Utilization of COMSOL Multiphysics‘ JAVA API for the Implementation of a Micromagnetic Modeling and Simulation Package with a Customized User Interface

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Abstract: One of the big advantages of COMSOL Multiphysics is the possibility to implement user-defined partial differential equations (PDE) which can be coupled to COMSOL's predefined application modes. However, using the tool's standard user interface requires manual implementation of the PDEs and a multitude of problem-specific parameters. This process is not just error-prone but also very time consuming. As an alternative to this manual implementation one can use COMSOL's Java Application Programming Interface (API) which provides an easy and efficient way to create a user-defined simulation package. Here, we demonstrate the usage of COMSOL's Java API by our implementation of a micromagnetic modeling and simulation package. Therein, the Landau-Lifshitz-Gilbert equation is coupled to Maxwell's equation for the magnetic field. With this implementation magnetic structures with dimensions in the order of several nanometers can be analyzed concerning their magnetic configuration.

Micromagnetic Modeling

Landau-Lifshitz-Gilbert equation (LLG)

$$\frac{\partial \boldsymbol{m}}{\partial t} = -\mu_0 \gamma \boldsymbol{m} \times \boldsymbol{H}_{eff} + \mu_0 \alpha \boldsymbol{m} \times \frac{\partial \boldsymbol{m}}{\partial t}$$

$$\boldsymbol{H}_{eff} = -\frac{2A_{ex}}{\mu_0 M_S}\Delta \boldsymbol{m} - \frac{2K}{\mu_0 M_S}\langle \boldsymbol{m}, \boldsymbol{e}\rangle \boldsymbol{e} + \boldsymbol{H}_{dem} + \boldsymbol{H}_{ext}$$

