Advanced Visualization Techniques for Plasma Physics Simulations

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Plasma physics is rich in complex, collective phenomena and encompasses major areas of research including plasma astrophysics and fusion energy science. To develop practical fusion energy, for example, scientists have made extensive use of numerical simulations to advance the understanding of energy and particle transport in fusion devices. These simulations output vast amounts of field and particle data, which require a new set of tools for validating, analyzing and understanding the modeled phenomena. In this talk, I will present several visualization techniques developed by the UC Davis team of the SciDAC Ultrascale Visualization Institute to assist plasma physics scientists with their data analysis needs. These techniques allow the scientists to see their data more completely and faithfully, and in new ways enabling validation and discovery.

Scientists at Princeton Plasma Physics Laboratory have been developing microturbulence codes in fusion to gain an improved understanding of the turbulent transport in magnetically confined toroidal plasmas. The diagnostic of tokamak transport can start from a direct visualization of the density, velocity, temperature, and potential fluctuations generated by the microinstabilities. We have developed a high-fidelity volume visualization technology for examining 3D plasma flow on a toroidal coordinate system. Previous visualization solutions were based on isosurface methods, which provide limited and incomplete views of the data. The new visualization capability can help scientists better understand three-dimensional structures of the modeled phenomena.

The particle-in-cell method has been used to simulate and study how to control the loss of energy due to transport out of the hot plasma core. New particle data visualization methods are needed to effectively visualize this complex phenomenon. Positions and velocities of sample particles are followed in time as they interact with the self-consistent field that they produce and with the externally imposed confinement magnetic field. With simulations using over a billion particles, the amount of data produced can truly be overwhelming. Traditional analyses for these simulations have been limited to the evaluation of macroscopic quantities such as the heat and particle fluxes in different regions of the plasma, the field energy, the flows, and other derived quantities calculated using the moments of the particle distribution functions. The resulting visualizations have been mainly X-Y plots, with a few contour plots being evolved in time. We have developed an interactive interface for multidimensional visualizations of fundamental particle quantities that elevate the analysis to a whole new level for the fusion scientists. With these new ways of exploring data, scientists can more effectively confirm or discover properties of their data that could not be seen before.

Finally, a new approach has been developed for dissecting and analyzing 3D vector fields. By precomputing a set of pathlines representing the temporal aspects of the flow field, our technique allows scientists to filter these pathlines according to their geometric characteristics. This new interactive vector field visualization technique nicely complements the multidimensional filtering interface introduced for visualizing particles.

The interactive 3D visualization techniques that we have developed give the plasma physics scientists new ability to examine the complex structure and evolution of the essential features in their turbulence simulation data. The resulting visualizations also allow scientists to more effectively communicate their findings to others.