LBMengine.jl: An LBM-based library for simulation of microswimmers in julia

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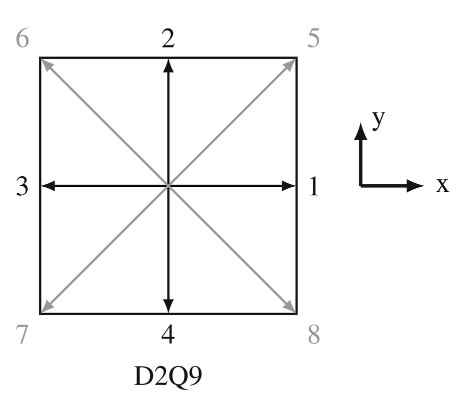
The simulation of active objects and hydrodynamics in the micro scale involves several challenges. These include, but are not limited to, solving the Navier-Stokes equations with complex boundary conditions and performing solid-fluid momentum exchanges. The aim of LBMengine.jl is to efficiently and conveniently put together the schemes and techniques needed to accurately solve these problems and simulate microswimmers.

What is the Lattice Boltzmann Method (LBM)?

Stemming from kinetic theory, the LBM decomposes the fluid into several "auxiliary" fluids of density f_i that evolve with a prescribed, constant fluid velocity $\mathbf{c}_i$. Each auxiliary fluid then contributes to the mass and momentum densities of the desired fluid [1]. Because of this, the LBM is best suited for time-dependent problems, and can deal efficiently with complex boundary conditions, both of which are necessary for the simulation of swimming techniques [2].



$$\rho(\boldsymbol{x},t) = \sum_i f_i(\boldsymbol{x},t), \quad \rho\boldsymbol{u}(\boldsymbol{x},t) = \sum_i \boldsymbol{c}_i f_i(\boldsymbol{x},t)$$

$$f_i(\boldsymbol{x}+\boldsymbol{c}_i\Delta t, t+\Delta t) - f_i(\boldsymbol{x},t) = -\frac{\Delta t}{\tau}(f_i - f_i^{\mathrm{eq}})$$

Benchmarks

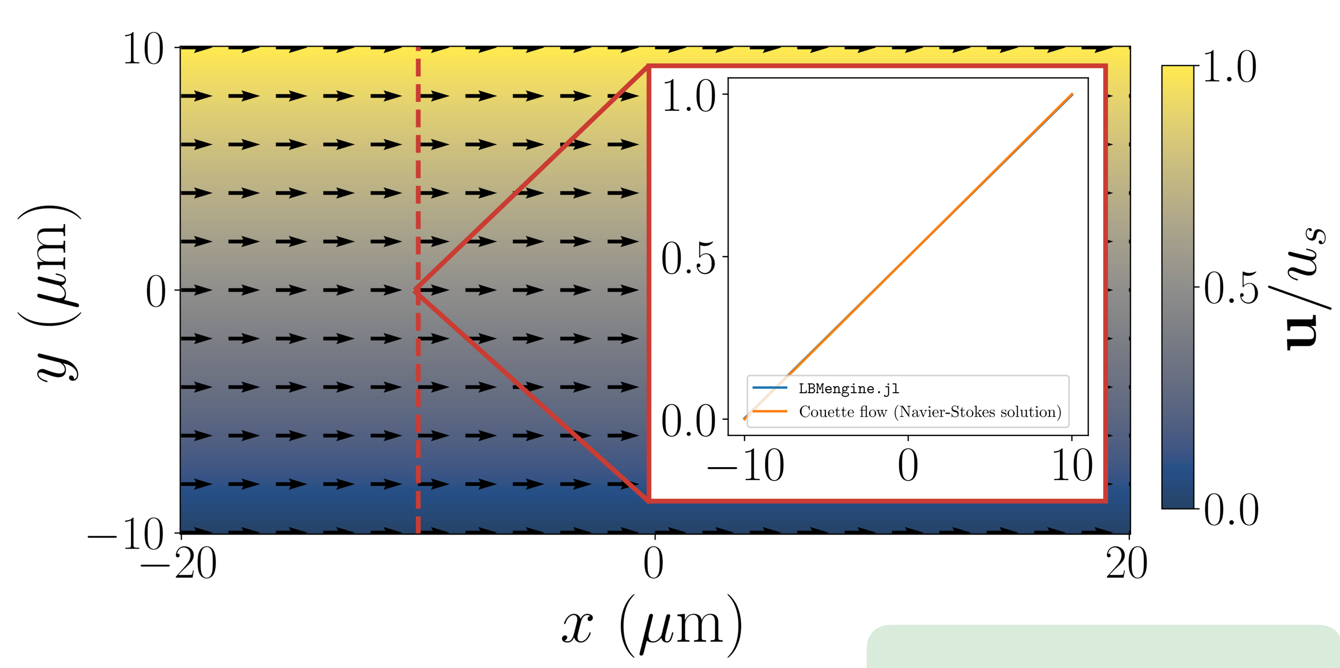


Figure 1: Couette flow; two plates separated by 20 µm are simulated; the top plate moves, shearing the fluid, while the bottom one remains fixed.

