The Lattice Boltzmann Equation For Fluid Dynamics And Beyond Numerical Mathematics And Scientific Computation

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An Accurate Curved Boundary Treatment in the Lattice Boltzmann Method Bentham Science Publishers
The lattice Boltzmann method (LBM) is a modern numerical technique, very efficient, flexible to simulate different flows within complex/varying geome tries. It is evolved from the lattice gas automata (LGA) in order to overcome the difficulties with the LGA. The core equation in the LBM turns out to be a special discrete form of the continuum Boltzmann equation, leading it to be self-explanatory in statistical physics. The method describes the micro scopic picture of particles movement in an extremely simplified way, and on the macroscopic level it gives a correct average description of a fluid. The av eraged particle velocities behave in time and space just as the flow velocities in a physical fluid, showing a direct link between discrete microscopic and continuum macroscopic phenomena. In contrast to the traditional computational fluid dynamics (CFD) based on a direct solution of flow equations, the lattice Boltzmann method provides an indirect way for solution of the flow equations. The method is characterized by simple calculation, parallel process and easy implementation of boundary conditions. It is these features that make the lattice Boltzmann method a very promising computational method in different areas. In recent years, it receives extensive attentions and becomes a very potential research area in computational fluid dynamics. However, most published books are limited to the lattice Boltzmann methods for the Navier-Stokes equations. On the other hand, shallow water flows exist in many practical situations such as tidal flows, waves, open channel flows and dam-break flows.

The Lattice Boltzmann Equation Springer Science & Business Media
Here is a basic introduction to Lattice Boltzmann models that emphasizes intuition and simplistic conceptualization of processes, while avoiding the complex mathematics that underlies LB models. The model is viewed from a particle perspective where collisions, streaming, and particle-particle/particle-surface interactions constitute the entire conceptual framework. Beginners and those whose interest is in model application over detailed mathematics will find this a powerful 'quick start' guide. Example simulations, exercises, and computer codes are included.

Lattice Boltzmann Method for 3-D Flows with Curved Boundary World Scientific
In this work, we investigate two issues that are important to computational efficiency and reliability in fluid dynamics applications of the lattice Boltzmann equation (LBE): (1) Computational stability and accuracy of different lattice Boltzmann models and (2) the treatment of the boundary conditions on curved solid boundaries and their 3-D implementations. Three a thermal 3-D LBE models (D3Q15, D3Q27) are studied and compared in terms of efficiency, accuracy, and robustness. The boundary treatment recently developed by Filippova and Hanel and Mei et al. in 2-D is extended to and implemented for 3-D. The convergence, stability, and computational efficiency of the 3-D LBE models with the boundary treatment for curved boundaries were tested in simulations of four 3-D flows: (1) Fully developed flows in a square duct, (2) flow in a 3-D lid-driven cavity, (3) fully developed flows in a circular pipe, and (4) a uniform flow over a sphere. We found that while the fifteen-velocity 3-D (D3Q15) model is more prone to numerical instability and the D3Q27 is more computationally intensive, the D3Q19 model provides a balance between computational reliability and

efficiency. Through numerical simulations, we demonstrated that the boundary treatment for 3-D arbitrary curved geometry has second-order accuracy and possesses satisfactory stability characteristics.

Lattice Boltzmann Modeling for Chemical Engineering World Scientific

The lattice Boltzmann equation (LBE) is an alternative kinetic method capable of solving hydrodynamics for various systems. Major advantages of the method are owing to the fact that the solution for the particle distribution functions is explicit, easy to implement, and natural to parallelize. Because the method often uses uniform regular Cartesian lattices in space, curved boundaries are often approximated by a series of stairs that leads to reduction in computational accuracy. In this work, a second-order accurate treatment of boundary condition in the LBE method is developed for a curved boundary. The proposed treatment of the curved boundaries is an improvement of a scheme due to Filippova and Haenel. The proposed treatment for curved boundaries is tested against several flow problems: 2-D channel flows with constant and oscillating pressure gradients for which analytic solutions are known, flow due to an impulsively started wall, lid-driven square cavity flow, and uniform flow over a column of circular cylinders. The second-order accuracy is observed with solid boundary arbitrarily placed between lattice nodes. The proposed boundary condition has well behaved stability characteristics when the relaxation time is close to 1/2, the zero limit of viscosity. The improvement can make a substantial contribution toward simulating practical fluid flow problems using the lattice Boltzmann method.

