CERFACS

JOB OFFER – STAGE

Quantum Lattice Boltzmann Method for Solving Navier-Stokes Equations

OFFER INFORMATION

Reference: ALGO-2025-LG-01
Team: ALGO
Location: 42 Avenue Gaspard Coriolis – 31057 Toulouse

Supervisors : Luc GIRAUD

Gratification: 700€ net per month - M2 level or last year at engineering school

Period: 6 months - from: 01/04/2025

Key words: Quantum, Lattice Boltzmann Method, Algorithm

CERFACS

Cerfacs is a private research, development, transfer and training center for modeling, simulation and high-performance computing. Cerfacs designs, develops and proposes innovative software methods and solutions to meet the needs of its partners in the aeronautics, space, climate, environment and energy sectors. Cerfacs trains students, researchers and engineers in simulation and high-performance computing.
Cerfacs works closely with its seven partners: Airbus, Cnes, EDF, Météo France, Onera, Safran et TotalEnergies.

HOSTING TEAM - ALGO

Within the Algo-COOP team, the Algo group conducts research in the fundamentals of high performance simulation. This includes a wide range of topics in applied mathematics, such as scalable algorithms in numerical linear algebra, iterative and direct algorithms for large linear systems, novel methods for solving partial differential equations, data assimilation, optimisation, uncertainty quantification and scientific machine learning.

CONTEXT

The recent development of quantum computers opens the question of whether we can use them to simulate complex physical phenomena modeled by partial differential equations (PDEs). Quantum algorithms for solving PDEs could significantly reduce computational complexity for certain classes of PDEs, especially those having a unitary and linear evolution like the Schrödinger equation. Many challenges remain in developing efficient quantum numerical schemes for PDEs with a non-unitary and/or non-linear evolution, like the Navier-Stokes equations, and in implementing simulations on current quantum hardware, including qubit coherence, error rates, and the need for sophisticated error correction techniques.

In classical computing, the evolution of computational fluid dynamics has seen remarkable advancements due to parallel computing processors and platforms, which have significantly heightened efficiency in mathematical models over the past decade. This progress has laid the groundwork for sophisticated methods such as the Lattice Boltzmann Method (LBM).

Unlike traditional macroscopic approaches, LBM operates at the mesoscopic scale, modeling fluid flow through the interactions of fictitious particles on a discrete lattice. This method discretizes velocity space, enabling efficient and highly parallelizable simulations on regular grids. Rooted in the Boltzmann equation, LBM employs a collision-streaming process to capture the essential physics of fluid behavior, utilizing models like the Bhatnagar-Gross-Krook (BGK) for particle redistribution.

LBM's inherent parallelism and capacity to handle complex geometries and boundary conditions make it a versatile tool for applications ranging from microfluidics to multiphase flows. Despite challenges related to discretization and computational demands, LBM offers significant advantages in simulating intricate fluid dynamics, positioning it as a valuable asset in both engineering and scientific research.

The Quantum Lattice Boltzmann Method (QLBM) advances fluid dynamics simulation by integrating principles of quantum computing, specifically quantum walks. These quantum walks enable particles to concurrently explore multiple lattice paths via superposition, akin to classical LBM's framework for particle movement and collision. QLBM seeks to enhance complex fluid dynamics simulations by potentially achieving quantum speedup for high-dimensional models and has already been addressed by the research community:
Budinski [1] introduced an innovative quantum algorithm that addresses the advection–diffusion equation through LBM and extended it to solve the 2D Navier–Stokes equations using stream function–vorticity formulation [2]. Itani and Succi [3] examined the Carleman linearization of the collision term in the lattice Boltzmann equation. Utilizing this linearization technique, Itani et al. [4] proposed a quantum lattice Boltzmann algorithm where both collision and streaming are facilitated by unitary evolution.

In previous methods, complete state measurement and subsequent reinitialization were required after each computation of one time step. Sanavio and Succi [5] presented a quantum algorithm for addressing the non-linear component of the Lattice-Boltzmann method, incorporating the Carleman linearization technique to approximate non-linearity. Wawrzyniak et al. [6] introduced a novel approach for encoding and executing the lattice-Boltzmann method as a quantum algorithm, proposing a hybrid quantum algorithm wherein only the computation of the moments of the distribution functions is performed as a classical post-processing step, while the full non-linearity is managed within the quantum algorithm. Despite the need for full state measurement after each time step, they successfully represented the non-linear equilibrium distribution function without relying on approximation techniques.