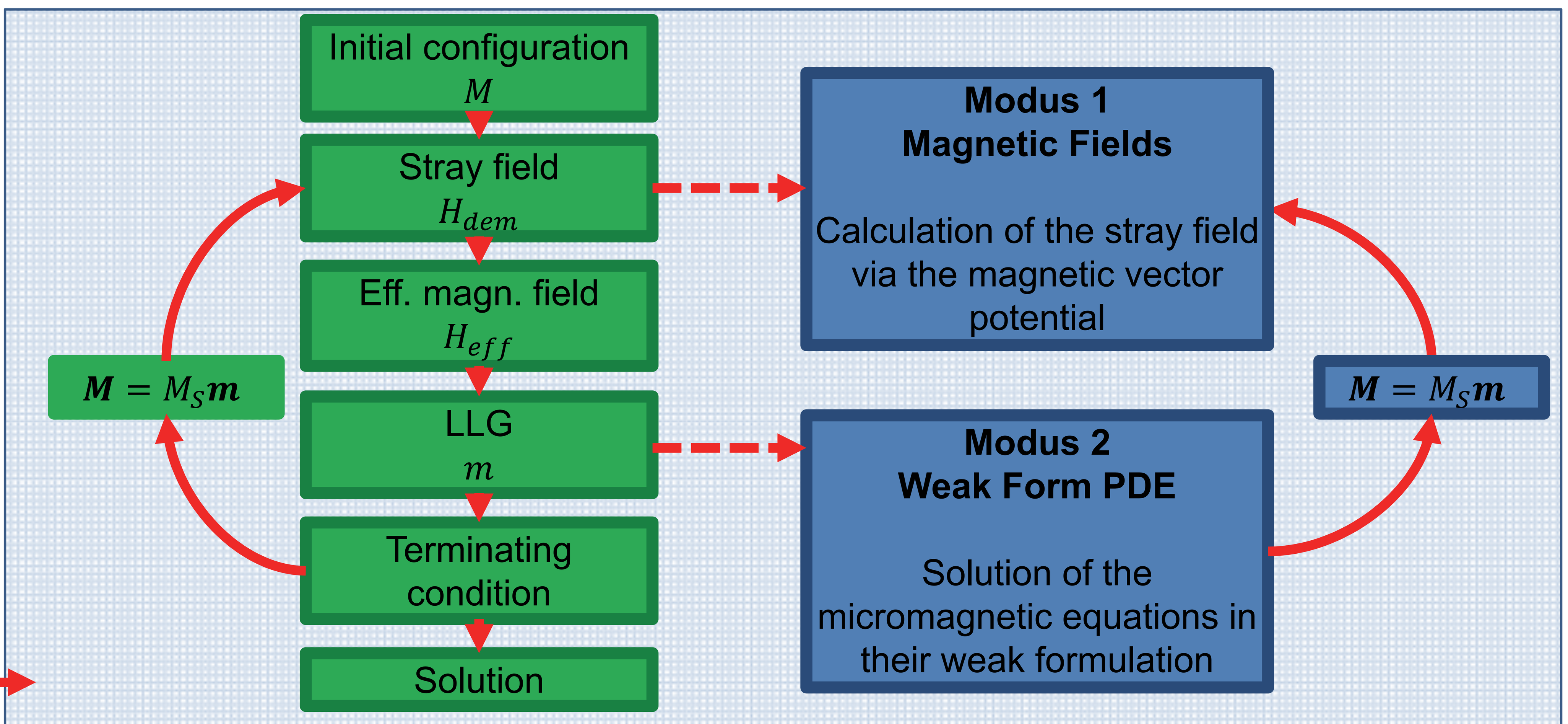
Weak formulation of the LLG

$$\int_\Omega \left\langle \boldsymbol{\psi}, \frac{\partial \boldsymbol{m}}{\partial t} - \alpha \boldsymbol{m} \times \frac{\partial \boldsymbol{m}}{\partial t}\right\rangle d\Omega = \frac{2A_{ex}}{\mu_0 M_S}\sum_{x,y,z}\int_\Omega \left\langle \left(\boldsymbol{m} \times \frac{\partial \boldsymbol{m}}{\partial x_i}\right), \frac{\partial \boldsymbol{\psi}}{\partial x_i}\right\rangle d\Omega + \frac{2K}{\mu_0 M_S}\int_\Omega \langle \boldsymbol{\psi}, \boldsymbol{m} \times \boldsymbol{e}\rangle\langle \boldsymbol{m}, \boldsymbol{e}\rangle d\Omega + \int_\Omega \langle \boldsymbol{\psi}, \boldsymbol{H}_{dem} + \boldsymbol{H}_{ext}\rangle d\Omega$$

Maxwell‘s equations for the magnetic field

$$\sigma \frac{\partial \boldsymbol{A}}{\partial t} + \nabla \times \boldsymbol{H} = \boldsymbol{J}_e$$

$$\boldsymbol{B} = \nabla \times \boldsymbol{A}$$

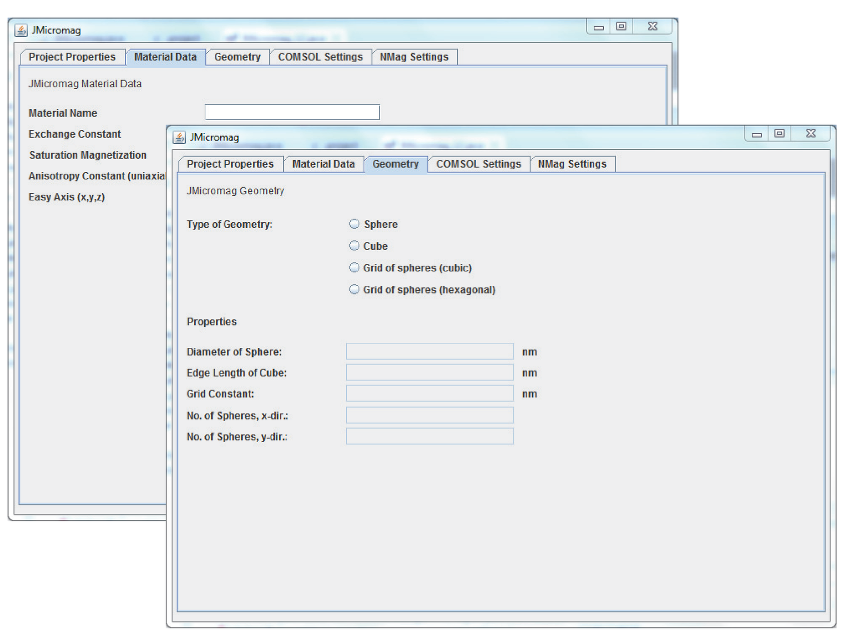


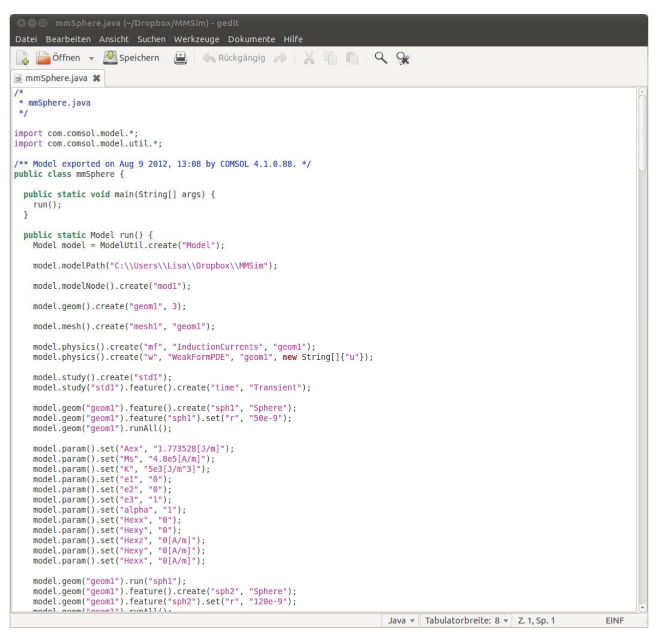
Schematical process of micromagnetic simulations (green) and the correspondent implementation in COSMOL Multiphysics (blue). Every configuration of the magnetic moment results in a new stray field and consequently, a new magnetic moment has to be computed. These steps have to be iterated until a terminating condition is fulfilled. The conversion between magnetization M and magnetic moment m is self-evident but plays a key role for the implementation. The coupling between the LLG and Maxwell's equations is carried out by the stray field which is calculated by Maxwell's equations and contributes to the effective magnetic field in the LLG.

