Projecte de Treball Fi de Màster (TFM)

Màster en Modelització Computacional Atomística i Multiescala en Física, Química i Bioquímica
UB/UPC

Títol	Allaus i efectes de desordre mitjançant simulacions micomagnètiques
Title	Avalanches and disorder effects by means of micromagnetic simulations

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Universitat	Universitat de Barcelona
Tutor	

Curs	**2023-24**

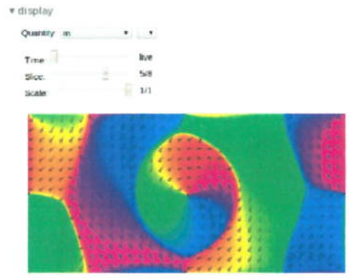
Summary

When a magnetic field is applied to a ferromagnetic material its domains start to move in order to align the spins to the field. Rather to be a continous evolution, the domain motion occurs through jumps that follow the features of avalanche dynamics. This project aims to explore the different origins and causes of avalanches by means of micromagnetic calculations of spin dynamics. This will involve the simulation of large domains under different constraints and initial conditions. The student will learn about spin dynamics starting from a simple macrospin model to the State-of-the art micromagnetic codes.

Keywords	Micromagnetic simulations, avalanches, domain wall motion

Breu descripció del projecte

The sound bursts generated when switching a ferromagnet were the first experimental evidence of the existence of magnetic domains. These bursts correspond to magnetization jumps and their sizes distribution follow the features of avalanche statistics [1]. The origin of the avalanches lies on the disorder of the order parameter, which is intrinsic to real materials due to their defects and polycrystalline structure. This avalanche behaviour of the domain wall motion is particularly relevant on the field of domain wall engineering, where the focus is on the physical properties and motion control of the domain wall [2].



The student enrolling in this project, supervised by Dr. Blai Casals and Dr. Eduardo Mendive, will describe magnetic domain motion and avalanches by predicting computationally their time evolution when they are subject to different constraints, external magnetic fields, and initial conditions. The most used tool to describe such dynamics is based on the application of the famous Landau-Lifshitz-Gilbert (LLG) equation, a differential equation of motion that includes the effect of both an effective local magnetic field and damping effects.

In the first part of the project the student will build their own code and will apply it to solve the LLG equation in simple situations, which will establish a fundamental understanding of micromagnetism. Non-trivial micromagnetic simulations involving avalanches and other complex phenomena will be performed by employing the famous mumax^3 package [3]. Mumax^3 is an advanced program designed to accelerate micromagnetic simulations thanks to its GPU parallelization, which can reach speed-ups of several orders of magnitude even using inexpensive gaming graphics cards. The figure shows a browser-based interface that will allow the control and manage of simulations, as well as to monitor their outputs on-the-fly.The central tasks of this project can be summarized as the following:

- **Task01:** To perform an extensive literature review of domain motion and avalanches in materials and micromagnetism.
- **Task02:** To learn the basics of micromagnetics along with the creation of an own-built code to simulate simple situations. These might include the precession, damping as well as the inclusion of anisotropy in a single domain.
- **Task03:** To learn the use of mumax^3 and apply it to non-complex cases, such as the minimization of simple magnetic structures and the motion of domains in trivial configurations.
- **Task04:** To simulate avalanches in well-understood conditions and reproduce published results [4]. This will lay out the groundwork to investigate the effect of initial disorder to advance the fundamental understanding of avalanches.
- **Task05:** To study the statistics of avalanches.

Task 02 will be a central but simpler exercise to consolidate fundamental understanding, while tasks 03 and 04 will involve the study of complex magnetic configurations and the subsequent analysis of results. Task 05 will be considered and done depending on the evolution of the project. The student should be strongly interested in magnetism, material properties, and prediction of dynamics by means of computational simulations. Being at the groups of Dr. Blai Casals and Dr. Eduardo Mendive will offer the opportunity to work with both theorists and experimentalists and analyse the project outputs alongside real experiments.

[1] *Crackling noise*, Nature **410**, 242–250 (2001)
[2] *Avalanches from charged domain wall motion in BaTiO3 during ferroelectric switching*, APL Mater. **8**, 011105 (2020)
[3] *The design and verification of MuMax3*, AIP Advances **4**, 107133 (2014)
[4] *Barkhausen noise from formation of 360 domain walls in disordered permalloy thin films,* Phys. Rev. Research **5**, L022006 (2023)

Competències addicionals (opcional)
This project will contribute to obtain the following competences: • Understanding of micromagnetism and knowledge to perform micromagnetic simulations accelerated by GPUs. • Understanding of the formation and dynamics of magnetic domains in materials, especially focusing on avalanches and its statistics. Knowledge to use highly parallel codes with a LINUX environment

	Tasques a desenvolupar	**Cronograma** (setmanes)																	
Tasca	**Descripció**	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
T01	**Bibliografy (aprox. 50 h)**	X	X	X	X					X	X	X	X						
T02	**Basics of micromagnetics and desing of basic own code of dynamics of micromagnetis (aprox. 75h)**			X	X	X	X												
T03	**Calculations stage 1: Introduction to mumax^3 (aprox. 50h)**							X	X	X	X	X							
T04	**Calculations stage 2: Avalanches (aprox. 100h)**										X	X	X	X	X				
T05	**Analysis and statistics of results (aprox. 75h)**									X	X	X		X	X	X			
T06	**Redacció de la memòria i preparar l'exposició (aprox. 100h)**														X	X	X	X	X

Observacions i comentaris
Per a la realització del treball pròpiament dit es preveu una dedicació d'unes quatre hores diàries durant cinc dies a la setmana, amb la opció de modificació de l'horari per poder adaptar-se millor a l'horari acadèmic de l'estudiant. **Recordeu que el TFM son 18 ECTS=18*25=450 hores de dedicació de l'estudiant (un 20% han de ser tutelades pel director). Calculeu 18-20 setmanes de març a juny (inclosos) per fer totes les tasques (inclosa la redacció de la memòria).**

Signatura (el director del TFM)

Dr. Blai Casals

Dr. Eduardo Mendive Tapia

Signatura (el tutor del TFM, si s'escau)