This six-month internship opportunity at CERFACS in Toulouse presents a quantum computing algorithm designed to implement the Quantum Lattice Boltzmann Method (QLBM) for solving the Navier-Stokes equation, leveraging the capabilities of quantum computing.

MISSION

1. OBJECTIVE

The main objective of this internship is to investigate quantum computing algorithms specifically for fluid simulation using the Lattice Boltzmann Method (LBM). The aim is to utilize the computational benefits of quantum computers to improve the efficiency and accuracy of fluid dynamics simulations.

2. RESEARCH PLAN

- **Phase 1: Literature Review and Preliminary Studies**
  - Quantum Computing Basics: Learn about qubits, quantum gates, and basic algorithms.
  - Literature Review: Summarize existing research on Quantum Lattice Boltzmann Method for Navier-Stokes equations.
  - Objectives: Assess quantum computing and Quantum Lattice Boltzmann algorithm status.
  - Deliverable: Provide a thorough literature review and report on improvements and research gaps.

- **Phase 2: Development of Quantum Algorithms**
  - Algorithm Design: Create and optimize quantum algorithms for the Lattice Boltzmann Method, using existing QLBM algorithms for collision and streaming steps.
  - Simulation: Conduct small-scale fluid flow simulations with quantum algorithms on simulators or quantum hardware.
  - Objectives: Develop and test quantum LBM algorithms for basic fluid dynamics scenarios.

Deliverable: A working prototype of the QLBM algorithm.

- **Phase 3: Reporting and documentation**
  - Documentation: Compile comprehensive documentation of the completed work, detailing algorithms, simulations, and performance analyses.

  - Final Presentation: Deliver a presentation to the research group, emphasizing the role of quantum computing in fluid dynamics simulations.

  - Objectives: Summarize the internship activities and suggest future research directions based on the results

3. EXPECTED OUTCOMES

- Development of quantum algorithms for the Lattice Boltzmann Method.
- Successful implementation and testing of quantum LBM algorithms on quantum simulators or hardware.
- Comparative analysis of quantum and classical LBM approaches.
- Identification of potential areas for further research and development in quantum fluid dynamics simulations.

4. REQUIRED RESOURCES

- Access to quantum computing simulators or hardware (e.g., IBM Q Experience, Microsoft Azure Quantum).
- Classical computing resources for algorithm development and testing.
- Mentorship from experts in quantum computing and fluid dynamics.

WHAT WE OFFER AT CERFACS

- Broad access to technology, a rich interpersonal environment, in-house skills recognized nationally and internationally.
- An inclusive and equitable work environment.
- A structure accessible to people with disabilities.
- Possibility of benefiting from 1.83 days of reduced working hours per month, linked to your choice of a 39-hour rather than 35-hour working week.
- 50% reimbursement of public transport costs.

HOW TO APPLY ?

To apply, please send your CV and covering letter to luc.giraud@cerfacs.fr , applications are open until 30/04/2025.

See you soon at CERFACS!

REFERENCES

[1] L. Budinski, Quantum algorithm for the advection–diffusion equation simulated with the lattice Boltzmann method, Quantum Information Processing 20, 57 (2021).

[2] L. Budinski, Quantum algorithm for the Navier–Stokes equations, arXiv preprint arXiv:2103.03804 (2021).

[3] W. Itani and S. Succi, Analysis of carleman linearization of lattice boltzmann, Fluids 7, 24 (2022).

[4] W. Itani, K. R. Sreenivasan, and S. Succi, Quantum algorithm for lattice boltzmann (qalb) simulation of incompressible fluids with a nonlinear collision term, arXiv preprint arXiv:2304.05915 (2023).

[5] C. Sanavio, and S. Succi. Lattice boltzmann–carleman quantum algorithm and circuit for fluid flows at moderate reynolds number. AVS Quantum Science, 6(2), 2024.

[6] D.Wawrzyniak, J. Winter, S. Schmidt, T. Indinger, U.Schramm, C. Janssen, and N. A. Adams, Unitary quantum algorithm for the lattice-boltzmann method. arXiv:2405.13391v2 (2024).