Parallel Micromagnetics Problems Solver

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Simulation Types

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List of Changes

VERSION DATE	**CHANGES**
1.0.00 01/07/2012	
1.1.00 30/07/2012	
1.1.01 28/08/2012	
1.1.02 29/01/2013	
1.2.00 12/12/2013	• Added the sections 1.6 Micromagnetic theory and equations and 1.7 Comparative chart of the Problem Types.
1.2.01 26/06/2014	• Updated the section 1.7 Comparative chart of the Problem Types.

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1. Simulation Types

In the main menu window of the application, you can see all types of simulations that the application is able to solve. The only simulation types which will appear enabled correspond to the program license you've purchased.

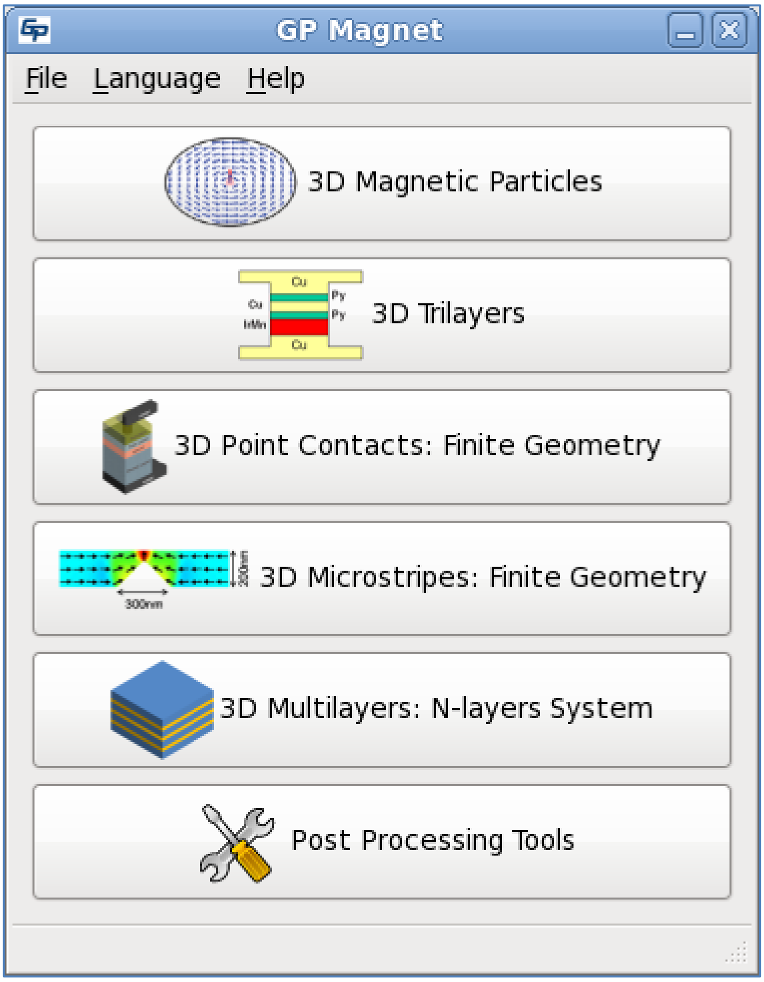


Figure 1 - GPMagnet Main Menu Window

1.1. 3D Magnetic Particles

This simulation type is **available in all versions** of GPMagnet (Basic, Advanced and Expert).

Use this simulation type if you are interested in simulating a sample with different shapes (cube, rectangle, ellipsoid, ring or whatever you need) made by a single ferromagnetic material. You can compute its equilibrium state or study its hysteresis loop under static magnetic fields along any spatial direction. The magnetization dynamics governed by the Landau-Lifshitz-Gilbert (LLG) equation under different fields can be also studied with this type of simulation. The available contributions to the effective field are the exchange, the demagnetizing, the magnetocristalline anisotropy (uniaxial or cubic) and the Zeeman due to the external magnetic field.

External current influence is also possible to compute for **Advanced and higher versions**.

