Ultra Fast Programs Developed for Future Ultra Fast Computers

The speed of light is too slow

Los Alamos researchers are developing new numerical simulations to take advantage of a major leap in computing power expected midway through 2008, from an unexpected source: videogame technology. Due to physical limitations, such as the speed of light, moving data between and even within modern microchips is more time consuming than performing the actual computations. As a result, traditional programming styles are unable to fully exploit the potential of modern optimized microprocessors.

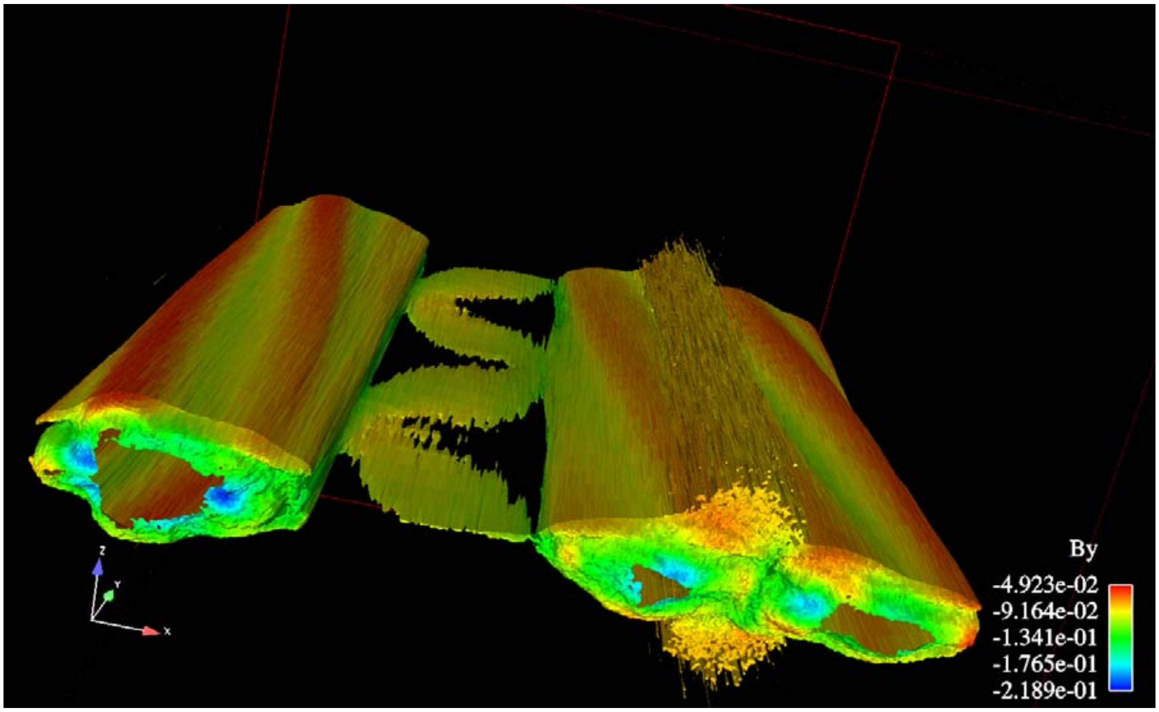
Several years ago a computer code called VPIC was developed at Los Alamos to model plasma physics in a way that takes advantage of these optimized microprocessors, and was recently adapted to run on the next iteration of Roadrunner, the newest computer under development by IBM and Los Alamos. The code has attained unprecedented levels of performance by minimizing the amount of data movement necessary to perform simulations.

Los Alamos National Laboratory is partnering with IBM to reach for the elusive petaflop, equal to a million billion calculations per second. For decades, scientific applications drove the need for higher computer performance, but lately the driving force has not come not from science but from the unlikely world of entertainment, via the videogame.

It's not surprising then, that the next generation computing platform at Los Alamos National Laboratory, named Roadrunner, should make heavy use of videogame technology. The upgraded, hybrid architecture of Roadrunner's third phase — due in the summer of 2008 — contains both AMD Opteron and IBM Cell Enhanced Double Precision (eDP) processing elements. Roadrunner is expected to contain ~13000 IBM Cell eDP microprocessors, the same family of processors used in the Sony PlayStation 3. The Roadrunner base system currently installed at Los Alamos operates at 70 teraflops. The Roadrunner third phase hybrid system is expected to reach a peak performance of more than a petaflop.

