Lattice - Boltzmann Method In Fluid Dynamics

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Lattice - Boltzmann method and Von Karman vortex street

LBM - fluid modeling technique that simulates flow by modeling particle distributions on a lattice grid

Von Karman street is a repeating pattern of swirling vortices (vortex trail), caused by a process known as vortex shedding, which is responsible for the unsteady flow separation of a fluid around blunt bodies.

https://en.wikipedia.org/wiki/K%C3%A1rm%C3%A1n_vortex_street

Implementation details

- Implemented in Python 3.10
- Object oriented approach
- GPU acceleration - ~4 times faster than CPU implementation
- Average runtime for 20000 iterations simulation: 35 min + animation saving time
- Most important libraries used:
  - Numpy
  - Numba
  - Matplotlib

Parameters for the following

simulations (Re, u_in will change):

$N_x = 520$, $N_y = 180$ system size

$u_{in} = 0.04$ velocity in lattice units

$\mathrm{Re} = 220$ Reynolds number

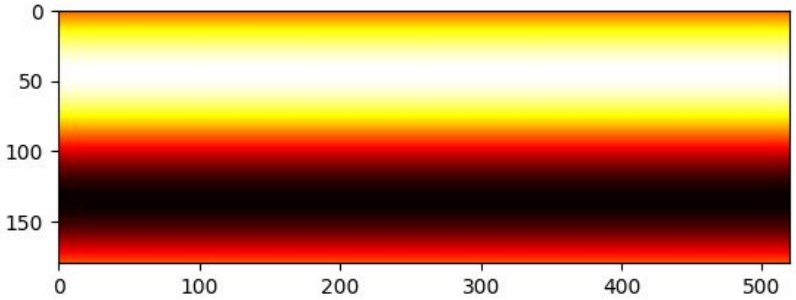
$$\nu_{LB} = \frac{u_{in}(N_y/2)}{\mathrm{Re}}$$ viscosity