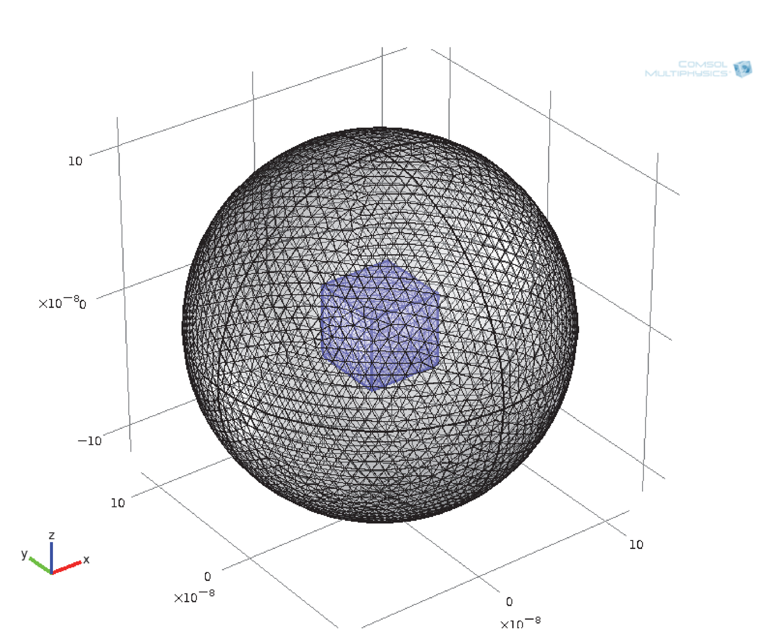
JMicromag

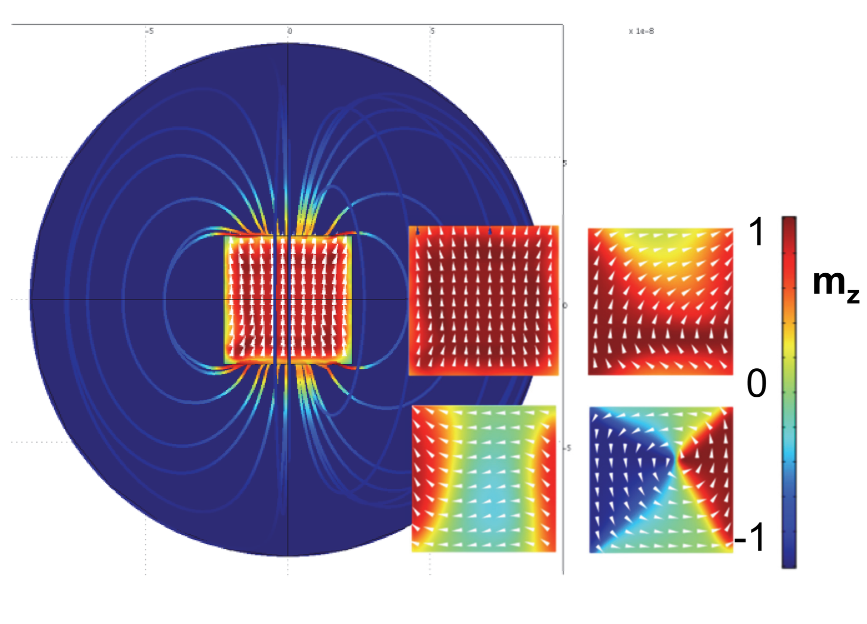
For the efficient usage of our newly implemented modeling features in COMSOL Multiphysics the new user interface „JMicromag“ has been developed, taking advantage of COMSOL‘s JAVA API. Within JMicromag the user can specify necessary material parameters, geometry options and simulation settings. The interface itself generates the simulation‘s input file with all parameters, equations and problem specific settings.

The input file, namely a Model-Java file, can easily be imported into COMSOL Multiphysics where the user can start the simulation with one mouse-click. Moreover, the user can use all the postprocessing capabilities of COMSOL Multiphysics. In this way, the manual implementation of PDEs and problem specific parameters is avoided to save time and to simplify the modeling process. Even untrained users are able to set up micromagnetic simulations in COMSOL.









Setting up the model in JMicromag → Generated Model-Java file → Import of Model-Java file in COMSOL Multiphysics → Computation and postprocessing in COMSOL Multiphysics

Conclusion: We have created a micromagnetic simulation package by implementing the weak formulation of the Landau-Lifshitz-Gilbert equation and its coupling to Maxwell's equations within COMSOL Multiphysics. Furthermore, we have developed the specialized user interface “JMicromag” which allows the user to perform micromagnetic simulations in a very efficient and user-friendly way. With these enhancements, COMSOL Multiphysics can be used to simulate and evaluate micromagnetic problems for arbitrary geometries and materials.

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