Time-implicit Solution of the Lattice Boltzmann Equation Createspace Independent Publishing Platform

Lattice-gas cellular automata (LGCA) and lattice Boltzmann models (LBM) are relatively new and promising methods for the numerical solution of nonlinear partial differential equations. The book provides an introduction for graduate students and researchers. Working knowledge of calculus is required and experience in PDEs and fluid dynamics is recommended. Some peculiarities of cellular automata are outlined in Chapter 2. The properties of various LGCA and special coding techniques are discussed in Chapter 3. Concepts from statistical mechanics (Chapter 4) provide the necessary theoretical background for LGCA and LBM. The properties of lattice Boltzmann models and a method for their construction are presented in Chapter 5.

Oxford University Press

A careful comparison of the performance of a commercially available Lattice-Boltzmann Equation solver (Power-FLOW) was made with a conventional, block-structured computational fluid-dynamics code (CFL3D) for the flow over a two-dimensional NACA-0012 airfoil. The results suggest that the version of PowerFLOW used in the investigation produced solutions with large errors in the computed flow field; these errors are attributed to inadequate resolution of the boundary layer for reasons related to grid resolution and primitive turbulence modeling. The requirement of square grid cells in the PowerFLOW calculations limited the number of points that could be used to span the boundary layer on the wing and still keep the computation size small enough to fit on the available computers. Although not discussed in detail, disappointing results were also obtained with PowerFLOW for a cavity flow and for the flow around a generic helicopter configuration.Lockard, David P. and Luo, Li-Shi and Singer, Bart A. and Bushnell, Dennis M. (Technical Monitor)Langley Research CenterBOLTZMANN TRANSPORT EQUATION; TURBULENCE MODELS; BOUNDARY LAYERS; COMPUTER PROGRAMS; COMPUTATIONAL FLUID DYNAMICS; AIRFOILS; CAVITY FLOW; FLOW DISTRIBUTION

Theory of the Lattice Boltzmann Equation Springer

We construct a multi-relaxation lattice Boltzmann model on a two-dimensional rectangular grid. The model is partly inspired by a previous work of Koelman to construct a lattice BGK model on a two-dimensional rectangular grid. The linearized dispersion equation is analyzed to obtain the constraints on the isotropy of the transport coefficients and Galilean invariance for various wave propagations in the model. The linear stability of the model is also studied. The model is numerically tested for three cases: (a) a vortex moving with a constant velocity on a mesh periodic boundary conditions; (b) Poiseuille flow with an arbitrasy inclined angle with respect to the lattice orientation: and (c) a cylinder &symmetrically placed in a channel. The numerical results of these tests are compared with either analytic solutions or the results obtained by other methods. Satisfactory results are obtained for the numerical simulations. Bouzidi, MHamed and DHumieres, Dominique and Lallemand, Pierre and Luo, Li-Shi and Bushnell, Dennis M. (Technical Monitor) Langley Research Center NASA/CR-2002-211658, NAS 1.26:211658, ICASE-2002-18

Rigorous Navier-Stokes Limit of the Lattice Boltzmann Equation John Wiley & Sons

Programming has become a significant part of connecting theoretical development and scientific application computation. Fluid dynamics provide an important asset in experimentation and theoretical analysis. Analysis and Applications of Lattice Boltzmann Simulations provides emerging research on the efficient and standard implementations of simulation methods on current and upcoming parallel architectures. While highlighting topics such as hardware accelerators, numerical analysis, and sparse geometries, this publication explores the techniques of specific simulators as well as the multiple extensions and various uses. This book is a vital resource for engineers, professionals, researchers, academics, and students seeking current research on computational fluid dynamics, high-performance computing, and numerical and flow simulations.

A Lattice Boltzmann Equation Model for Thermal Liquid Film Flow Springer Science & Business Media

This unique professional volume is about the recent advances in the lattice Boltzmann method (LBM). It introduces a new methodology, namely the simplified and highly stable lattice Boltzmann method (SHSLBM), for constructing numerical schemes within the lattice Boltzmann framework. Through rigorous mathematical derivations and abundant numerical validations, the SHSLBM is found to outperform the conventional LBM in terms of memory cost, boundary treatment and numerical stability.This must-have title provides every necessary detail of the SHSLBM and sample codes for implementation. It is a useful handbook for scholars, researchers, professionals and students who are keen to learn, employ and further develop this novel numerical method.

LATTICE BOLTZMANN EQUATION GRIN Verlag

This book covers the fundamental and practical application of the Lattice Boltzmann method (LBM). This method is a relatively new simulation technique for the modeling of complex fluid systems and has attracted interest from researchers in computational physics.