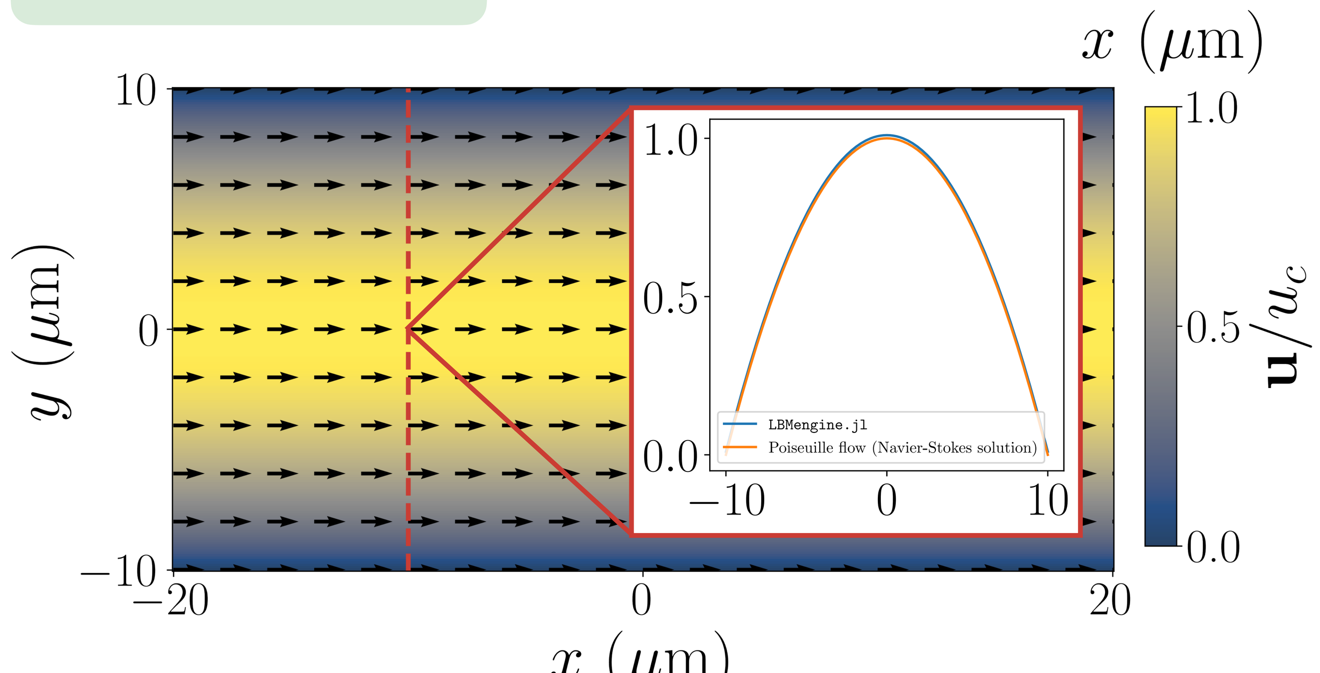


Figure 2: Poiseuille flow; two fixed plates separated by 20 µm are simulated; a body-force is applied to the fluid, driving it.

