CS-E4870 Research Project Proposal

ReSoLVE Finnish Academy of Science Centre of Excellence - Computer Science

Project title:

Improved boundary condition implementation for high order finite differences

Project supervisors:

Dr. Matthias Rheinhardt, Dr. Frederick Gent, Prof. Maarit Käpylä

Project description and goals:

We will be working with the Pencil Code (http://pencil-code.nordita.org/), an open-source high-order finite-difference solver for partial differential equations. It is highly modular and can easily be adapted to different types of problems ranging from, e.g., compressible flows over magnetohydrodynamic (MHD) instabilities to dust coagulation and chemical networks. The code runs efficiently under message passing interface (MPI) on massively parallel shared- or distributed-memory computers. It is being maintained and further developed by an international team of more than 30 developers.

At Aalto it is used by the ReSoLVE Centre of Excellence Dynamo Group (http://research.cs.aalto.fi/cmdaa/index.shtml) to study turbulent magnetohydrodynamical flows in general and in particular to simulate magneto-convective dynamos in the Sun and other stars. Our objective is to understand the processes, which give rise to the solar magnetic field and its characteristic structures. The solar field interacts with the Earth's magnetic field through the solar wind and especially magnetic storms, which can impact Earth satellites, environmental health (exposure to radiation in flight) and technological infrastructure.

The aim of this project is to implement the boundary conditions $f|_{\partial V} = C$, (Dirichlet) and $\partial f/\partial n|_{\partial V} + cf|_{\partial V} = C$, where ∂V denotes the boundary of the domain and $\partial f/\partial n$ the normal derivative while c and C are given functions on the boundary, in strict consistency with the respective order of the difference scheme (six, eight or ten), both for equidistant and non-equidistant grids.

Key skills:

The candidate should have some knowledge of high-level language programming, with ability to adapt to various languages. A high standard of consistently laid out and effectively commented code is expected, in order to interact smoothly with the many concurrent developers of the code. Some experience in working with Fortran may be helpful, but is not required, as sufficient familiarity will be acquired during the project.

Some knowledge of solving ordinary (or partial) differential equations, either analytically or numerically will need to be acquired. It will be necessary to manipulate Taylor series to derive appropriate one-sided finite difference schemes for first and second derivatives. Interest in astronomy, astrophysics or solar physics is welcome, but exterior to the project.

Outcomes:

The student shall implement at least two optional modules (for sixth and eighth order) to the Pencil Code for the new boundary conditions. The student shall apply tests of accuracy, efficiency and stability to validate the implementation. Optionally, the student shall similarly include a tenth order module.

The student shall acquire competence in Fortran language and experience of a coding environment with the highest standards of format, commenting, optimization and verification.

The student shall acquire experience of collaborating internationally with code developers, and potentially as part of a cross-disciplinary collaboration involving computer science, solar physics and applied mathematics.