Block Preconditioning Approaches to Physics-Compatible Electromagnetics and Plasma Simulations

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Multifluid continuum plasma models present algorithmic difficulties as the strong nonlinear coupling of fluid and electromagnetic fields result in several time-scales (including plasma and cycloctron frequencies for each fluid species, as well as the speed of light), many of which may be much faster than time-scales of interest. An effective approach to simulating such systems is to employ fully implicit or implicit-explicit time integration to account for but step over fast physics while accurately resolving slower time-scales. This presents a challenge to linear solvers as the discretization of fast time-scales manifests in stiff modes in resulting linear systems. To complicate things further, compatible discretizations are often used for the electromagnetic unknowns (edge elements for electric fields and face elements for magnetic fields) in order to implicitly enforce solenoidal and charge conservation conditions, and this precludes the use of monolithic algebraic multigrid methods that depend on co-located degrees of freedom.

This work focuses on the development of block preconditioners for linear systems arising from compatible finite element discretizations of multifluid plasma systems. These block preconditioners segregate degrees of freedom by discretization type (node, edge, and face) so that scalable AMG solvers can be applied to sub-blocks. This work builds on our recent development of block solvers for compatible discretizations of the first order Maxwell equations for slow time-scales relative to the speed of light. We demonstrate the robustness and algorithmic scalability of this solution method on test problems in pure electromagnetics and plasma simulation over a variety of realistic time-scales.

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