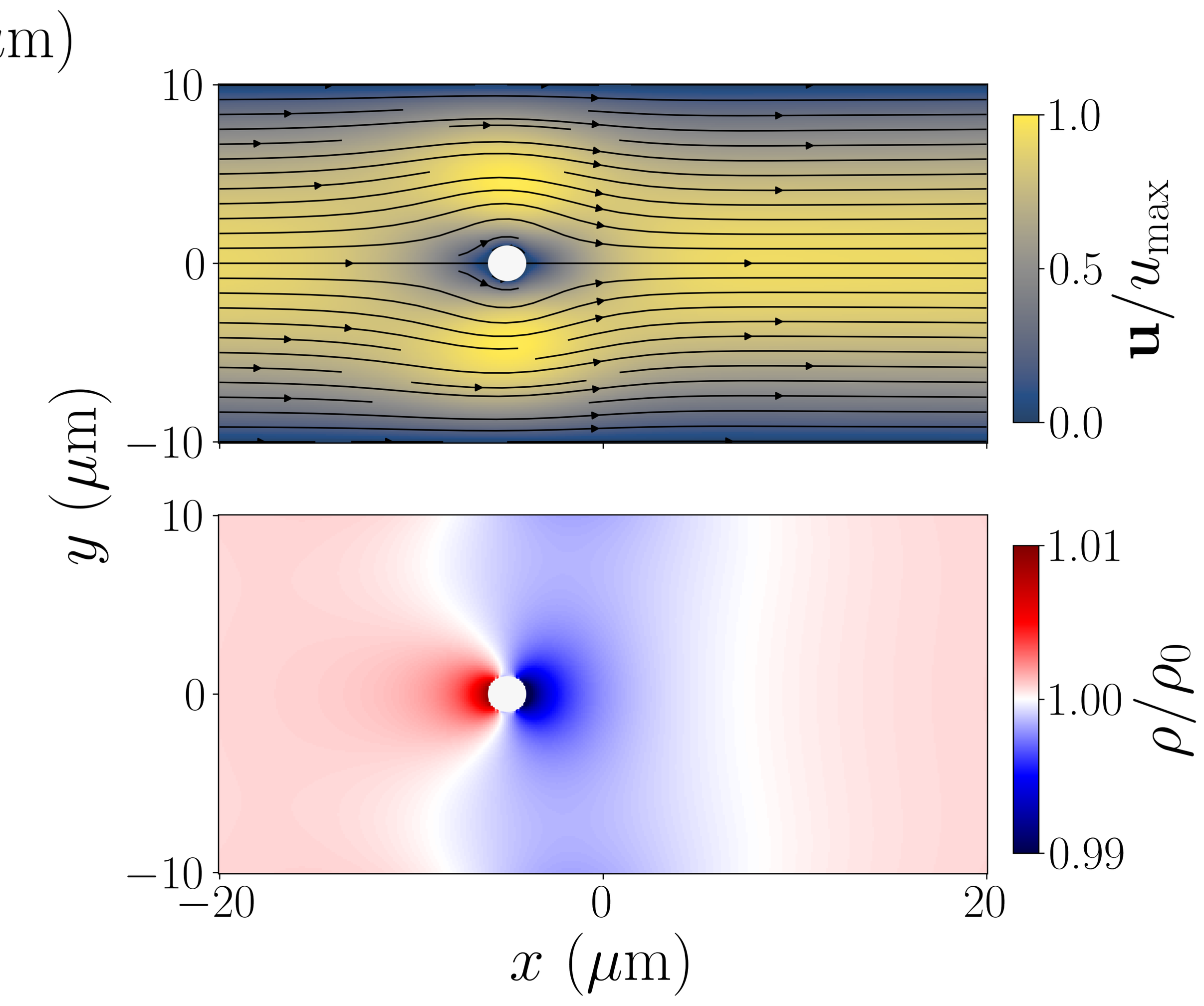


Figure 3: A circular obstruction is placed in an otherwise standard Poiseuille flow system.

