RÉPUBLIQUE FRANÇAISE
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PROPOSITION DE STAGE EN COURS D'ETUDES

Référence : **DAAA-2026-22**
(à rappeler dans toute correspondance)

Lieu : Châtillon

Département/Dir./Serv. : DAAA/AIMF

Tél. :

Responsable(s) du stage : Daniel Huerga, Alexandre Suss, Emeric Martin, Florent Renac

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DESCRIPTION DU STAGE

Thématique(s) : 09 - Méthodes et outils numériques pour les simulations hautes-performances

Type de stage : ☒ Fin d'études bac+5 ☒ Master 2 ☐ Bac+2 à bac+4 ☐ Autres

Title: Quantum-inspired approaches to lattice-based fluid dynamic simulation

Subject: Precise and robust solution of the Navier-Stokes equations describing the dynamics of fluids and their emergent phenomena pose important challenges to state-of-the-art computational fluid dynamic (CFD) methods. Indeed, even with current high-performance computers, the direct numerical simulation of turbulence, capturing all scales, is restricted to very limited configurations. Lattice based methods, based on a mesoscopic bottom-up approach linking the molecular dynamics to the continuous Navier-Stokes equations in certain limits, are designed to capture emergent phenomena originated at lower scales, while providing with fast algorithmic strategies. In particular, the lattice Boltzmann method (LBM) and lattice gas cellular automata (LGCA) describe the fluid as particles moving on regular lattices, where they evolve in a two-step collision-streaming process [1]. However, although the algorithmic strategy is local and highly parallelizable, the high-dimensionality of the data arrays yields to large memory footprints.

Tensor networks methods provide low-rank approximations of high-dimensional tensors by leveraging the structure of the problem. Developed within the context of strongly-correlated quantum systems, they furnish a language based on the entanglement structure and are at the core of density-matrix renormalization group, an efficient algorithm for the simulation of quantum phases of matter in one-dimension [2]. With the recent advent of quantum computers, they have become central in the debate of quantum advantage [3]. More recently, they have been applied to other areas and opened a promising route towards the simulation of turbulence in fluid dynamics [4].

In this internship, we will explore the possibilities of tensor-network methods to reduce the memory footprint of lattice-based methods, LBM and LGCA. Both methods are the subject of recent efforts towards their implementation on quantum computers, and can be encoded as different limits of a general hard-core bosonic system on a lattice [5]. We will focus on a particular type of tensor-network, the matrix product state, which provides a controlled approximation that can be systematically improved upon tuning a parameter, the 'bond' dimension, related to the entanglement support of the system. We aim at understanding the relations of bond dimension with typical fluid parameters like Reynolds and Mach number. We will explore different tensor decompositions, including recent advances in tensor cross interpolation [6], and evaluate their advantages and limitations in terms of accuracy, stability, and runtime. Results will be compared to state-of-the-art LBM and CFD results.

[1] D. A. Wolf-Gladrow, Lattice cellular automata and lattice Boltzmann models, Springer (2000)

[2] U. Schollwöck, Ann. Phys. 326, 96 (2011)

[3] Y. Zhou, E. M. Stoudenmire, X. Waintal, Phys. Rev. X 10, 041038 (2020)

[4] N. Gourianov et al., Nature Computational Science 2, 30 (2022)

[5] B. Wang, Z. Meng, Y. Zhao, Y. Yang, arxiv :2502.16568 (2025)

[6] Y. Núñez-Fernández et al., SciPost Phys. 18, 104 (2025)

Est-il possible d'envisager un travail en binôme ? Non

Méthodes à mettre en œuvre :

- ☒ Recherche théorique
- ☐ Travail de synthèse
- ☒ Recherche appliquée
- ☐ Travail de documentation
- ☐ Recherche expérimentale
- ☐ Participation à une réalisation

Possibilité de prolongation en thèse :

Durée du stage : Minimum : 5 mois Maximum : 6 mois

Période souhaitée : February to September 2026

PROFIL DU STAGIAIRE

Connaissances et niveau requis :

Background in applied mathematics, scientific computing, quantum mechanics; good programming skills and motivation to learn

Ecoles ou établissements souhaités :

MSc in Physics, Chemistry, Mathematics, Engineering with excellent academic records