Final Report

GPS-TTBP: Advanced Visualization Techniques for Gyrokinetic Particle Simulations

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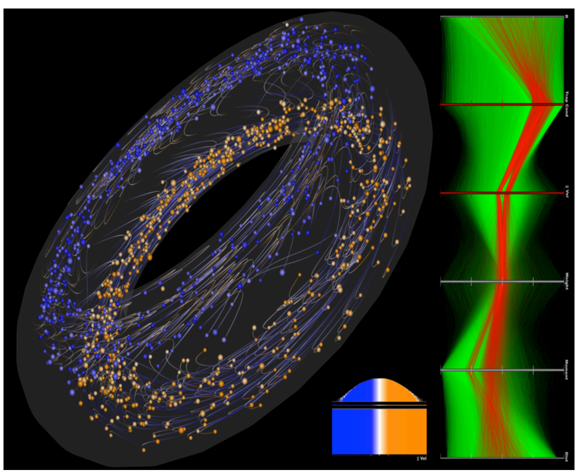
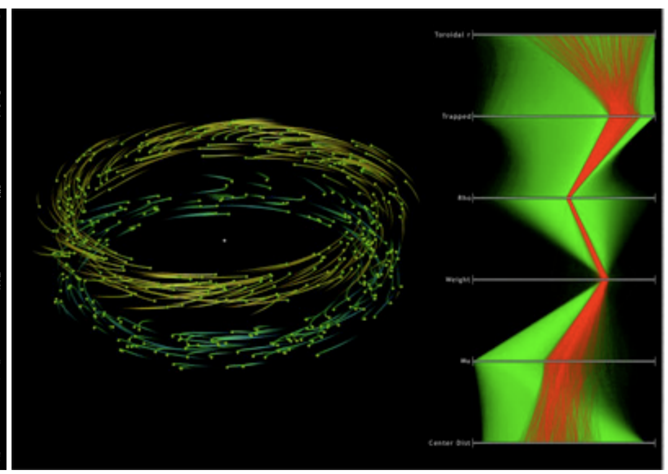
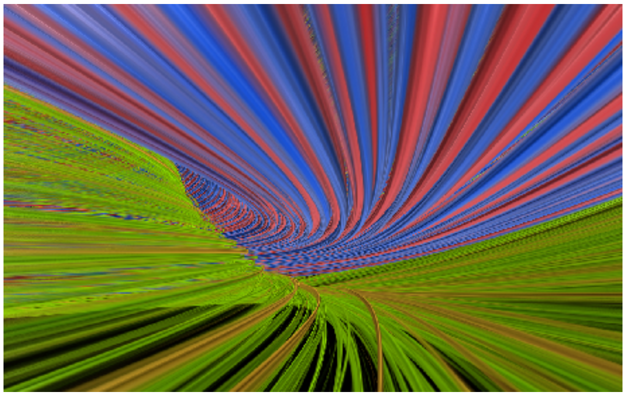
Accomplishments

In this project, we have developed techniques for visualizing large-scale time-varying multivariate particle and field data produced by the GPS_TTBP team. Our basic approach to particle data visualization is to provide the user with an intuitive interactive interface for exploring the data. We have designed a multivariate filtering interface for scientists to effortlessly isolate those particles of interest for revealing structures in densely packed particles as well as the temporal behaviors of selected particles. With such a visualization system, scientists on the GPS-TTBP project can validate known relationships and temporal trends, and possibly gain new insights in their simulations. The two images below created using this new interface effectively highlight particles of interest. The dataset was provided by the Princeton Plasma Physics Laboratory (PPPL). We have tested the system using over several millions of particles on a single PC. We will also need to address the scalability of the system to handle billions of particles using a cluster of PCs.

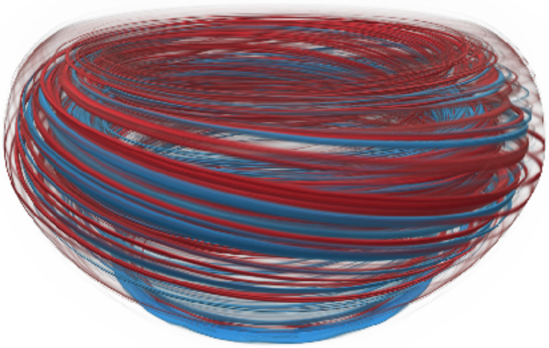
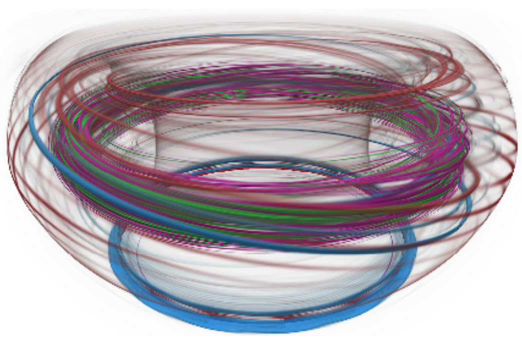




