What are steady and unsteady state flows? What are pathlines and streamlines?

2. Briefly describe any three classifications of vector-field visualization techniques.

3. State any three features for feature-based vector field visualizations. Describe any two features in detail. Why is feature-based visualization important for vector field data?

Conclusion[5 pts]

Compare and contrast results and note any interesting observations when exploring data. You can also elaborate on challenges faces when implementing the project. Also, tell us what you learned from this assignment and add references, if any.

What to turn in:

Write a **report documenting your results**, including any necessary plots/figures, and answering any questions asked above. Be sure to explain any figures you submit and to write a **conclusion** at the end of your report. Your homework is primarily graded upon your report. Please submit your report on Canvas in PDF format. Please also submit your code/.pvsm files as compressed zip files.

- Your report should be in PDF format and should stand on its own.
- It should describe the methods used.
- It should explain your results and contain figures.
- It should also answer any questions asked above.
- It should cite any sources used for information, including source code.

Note: Any figures/plots in the report should be captioned appropriately. Also be sure to include axis labels in all plots.

This homework assignment is due on **March 20, 2024 by 11:59 am**. If you don't understand these directions or have questions, please send questions to teach-cs6635@sci.utah.edu or come see one of the TAs or the instructor during office hours **well in advance of the due date.**