A High-Level Quantum Lattice Boltzmann Solver for Pure Advection with Subregion Local Measurement

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Abstract

The Lattice Boltzmann Method (LBM) is widely used for high-performance fluid simulation, yet its implementation on quantum architectures is still challenging due to complex circuit synthesis and the so-called read-out bottleneck [1]. In this talk, we present a complete quantum solver for the linear advection equation, highlighting two advances in quantum fluid dynamics (QFD). First, we implement the full LBM advection cycle in Qrisp [2], a high-level functional quantum programming language. Using automated uncomputation and structured variable management, we obtain a clear and modular mapping of the streaming step onto quantum registers. Unlike other algorithms that assume infinite domains, our approach incorporates physically relevant boundary conditions, including periodic, simple bounce-back, and slip setups, realized directly through high-level functional constructs. Second, we introduce a local measurement protocol based on algorithms for quantum amplitude estimation and amplification [3] to extract the macroscopic fluid density in selected subregions of the computational domain. By focusing on localized areas of interest, this strategy avoids the exponential cost of full state tomography. Simulations of pure advection demonstrate that the solver preserves sharp profiles without the numerical diffusion typical of classical discretizations. We further analyze circuit requirements and discuss how subregion-aware measurement supports scalable hybrid quantum–classical workflows, particularly when localized flow information is required for real-time analysis or boundary coupling.

References

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