$$\tau = 3\nu_{LB} + \frac{1}{2}$$ relaxation time

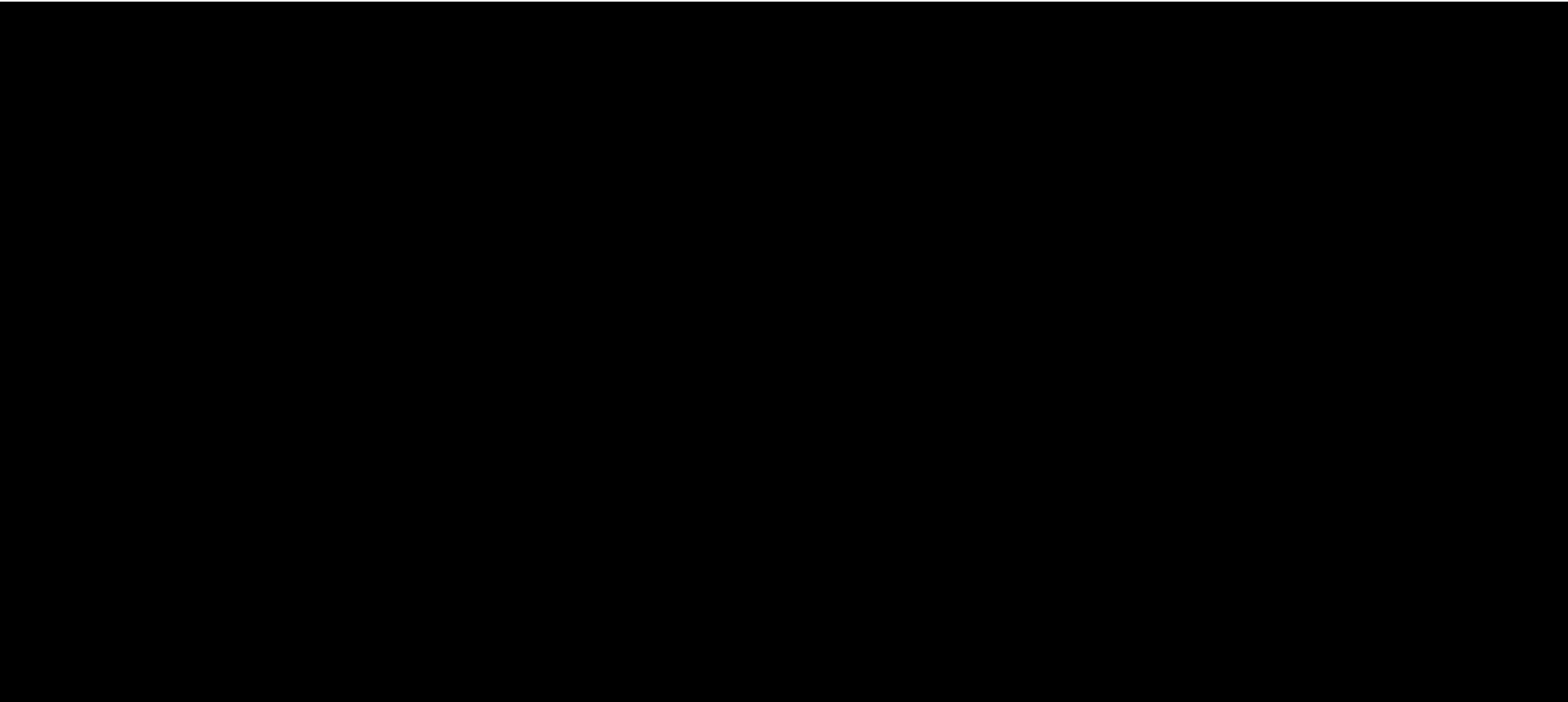
Initial state and visualization

Each visualization shows the squared absolute value of the velocity distribution

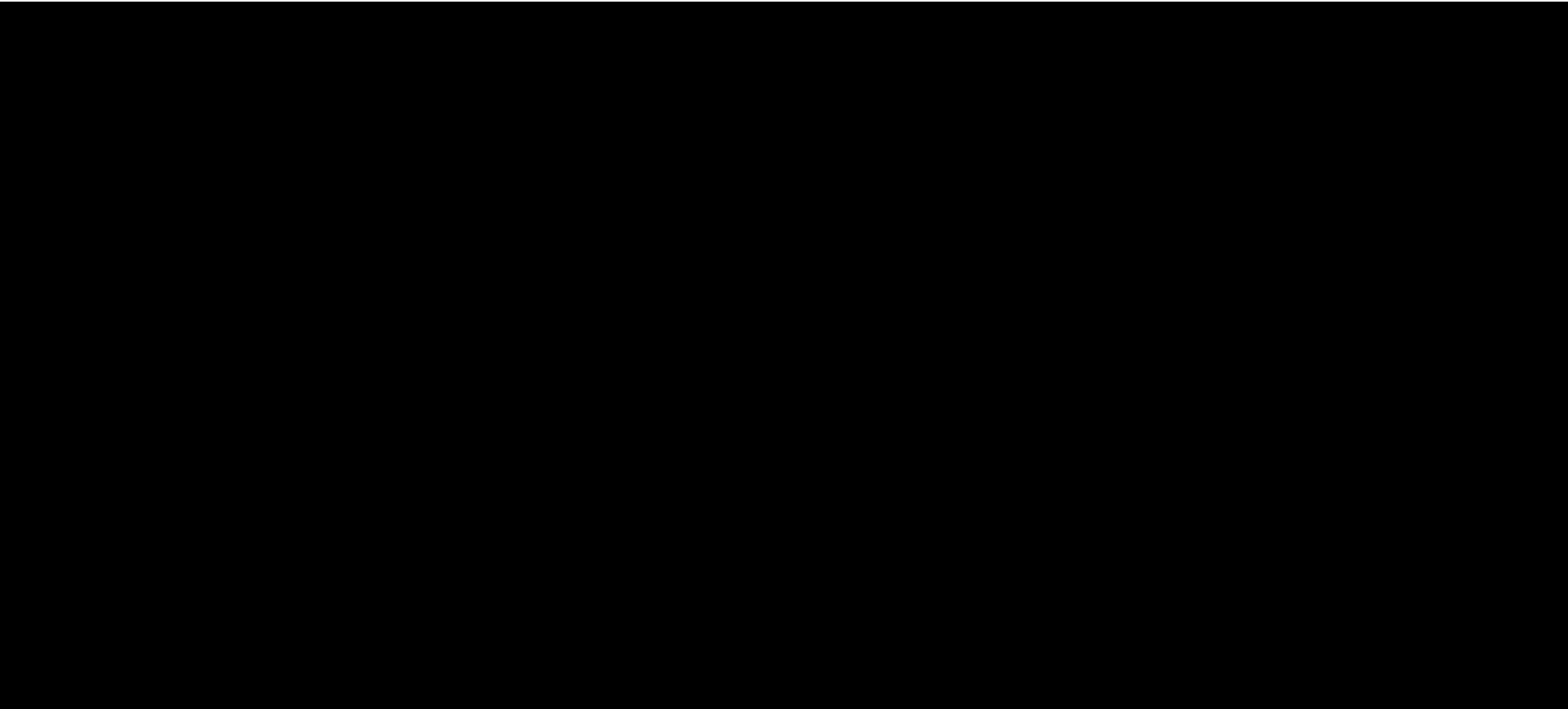
Obstacles are drawn in white. Brighter colors indicate faster flow.



