Investigation of an approximate multiscale network flow solver for two phase flow in porous media

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Introduction

Pore network modeling, introduced in the pioneering work of Fatt [1], is a powerful tool used to study multiphase flow in porous media at the pore scale. Since their introduction, pore network flow solvers of increasing complexity have been developed to study a wide range of phenomena such as: the effect of pore-structure on relative permeability; the relationship between capillary pressure and fluid-fluid interfacial area; the effect of inertia on interface displacement patterns; and ganglion dynamics. However the computational complexity of network flow solvers are typically of $\mathcal{O}(n^2)$ where n is the number of pores. This introduces an upper bound on the simulation domain size for which network flow solvers are feasible.

Multiscale Solver

In order to overcome this limitation we have developed an approximate multiscale network flow solver for immiscible two-phase flow in pore networks [2]. Here, the network is initially divided into an arbitrary number of subnetworks (see Figure 1). The solver then consists of three main steps. First, a linear system for the global elliptic pressure problem is solved in order to obtain flux boundary conditions across the subnetworks. Second, localized two-phase flow problems in the subnetworks are advanced in time until a global time step has elapsed. This results in a change of fluid saturation distribution within each subnetwork, which in turn affects the global pressure problem. Finally, the states of pore throats between the subnetworks are updated. Similar domain decomposition approaches have been used to simulate e.g., single-phase diffusive transport in pore networks [3], immiscible two-phase flow using the VOF method [4].

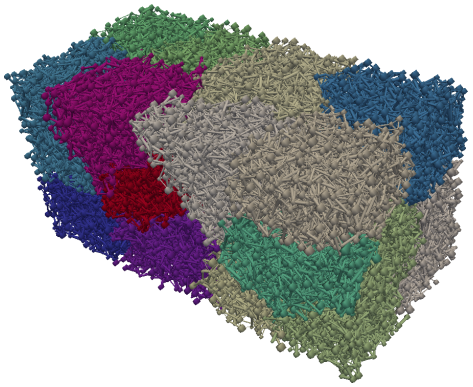
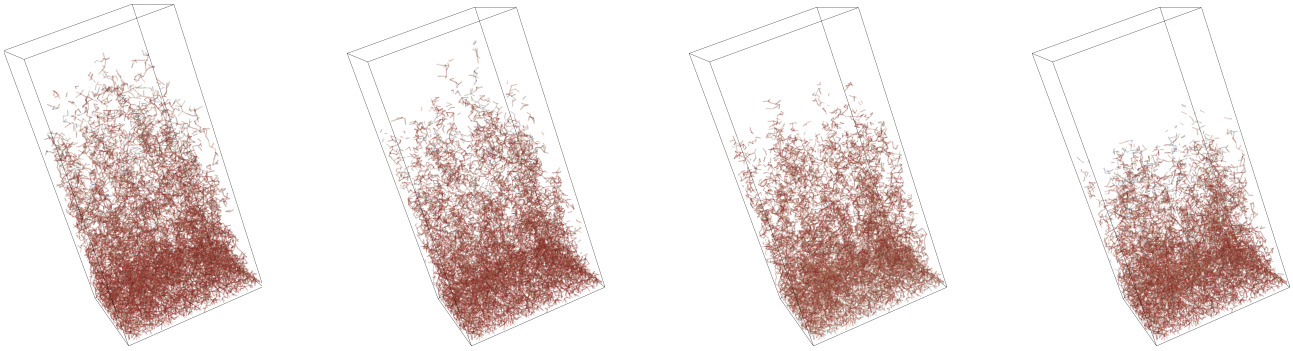


Figure 1: Visualization of a pore network partition

Results

In order to investigate the accuracy and speedup of the multiscale network flow solver, two sets of drainage simulations executed with unfavorable viscosity ratios $M = \frac{\mu_n}{\mu_w} \in \{0.01, 0.1\}$ and capillary number $Ca = 10$ are considered. A visualization of the drainage simulation executed with $M = 0.01$ is shown in Figure 2. The accuracy of the multiscale algorithm depends on the size of the global time. The multiscale solution converges to the fine-scale solution as the global time step parameter $\delta_{\Delta S} \to 0$ with an excellent quantitative match obtained with $\delta_{\Delta S} = 0.001$.



(a) fine-scale simulation *(b)* $\delta_{\Delta S} = 0.001$ *(c)* $\delta_{\Delta S} = 0.002$ *(d)* $\delta_{\Delta S} = 0.005$

Figure 2: Snapshot of drainage simulations with viscosity ratio $M = 0.01$ and capillary number $Ca = 10$ at an average network saturation of $S_n = 0.2$ using (a) the fine-scale flow solver and (b-d) the multiscale flow solver with upscaling parameter $\Upsilon = 1000$ and different values of the global time-stepping parameter $\delta_{\Delta S}$. Only pore throats occupied by the non-wetting phase are shown.

The speedup obtained by the multiscale algorithm for different time-stepping parameters are listed in Table 1. It can be seen that a larger speedup is obtained at lower viscosity ratios and larger $\delta_{\Delta S}$.

Table 1: Speedup factor achieved in executing a drainage simulation with the multiscale algorithm using an upscaling factor $\Upsilon = 1000$, and a capillary number $Ca = 10$ in a network containing 100'000 pore bodies.

	$M = 0.01$	$M = 0.1$
$\delta_{\Delta S} = 0.001$	6.5	3.3
$\delta_{\Delta S} = 0.002$	8.4	4.5
$\delta_{\Delta S} = 0.005$	9.7	5.4

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