MuFA

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Program structure

MuFA is a program meant to assist end users with both the creation of MuMax3 simulation scripts in batch and multi-type Fourier analysis of the simulation results. The program consists of two independent modules, the SBG is responsible for the scripts creation part and the MFA is responsible for the Fourier analysis part.

In order to execute both of the two modules, Python3 interpreter should have been installed and for MFA, additional modules Numpy and Matplotlib are required. To utilize SBG, run the file named "SBG.py". To utilize GUI-version MFA, run the file named "MFA_GUI.py", and to utilize multiprocessing accelerated MFA, run the file named "MFA_Multicores.py".

1. SBG

The SBG is a GUI program for the creation of MuMax3 simulation scripts in batch. It consists of a main window and several buttons that will direct users to subwindows allowing for creation of MuMax3 simulation scripts (For a detailed description of MuMax3 API, see: http://mumax.github.io/api.html). The GUI of the main window of SBG is shown in Fig 1. Below, we introduce the functionality of each button and entry of SBG.

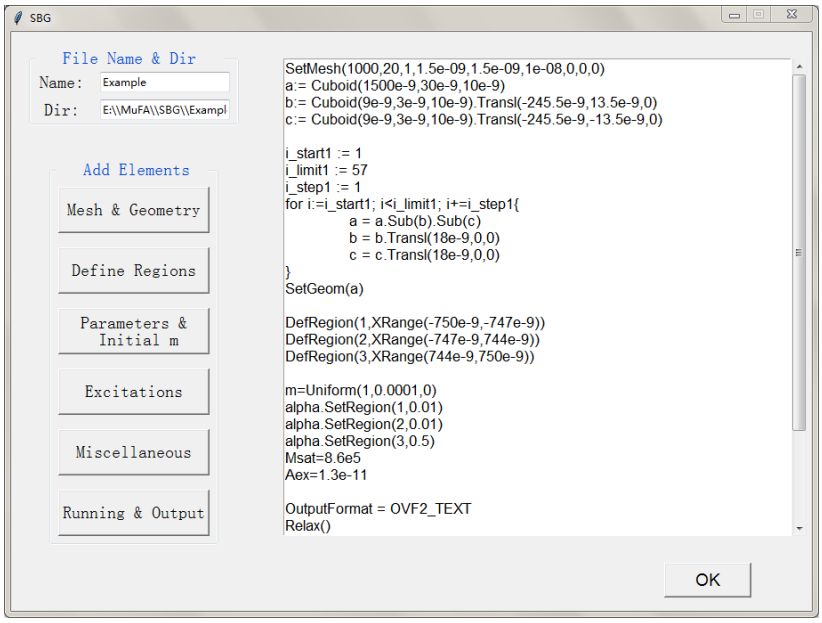

Figure 1. The GUI of SBG main window.

1.1 File Name & Dir

• ‘Name’: Input the basic file name of the scripts into this entry.

• ‘Dir’: Input the directory in which user wants to generate the scripts into this entry.

Note that for users of Windows system, the “\” in directory address string must be replaced by “\\” or “/”.

1.2 Mesh & Geometry

‘Mesh & Geometry’ button is responsible for the definition of the mesh size used in simulation and sample geometry. As shown in Fig 2. There are two modes for mesh definition. By clicking the tabs, user can switch the definition modes:

• ‘Fixed mode’: user inputs a fixed mesh size and the mesh sizes are the same in all of scripts.

• ‘Sweep mode’: user inputs a start size, an end size and a step size for x, y, z direction respectively. This leads to the mesh sizes in output scripts change step by step from each other.

