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A Multilevel Multiscale Mimetic (M^3) Method for Two-Phase Flows in Porous Media

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In many subsurface applications, homogenization (or upscaling) techniques are necessary to develop computationally feasible models on scales coarser than the variation of the coefficients of the continuum model. The accuracy of such techniques depends dramatically on assumptions that underlie the particular upscaling methodology used. For example, decoupling of fine- and coarse-scale effects in the underlying medium may utilize artificial internal boundary conditions on sub-cell problems. Such assumptions, however, may be at odds with the true, fine-scale solution, and hence, may lead to significant errors in computed coarse-scale quantities. To address this problem we are developing truly multilevel methods that do not make such a rigid distinction between resolved and unresolved (coarse and fine) spatial scales. Specifically, we are interested in developing techniques that draw on various aspects of robust and efficient multilevel solvers to upscale or homogenize the underlying mathematical model, and not simply the parameters of the model.

In this talk we develop a new multilevel multiscale mimetic (M^3) method for discretizations of the first order system for pressure and bulk fluid velocity. This work combines an algebraically-based sub-grid modeling technique recently proposed by Y. Kuznetsov with an algebraic multigrid (AMG) method for approximating the flux coarsening parameters. The use of a robust variational multigrid algorithm, such as AMG, efficiently captures the effects of the fine-scale structure on the flow, and hence, provides accurate estimates of the problem dependent flux coarsening parameters in a very small number of iterations. By design, the structure of the coarse-scale system is identical to the original fine-scale system, hence we can apply the coarsening procedure recursively to obtain a multilevel algorithm. This algorithm is very flexible with a number of free parameters, including the number of coarse levels, the coarsening factor for each level, and the accuracy of the flux coarsening. We demonstrate the new M^3 method using the IMPES time discretization approach for the mimetic finite difference (MFD) discretization of two-dimensional benchmark problems with highly heterogeneous permeability fields.