1.2. 3D Trilayers

This simulation type is **not available in the Basic version. It is available in all higher versions** (Advanced and Expert).

It is specially designed to simulating the magnetic behaviour of a single magnetic layer (usually called "free layer") placed at the top of a tri-layer structure, where both the bottom (fixed) and the top (free) layers are magnetic, whereas the non-magnetic intermediate one could be either non-conducting (Magnetic Tunnel Junction, MTJ) or conducting (Spin Valve, SV). The magnetization dynamics due to Spin-Transfer-Torque under vertical (along the z-axis) current flowing uniformly along the whole cross-section of the multilayer is now studied by the corresponding augmented LLG equation. The only dynamics occurring in the "free" layer will be taken into account, namely the magnetization of the bottom layer is assumed to be "fixed in time". Here the current can be static, a pulse or an arbitrary periodic function of time. The magnetostatic field produced by the bottom-fixed layer in the top-free layer and the Oersted field produced by this current, can be both included as additional contributions to the total effective field. Of course, the simulated free layer can consist on several cells across its thickness.

1.3. 3D Point Contacts: Finite Geometry

This simulation type is **not available in the Basic version. It is available in all higher versions** (Advanced and Expert).

It can be considered as an extension of the previous type, when the applied current is forced to flow along the vertical z-axis through a confined region of reduced dimensions (the nanocontact or point-contact area) with respect to the extended dimension of the free layer. The spatial dependence of the injected current and its corresponding Oersted field can be straightforwardly simulated.

1.4. 3D Microstripes: Finite Geometry

This simulation type is **not available in the Basic version. It is available in all higher versions** (Advanced and Expert).

It is devoted to the study of the magnetization dynamics in a single-layer sample traversed by an electric current flowing, longitudinally to the device plane. Both, field and current, induced domain wall motion can be studied. Such dynamics are governed by the extended LLG equation which includes both the adiabatic and the non-adiabatic Spin-Transfer-Torque contributions. Finite and infinite strips can be simulated by selecting proper boundary conditions.

1.5. 3D Multilayers: N-layers System

This simulation type is **available only in the Expert version**.

With this simulation type, it is possible to simulate the magnetic behaviour of the several layers constituting the device. Each layer can be made by a different material.

1.6. Micromagnetic theory and equations

The micromagnetic equations used, so as the numerical methods employed by GPMagnet are out of scope of this manual. The user can find a complete description of them in the topical review published by our team of physicists:

“Micromagnetic simulations using Graphic Processing Units”
L. Lopez-Diaz, D. Aurelio, L. Torres, E. Martinez, M. A. Hernandez-Lopez, J. Gomez, O. Alejos, M. Carpentieri, G. Finocchio and G. Consolo.
J. Phys. D: Appl. Phys. 45 (2012) 323001
http://iopscience.iop.org/0022-3727/45/32/323001

From the GPMagnet version 1.2.00 (December 2013), Spin Hall Effect (SHE) and Rashba field are included according to the following expression:

$$\begin{aligned}(1+\alpha^2)\frac{d\mathbf{m}}{dt} = &-\gamma\left(\mathbf{m}\times\mathbf{B}_{\mathrm{eff}}+\alpha\,\mathbf{m}\times(\mathbf{m}\times\mathbf{B}_{\mathrm{eff}})\right)\\ &+\frac{\hbar\gamma\theta_{\mathrm{SH}}}{2\mathrm{e}M_{\mathrm{S}}t}\left(\mathbf{m}\times\left(\mathbf{m}\times(\hat{\mathbf{z}}\times\mathbf{j})\right)-\alpha\mathbf{m}\times(\hat{\mathbf{z}}\times\mathbf{j})\right)\\ &+\frac{\alpha_{\mathrm{R}}\gamma P}{2\mu_{\mathrm{B}}M_{\mathrm{S}}}\left(-\mathbf{m}\times(\hat{\mathbf{z}}\times\mathbf{j})-\alpha\mathbf{m}\times\left(\mathbf{m}\times(\hat{\mathbf{z}}\times\mathbf{j})\right)\right)\end{aligned}$$

