Lattice Boltzmann Method solver for CFD simulation

CFD Lab Project: Final presentation

By: Siva Karthikeya

July 13th, 2023

Contents

Motivation

- Explore capabilities of Lattice Boltzmann Method (LBM) over Navier-Stokes solvers

- Accurately simulate complex fluid flow in Lid Driven Cavity

- Most importantly, to code a not-so-familiar Fluid Solver from scratch.

Brief overview of LBM

- Mesoscopic particle-based simulation method

- Simulates *weakly compressible flows* (Mach No << 1)

- Origins in statistical mechanics - based on the Boltzmann equation:

$$\frac{\partial f}{\partial t} + \vec{v} \cdot \nabla f = \Delta(f - f^{eq})$$

- f denotes the probability density to find fluid molecules in an infinitesimal volume at time t having the velocity v.

- Advantages: ease of parallelization, treatment of complex boundaries, handling multiphase and multicomponent flows

Implementation

1. Extended a 2D Finite Difference Navier-Stokes C++ flow solver to a 3D LBM (Lattice Boltzmann Method) flow solver.
2. Utilized the D3Q19 lattice structure- defines the discrete directions and weights for particle propagation and collision operations.
3. Modified the solver code to incorporate an additional dimension, enabling simulations in three dimensions.
4. Implemented the collision and propagation steps in accordance with the D3Q19 lattice structure to simulate the particle-based fluid flow behavior.
5. Adapted the boundary conditions to accurately represent the Lid Driven Cavity geometry in three dimensions.

Results

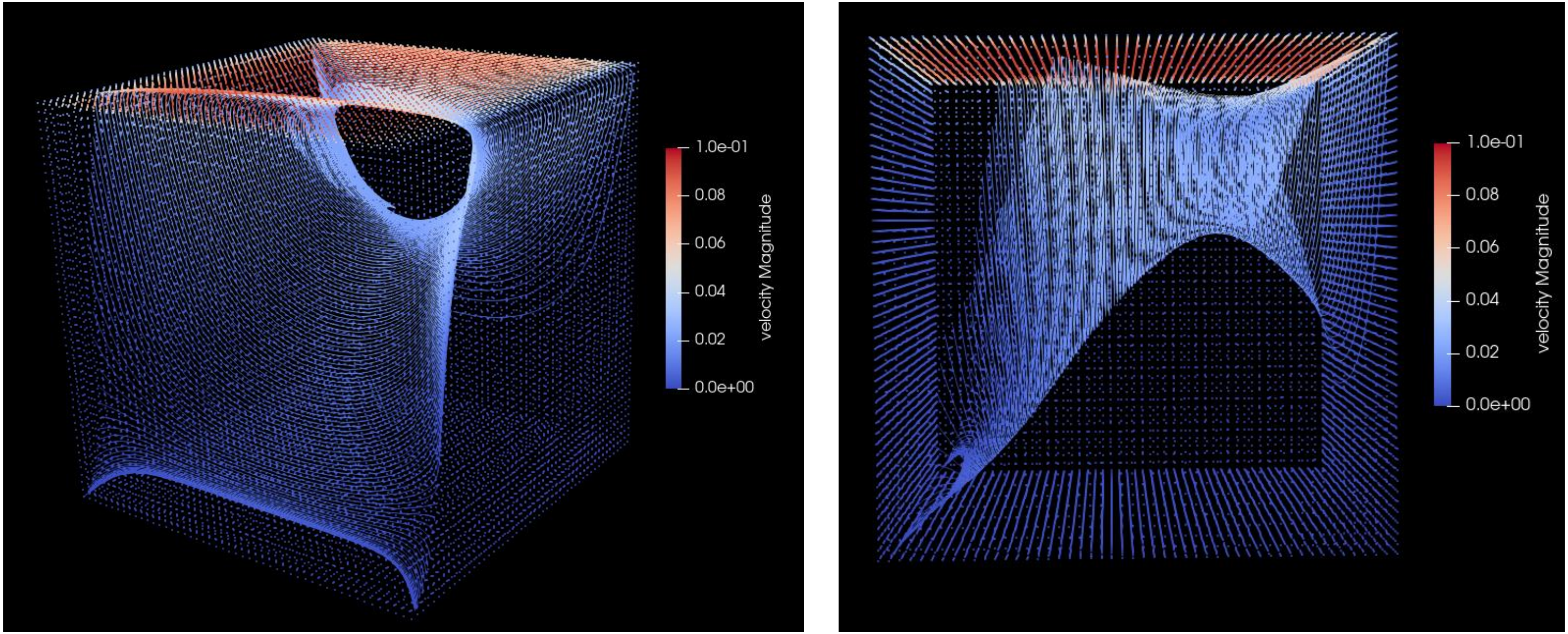

Figure1: Streamlines inside a 3-dimensional grid with point velocities at steady state (t=100)