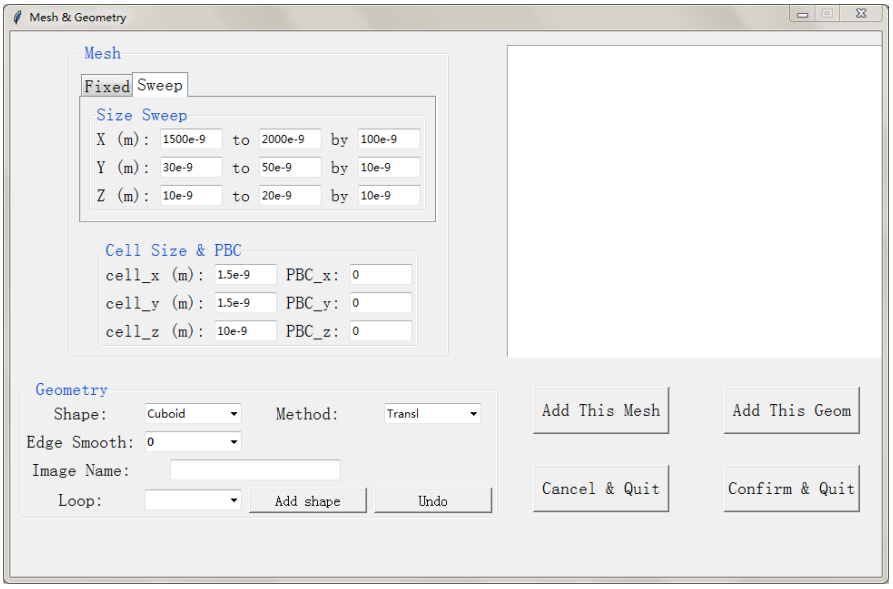

Figure 2. The GUI of Mesh & Geometry subwindow.

Specify the mesh cell size via ‘cell_x/y/z’ entries. ‘PBC_x/y/z’ defines the periodic boundary conditions in x, y, z direction, respectively. After the definition of mesh parameters, click ‘Add This Mesh’ to input the mesh term into the edit window.

To define the geometry of the model, user selects several shapes, such as cuboid and the transformation for the shapes from the ‘Shape’ menu and ‘Method’ menu. When user choose the ‘ImageShape’, an image name should be given in the ‘Image Name’ entry. ‘Loop’ menu provides three kinds of loop template in Go language. It is utilized to generate complicated periodic geometry, e.g. magnonic crystal. If user wants to add only one of the ‘Shape’, ’Method’ or ‘Loop’ elements, set the other two to “None”. Click ‘Add shape’ button to add current shape to the final geometry. After the definition of the geometry, click ‘Add This Geom’ button to input the geometry term into the edit window.

Usually, the parameters of the geometry are directly keyed in the edit window. If ‘Sweep mode’ is used during the definition of the mesh, user can utilize arbitrary number of “x”, “y” or “z” instead

of real numbers to change the geometry size in order to make it be consistent with the mesh size. This is not only effective in geometry definition, but also valid in other definitions involved regions. The following three buttons work the same in all of subwindows.

• 'Undo': it is responsible for the undo operation.

• 'Cancel & Quit': delete all of content in edit window and kill this subwindow.

• 'Confirm & Quit': add all of content to the edit window of the main window and kill this subwindow.

1.3 Define Regions

'Define Regions' button is responsible for the definition of the simulation space division. The definition of the regions is similar to the process of geometry definition (Section 1.2). User selects the 'Shape' and the 'Method', then clicks 'Add Shape' button to add current shape to the final region shape. Finally, click 'Add This Region' button to add this region to the edit window. Regions are automatically numbered. In other definition procedures that involved in setting a parameter or excitation to specified regions, the regions are automatically numbered too. Parameters are directly input into the edit window. 'Delete Region' button is responsible for the undo operation.

1.4 Parameters & Initial m

'Parameters & Initial m' button is responsible for the definitions of material parameters and the initial magnetization configuration.

• 'Initial m': initial magnetization configuration is determined via this menu, and additional operation can be added from 'Method' menu. After the definition, click 'Add Initial m' button to add the initial magnetization configuration to the edit window.

