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Efficient Region Decomposition for Parallel Simulation Accounting for Uncertainty in the Reservoir Model

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Abstract

Reservoir region delineation is essential for parallel flow simulation of large reservoir models. We argue that the delineation of least correlated, most sensitive regions mitigates the requirements for load-balancing and flux-matching that are the bane of current parallel simulation procedures. The optimal choice of sub-regions satisfies two conditions. First, the values of permeability in the sub-regions should have the greatest influence on the performance of injection and/or production wells. Second, the sub-regions should exhibit the least possible correlation with one another. Principal component analysis (PCA) of sensitivity matrices readily identifies regions meeting both the conditions. There are two methods for obtaining sensitivity matrices: i) the Hessian matrix calculated internally by a flow simulator, and ii) a covariance matrix calculated using a suite of realizations. The latter method is more robust and effective in terms of fluid flow connectivity, computational cost, availability to implement and capability of capturing uncertainty of reservoir models. In this paper, we focus on domain delineation using the covariance matrix and apply the method to a series of examples. We discuss key advantages of this method over the alternative of using the Hessian matrix.

Introduction

Reservoir simulators have been comprehensively used for the evaluation of reservoir flow performance and management. One of the main issues in performing reservoir flow simulation is the computational cost especially in single *cpu* computational environments. The computational expenses for solving the linear system of algebraic equation that arises in multiphase flow are about 60-80% of the total computational expenses (Liu *et al*. 2000).

Strategies to mitigate the high computational expenses of reservoir simulators, such as use of limited number of gridblocks, poor resolution of simulation models, etc. introduce other problems. Limitation on the number of gridblocks, in other words the problem of size, hinders the spatial resolution of reservoir description, thereby limiting the numerical accuracy of the flow simulation results; furthermore, if the reservoir simulations involve multiple components and multiphase fluid flows, this problem is even more severe.

The advents of parallel computing systems and distributed computing systems directly address these problems. This new generation of parallel computing systems enables multi-region, multi-scale reservoir simulations dealing with millions of gridblocks (Zhang *et al*. 2001). To apply these methods, the reservoir needs to be delineated into several sub-regions such that each sub-region is simulated on a differently assigned *cpu*s. The non-linear governing equations describing the flow system are partitioned in space and time to be solved in each sub-region. In order to retain the accuracy of the flow simulations, it is necessary to specify the fluxes at the boundaries of the sub-regions correctly. The boundary fluxes have to be updated over the course of the simulation and this adds to the computational expense.

Petroleum reservoirs are complex and are described by parameters correlated in space. The criteria for sub-region decomposition should simultaneously take into consideration the spatial characteristics of the reservoir attributes as well as the configuration of wells. Often reservoirs are composed of several different sedimentary classifications, which affect petrophysical properties such as pore size distributions, porosity, permeability, capillary pressure, saturation, etc. Properly decomposed sub-regions should capture distinct differences between these features. Also, well configurations need to be considered while defining the dimensions of each sub-region, especially if coarsening of gridblocks is performed along with sub-region decomposition (Ma and Chen 2004).

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