Embedded Boundary Algorithms for Moving Domain and Two-Phase Flows

Advanced Simulation of Subsurface Flow and Transport at the Pore Scale

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Abstract

During carbon sequestration in porous rock structures, chemical reactions occur that change the flow channel geometry through mineral dissolution and precipitation. Flows can be multi-phase, consisting of supercritical CO2 and brine. Since transport properties at the fluid-rock interface are sensitive to the flow environment, quantitative predictive modeling requires an accurate and robust approach to time-dependent complex geometries that can accurately resolve gradients in the presence of discontinuities. Toward that end we have developed new finite volume embedded boundary algorithms for incompressible Navier-Stokes flows in time-dependent domains. This presentation will focus on the challenges associated with the fluid solver in the absence of chemical reaction.

To model single-phase flows with time-dependent domains, we developed a Godunov projection scheme consisting of operations on fixed domains, each representing the configuration at a particular time, and extrapolations from one time domain to another. This enables the use of existing fast scalable multigrid solvers. Second-order accuracy will be demonstrated for the combined scheme.

Two-phase flows are treated as two individual moving-domain problems, coupled through jump relations on the material interface. For pressure Poisson problems there is a (Dirichlet) jump in pressure associated with surface tension, and a (Neumann) jump in pressure gradient associated with specific gravity. The approach to reconciling these jumps is based on the iterative substructuring method in domain decomposition. A BiCGSTAB solver with a Neumann-Neumann preconditioner determines the interface values without explicit construction of the capacitance matrix. A similar problem is encountered in the implicit heat problem associated with viscous source terms, and again the iterative substructuring method provides a scalable solution. It will be demonstrated that these two-phase coupled solvers scale in proportion to the number of computational cells, and provide second-order accuracy. Preliminary results for gravity-driven two-phase flow will be presented.

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