Where $\mathbf{m}=\mathbf{M}/M_{\mathrm{S}}$ is the normalized magnetization, $\gamma = 1.76\times 10^{11}\mathrm{s}^{-1}\mathrm{T}^{-1}$ the electron gyromagnetic ratio, α the Gilbert damping constant and $\mathbf{B}_{\mathrm{eff}}$ the effective magnetic field. The last two terms represent respectively the SHE and Rashba torques on the magnetization, where $\mathbf{j}$ is the injected current, θ_{SH} the Spin Hall angle factor, e the electron charge, t the ferromagnetic layer thickness, α_{R} the Rashba constant, P the spin polarization and μ_{B} the Bohr magneton.

From the GPMagnet version 1.2.00 (December 2013), also the Dzyaloshinskii-Moriya Interaction (DMI) contribution to the effective field is considered. Two kinds of DMI can be selected in the simulation:

- Interfacial DMI, according to the equation:

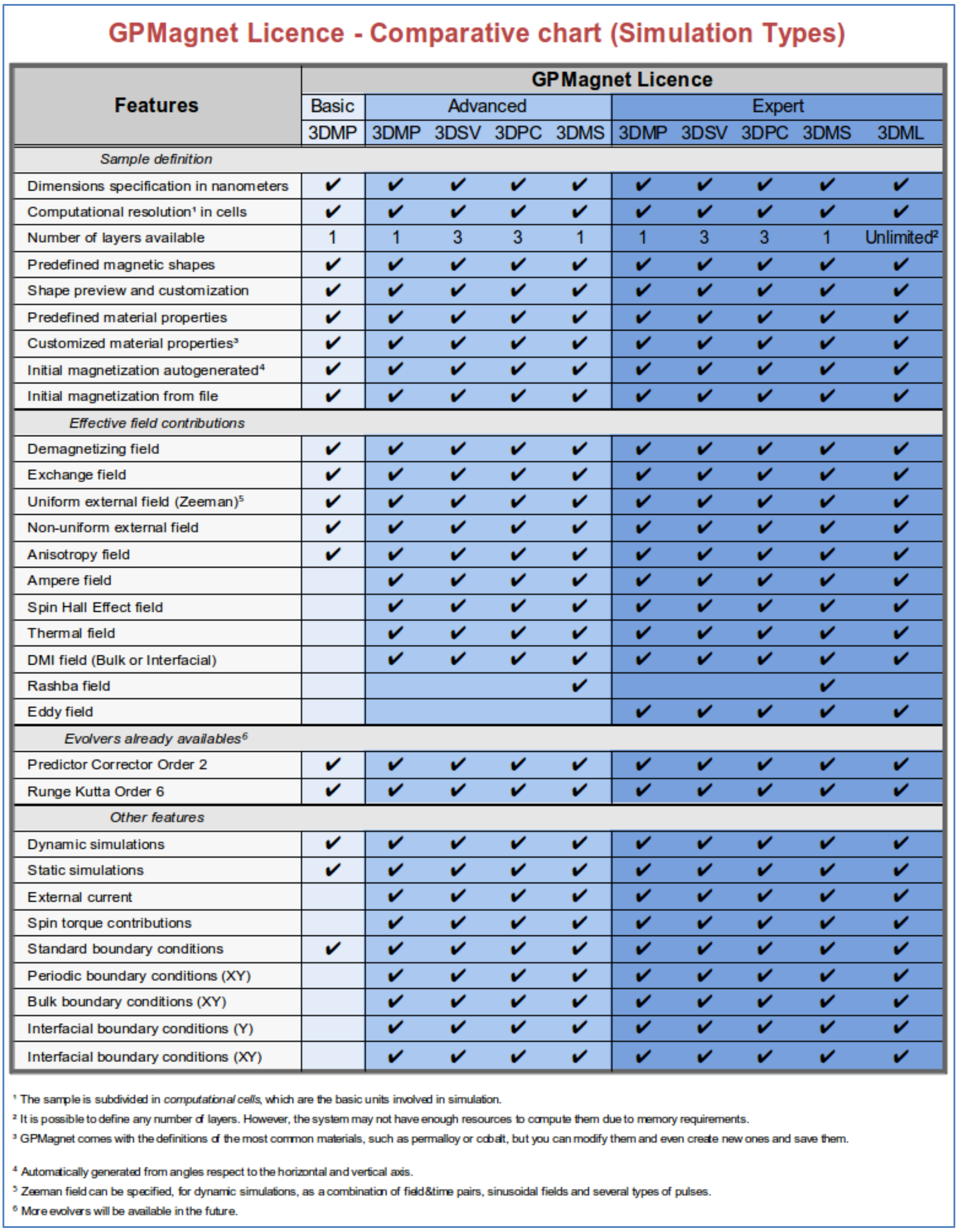
$$\mathbf{B}_{\mathrm{DMI}} = -\frac{2D}{M_{\mathrm{S}}}[(\nabla\cdot\mathbf{m})\hat{\mathbf{z}}-\nabla m_{\mathrm{z}}]$$