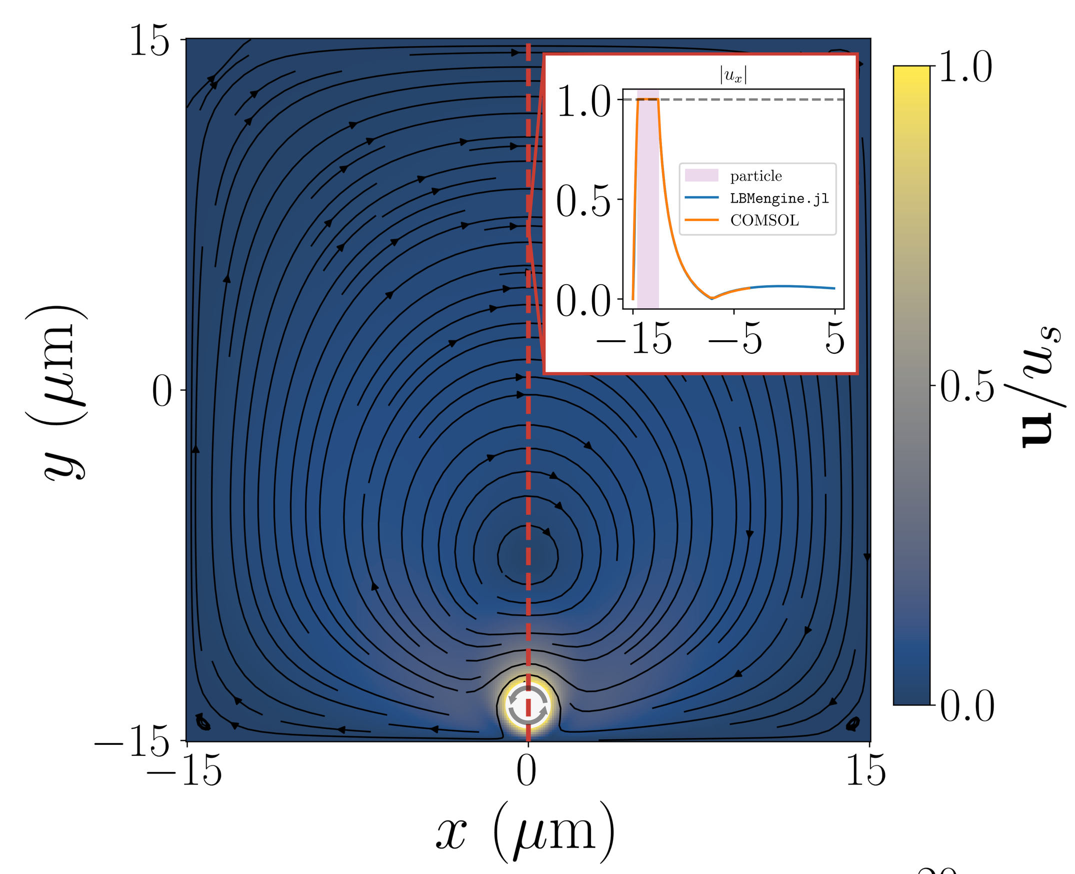


Figure 4: A rotating, circular particle is placed near a wall inside a box until equilibrium conditions are achieved.