The VPIC code is used to do "first principles" simulations, attempting to model the laws of physics with very few assumptions, giving insight to phenomena difficult to recreate in the lab or understand with more approximate theories. VPIC represents plasma as a large number of particles "pushed" by electric and magnetic fields, which are affected by the electrical currents generated by the particles. As the performance of microprocessor cores increased rapidly over the past decades, ever larger first principles plasma simulations were possible on a wide range of phenomena, such as plasma instabilities, laser-plasma interaction, magnetic reconnection, space plasma, and magnetic fusion plasma.

When achieved, petaflop performance will enable previously impossible simulations in numerous areas of plasma physics. For instance, first principles, kinetic, three-dimensional studies of laser-plasma instability inside cavities that form during inertial confinement fusion, a problem of central importance to achieving fusion ignition at Lawrence Livermore National Laboratory's National Ignition Facility, will be possible. Likewise, fully resolved — spanning relevant length and time scales — first principles three-dimensional simulations of magnetic reconnection, the biggest unsolved problem in plasma physics and a problem with applicability ranging from astrophysics to magnetic fusion devices, are within reach. Other topical areas within reach of this capability include ultra-intense laser-matter interaction, space and astrophysical plasmas, shocks, radiographic source modeling, plasma turbulence, and thermonuclear burning plasma media.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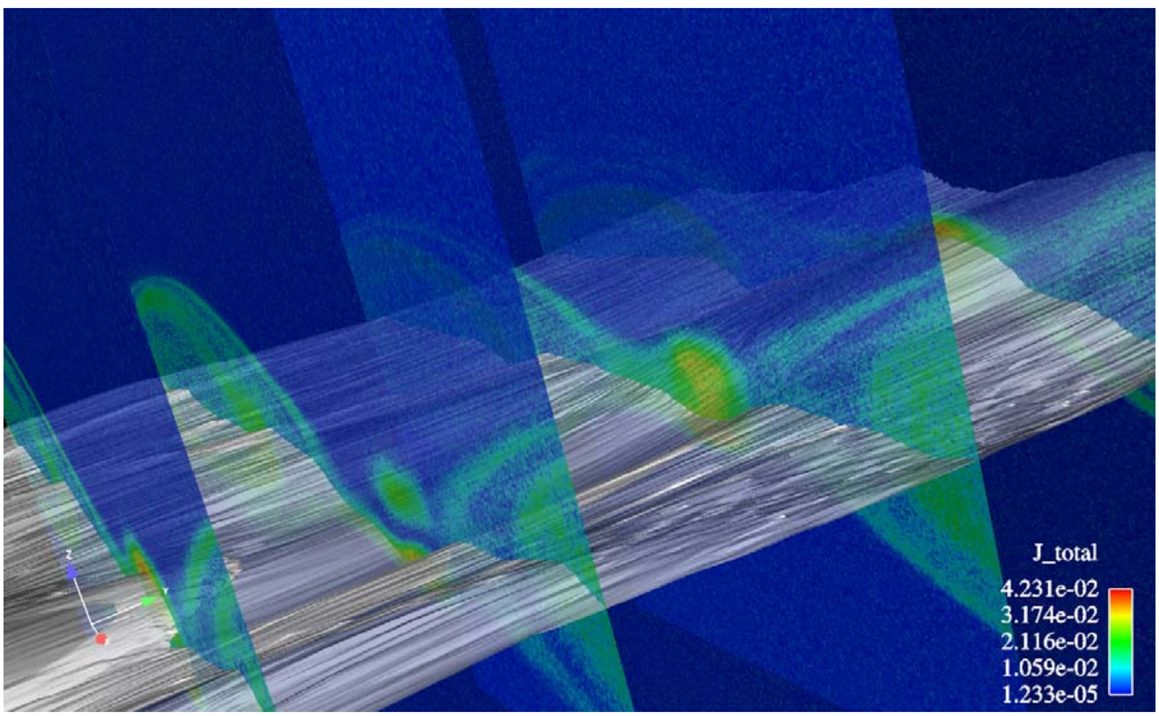
