Adaptive Mesh Refinement Algorithms for Parallel Unstructured Finite-Element Codes

At LLNL, the state-of-the-art solvers used for solid mechanics and electromagnetic simulations have sufficient architectural and functional maturity to benefit from the introduction of appropriate adaptive mesh refinement (AMR) strategies. These new tools will enable analysts to conduct more reliable simulations at reduced cost, in terms of both analyst and computer time. Previous academic research in AMR has produced a voluminous literature focused on error estimators and demonstration problems. Relatively little progress has been made on producing efficient implementations suitable for large-scale problem solving on state-of-the-art computer systems. Research issues that we will consider include: effective error estimators for nonlinear structural mechanics and electromagnetics problems, local meshing at irregular geometric boundaries, and constructing efficient software for parallel computing environments.

Project Goals

The objective of this research is to implement AMR algorithms in unstructured finite-element codes used for solving nonlinear structural and electromagnetics problems on ASC-class, multiprocessor parallel (MPP) computers.

Relevance to LLNL Mission

Many programmatic problems will be solved with greater precision and accuracy using the new AMR technology. Successful completion of this project will position LLNL as a leader in parallel finite-element technology, providing capabilities not present in other analysis systems.

FY2005 Accomplishments and Results

A parallel AMR capability has been added to Diablo, a structural analysis code. This includes the data structures and algorithms required to refine a user-defined mesh and error estimators based on patch recovery techniques and residual computations.

Various test problems have been constructed to confirm the correctness of the implementations. The AMR implementation is able to perform both isotropic and anisotropic refinement as well as derefinement of a mesh (Fig. 1). Anisotropic refinement

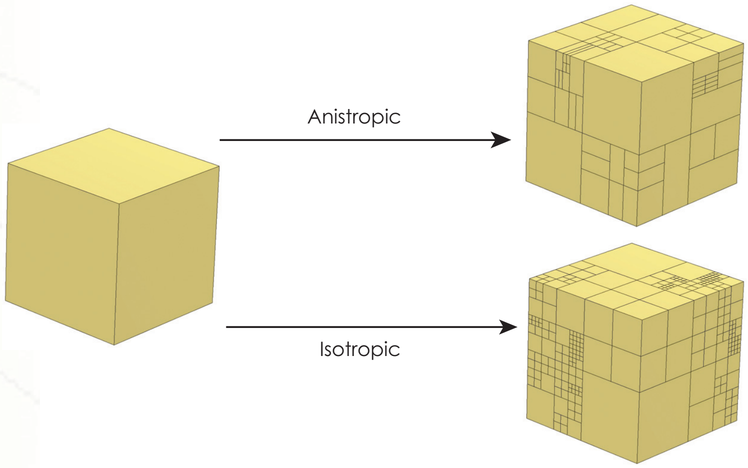

Figure 1. Meshes generated using isotropic and anisotropic h-refinement.

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(refinement based on a directional error estimator) and derefinement are crucial for solving highly transient problems and implicit analysis, where the cost of solving equations can increase considerably with problem size. Savings of the order of 40% in both numbers of elements used and total CPU time required have been observed for some representative test problems.

Gregory patches are used to track evolving nonplanar boundaries. This allows the refined mesh to accurately capture the large geometric changes that are often encountered in structural analysis (Fig. 2).

Figure 3 shows mesh refinement for two bodies in contact. Algorithm and software documentation are being produced using the Unified Modeling Language that will form the basis of the abstraction of the AMR schemes. Coupled thermomechanics simulations have been conducted to demonstrate the capabilities of the current AMR implementation in Diablo.

For electromagnetics, both local and residual-based patch recovery have been developed and implemented within the EMSolve production code. Figure 4 shows results obtained from an eddy current pipe demonstration problem. In this example, an alternating current flows up and down the inner surface of a metal pipe. The current diffuses outward into this pipe. The exact solution is a magnetic field that wraps around the core of the pipe with an amplitude that oscillates while decaying radially as a cylindrical Bessel function. Good agreement between actual and estimated errors has been observed for this and several other relevant test problems.

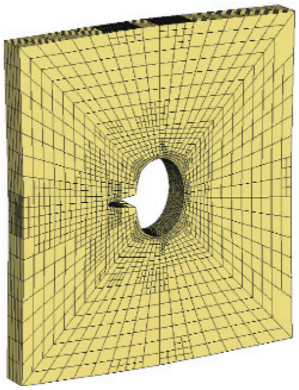

Figure 2. Refined mesh created using Gregory patches to track nonplanar boundaries.

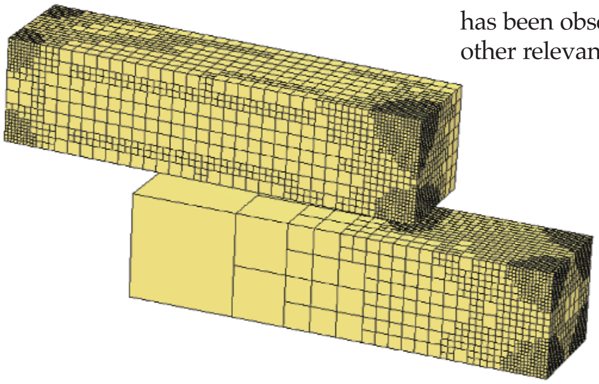

Figure 3. Refined meshes created for two bodies in contact.

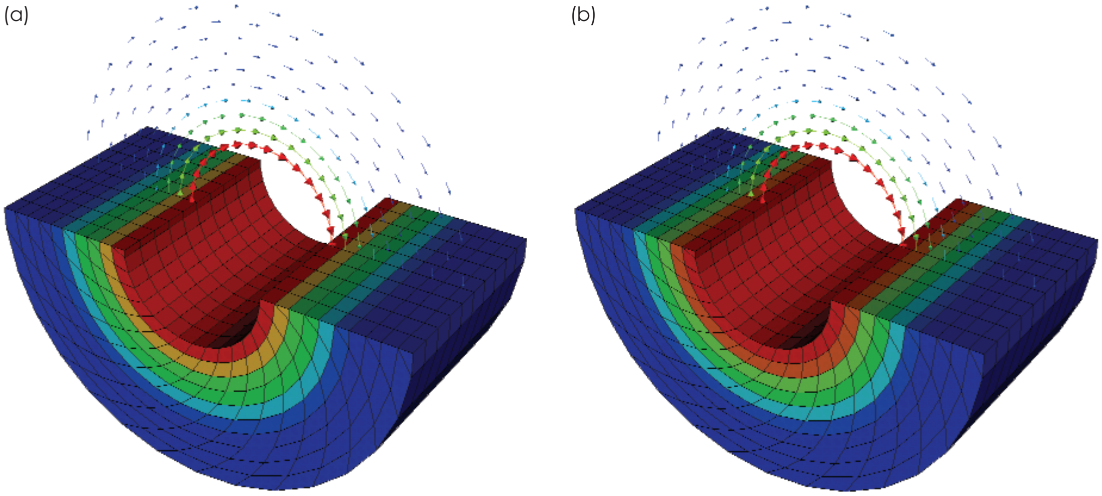

Figure 4. Results for the eddy current pipe: (a) actual error, and (b) error estimated using a patch recovery scheme, showing the effectiveness of the error estimator.