• 'Parameters': all of material parameters are specified by this menu. First, choose the material parameter, then key the corresponding value into the 'Function' entry. Next, add additional operations from 'Method' menu. Finally, click 'Add This Para' button to add this parameter to the edit window.

Note that if the value of the material parameter is a vector, please input it in the form of "vector(X, Y, Z)".

1.5 Excitations

In 'Excitations' subwindow, user can define both the magnetic field and spin-polarized current excitations (the fixed layer and space layer parameters are defined in 'Parameters & Initial m' subwindow). There is no difference between the definitions of these two kinds of excitations except for the unit. So we only introduce the definition of the magnetic field excitations.

As shown in Fig 3. Due to the excitation field is a vector, user should input the function of the excitation in the form of "vector(X, Y, Z)". It should be noted that the amplitude and the frequency values must be replaced by "amp" and "f". The specified values can be input via the entries at the left bottom of the window. The 'Method' menu provides available method corresponding to the excitation. Similar to the size of the mesh and the geometry, the amplitude and the frequency of excitations are also parameters which can be swept. The detailed process of the definition see Section 1.2 Mesh & Geometry.

'Misc' menu provides several seldom used elements. Click 'Add This Misc' button to add one. 'Add This B_ext' and 'Add This J_ext' button are responsible for adding magnetic field excitation

term and current excitation term to the edit window, respectively.

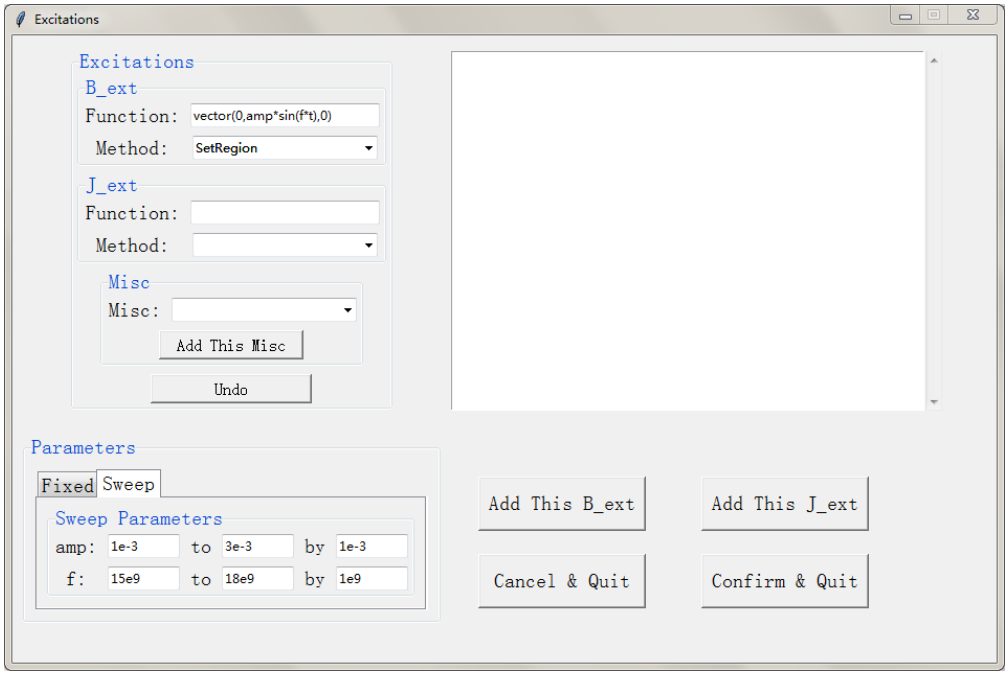

Figure 3. The GUI of Excitations subwindow.

1.6 Miscellaneous

'Miscellaneous' button is responsible for adding several special elements to the script. There are four categories in the miscellaneous subwindow. They are 'Moving Simulation Window', 'Magnetic Force Microscopy', 'Extensions' and 'For loops'. For the first three categories, there are detailed descriptions in http://mumax.github.io/api.html. The 'For loops' menu offers the template of loop in Go language from one cycle to triple cycle. We introduce this class to increase the flexibility of the modeling procedure. There are four buttons corresponding to the four categories. Click corresponding button to add the selected item to the edit window.

