Michael Pernice

Performance of a Newton-Krylov-FAC Method for Equilibrium Radiation Diffusion on Locally Refined Grids

Los Alamos National Laboratory
P O Box 1663
MS B265
Los Alamos
NM 87544
pernice@lanl.gov

Radiation transport plays an important role in numerous fields of study, including astrophysics, laser fusion, and combustion applications such as modeling of coal-fired power generation systems and wildfire spread. A diffusion approximation provides a reasonably accurate description of penetration of radiation from a hot source to a cold medium. This approximation often features a nonlinear conduction coefficient that leads to formation of a sharply defined thermal front, or Marshak wave, in which the solution can vary several orders of magnitude over a very short distance.

Classic solution techniques use a linearized conduction coefficient. This introduces a first order error in time, and requires small time steps to manage the size of this error. Numerous recent studies have shown that fully implicit time integration methods provide more accurate predictions of the position of the thermal front, even when using large time steps. Fully implicit approaches require the solution of a large-scale system of nonlinear equations at each time step. Newton-Krylov methods, usually preconditioned by a multigrid method, have been instrumental in demonstrating that a fully implicit approach is practical.

The shape of the thermal front can be very complex as it interacts with different materials having different conduction properties. Resolving these localized features with a global fine mesh can be prohibitively expensive. Adaptive mesh refinement (AMR) concentrates computational effort by increasing spatial resolution only locally, and a properly designed method is capable of greatly reducing the computational cost needed to achieve a desired accuracy. AMR can readily be incorporated into the Newton-Krylov solution framework, by properly accounting for the presence of local refinement in the preconditioner. In particular, the Fast Adaptive Composite grid (FAC) method of McCormick and Thomas is well suited for this purpose.

We report on efforts to solve equilibrium radiation diffusion problems using structured AMR and the Newton-Krylov-FAC method. While structured AMR facilitates reuse of existing software written for logically rectangular grids, discretization at locations near changes in resolution must be treated carefully in order to avoid the creation of artificial sources. We describe our FAC solver and report on its performance, both as a standalone solver and as a preconditioner within Newton-Krylov iterations.