Rapid Analysis of Plasma Instabilities in Fusion Science
Allen R. Sanderson\textsuperscript{1}, Prabhat\textsuperscript{2}, O. Rübel\textsuperscript{2}, G. Weber\textsuperscript{2}, H. Childs\textsuperscript{2}, J. Meredith\textsuperscript{3}, S. Ahern\textsuperscript{3}, David Pugmire\textsuperscript{3}
\textsuperscript{1}University of Utah; \textsuperscript{2}Lawrence Berkeley National Laboratory; \textsuperscript{3}Lawrence Livermore National Laboratory; \textsuperscript{3}Oak Ridge National Laboratory

Summary
Developing a reliable energy system that is economically and environmentally sustainable is the long-term goal of Fusion Energy Science (FES) research and is a worldwide effort. As fusion experiments have increased in size and complexity (too expensive to duplicate), there has been concurrent growth in the importance of simulation and visualization. Scientists from the SciDAC Visualization and Analytics Center for Enabling Technology (VACET) working closely with fusion scientists have developed new capabilities for visually exploring and, ultimately, understanding fusion simulation data sets. These new techniques leverage DOE’s parallel computing platforms enabling the: (1) rapid exploration of datasets containing millions to billions of values, (2) rapid extraction of features of interest within a large simulation, and (3) interactive visualization of the analysis results. These techniques have helped fusion scientists reduce the time spent in analysis and further the utility of fusion reactor simulations.

A critical characteristic of a typical fusion reactor is the growth of instabilities in the plasma due to the large gradients of density and temperature, the field geometry, and the inherent self-consistent interactions between charged particles and electromagnetic waves. Identifying and understanding these plasma instabilities is critical in the design of fusion reactors such as the International Thermonuclear Experimental Reactor (ITER), a Tokomak reactor scheduled for completion in 2018. Plasma instabilities occur on very different spatial and temporal scales and can represent highly unique phenomena.

For instance, fusion scientists are actively exploring the micro-scale instabilities created by microturbulence within the plasma. The waves generated by this turbulence can trap particles within the electric field, resulting in a radial diffusion of plasma particles across the confining magnetic field. On the macro scale fusion scientists are interested in “magnetic island” formation due to anisotropic plasma equilibration relative to the magnetic field. As with microturbulence, magnetic island formation allows plasma particles to escape from the confining magnetic field. Understanding these two phenomena is necessary in the ultimate understanding and control of the rate of energy loss and plasma deposition on the wall of the fusion reactor.

The SciDAC VACET team has developed new technologies that are currently in use in the fusion community. The software deployed enables; (1) the rapid finding and tracking of a plasma particle within a given simulation (previously this task required hours to complete...
and now requires only seconds); (2) the replacement of a manual particle search process with one that is automated and based upon state-of-the-art machine learning, and (3) the rapid identification of “magnetic islands” within the magnetic field.

Working with researchers from the SciDAC Scientific Data Management Center, the VACET team developed a method for the rapid visual exploration of very large, multivariate, time-varying datasets. Initially developed for analyzing particles in laser wakefield simulations, this method was expanded to meet the needs of fusion scientists. This expanded capability includes the ability to perform explorations and track particles on a cumulative basis as well as utilizing derived data.

The VACET team, in collaboration with the SciDAC Center for Extended Magnetohydrodynamic (MHD) Modeling, has developed analysis tools for automatically identifying and extracting magnetic islands. This analysis tool, which has its foundation in time-frequency techniques, allows fusion scientists to either work directly within their simulation codes using portable libraries or work offline after a simulation has completed.

The new capabilities provided by the VACET team to the fusion research community are implemented in production-quality, parallel-capable, visual data exploration software that runs on virtually all modern platforms, ranging from desktop-class machines to DOE’s petascale computer systems.

**Recent Publications**


For further information on this subject contact:

Name: Allen R. Sanderson
Organization: SCI Institute, University of Utah.
Email: allen@sci.utah.edu
Phone: (801) 585-0769

Note: This work was funded in part by the SciDAC2 Visualization and Analytics Center for Enabling Technologies and ASCR’s Visualization Base Program by the Director, Office of Science, Office of Advanced Scientific Computing Research, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.