“Adaptive multiscale simulations in highly heterogeneous porous media”

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Summary:

This work discusses our recent advances in adaptive multiscale simulations for flow and transport in highly heterogeneous porous media. Our aim is to develop adaptive multiscale methods which are flexible and can take into account various physics. We explore adaptive coarsening and efficient localization procedures.

The high degree of variability and multiscale nature of formation properties such as permeability pose significant challenges for subsurface flow modeling. Geological characterizations that capture these effects are typically developed at scales that are too fine for direct flow simulation, so techniques are required to enable the solution of flow problems in practice. Upscaling or subgrid capturing procedures have been commonly applied for this purpose and are effective in many cases. A few of our recent accomplishments address the adaptivity issues in multiscale simulations.

One of our accomplishments is to develop an adaptive multiscale simulation technique for multi-phase transport in highly heterogeneous porous media. The method is based on a finite volume methodology and resolves both coarse scale and fine scale flow patterns. The transport equation describing the dynamics of the phases is usually convection dominated. It is a challenging task to develop a multiscale method for convection dominated equations describing multi-phase flow dynamics, where the velocity field is heterogeneous and varies in time. In general, there is a strong need for multiscale methods which are not limited to convection dominated equations and can handle various physical processes (gravity, capillarity, and etc) without significant modifications. Our approach has some similarities with multiscale framework developed for nonlinear equations and can be easily coupled to multiscale methods for flow equations. The main idea of the proposed approaches is to determine accurate and efficient multiscale basis functions and the global coarse-grid formulation of the problem. The multiscale basis functions are constructed as a function of average saturation in each coarse block, and then used in the global formulation of the problem. An adaptive simulation is performed and the subgrid basis functions are used away from sharp interfaces. Our multiscale approach allows us to perform downscaling in the regions of interest and incorporate more functionality into the coarse-scale quantities. Using this adaptive technique, we solve 3-D SPE benchmark problem, and demonstrate accurate results. A representative numerical result for a five-spot injection problem for two-phase flow and transport is presented in Fig. 1, where the resolved saturation field is compared to the one obtained with our adaptive multiscale approach for a cross section of 3-D SPE benchmark permeability field (SPE 10).

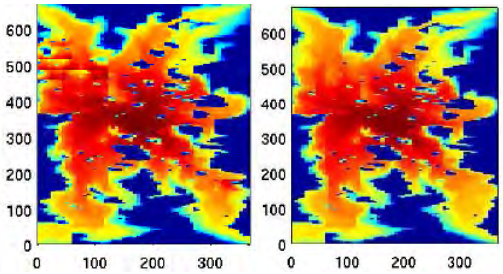

Fig.1. Comparison of resolved (left) and adaptive multiscale (right) solutions.

In multiscale simulations of flow and transport, coarse grids play an important role. By an appropriate choice of a coarse grid, one can significantly improve the accuracy of multiscale methods and reduce the computational cost. Recent studies on the use of limited global information in multiscale simulations allow us to make a judicial choice in setting up coarse grids.

Coarsened grids obtained by upscaling are usually constrained to be on a specific grid format, e.g., corner-point grid format (logically hexahedral grids) or PEBI grid format (orthogonal Voronoi grids). In general, grid constraints put severe limitations on upscaling and make it very difficult to capture the important features in the underlying geomodels in an appropriate way. Indeed, upscaled subsurface flow models often fail to capture important subscale features, such as narrow high-flow channels or shale barriers (low permeable obstacles). However, because small scale structures of this kind may have a profound impact on the resulting flow regime, and therefore should be reflected in the upscaled model, it is common to spend significant effort on constructing simulation grids that are tuned to dominant features of the geomodel. Unfortunately, grid constraints make it hard to develop fully automated coarse grid generation procedures that capture adequately the impact of small scale structures. We present a generic, semi-automated algorithm for generating non-uniform coarse grids for modeling subsurface flow. The method is applicable to arbitrary grids and does not impose smoothness constraints on the coarse grid. One therefore avoids conventional smoothing procedures that are commonly used to ensure that the grids obtained with standard coarsening procedures are not too rough. The coarsening algorithm is very simple and essentially involves only two parameters that specify the level of coarsening. In the coarsening algorithm, single-phase flow information is used. Consequently the algorithm allows the user to specify the simulation grid dynamically to available computer resources, and, e.g., use the original geomodel as input for flow simulations. This is of great importance since coarse grid-generation is normally the most time-consuming part of an upscaling phase, and therefore the main obstacle that has prevented simulation workflows with user-dependent resolution. We apply the coarsening algorithm to a series of two-phase flow problems on both structured (Cartesian) and unstructured grids. The numerical results demonstrate that one consistently obtains significantly more accurate results using the proposed non uniform coarsening strategy than with corresponding uniform coarse grids with roughly the same number of cells. A representative numerical example is presented in Fig.2.

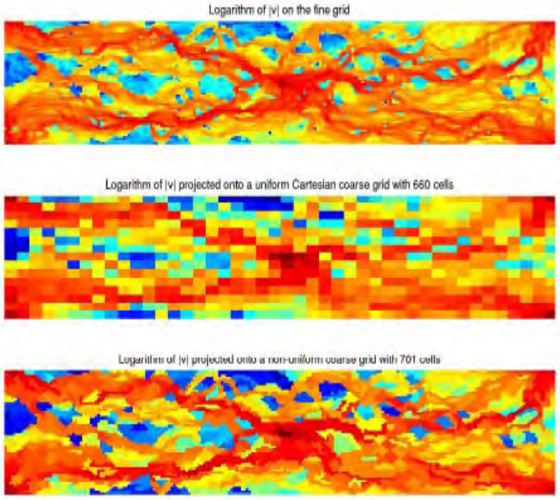

Fig.2. The log of absolute value of velocity for the fine-scale (top), uniform coarse-scale (middle) and non-uniform coarse-scale (bottom) solutions on 20 times coarser grid.

More information about ongoing research and other projects can be found at http://www.math.tamu.edu/~yalchin.efendiev/doe_DE-FG02-05ER25669.html