- Bulk DMI, according to the equation:

$$\mathbf{B}_{\mathrm{DMI}} = -\frac{2D}{M_{\mathrm{S}}}(\nabla\times\mathbf{m})$$

Where in both expressions D is the DMI constant.

1.7. Comparative chart of the Problem Types



GPMagnet Licence - Comparative chart (Simulation Types)

Features	GPMagnet Licence									
	Basic	Advanced				Expert				
	3DMP	3DMP	3DSV	3DPC	3DMS	3DMP	3DSV	3DPC	3DMS	3DML
Sample definition										
Dimensions specification in nanometers	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Computational resolution[1] in cells	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Number of layers available	1	1	3	3	1	1	3	3	1	Unlimited[2]
Predefined magnetic shapes	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Shape preview and customization	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Predefined material properties	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Customized material properties[3]	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Initial magnetization autogenerated[4]	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Initial magnetization from file	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Effective field contributions										
Demagnetizing field	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Exchange field	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Uniform external field (Zeeman)[5]	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Non-uniform external field	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Anisotropy field	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Ampere field		✔	✔	✔	✔	✔	✔	✔	✔	✔
Spin Hall Effect field		✔	✔	✔	✔	✔	✔	✔	✔	✔
Thermal field		✔	✔	✔	✔	✔	✔	✔	✔	✔
DMI field (Bulk or Interfacial)		✔	✔	✔	✔	✔	✔	✔	✔	✔
Rashba field					✔				✔	
Eddy field						✔	✔	✔	✔	✔
Evolvers already availables[6]										
Predictor Corrector Order 2	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Runge Kutta Order 6	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Other features										
Dynamic simulations	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Static simulations	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
External current		✔	✔	✔	✔	✔	✔	✔	✔	✔
Spin torque contributions		✔	✔	✔	✔	✔	✔	✔	✔	✔
Standard boundary conditions	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Periodic boundary conditions (XY)		✔	✔	✔	✔	✔	✔	✔	✔	✔
Bulk boundary conditions (XY)		✔	✔	✔	✔	✔	✔	✔	✔	✔
Interfacial boundary conditions (Y)		✔	✔	✔	✔	✔	✔	✔	✔	✔
Interfacial boundary conditions (XY)		✔	✔	✔	✔	✔	✔	✔	✔	✔

[1] The sample is subdivided in *computational cells*, which are the basic units involved in simulation.

[2] It is possible to define any number of layers. However, the system may not have enough resources to compute them due to memory requirements.

[3] GPMagnet comes with the definitions of the most common materials, such as permalloy or cobalt, but you can modify them and even create new ones and save them.

[4] Automatically generated from angles respect to the horizontal and vertical axis.

[5] Zeeman field can be specified, for dynamic simulations, as a combination of field&time pairs, sinusoidal fields and several types of pulses.

[6] More evolvers will be available in the future.

Figure 2 - Comparative chart of the GPMagnet Problem Types