To visualize the field data, we choose to use direct volume rendering. Because the data provided by PPPL is on a curvilinear mesh, several processing steps have to be taken. The mesh is curvilinear in nature, following the shape of a deformed torus. Additionally, in order to properly interpolate between the given slices we cannot use simple linear interpolation in Cartesian space but instead have to interpolate along the magnetic field lines given to us by the scientists. With these limitations, building a system that can provide an accurate visualization of the dataset is quite a challenge to overcome. In the end we use a combination of deformation methods such as deformation textures in order to fit a normal torus into their deformed torus, allowing us to store the data in toroidal coordinates in order to take advantage of modern GPUs to perform the interpolation along the field lines for us. The resulting new rendering capability produces visualizations at a quality and detail level previously not available to the scientists at the PPPL, as demonstrated by the two images shown below.

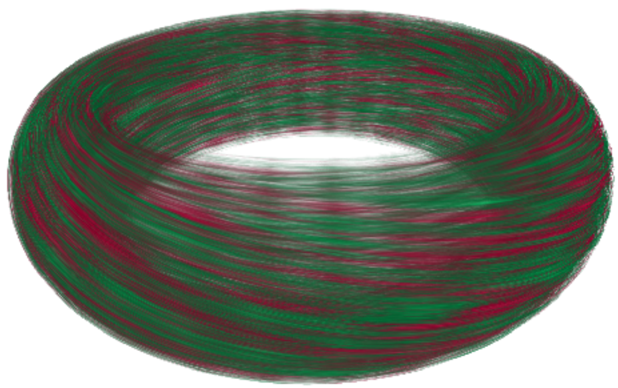



The second dataset we have worked on was provided by Professor C.S. Chang at the New York University. This plasma dataset is similar to the PPPL dataset, but still different enough to be challenging to visualize. Instead of a curvilinear volume (albeit a deformed and twisted one) this dataset is a set of point mesh slices. This data however also requires that interpolation be done along magnetic field lines instead of along simple Cartesian space. Because of this, we can not store them in toroidal space for the GPU. Instead, each slice is stored in cylindrical space using a triangulated mesh, and interpolation is forced at the shader level by sampling two slices at a time. Similar deformation methods were used, but rendering is not the only goal. Instead, Professor Chang also wants to decompose/segment the volume based on frequency analysis, rendering the high frequency and low frequency bands using different colors. However, we are able to efficiently pack this into video memory for rendering, producing the two images shown below. The left one is the unfiltered image, and the right one with the data segmented.

Even though this project came to an end, we plan to continue our collaboration with PPPL. The latest dataset provided by PPPL is more of a combination of the NYU and previous PPPL datasets. Whereas the old PPPL dataset can be stored in a twisted toroidal space, the new one cannot be stored so easily. Instead, they have to be untwisted as the NYU data is, but still stored with the efficiency of toroidal space. Additionally, unlike the NYU and the first PPPL datasets, this new dataset also come with additional variables such as velocity. We plan to visualize that velocity data by constructing stream surfaces within the torus in order to highlight the features of the flow field. However, as the flow field stores values in cylindrical rather than

Cartesian space, and as the data is stored in toroidal space, integrating the stream surface becomes rather difficult. Included is an image of a timestep from the dataset. As work on this dataset is ongoing, the image shown below does not represent what we hope to achieve in the final visualization but instead allows us to verify our current understanding of the nature of the data.



In summary, in this project we have successfully created new capabilities for the scientists to visualize their 3D data at higher accuracy and quality, enhancing their ability to evaluate the simulations and understand the modeled phenomena.

Publications

- Carlos D. Correa, Robert Hero, Kwan-Liu Ma: A Comparison of Gradient Estimation Methods for Volume Rendering on Unstructured Meshes. IEEE Transactions on Visualization and Computer Graphics, 17(3): 305-319 (2011).
- Chad Jones and Kwan-Liu Ma. Visualizing Flow Trajectories using Locality-based Rendering and Warped Curve Plots. IEEE Transactions on Visualization and Computer Graphics, 16(6):1587-1594,(2010).
- Jishang Wei, Chaoli Wang, Hongfeng Yu, and Kwan-Liu Ma. A Sketch-based Interface for Classifying and Visualizing Vector Fields. In Proceedings of PacificVis 2010, pp. 129-136.
- Ove Daae Lampe, Carlos D. Correa, Kwan-Liu Ma, and Helwig Hauser. Curve-Centric Volume Reformation for Comparative Visualization. IEEE Transactions on Visualization and Computer Graphics, 15(6):1235-1242 (2009).
- Chaoli Wang, Hongfeng Yu, and Kwan-Liu Ma. Importance-Driven Time-Varying Data Visualization. IEEE Transactions on Visualization and Computer Graphics, Volume 14, Number 6, October 2008, pp. 1547-1554.
- Chad Jones, Kwan-Liu Ma, Stephane Ethier, Wei-Li Lee. An Integrated Exploration Approach to Visualizing Multivariate Particle Data. IEEE Computing in Science and Engineering, Volume 10, Number 4, July/August 2008, pp. 20-29.