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A Massively Parallel Semicoarsening Multigrid for 3D Reservoir Simulation on Multi-core and Multi-GPU Architectures

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In this work, we have designed and implemented a massively parallel version of the Semicoarsening Black Box Multigrid Solver [1], which is capable of handling highly heterogeneous and anisotropic 3D reservoirs, on a parallel architecture with multiple GPUs. For comparison purposes, the same algorithm was also implemented on a shared-memory multi-core parallel architecture using OpenMP. The parallel implementation exploits the parallelism in every module of the original Multigrid algorithm, including both setup stage and solution stage, without modifying the original algorithm basic steps. The benefits of this approach are twofold: maintaining the inherent strong linear convergence of the serial Multigrid algorithm, and making advantage of the shared-memory architecture to minimize the need for communication.

The design of the algorithm uses a combination of plane relaxation and semicoarsening to efficiently handle anisotropies in 3D, [2]. Sense the z-direction in most reservoir models is a direction of strong-coupling compared to the x- and y- directions, semicoarsening is employed in the z-direction, and plane relaxation is used for relaxation on x-y planes. Besides solving 2D-systems for plane-relaxation, during the setup stage, a set of 2D systems must be also solved on each multigrid level to get an approximate representation of the exact prolongation operator described in [1]. For solving both types of 2D systems, we used a parallel version of the 2D standard-coarsening operator-induced multigrid [3]. To be able to handle problems involving high anisotropies in the x- and y- directions, we used alternating line-relaxation with zebra ordering to parallelize across multiple line solves. For the coarsest-solve, we use multicolor Gauss-Seidel algorithm, with four colors to handle the nine-point stencils of the coarsest structured grid.

There are several differences in the 2D-solver requirements between the setup-stage systems and the solution-stage systems. The setup-stage systems are independent and directly parallelizable. On the other hand, for parallelizing