An Algebraic Two-Level Preconditioning Strategy For Solving Radiation Diffusion Systems

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A novel two-level preconditioning strategy is presented for solving linear systems arising in the radiation-hydrodynamics simulations. The governing equations of radiation diffusion are

$$\begin{cases} \frac{\partial E_R}{\partial t} - \nabla \cdot \left(\frac{c\lambda(E_R)}{\kappa_R}\nabla E_R\right) = c(B(T_e) - E_R) \\ \rho C_{V_e}\frac{\partial T_e}{\partial t} - \nabla \cdot \left(D_e \nabla T_e\right) = \omega_{ei}\left(T_i - T_e\right) - c\left(B(T_e) - E_R\right) \\ \rho C_{V_i}\frac{\partial T_i}{\partial t} - \nabla \cdot \left(D_i \nabla T_i\right) = -\omega_{ei}\left(T_i - T_e\right) \end{cases}$$

In these equations

- E_R is radiation energy density,
- T_e, T_i are electron and ion temperatures,
- c is light speed, $\lambda(E_R)$ is flux limiter,
- κ_R is Rosseland absorption coefficient of mean free path,
- ρ is material density, C_{V_e}, C_{V_i} are electron and ion heat capacities,
- D_e, D_i are conduction coefficients of electron and ion,
- ω_{ei} is electron-ion coupling coefficient, and
- $B(T_e)$ is Planck function.

The main idea of our method is to decouple one variable from the other two by a special coarsening strategy, where all the variables related to electron temperature are forced selected coarse points (C-points), other variables (radiation energy and ion temperature) are all forced to be fine points (F-points). So, only several scalar equations need to be solved instead of the coupled linear systems, and the classical-AMG method is used to solve those scalar equations. Numerical results are presented, including parallel simulations performed on hundreds of processors.