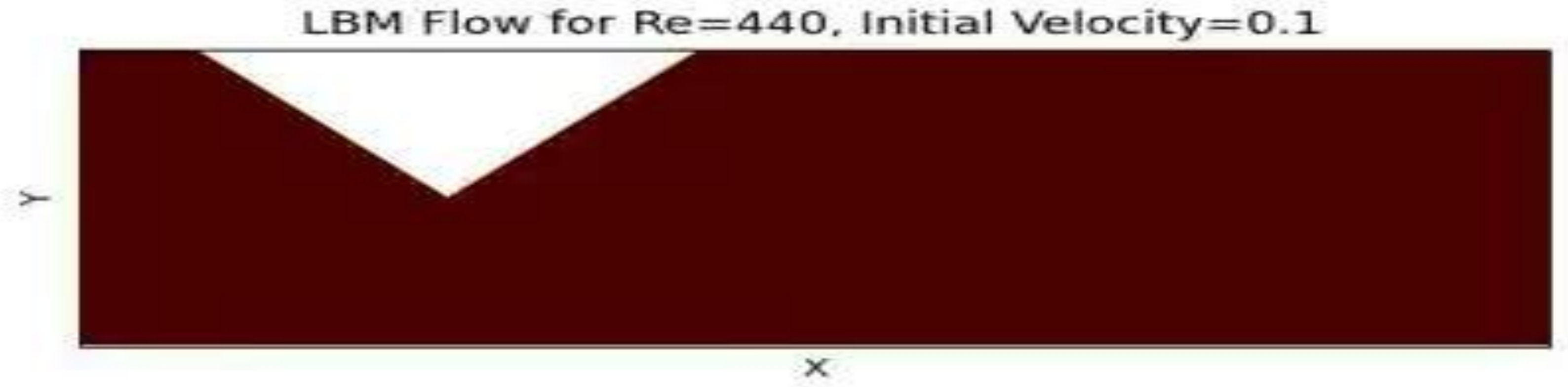
Flow behind a wedge, wall BC; RE = 220, u_in = 0.04



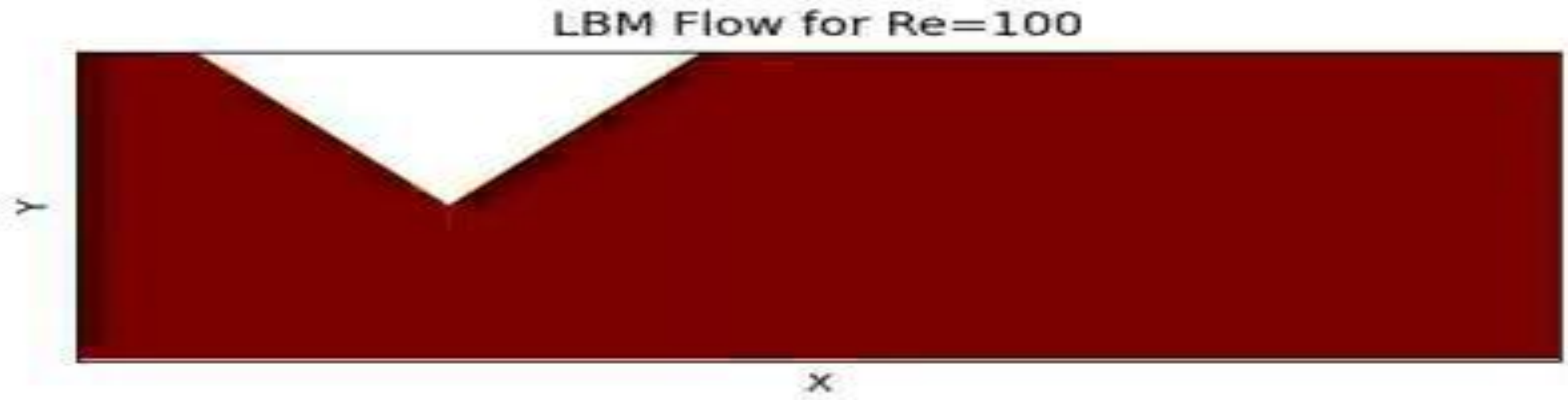
Flow behind a wedge, wall BC; RE = 220, u_in = 0.01



