Computational Fluid Dynamics with the Lattice Boltzmann Method

Overview, computational issues and biomedical applications

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Abstract

After two decades of intensive research the Lattice Boltzmann Method[1] (LBM) emerged as a powerful alternative model to study fluid dynamics. Applications are plentiful[2] and range from e.g. flow in porous media[3] to suspension flows[4] or blood flows[5, 6]. Originally LBM was valid for incompressible (athermal) Newtonian flows, but now the method has been extended to allow for e.g. non-Newtonian rheology[7].

The LBM is a large collection of models, but they all share the property that they numerically solve the Boltzmann Equation using a fixed regular lattice and a small set of discrete velocities. The discrete velocities are such that they match the underlying lattice, thereby transforming the advection operator to a streaming from one lattice node to a neighbouring lattice node. The LBM algorithm becomes a very clean streaming from lattice node to lattice node, followed by a collision operator that is local to lattice nodes. This computational structure allows for highly efficient parallel implementations of the LBM[8]. However, if the fluid domain becomes very irregular, like in any other parallel computation, special care must be taken to get well balanced computations[9].

LBM has found applications in many domains. As an example I will discuss biomedical applications, and most specifically blood flow simulations[5, 6, 10, 11].

References

1. S. Succi, *The Lattice Boltzmann Equation for Fluid Dynamics and beyond* (Clarendon Press, Oxford, 2001).
2. S. Chen and G. D. Doolen, Annu. Rev. Fluid Mech. **30**, 329 (1998).
3. A. Koponen, B. D. Kandhai, E. Héllen, et al., Physical Review Letters **80**, 716 (1998).

4. B. Chun and A. J. C. Ladd, Physical Review E (Statistical, Nonlinear, and Soft Matter Physics) **75**, 066705 (2007).
5. A. M. M. Artoli, A. G. Hoekstra, and P. M. A. Sloot, Journal of Biomechanics **39**, 873 (2006).
6. A. G. Hoekstra, in *Computational Fluid and Solid Mechanics 2005*, edited by K. J. Bathe, 2005), p. 672.
7. B. CHOPARD, R. OUARED, D. A. RUEFENACHT, et al., Int. J. Mod. Phys. C **18**, 712 (2007).
8. B. D. Kandhai, A. Koponen, A. G. Hoekstra, et al., Computer Physics Communications **111**, 14 (1998).
9. L. Axner, J. Bernsdorf, T. Zeiser, et al., Journal of Computational Physics **227**, 4895 (2008).
10. A. M. M. Artoli, A. G. Hoekstra, and P. M. A. Sloot, International Journal of Modern Physics C **13**, 1119 (2002).
11. A. M. M. Artoli, A. G. Hoekstra, and P. M. A. Sloot, International Journal of Modern Physics B **17**, 95 (2003).