Parallel Aspects of a Fully Implicit and Nonlinearly-Consistent Euler Equation Set

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At Los Alamos National Laboratory (LANL) a numerical model, HIGRAD, has been developed to study the movement of wildfires and other extreme atmospheric phenomena such as hurricanes. Until recently, HIGRAD's dynamic equations, the Euler equation set, were solved using either an explicit approach (the Method of Averaging, MOA) or a nonlinear semi-implicit approach using the Jacobian-Free Newton-Krylov (JFNK) method. The little known MOA method is a nested algorithm in which velocities and forces are computed and then averaged within a inner loop using first-order numerics with these average quantities then being used in an outer loop that employs a higher-order numerical scheme. Being the MOA is explicit, the method runs both efficiently on parallel machines and is highly scalable. However, because the MOA method is explicit, in certain weather regimes, such as very light winds, the method is not numerically efficient with respect to implicit methods. For these regimes, the nonlinear semi-implicit JFNK solver is typically used.

A potential problem does exist with both these numerical approaches, in certain flow regimes, their respective solutions are currently only first-order in time. To circumvent this problem we are developing a version of HIGRAD which will eventually employ the JFNK method on the entire system, both dynamics and physics. By solving for all model variables in a fully implicit and non linear-consistent manner we believe that we can achieve our goal of a having a fully second-order in time weather prediction model. As a starting place, we have embedded the entire Euler equation set into the JFNK machinery. One of the keys to solving this system efficiently is the development of a robust preconditioner. To this end we have developed a preconditioner which uses the semi-implicit method to solve an approximate form of the governing equations. Being that this preconditioner was designed to attack the fastest waves in the system and not other features in the implicit system such as advection, the preconditioning technique is labeled as a "physics-based" preconditioner. Note that this "physics-based" preconditioner requires the inversion of only one equation, the energy equation, and thus this approach uses considerably less memory than other preconditioning techniques which typically would invert an approximate form of the entire coupled Euler equation system. Details concerning the development of the "physics-based" preconditioner will be presented at the conference.

The matrix formed by the semi-implicit procedure requires the use of a linear solver to invert it. Typically, in a semi-implicit method, the implicit equation which results must be solved to a relatively tight tolerance for stability considerations; however, being that the semi-implicit technique is embedded within a preconditioner this constraint can be somewhat relaxed. Nevertheless, a robust linear solver should be used for optimal efficiency of the method. We intend to demonstrate how various linear solvers such as SSOR, Krylov, and multi-grid perform with respect to each other in approximately inverting the semi-implicit matrix and ultimately the efficiency of the entire JFNK procedure. Additionally, each linear solver has specific issues with how well it does in parallel, details concerning the parallel efficiency of each solver will be presented at the conference.