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Tightly Coupled Geodynamic Systems: Software, Implicit Solvers & Applications

Dave A. May[1], Laetitia Le Pourhiet[2], Jed Brown[3]
[1]*Institute of Geophysics, ETH, Zurich, Switzerland*
[2]*ISTeP, UPMC, Paris, France*
[3]*MCS, Argonne National Laboratory, USA*
dave.mayhem23@gmail.com

The generic term "multi-physics" is used to define physical processes which are described by a collection of partial differential equations, or "physics". Numerous processes in geodynamics fall into this category. For example, the evolution of viscous fluid flow and heat transport within the mantle (Stokes flow + energy conservation), the dynamics of melt migration (Stokes flow + Darcy flow + porosity evolution) and landscape evolution (Stokes + diffusion/advection over a surface).

The development of software to numerically investigate processes that are described through the composition of different physics components are typically (a) designed for one particular set of physics and are never intended to be extended, or coupled to other processes (b) enforce that certain non-linearity's (or coupling) are explicitly removed from the system for reasons of computational efficiency, or due the lack of a robust non-linear solver (e.g. most models in the mantle convection community).

Here we describe a software infrastructure which enables us to easily introduce new physics with minimal code modifications; tightly couple all physics without introducing splitting errors; exploit modern linear/non-linear solvers and permit the re-use of monolithic preconditioners for individual physics blocks (e.g. saddle point preconditioners for Stokes).

One of the simplest multi-physics systems to consider is that which arises from a mixed finite element discretisations applied to Stokes flow. Using the Stokes system as a prototype, we demonstrate the functionality of this infrastructure by presenting a number of visco-plastic shear banding experiments employing different boundary conditions. Additionally, we present results from coupling Stokes flow with the evolution of the material coordinates and show how temporal stability can be achieved when the splitting error associated with time stepping is eliminated.