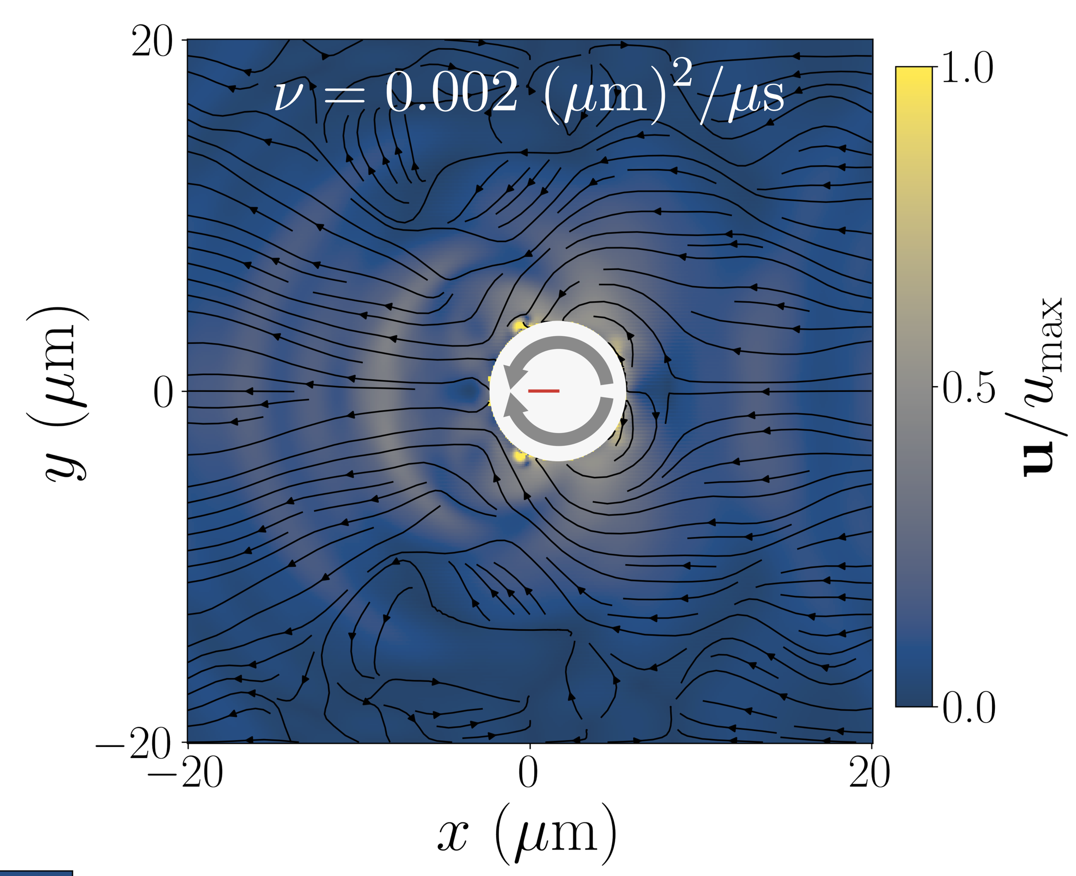


Figure 5: A circular particle pulls low-viscosity fluid backwards from either side, as indicated by the gray arrows. The particle swims towards $\hat{\mathbf{x}}$, with the trajectory of the particle center being shown in red.

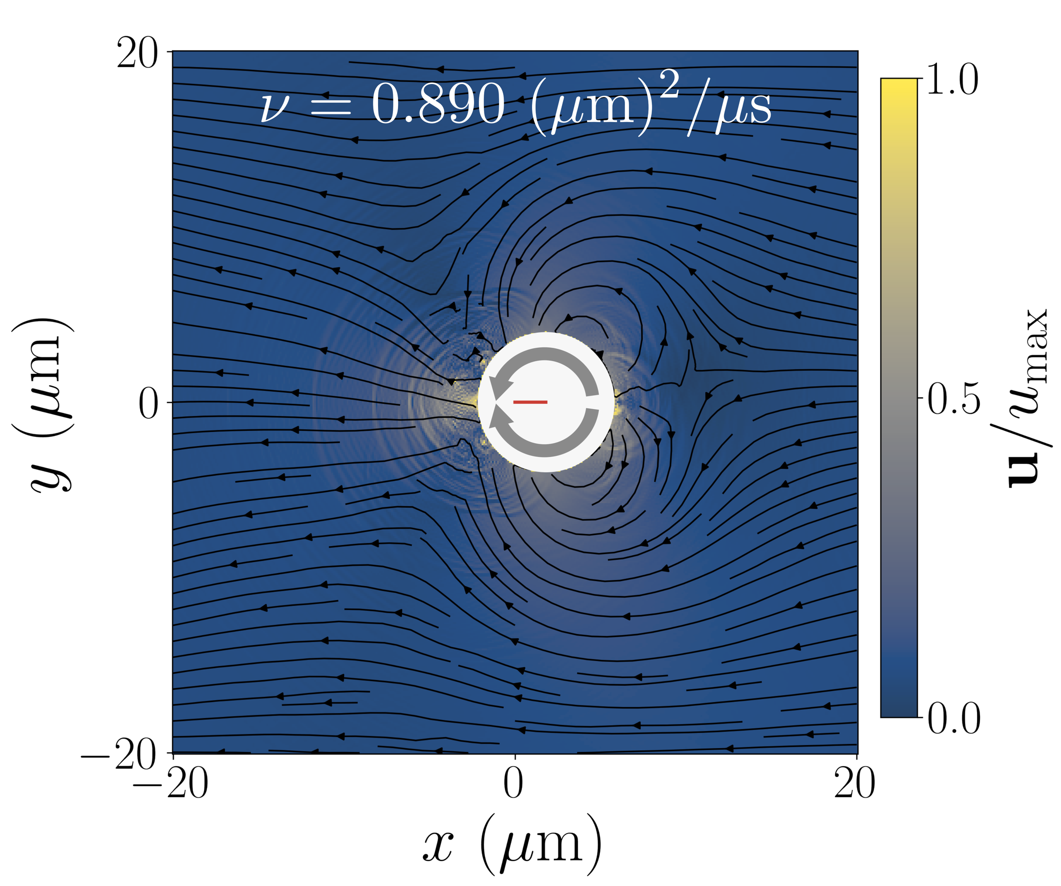


Figure 6: The same swimmer as the one shown in Figure 5, but submerged in water.

Future steps

The benchmarks shown above describe fairly well what LBMengine.jl is currently capable of. Development is underway to achieve, among other things:

- Better performance (CPU parallelization and GPU acceleration).
- Improved stability in high viscosity systems.
- The implementation of more diverse microswimmers.

Bibliography

[1] Krüger, T. et al. The Lattice Boltzmann Method: Principles and Practice. (Springer International Publishing, Cham, 2017).

[2] Kuron, M., Stärk, P., Burkard, C., De Graaf, J. & Holm, C. A lattice Boltzmann model for squirmers. The Journal of Chemical Physics 150, 144110 (2019).

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