Recent Advances in Optimization-based Mesh Quality Improvement and Their Use in ALE Applications

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In this poster presentation, we describe recent work related to optimization-based mesh quality improvement techniques including parallelization of the algorithms, creation of a new mesh boundary smoothing capability, and use of these algorithms in Arbitrary Lagrangian Eulerian (ALE) applications. For many years, ASCR has supported fundamental research on an optimization-based appraoch to mesh quality improvement via node point movement. The results of this work have been the development of a new "Target-Matrix" paradigm for flexibly defining mesh quality metrics and a number of solution strategies that utilize variants of Newton's method, nonlinear conjugate gradients, and non-smooth steepest descent. Over the years, we have encapsulated our research into the Mesquite mesh quality improvement toolkit and have used this software as a delivery vehicle for our research results and to impact DOE applications. However, the Mesquite software has been limited by a serial implementation and the lack of an automatic mesh-boundary smoothing capability. We have recently performed research in both of these areas and will present our new algorithms along with results of their use in a specific ALE simulation arising in a LLNL application.

The parallel smoothing implementation starts with the decomposition of the domain defined by the application and requests one layer of ghost nodes, along with node ownership information and the MPI communicator. Given this simple information, we determine independent sets of vertices to be smoothed on processor boundaries using a coloring algorithm based on a parallel pseudo-random number generator. The first set of these vertices, along with the interior nodes, are smoothed using either local or global optimization techniques. The remaining processor boundary nodes are placed into independent sets and are iteratively smoothed using local techniques. New grid point locations are communicated at each step to ensure consistent and correct execution of the parallel algorithm. Preliminary tests show that this algorithm scales extremely well to hundreds of processors, with efficiencies near 95%. Ongoing work will test the scalability to 1000's of processors.

The mesh boundary work has focused on optimizing three-dimensional elements while simultaneously constraining boundary vertices to the original faceted representation defined by the mesh. In this case, we limit ourselves to using steepest descent algorithms with the gradient descent direction projected onto the tangent plane of the surface. This method works well in practice in that it is straight forward to implement and inexpensive to execute. The latter criteria is critical for the motivating use case of smoothing along material interfaces at each step of an ALE calculation.

We show preliminary results of the parallel smoothing algorithms and mesh boundary techniques in the context of ALE simulations. These techniques typically use relatively simple geometric approaches to combat deteriorating mesh quality as the number of mesh remaps increase. In these schemes, there are often no barriers to mesh element inversions and solution behaviors are neglected which may lead to inaccuracies. We show that our approach perserves large-scale features of the remapping, honors fixed internal and boundary nodes, and prevents element inversion.

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