Geophysical Research Abstracts
Vol. 20, EGU2018-18066-1, 2018
EGU General Assembly 2018

Towards iterative and matrix-free Finite Element solvers for geodynamic applications

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Modelling lithospheric deformation requires the coupling of several physical processes (e.g., deformation, fluid flow, temperature diffusion) spanning over various scales. In order to resolve the nonlinear localisation mechanisms with accuracy, numerical models have to handle computational domains that include a large number of grid points. To enable efficient computations and to achieve a fast time to solution, newly developed algorithms must optimally use the capabilities of modern hardware, designed for parallel execution. Additionally, current hardware is way more efficient in performing floating point operations than in accessing and transferring memory.

To overcome this issue, matrix-free iterative methods unveil their ability to perform local operations avoiding excessive memory requirements, which is one of the actual bottlenecks of direct methods. The significant amount of time usually required to reach a solution iteratively can nowadays be drastically reduced by utilising the concurrent thread execution of modern hardware accelerators, such as graphic processing units (GPUs).

We successfully implemented massively parallel iterative solvers running on modern GPU clusters using the finite difference (FD) method combined with pseudo-transient continuation on regular meshes. However, the FD method reaches its limit when modelling complex geometries on irregular meshes. The finite element (FE) method provides an interesting alternative to resolve irregular structures and allows for local mesh refinement. Further, the accuracy of the solution can be easily increased by selecting a higher order element type.

The goal of this study is to develop matrix-free iterative solvers using the FE method by analogy to the recently developed GPU based FD algorithms. Combining the robustness of the FE method with the computationally efficient iterative FD method provides a powerful tool to tackle a wide range of challenging geodynamic questions.