Parallel AMR Code for Compressible MHD or HD Equations

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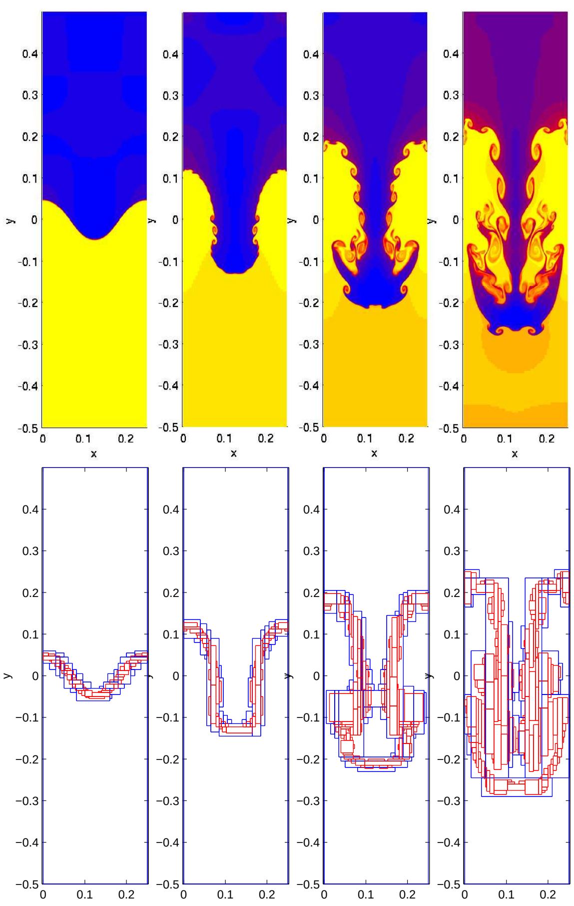
Numerical simulation for astrophysics phenomena has become popular and important in the last decade. Many astrophysics problems can be formulated as hydrodynamics (HD) or magneto-hydrodynamics (MHD) system of equations. Therefore, many numerical simulation codes are based on correctly solving these equations.

We have developed a modern code to solve the magneto-hydrodynamic (MHD) and hydrodynamic (HD) equations. The code consists of several approaches for solving the MHD (and HD) by high-resolution schemes with finite-volume and finite difference methods. Currently, we have implemented HLLE, HLLC (including our newly developed version for MHD [4]), Roe's approximate Riemann solvers, CLAWPACK of Leveque, and Colella's multi-dimensional scheme for second-order method, PPM (available only for HD) for third-order, and WENO for fifth-order methods. Both dimensional split and unsplit versions are included in our code. Our framework has a capacity to incorporate other solvers easily without much recoding.

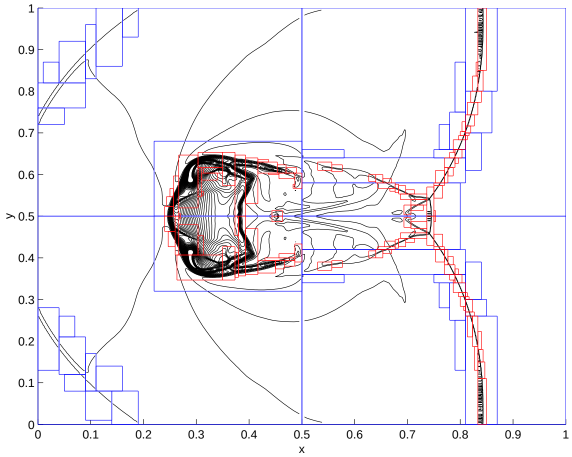
A real astrophysics problem contains multiple time and length scales that must be resolved simultaneously. Therefore a framework that implements adaptive mesh refinement (AMR) with nested block-structure is developed in our code. Our adaptive mesh refinement framework basically inherits all of the features of Berger and Colella's method [1]. We also enhanced Berger's AMR by an improved clustering algorithm and user flexible control over the refinement [3], by allowing staggered grid variables for vector-field components, by adding the cylindrical and spherical geometries. We implemented a novel approach [6] for maintaining divergence free condition for AMR. The novel approach can be applied to any refinement ratio and any curvilinear grid, and is more efficient and flexible than the previous full-reconstruction approach of Balsara [2].

Our code can handle cylindrical and spherical geometries as orthogonal curvilinear grid as well as Cartesian geometry. We also enhance the AMR capabilities by preserving the conservative quantities and preserving the divergence free constraint for vector-field.

The code is fully parallelized with message passing interface (MPI) and a dynamic load balancing scheme is incorporated to improve the parallel efficiency. The computation and communication are interlaced to achieve full parallelization.



HD example — The Rayleigh-Taylor instability problem and three-level AMR grid. Refinement ratio is 3.



MHD example — The cloud shock interaction problem. Refinement ratios are 3 and 2.

Two examples are shown here to demonstrate the capability of our code. The first one is a Rayleigh-Taylor problem, calculated via fifth order WENO scheme. Two refinement levels with ratio of 3 are used. The output time from the left to right is 0.5,1.0,1.5, and 1.9. The second example is an MHD problem, which models the disruption of a high density cloud by a strong shock wave. We used a three-level refinement with ratios of 3 and 2. The divergence-free condition is preserved to machine round-off error. Our code is designed in a way that existing codes for a single grid can be easily incorporated. More details about the code and solvers can be found in paper [5].

Acknowledgements

Los Alamos Report LA-UR-03-8926.This research was performed under the auspices of the Department of Energy. It was supported by the Laboratory Directed Research and Development Program at Los Alamos.

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