UKAIRS Abstract: Integrating Multi-Physics Modelling and Machine Learning in Spintronics: Enhancing Micromagnetic

**Abstract for Working phase (200 to 250 words):**

Skyrmions, a type of magnetic textures, are often simulated to design and build new electronic devices as a type of beyond-CMOS technologies. Landau-Lifshitz-Gilbert (LLG) equation is the most fundamental formula describing the motions of magnetic moments in ferromagnetic materials. To enhance micromagnetic simulation workflows based on the non-linear LLG equation for Skyrmion dynamics, machine-learning methods are used to accelerate the complex computation while bypassing the conventional Fast Fourier Transform (FFT) calculations. A micromagnetic toolkit built on COMSOL Multiphysics (developed by Theoretical spintronics group at FUDAN University) is implemented to model and simulate the transient response of the Skyrmions. By adjusting the key parameters within the equation, such as Dzyaloshinskii-Moriya Interactions (DMI) strength, material size, and anisotropy constant, the presence of Skyrmion, dynamic response and its annihilation, switching time can be determined accurately and extracted as key label features. COMSOL with MATLAB Simulink will be scripted to automate parameters sweep to generate large number of datasets for model training. We will train a regression model: a convolutional encoder first compresses the magnetisation as it extracts key spatial features by calculating convolutions, after which fully connected layers predict the target quantities. The resulting model is intended to serve as an accelerator, lowering computational complexity for existing micromagnetic computation with satisfied generalization capability.

**Literature Review (300 words):**

Since the middle of the 20th century, silicon-based semiconductor is used widely for the information storage and transmission. Though the numbers of transistors used in CMOS technologies is increasing exponentially every year according to the Moore’s law for obtaining higher gain and signal-to-noise ratio (SNR) [1], the power budgets have started to limit its increment. Beyond-CMOS technology has been developed due to its potential of dealing with the scalability problem and achieving lower energy consumption [2].

A new class of devices created from the field of condensed matter physics, called spintronics, is one of the Beyond-CMOS technology in the post-von Neumann computing architecture. Spintronic device has the advantage of high degree of scalability and low power consumption due to the property of combining both electron spin and its charge to provide more degree of freedom (DOF) compared to CMOS technology [3], [4], [5]. Magnetic skyrmion is a type of the spin textures, which exhibits high endurance and rapid information carriers. Physics behaviour of skyrmion is simulated under different parameters to discover and build a wide range of beyond-CMOS electronic devices.

LLG dynamics are often solved by the Finite Difference Method (FDM), introducing the computational complexity caused by the long-range cell interactions [6]. Researchers have pointed out that deep leaning method can be used to accelerate the calculation process [6], [7], [8]. Though the neural network they designed have successfully boosted the rate of simulation 10 time faster than traditional FDM method, it still faces the issue of weak generalization capability and scalability, especially in Multiphysics coupling.

**What have I learnt from this (200 to 250 words):**

I have previously used Machine Learning algorithm to analyse and train all kinds of sensor data collected from human body for biomedical applications, such as EMG and plantar pressure. In this Spintronics project proposed by April Ai Hub, I have the chance to study the fundamental physics principles in Micromagnetic and implement customized AI algorithm for science. I could obtain many inspirations from a research field that I have never attached before, and to reflect on to the field that I am familiar with.

After this two-month internship, I will be able to construct any geometric objects and simulate the micromagnetic response in time and frequency domain. My computing skillset will also be improved by designing neural networks for specific physics applications. Collaborating with extraordinary researchers and peer students is also beneficial for my communication skill.

**Keywords:**

Spintronics, Micromagnetic, Multi-physics Simulation, Machine Learning, AI for Science

**References:**

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