Towards Implicit Resistive Magnetohydrodynamics with Local Mesh Refinement

M. Pernice[1], L. Chacón[2]
[1] *Computer and Computational Sciences Division*
[2] *Theoretical Division*
Los Alamos National Laboratory, Los Alamos, NM 87545

Abstract

Efficient and accurate solution of the resistive magnetohydrodynamics model presents a significant challenge due to the presence of multiple length and time scales. Explicit time stepping methods introduce stringent CFL restrictions on the time step in order to maintain stability. This restriction is relieved by semi-implicit approaches, but accuracy considerations place practical limits on the time step that are much smaller than the time scale of phenomena of interest. Recently, it has been shown that fully implicit approaches are practical, which allow time steps that are much closer to time scales of interest and facilitate use of higher-order time differencing schemes.

An implicit approach can only be competetive with more traditional approaches through the use of efficient, robust methods to solve large-scale systems of nonlinear equations at every time step. In particular, a Newton-Krylov method, in combination with a physics-based preconditioner that respects the key couplings of interest, has been shown to be up to an order of magnitude faster than an explicit method, while delivering comparable accuracy. A key element of this approach is the use of efficient multigrid methods to implement the preconditioner.

On the other hand, it is impractical to resolve fine spatial features with a globally fine mesh. As a result, local mesh refinement is increasingly being used. When local mesh refinement is combined with explicit or semi-implicit time stepping methods, new strategies, such as local time stepping, must be introduced. The use of smaller time steps on the finest regions may dominate the cost of the calculation, depending on how much of the computational domain is covered by the finest mesh. Implicit methods allow a single global time step that is restricted only by the desired accuracy. The same physics-based preconditioner can still be used; however its implementation must now account for the variation in local mesh spacing in order to remain competetive.

We describe our efforts to combine implicit time stepping with local mesh refinement in a resistive magnetohydrodynamics model. The Newton-Krylov method and physics-based preconditioning remain at the heart of the scheme, but the preconditioner is now implemented using the Fast Adaptive Composite grid (FAC) method to explicitly account for variations in local mesh spacing. Straightforward modifications to the discretization scheme that are needed at changes in mesh resolution will also be described. The parallel implementation features the use of SAMRAI to manage complex data structures associated with dynamic, locally refined meshes; solvers from PETSc to drive the solution process; and structured multigrid solvers from the hypre package to solve subproblems on the coarsest level. These various packages are coupled through a seamless interface that minimizes data copying. Another key feature is the use of multiple data representations that allow the most natural implementation of different phases of the calculation.