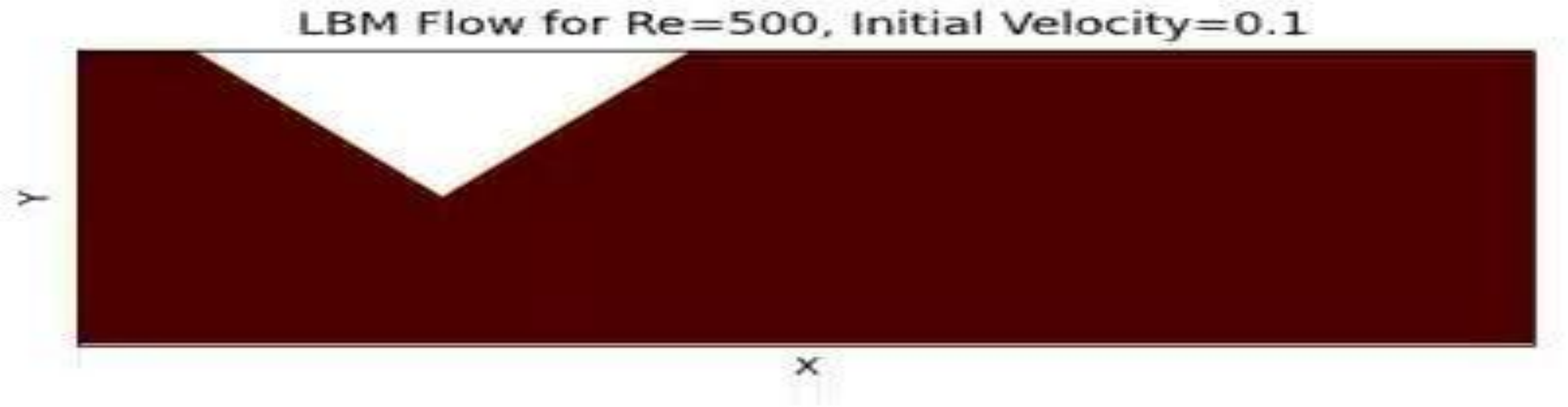
Von Karman street, wall BC; RE = 440, u_in = 0.01



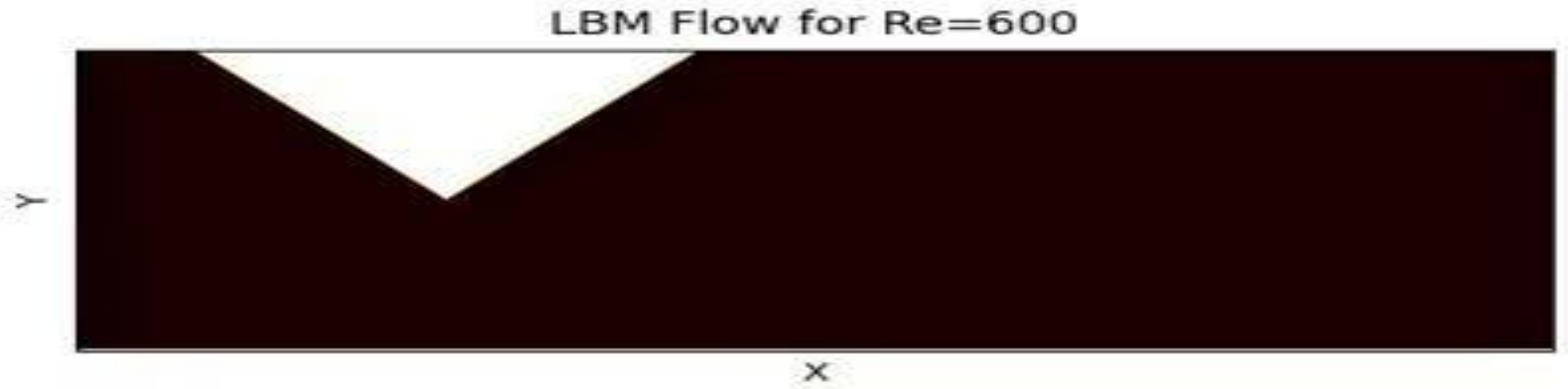
Stokes flow, wall BC; RE = 100, u_in = 0.1



Flow with an attached vortex, wall BC; RE = 500, u_in = 0.1



Slow vortex shedding, wall BC; RE = 600, u_in = 0.04



Conclusions

Low RE vs. high RE:

- Low RE - faster system evolution, slower vortices (or none), smaller shedding
- High RE - slower system evolution, faster vortices, bigger shedding

Different regimes for u_in = 0.1:

- Creeping (Stokes) flow - smooth, no vortices - low RE ~ 100 (exp. < 1)
- Vortex trail - turbulent, alternating vortices downstream - medium RE ~ 440 (exp. ~ 200)
- Attached vortices - turbulent, persistent vortex near obstacle - high RE ~ 500 (as expected, though a bit low)

Difference from the expected values of RE likely caused by simulation parameters

Code and sources

https://github.com/LLynd/CMPP2024/tree/main/Lab4

Sources:

- https://www.fuw.edu.pl/~tszawello/cmpp2024/
- http://fab.cba.mit.edu/classes/864.20/people/filippos/links/final-projects/lbm/index.html
- https://github.com/Ceyron/machine-learning-and-simulation/blob/main/english/simulation_scripts/lattice_boltzmann_method_python_jax.py