Tutorial Session: “Micromagnetic Simulations”

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Since nanomagnetic systems are considered as promising candidates for future spintronic devices, new theoretical aspects describing the fundamental physics of magnetism beyond the micro-scale have been developed. Due to the complexity of the topic, micromagnetic simulations become more important. They help extending the theoretical framework and enable developing and testing new sample designs. The purpose of this tutorial session was to give an understanding of the basics of nanomagnetism and to introduce different simulation programs.

The first speaker ***Jonathan Leliaert*** from the *Ghent University* opened the session, by giving an outline of micromagnetic history. He pointed out, that Landau and Lifshitz investigated domain walls in the 40s and developed a micromagnetic theory by minimizing the total energy made up by exchange, Zeeman, anisotropy and magnetostatic terms. Gilbert improved the description in the mid-60s by introducing a phenomenological damping term. Consequently, the equation of motion describing the micromagnetic dynamics by precession and damping terms is named Landau-Lifshitz-Gilbert (LLG) equation. Jonathan Leliaert is part of the development team of *MuMax3*[1], which is one of many programs solving the LLG equations by finite-difference discretization methods (FDM). In his talk, he briefly shed light on the difference between the FDM and finite element codes (FEC), explaining that FDM codes are faster in performance, whereas FEC models offer more flexibility at the expense of performance. To demonstrate the easy accessibility of the MuMax3 web interface, Jonathan Leliaert performed a live simulation of a ferromagnetic rectangle for different anisotropy constants. In turn, to expose new, more sophisticated features of MuMax3, he showed a simulation of a more complex 3D-geometry in the shape of Brussels “Atomium”.

Next up, ***Kai Litzius*** and ***Matthias Sitte***, two speakers from the *University of Mainz* shared a talk. Kai Litzius started by giving further information on the basics of micromagnetic theories. He depicted the general working process of micromagnetic simulation programs by flowcharts, showing how the inputs are processed and controlled into an output by solving the LLG equation on a discretized grid. Kai Litzius is developing modules for *MicroMagnum*[2], which is a Python/C++ based program with a modular structure. The easy possibility to extend and write new modules is one of the major strengths of MicroMagnum, as he explained. As an example, the so-called "standard problem 4", essentially a rectangular sample in an S-state which gets exposed to an outer magnetic field, was simulated on the fly. More sophisticated examples were topological magnetic structures like skyrmions, which can be driven in racetracks by application of currents.

Matthias Sitte continued the talk introducing a new, yet unpublished software called *OMNeS*[3]. OMNeS is based on a finite element approach, allowing non-rectangular grids and therefore a better implementation of complex geometries. The interface is written in Python, to enable fast processing and easy accessibility. It will include a multiscale option; such that length and time scales will be adapted to the present simulation. Also, it is planned to implement multi-physical modules, which for example enable fully coupled magneto-elastic simulations.

The last speaker, ***Hans Fangohr*** from the *University of Southampton* and *European XFEL GmbH*, started with an overview of the most-used and best-known open-source micromagnetic simulator programs, also depicting the time-periods in which each program was actively maintained. He emphasized, that the first one, the Object Oriented MicroMagnetic Framework (OOMMF), is still used frequently and widely.

Marijan Beg and Hans Fangohr have developed a new Python interface that allows to drive the OOMMF simulation program from within a Python program. To demonstrate the low barriers towards learning of Python, they demonstrated short and basic code examples that drive micromagnetic simulations.

In addition to this Python interface, the team embedded their code in the Jupyter Notebook, leading to the name of a new package: *JOOMMF*[4] (Jupyter-OOMMF). JOOMMF basically uses the OOMMF calculator to carry out numerical simulation, but the simulation configuration, control and data analysis is done through the Jupyter notebook (using the Python language). Live simulations were performed, showing the effect of different Zeeman and anisotropy energies. Another example of a topological skyrmion was given, demonstrating more complex simulations. It is hoped that JOOMMF will allow researchers to carry out micromagnetic simulation research more effectively and more reproducibly.

Stimulated by the pleasant atmosphere, well-designed presentations and informative talks the event provided an excellent opportunity to get an introduction into micromagnetism and grant an insight into the state-of-the-art simulation tools with new features. Herewith, we would like to express our thanks to all the speakers and participants for a successful session!

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[1] http://mumax.github.io/
[2] http://micromagnum.informatik.uni-hamburg.de/
[3] https://www.omnes.uni-mainz.de/
[4] http://joommf.github.io/