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Efficient parallel solvers for multi-physics applications on HPC systems

Ludovic Räss (1), Thibault Duretz (2), and Yury Podladchikov (3)

(1) Stanford University, Department of Geophysics, Stanford, United States (lraess@stanford.edu), (2) Univ. Rennes, CNRS, Géosciences Rennes - UMR 6118, F-35000 Rennes, France , (3) University of Lausanne, Institute of Earth Sciences, Lausanne, Switzerland

Iterative and direct type of solvers are the two important categories of methods widely used to numerically solve various systems of partial differential equations. Direct type of solver handle well large contrasts in spatially variable petrophysical or hydraulic properties, but the memory requirements to perform a complete or partial factorisation of the coefficient matrix is the main bottleneck. Direct methods thus show their limit when applied to high-resolution 2-D, or 3-D calculations. In contrast, iterative methods do not require the assembly of a linear system of equations (matrix-free) and rely thus on local stencil type of operations only. One significant advantage of iterative type of solvers is their low and scalable memory requirements. However, iterative methods may exhibit poor convergence rates and struggle to resolve large contrasts in spatially variable material properties.

We aim to investigate the potential of iterative and matrix-free methods to accurately resolve multi-physics couplings in Earth sciences. We will utilise the flow field around viscous inclusions with large material contrasts as a benchmark case. We successfully apply a second order iterative method; the total number of iterations required to reach a defined convergence level scales thus linearly with the total number fo grid points involved in the computational domain. These results are particularly interesting for 3-D model configurations. In addition, we demonstrate that minimal smoothing of the inclusion boundaries prevents the algorithm to diverge but may lead to a solution that deviates from analytics. However, an increase in spatial grid resolution permits to retrieve an acceptable numerical solution.

While a high numerical resolution is mandatory in order to converge to an accurate solution, the number of iterations required to reach the solution only grows linearly with respect to total number of grid points. Yet, this approach efficiently uses the resources of current memory bounded hardware such GPU accelerators and is successfully applied to solve coupled multi-physics problem in Earth sciences on HPC systems.