1.7 Running & Output

'Running & Output' button is responsible for the definition of the scheduling output quantities and running type.

• 'Export Format': provides options that determine the coding form of the simulation output files. If user want to apply MFA for the analysis subsequently, he/she should choose "OVF2_TEXT" option.

• 'Output Type': specifies the Output type.

• 'Slicing': For the purpose of saving storage space, user can only save part of the output via selecting one of the items provided by this menu.

• 'Quantities': specifies output quantity.

• 'Method': provides corresponding operations for the output quantity.

• 'Running': provides options of running type and parameters of the differential equation solver.

1.8 OK

After finishing the input of all of essential elements mentioned above, click 'OK' button to generate

scripts in the specified directory.

1.9 Other features

The name of the generated files contain the information of model size and excitations applied in the simulation. CTRL + C and CTRL + V shortcuts are available in all edit windows.

Current version of SBG is developed in accordance with the version 3.9.1 of MuMax3. Since MuMax3 is an open-source program and is continually updated, maybe there will be several new properties which are not included in SBG in newer version of MuMax3. User can introduce these properties manually into the edit window of the main window.

In general, the coding style in SBG is "*object creation first, parameter assignment last*". Since the elements will be added at the location of the cursor, we recommend that users add all of desired simulation elements to the edit window first, then assign values to the parameters of these elements. This regulation can ensure the elements be placed at the right location. However, there are two exceptions of the regulation, i.e. the elements of which parameters can be swept. In detail, the parameters of "Mesh" and "Excitation" should be assigned to the corresponding entries simultaneously with the creation of the element. The parameter assignment can be done in the edit window of either subwindows or the main window.

2. MFA

The MFA is a multi-type Fourier analysis program for the results from micromagnetic simulations. Results from all of OOMMF-like (Object-Oriented Micromagnetic Framework) micromagnetic simulator, e.g. MuMax3, can be processed with MFA.

MFA supports three different common types of Fourier analysis in micromagnetic domain, i.e. 1D Fourier transform in time domain for the analysis of frequency composition of spin waves (FFT), 1D Fourier transform in time domain for the visualization of spatial distribution of spin-wave power at different frequency (Spectrum) and 2D Fourier transform for the acquisition of the spin-wave dispersion relationship (Dispersion Curve). It should be noted that for the last two types of analysis, the direction of the wave vector must lie in the x-direction.

We offer two ways to run the program — GUI and job control script. Unfortunately, limited by technique, the feature of multiprocessing acceleration cannot be used in current GUI version. Therefore, it is only suitable to perform analysis on the results from small-size and short-time simulations. MFA will utilize all the cores of CPU of user's computer to accelerate the file reading process by default, but the number of cores used can also be determined by the user.

For the reason that GUI is much easier to understand than the control script, and these two ways are essentially the same, we only introduce the parameters defined in job control script here.

2.1 Dir

Assign the name of the directory in which the results files stored to 'Dir'. For users of Windows system, please use "\\" or "/" instead of "\".

2.2 General geometry parameters

Assign the size of the whole sample to 'X', 'Y', 'Z', respectively. Assign the mesh cell size used in

the simulation to ‘x_cell’, ‘y_cell’, ‘z_cell’. ‘x/y/z_start’ and ‘x/y/z_end’ define the starting coordinates and ending coordinates of the area to be analyzed, respectively.

2.3 General time parameters

‘StartStage’ and ‘EndStage’ define the starting moment and ending moment of the time period to be analyzed. Note that the value of them should be integer that corresponding to the simulation stage. Assign the sampling period in time domain to ‘time_SP’. The unit of it is seconds.

2.4 FFT particular parameters

Parameters that only valid for ‘FFT’ analysis. ‘f_min’ and ‘f_max’ define the frequency range that will display in the final figure. The unit is GHz.

