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Efficient Nonlinear Gauss-Seidel Type Solvers for Black-Oil Type Models

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Models for multiphase flow in porous media account for several complex physical phenomena such as PVT behavior and interplay with the porous rock, which altogether make reservoir simulation a challenging task. High aspect ratios and strong petrophysical heterogeneity impose severe timestep (CFL) restrictions, and implicit discretizations are thus usually preferred over explicit ones. In a fully implicit discretization, one must solve a large nonlinear system of equations to advance the solution in time. In many cases, the computational cost can be significantly reduced by splitting the overall equation system into a pressure equation and one or more transport equations, and solve the two subproblems sequentially using specialized solvers.

Herein, we consider how to solve the transport equations as efficient as possible. For cases without capillary forces and with co-current flow only, the unknowns within a given cell will only depend on unknowns in the cell's upstream neighbors. By sorting the cells based on the total inter-cell fluxes, the flow equations can thus be permuted to a triangular form and solved very efficiently in $\mathcal{O}(n)$ in a cell-by-cell fashion. In the general case, the reordered system will also contain diagonal blocks consisting of multiple cells that are mutually dependent. These larger blocks can either be solved using a standard Newton-Raphson method or by a Gauss-Seidel method that sweeps repeatedly through the cells in some predefined order.

In this talk, we demonstrate the applicability of the reordering method to realistic reservoir configurations, and show how we can use the sequential splitting with reordering either as a standalone solver, or as a nonlinear preconditioner for the fully implicit nonlinear system.

References

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