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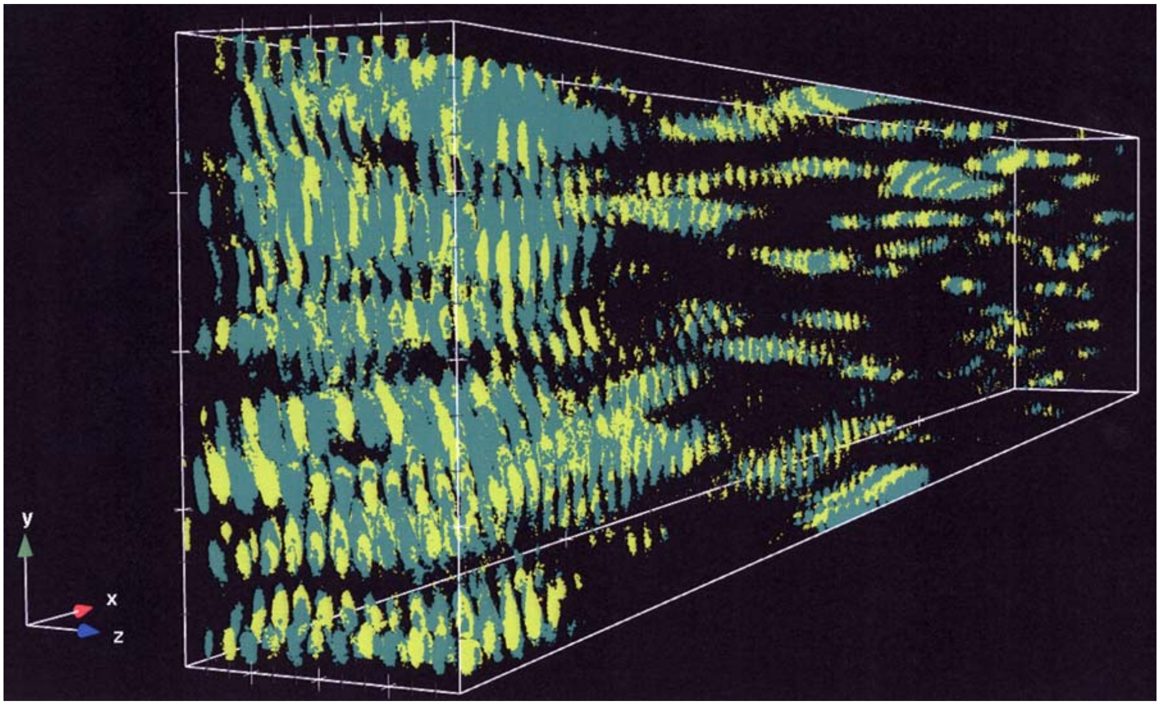

Figure: (Top) Magnetic islands and kink instability observed in three-dimensional fully kinetic VPIC simulations of magnetic reconnection in pair plasma with medium guide field. Shown are isosurfaces of density colored by y-magnetic field. (Middle) A three-dimensional fully kinetic VPIC simulation of magnetic reconnection in pair plasma with no guide field. The neutral current sheet (the horizontal surface) undulates from the growth of kink instability along the current sheet. The vertical panels show current density, and two magnetic islands are evident, with a neutral sheet located between the islands. Visible is a secondary magnetic island (the green blobs of current density located on the vertical planes above the neutral sheet). (Bottom) Stimulated Raman Scattering (SRS) in a three dimensional fully kinetic VPIC simulation of laser plasma instability in a regime relevant to the National Ignition Facility hohlraum plasma. Shown are density isosurfaces of longitudinal electric field. Of note is the SRS filamentation in the nonlinear state of the evolution. Only half the dataset is shown to showcase the SRS filamentation better. These simulations required tens of billion of particles running on thousands of processors for days on conventional supercomputing clusters. However, such simulations (and much larger) could be performed routinely on a petaflop supercomputer like Roadrunner.