2.5 Dispersion curve particular parameters

Parameters that only valid for ‘Dispersion Curve’ analysis. ‘space_SP’ is the sampling period in space domain along the direction of wave vector. Assign the highest frequency composition appearing in the final dispersion curve to ‘f_cutoff_dispersion’. Assign the largest value of the wave number appearing in the final dispersion curve to ‘klim’. ‘time_resample’ and ‘space_resample’ define the ratio of time resampling and space resampling, the value of them should be integer. We recommend using default settings to obtain high resolution.

2.6 Frequency spectrum particular parameters

Assign the highest frequency composition appearing in the final frequency specturm to ‘f_cutoff_colormap’.

2.7 General control

The parameters in this section are switches. Assign “1” to it means that this function is activated and assign “0” to it means that this function is disabled. The value of ‘export_x/y/z’ determines that which component of magnetic moments to be analyzed. Only one of the three can be “1”. The value of ‘FFT/Dispersion/Spectum_Switch’ determines the type of the analysis. Only one of the three can be “1”. The value of ‘Win’ determines if a two-dimensional Chebyshev window function be used in dispersion curve analysis. To enable the ‘Win’, python scientific computing module Scipy must have been installed. The value of ‘resampling’ determines if resample the data. We recommend setting this parameter to “0” to obtain high resolution.

2.8 Number of CPU cores used

Assign the number of CPU cores used to ‘CoreNum’. Set it to “0” to use all of the cores of CPU. It should be noted that MFA will utilize all of CPU cores of user’s computer in default setting. This may raise some instability, especially for some old computers. Thus, we recommend that user sets ‘CoreNum’ parameter to a number which is less than the number of core possessed by the CPU.

After the setting of all of above parameters, run this script via Python3 intepreter. To use GUI version, run the file named “MFA_GUI.py”, then a window will display on the desktop as shown in Fig 4. Next, choose the options and fill the entries. Finally, click ‘OK’ button.

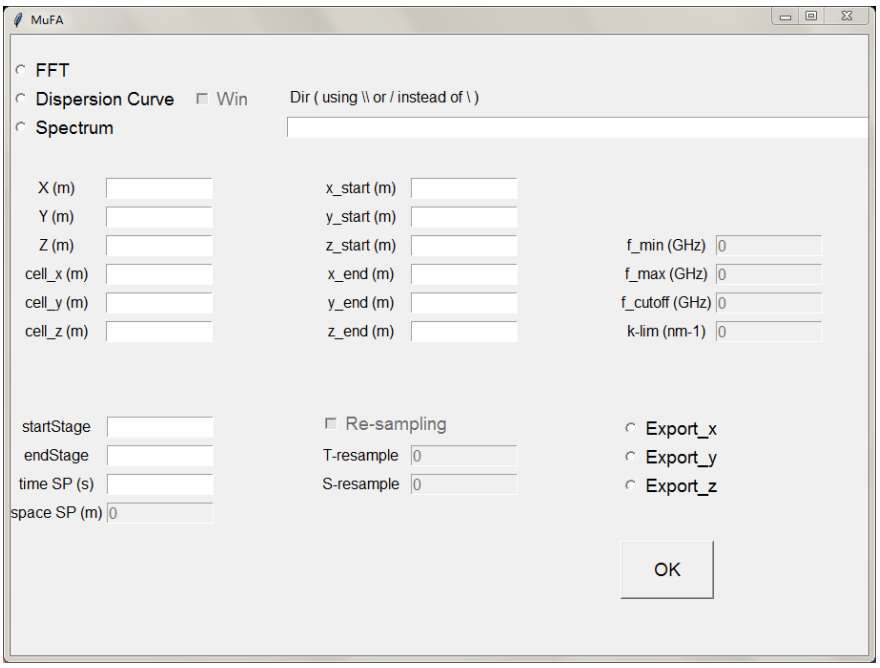

Figure 4. The GUI of MFA console.