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The Repair Paradigm: New Algorithms and Applications to Compressible Flow

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Summary

A repair method can be viewed as a way to correct values on a discrete mesh by redistributing the conserved quantity so that conservation and a maximum principle are preserved. The maximum principle is that new values should obey certain upper and lower bounds obtained from old values. In this way not only are nonphysical quantities eliminated, but oscillations are reduced (albeit not necessarily eliminated).

A critical part of Lagrangian-based methods for Computational Fluid Dynamics (CFD) is the ability to remap or interpolate data from one computational mesh to another. This is the case for the popular ALE schemes that perform Lagrangian steps followed by remaps to fixed grids.

Remapping is also essential for pure Lagrangian methods, since they can lead to tangled grids that must then be untangled with a concomitant remap step. Even if the basic scheme produces only physically meaningful quantities, a remapping method can create out-of-bounds quantities such as negative densities or pressures. In some CFD codes, the offending values are simply set to a small positive number when this occurs, at which point mass or total energy is no longer conserved.

Another context in which nonphysical data can occur is in divergence-free advection of a concentration that must retain values between zero and one.

High quality advection schemes, some of which are based on remapping ideas unavoidably have this default. The goal in this work is to improve upon and apply the repair idea. A repair method can be viewed as a way to correct values on a discrete mesh by redistributing the conserved quantity so that conservation and a maximum principle are preserved.

The maximum principle is that new values should obey certain upper and lower bounds obtained from old values. In this way not only are nonphysical quantities eliminated, but oscillations are reduced (albeit not necessarily eliminated).

We therefore seek repair algorithms that can be applied to CFD problems, advection problems, or other situations where values of a discrete variable must be placed in bounds without violating a conservation law and without introducing significant errors in the dynamics.

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The properties to be fulfilled by a repair method are:

Conservation: The sum of all masses in the new mesh must be equal to the sum of all masses in the old one.

Maximum principle: The density in the new cell must be bounded from below and from above.

The idea of this method is to repair as many cells as possible with a local treatment: first the upper bounds (then the lower) with an iterative process (the neighborhood being fixed). Then if some cells are still out of bounds, a global treatment is provided to fix these cells. Numerical tests are performed to show the effects of such methods on advection and hydrodynamics problems like the double nonsymmetric blastwave solved with an ALE code where the repair method is necessary for the code to produce a physically meaningful solution (see the figure).

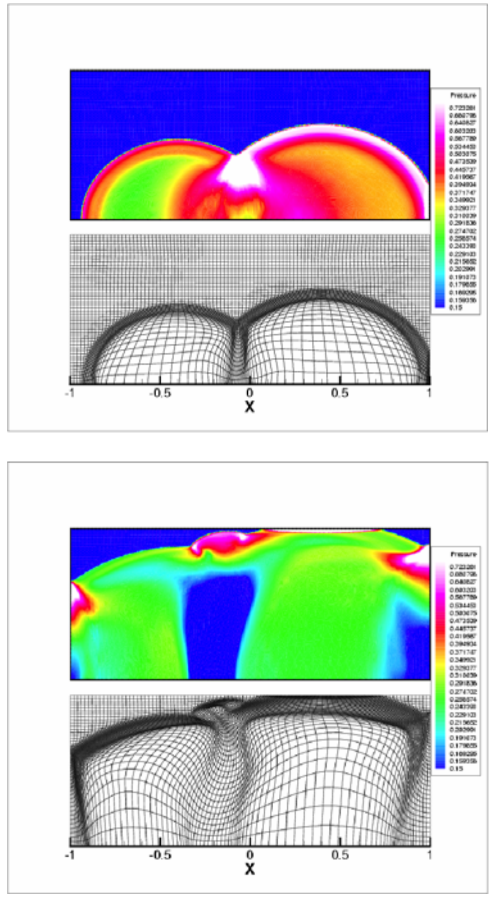

Figure 1: Interaction of two blastwaves in a box. Initially two half disks centered at X = (±0,5,0) have a high energy compared to the interior of the box. Top picture: t = 0.3, bottom picture: t = 0.8.

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