Parallel multi-domain Finite Element-based computational tool for variable-domain problems

In real-world applications, the usage of a single structured grid can be computationally intensive. Especially in applications where the grid is gradually growing over the course of a simulation. In this project we would like to try out a new *multi-domain and multi-block* grid generation and parallelization approach for layered problems. Real-world examples for such technique can be:

- ***basin modeling*** where sediments are deposited in layers on top of each other during a period of up to hundreds of millions of years.
- ***solidification or cooling*** of layers in additive manufacturing (3D printing)
- ***lithography*** where conductive material is deposited in layers on a wafer.

Project:

Uniform structured grids are widely used for numerical simulation (finite element, finite volume, and finite difference methods) of several types of problems. However, the usage of a single uniform grid can be computationally costly. Especially, when an impractically large number of grid elements is needed. For example, when using local grid refinements in the single domains or when multi-block domains require different grid resolutions in each domain.

To circumvent such a problem this project proposes a multi-domain grid generation approach. The current proposal application is the solidification of a material, for example chocolate, as it is printed, layer by layer into a desired shape. In the multi-domain proposal, each subdomain can have different grid resolutions with non-conforming resolutions between the subdomains. Each subdomain owns a subgrid, with a non-conforming grid resolution between the subdomains. The neighboring subgrids only communicate at the subdomain interfaces. The numerical discretization approach will be based on the finite element method, and the following tasks will be accomplished:

Tasks:

- Developing a stand-alone sequential and parallel computing code, by adopting the existing and the developed multi-domain framework
- Performing numerical experiments and benchmarking to validate the developed computational approach
  - Different grid in each block
  - Parallel computations
- Assessment of the memory and computational efficiency and the numerical accuracy of the developed approach and the comparison to the existing methods.
- Eventually, implementing the developed approach in an existing finite element library, e.g. DUNE/dealII/FeniCS/Kratos, etc.

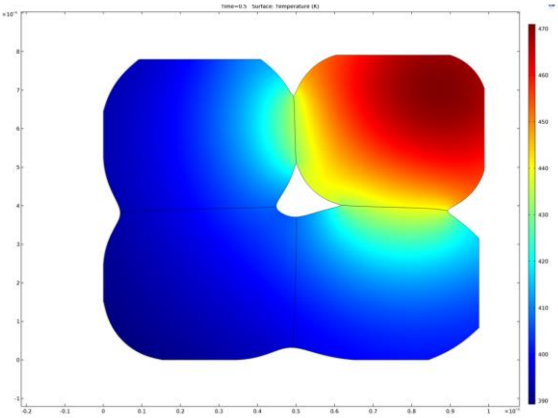
Your profile:

Do you fancy working on computational tool developments? Are you interested in contributing to the development of an efficient numerical solver for complex real-world problems? Do you have a passion for computational/numerical methods, programming, and software development? If so, then this project is right for you.

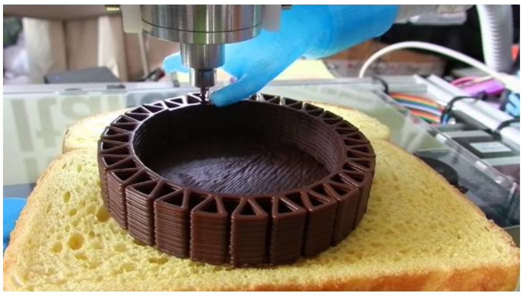
Required skills: Numerical methods, discretization schemes, finite element (or finite volume), programming skills, C++/Python/Matlab/Fortran

References:

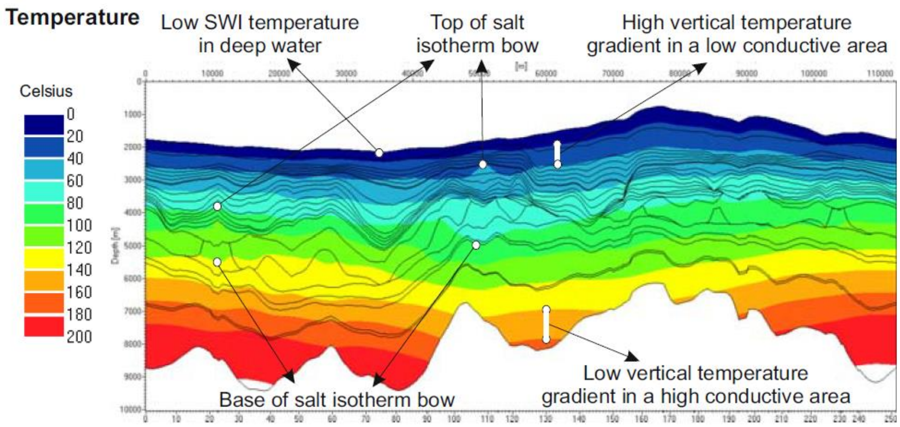
- Domain Decomposition Methods for Partial Differential Equations
  by *Alfio Quarteroni, and Alberto Valli*
- Domain decomposition methods for the numer- ical solution of partial differential equations
  by *Tarek P. A. Mathew*
- Domain Decomposition Methods - Algorithms and Theory
  By *Andrea Toselli, and Olof Widlund*
- Domain Decomposition: Parallel Multilevel Methods for Elliptic Partial Differential Equations
  by *Barry Smith*



Numerical simulation of 3D printing process, 2D view of temperature distribution in a micro-layer filament deposition (obtained from MSc thesis of Marten Broekens)



3D printed chocolate (obtained from www.fabbaloo.com)



Multi-layer geological basin heat flow analysis (from book of Fundamentals of Basin and Petroleum Systems Modeling, Thomas Hantschel, and Armin I. Kauerauf)