Arbitrary Lagrangian-Eulerian (ALE) Methods in Compressible Fluid Dynamics

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Arbitrary Lagrangian-Eulerian (ALE) methods are a popular class of methods for simulation of continuum mechanics problems with large shear deformation such as fluid flow and metal forming. The process consists of a classical Lagrangian step in which the mesh moves along with the modeled material, a rezone step in which the mesh is modified to preserve good quality throughout the computation, and a remapping step in which the solution is transferred from the old mesh to the new, rezoned one. We present new efficient techniques for the rezoning and remapping stages of the ALE framework and demonstrate some of their peoperties on results of real physical simulations from the field of fluid dynamics and plasma physics.

During the rezoning process, care must be taken to prevent unnecessary smoothing of the mesh which results in loss of simulation information gathered so far. We present a solution-sensitive method using a combination of geometrical operations and numerical optimization to reposition the nodes (without their reconnection) and thus to untangle even heavily distorted meshes. This method can be either used for the actual rezoning after the Lagrangian step, or utilized as a preprocessor to other efficient techniques, which cannot handle invalid elements (e.g. inverted or nonconvex cells) in the starting mesh, for example the Reference Jacobian Matrix (RJM) based methods. Another presented technique improves the mesh quality by reconnection of the nodes so, that the interpolation error of selected state variable (e.g. density or temperature) is minimized. Further applications of this technique include mesh improvement for solution of diffusion problems by Mimetic Finite Difference method.

The remapping procedure is required to be conservative, preserve local bounds and transfer at least linear functions exactly. A very fast and robust method uses high-order intercell fluxes and a posteriori correction (so called Repair) of possibly created new extrema of selected state variables. Here we present two methods in which preservation of local bounds is enforced already during the remapping process, and therefore no repair is needed. The first is based on constrained numerical optimization of intercell fluxes, gives good results, but can become nonlocal and thus too expensive in some extreme cases. Another remapping is based on the classic idea od Flux-Corrected Transport (FCT) and combines low-order fluxes (which preserve local bounds by default) with higher-order fluxes (generally unconstrained) in a way that meets all imposed requirements. This method is by definition local (and thus simple) and major part of the computation is independent on mesh dimension and topology.

Finally, we demonstrate effects of the new techniques in an ALE code simulating physical phenomena from fluid dynamics and plasma physics such as Rayleigh-Taylor instability, laser-plasma interaction and impact of an accelerated aluminum disc on massive target.

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