

Curved Mesh Correction Tool for 3D Complex Geometries

Accelerators that accelerate elementary particles and nuclei to high energies impact fields as diverse as the underlying symmetries of nature to basic energy sciences and medical applications (“Designing Accelerators: Precision Probes for Scientific Discovery,” *SciDAC Review*, Spring 2006, p12). Modern Accelerator science and technology relies heavily on high-end computing for modeling and simulation research and the SciDAC program facilitates a large part of this work.

In order to perform the analyses needed for the design of next-generation accelerators, researchers at the Stanford Linear Accelerator Center (SLAC) have been taking advantage of higher-order finite-element methods. Finite-element methods are useful techniques for numerical solutions of partial differential equations and integral equations, allowing integration of high-end computation with mathematical descriptions of physical systems. High-order finite-element methods are well known to provide higher rates of convergence, which can provide SciDAC applications with an effective means to address critical applications with dramatically reduced levels of computational effort.

However, when applying higher-order finite elements to these complex 3D domains, one complexity that arises is the need to have curved finite elements. The common approach to the construction of such meshes is to take advantage of available mesh generators to apply straight-sided mesh generation and then curve the mesh edges and faces adjacent to curved domain boundaries to conform to the boundaries. However, the resulting meshes often contain invalid elements because curving the mesh entities to conform to boundaries can lead to negative Jacobian determinants in the closures of elements.

To address this problem, Dr. Xiao-Juan Luo and Dr. Mark S. Shephard of SciDAC’s Interoperable Technologies for Advanced Petascale Simulations (ITAPS) team developed a curved mesh correction tool for SLAC, building on the ITAPS interoperable mesh technologies and expertise in curved mesh generation.

The curvilinear mesh procedure has been successfully applied by SLAC to meshes in the large-scale electromagnetic modeling of accelerator systems. The valid curvilinear meshes not only make the time-domain simulations stable but also improve the computer execution time up to 30% due to better conditioned matrices.

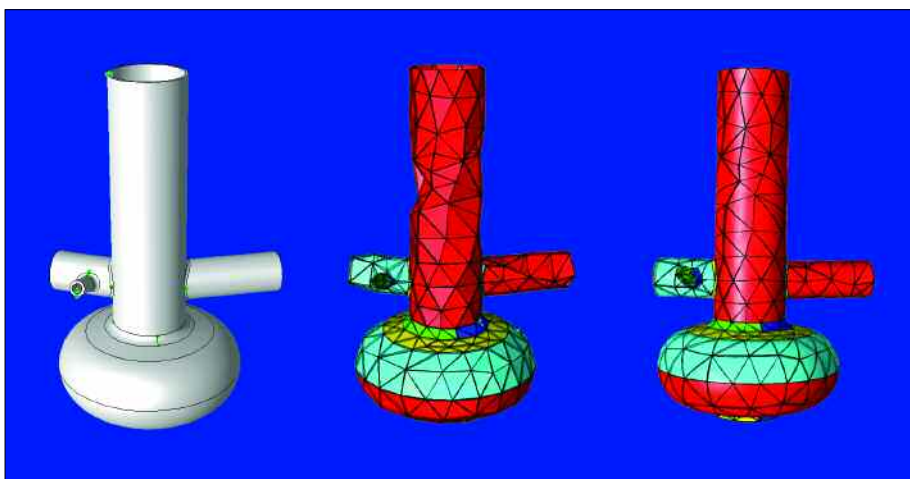


Figure 1. The ITAPS team is working with SLAC to support coupled cavity/structure simulations. A geometric model of a cavity structure is shown on the left. A straight-sided mesh representation (center) can be compared to a curved mesh model with matched layered elements through the thin sections (right). The improved geometric approximation and more optimal through the thickness mesh allows more stable and accurate simulation.

To ensure that the curved meshes are valid, the method developed by Dr. Luo and Dr. Shephard—both are researchers at the Scientific Computation Research Center at the Rensselaer Polytechnic Institute—assesses the closures of each element check to ensure that every mesh entity (edge/face) on the curved model boundaries is properly curved. The process of curving, or correcting a curved mesh, uses a set of curved local mesh modifications that are applied in a proper order that can effectively eliminate the invalid curved elements and make the resulting mesh valid.

More recently, ITAPS team members have begun to work with SLAC to be able, in the long run, to support coupled cavity/structure simulations (figure 1). The generation of the curved meshes for these situations introduces the additional difficulty of the complex thin 3D geometries of the structural walls, where multiple curved elements through the thin section are needed. Building on some preliminary work in this area, they are investigating a more advanced tool to support these classes of problems.

Dr. Lie-Quan Lee, one of the researchers using the curving tool at SLAC, discussed the application of curved meshes in electromagnetic accelerator simulation at the 2007 SciDAC meeting in Boston, and Dr. Luo and Dr. Shephard have presented information related to this project in several papers (see Further Reading).

The curved mesh correction tool is being refined and will be posted to the ITAPS Web site for downloading. Researchers interested in learning more about the tool are encouraged to contact the developers. Alternatively, more information can also be obtained from the SciDAC Outreach Center.

Contacts

Dr. Xiao-Juan Luo
xluo@scorec.rpi.edu, (518) 276-6713

Dr. Mark Shephard
shephard@scorec.rpi.edu, (518) 276-8044

SciDAC Outreach Center
<https://outreach.scidac.gov/>

Further Reading

L. Lee et al. 2007. Enabling technologies for petascale electromagnetic accelerator simulation. *J. Phys.: Conf. Ser.* **78**: 012040.
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X. Luo et al. 2004. Automatic p-version mesh generation for curved domains. *Eng. Comput.* **20(3)**: 273–285.

L. Yin, X. Luo, and M. Shephard. 2005. Identifying and meshing thin sections of 3-D curved domains. Presented at the 14th International Meshing Roundtable, San Diego, CA.
<http://www.imr.sandia.gov/papers/imr14/yin.pdf>