CPR-like Preconditioners for Large-Scale Linear Systems in Reservoir Simulations on GPU

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Objectives/Scope:
Fast solution for large-scale sparse linear systems is always required in reservoir simulations. Efficient linear solvers and preconditioners are critical to accelerate the solution process. GPUs are powerful parallel computing devices and they provide another way to speed linear solvers and preconditioners. This research focuses on the CPR-like (Constrained Pressure Residual) preconditioner development for black oil model and compositional model using GPU devices.

Methods, Procedures, Process:
Krylov subspace solvers are general purpose methods to sparse linear systems, such as GMRES, BiCGSTAB and ORTHOMIN, while AMG solvers are specialized in positive definite systems. For black oil model and compositional model, different primary unknowns may be selected while discretizing the mass conservation equations, such as phase pressures, phase saturations, and well bottom-hole pressures. The models can be highly heterogeneous and the linear systems are ill-conditioned. We know that the phase pressure unknowns dominate the overall error and linear systems are hard to solve using ILU preconditioners. CPR-type preconditioners have been designed by researchers, which are multiple-stage methods. ILU methods, such as ILU(0), ILU(k) or ILUT, are applied to the original linear system, and AMG method is employed for linear system corresponding to pressure unknowns. We have developed a GPU-based linear solver package, where parallel triangular solvers for lower triangular systems and upper triangular systems and AMG solver are implemented. Various AMG techniques are investigated, such as coarsening algorithms, interpolation operations, and many smoothers, such Gauss-Seidel smoother, domain decomposition smoother, ILU smoother, Jacobi smoother, block Jacobi smoother, and approximate inverse smoother. The classical CPR method and its derivatives, such as FASP, CPR-FP, CPR-PF, CPR-FPF and CPR-FFPS, are developed. Different ILU methods, such as ILU(k), ILUT, ILUC and block-wise ILU(k), are also studied.

Results, Observations, Conclusions:
Numerical experiments are performed on GPUs and CPUs to test the efficiency of parallel triangular methods, AMG methods and CPR-like preconditioners. The results show the those CPR-like preconditioners have strong parallel capability in solving reservoir models and Krylov subspace solvers with CPR-like preconditioners can be accelerated 7 times faster using Tesla C2050 GPUs.

Novel/Additive Information:
This research shows various combinations of ILU methods and AMG methods, which can serve as a guide for other researchers and simulator developers. Various optimization techniques, which deal with memory access and communications, have been designed for GPU computing, which will be helpful to the design of next generation reservoir simulators.

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