Results

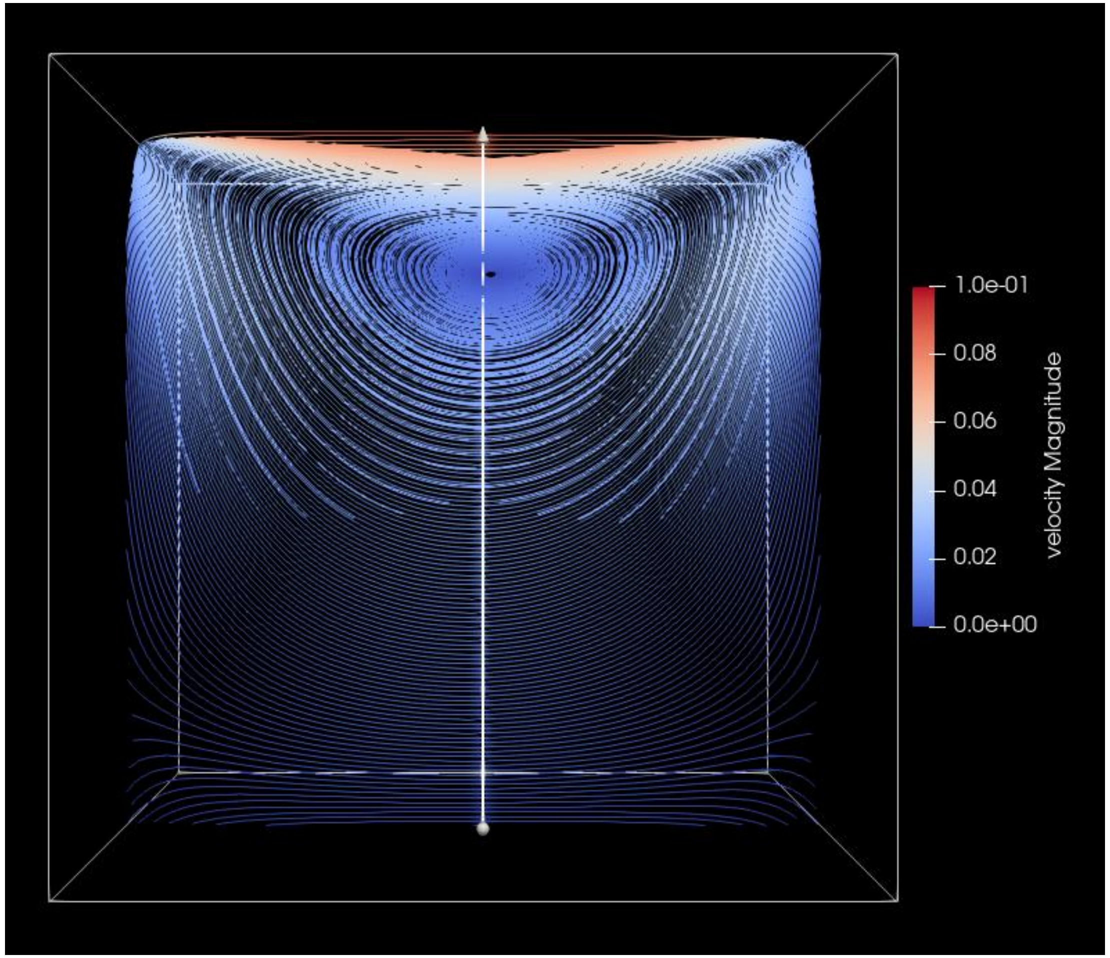

Figure2: Streamlines on the midplane of the 3D cavity at steady state (t=100)

Some observations due to increase in Reynolds Number (Different wall velocities: 0.01, 0.05, 0.1)

- Increase in computational time.
- Delayed steady state.

Challenges and Setbacks

- Understanding LBM theory and code implementation
- Grid Structure and Memory Management
- Code Optimization
- Implementing Advanced Boundary Conditions

Conclusion and Future Work

- Successful extension of 2D Navier-Stokes solver to 3D LBM solver for Lid Driven Cavity
- Implement advanced boundary conditions for arbitrary geometries
- Optimize solver performance and parallelization capabilities

Thank you!

Merge request link: https://gitlab.lrz.de/00000000014B4D55/group-d-cfd-lab/-/merge_requests/1