Introduction To The Lattice Boltzmann Method, An: A Numerical Method For Complex Boundary And Moving Boundary Flows World Scientific

In this paper a procedure for systematic a priori derivation of the lattice Boltzmann models for non-ideal gases from the Enskog equation (the modified Boltzmann equation for dense gases) is presented. This treatment provides a unified theory of lattice Boltzmann models for non-ideal gases. The lattice Boltzmann equation is systematically obtained by discretizing the Enskog equation in phase space and time. The lattice Boltzmann model derived in this paper is thermodynamically consistent up to the order of discretization error. Existing lattice Boltzmann models for non-ideal gases are analyzed and compared in detail. Evaluation of these models are made in light of the general procedure to construct the lattice Boltzmann model for non-ideal gases presented in this work.

Theory of the Lattice Boltzmann Method: Dispersion, Dissipation, Isotropy, Galilean Invariance, and Stability The Lattice Boltzmann Equation: For Complex States of Flowing Matter

Lattice Boltzmann Method introduces the lattice Boltzmann method (LBM) for solving transport phenomena – flow, heat and mass transfer – in a systematic way. Providing explanatory computer codes throughout the book, the author guides readers through many practical examples, such as: flow in isothermal and non-isothermal lid driven cavities; flow over obstacles; forced flow through a heated channel; conjugate forced convection; and natural convection. Diffusion and advection-diffusion equations are discussed with applications and examples, and complete computer codes accompany the coverage of single and multi-relaxation-time methods. Although the codes are written in FORTRAN, they can be easily translated to other languages, such as C++. The codes can also be extended with little effort to multi-phase and multi-physics, if the reader knows the physics of the problem. Readers with some experience of advanced mathematics and physics will find Lattice Boltzmann Method a useful and easy-to-follow text. It has been written for those who are interested in learning and applying the LBM to engineering and industrial problems and it can also serve as a textbook for advanced undergraduate or graduate students who are studying computational transport phenomena.

Lattice Boltzmann Modeling of Complex Flows for Engineering Applications Springer

Some rigorous results on discrete velocity models are briefly reviewed and their ramifications for the lattice Boltzmann equation (LBE) are discussed. In particular, issues related to thermodynamics and H-theorem of the lattice Boltzmann equation are addressed. It is argued that for the lattice Boltzmann equation satisfying the correct hydrodynamic equations, there cannot exist an H-theorem. Nevertheless, the equilibrium distribution function of the lattice Boltzmann equation can closely approximate the genuine equilibrium which minimizes the H-function of the corresponding continuous Boltzmann equation. It is also pointed out that the equilibrium in the LBE models is an attractor rather than a true equilibrium in the rigorous sense of H-theorem. Since there is no H-theorem to guarantee the stability of the LBE models at the attractor, the stability of the attractor can only be studied by means other than proving an H-function.

Large-Eddy Simulation Based on the Lattice Boltzmann Method for Built Environment Problems Springer Nature

Theory and Application of Multiphase Lattice Boltzmann Methods presents a comprehensive review of all popular multiphase Lattice Boltzmann Methods developed thus far and is aimed at researchers and practitioners within relevant Earth Science disciplines as well as Petroleum, Chemical, Mechanical and Geological Engineering. Clearly structured throughout, this book will be an invaluable reference on the current state of all popular multiphase Lattice Boltzmann Methods (LBMs). The advantages and disadvantages of each model are presented in an accessible manner to enable the reader to choose the model most suitable for the problems they are interested in. The book is targeted at graduate students and researchers who plan to investigate multiphase flows using LBMs. Throughout the text most of the popular multiphase LBMs are analyzed both theoretically and through numerical simulation. The authors present many of the mathematical derivations of the models in greater detail than is currently found in the existing literature. The approach to understanding and classifying the various models is principally based on simulation compared against analytical and observational results and discovery of undesirable terms in the derived macroscopic equations and sometimes their correction. A repository of FORTRAN codes for multiphase LBM models is also provided.

Lattice Boltzmann And Gas Kinetic Flux Solvers: Theory And Applications World Scientific

This book details the lattice Boltzmann method (LBM) applied to the built environment problems. It provides the fundamental theoretical knowledge and specific implementation methods of LBM from the engineering perspective of the built environment. It covers comprehensive issues of built environment with three detailed cases, solving practical problems. It can be used as a reference book for teachers, students, and engineering technicians to study LBM and conduct architecture and urban wind environments simulations, in the fields of architecture, building technology science, urban planning, HVAC, built environment engineering, and civil engineering.

Lattice Boltzmann Method Morgan & Claypool Publishers

Progress in Computational Physics is an e-book series devoted to recent research trends in computational physics. It contains chapters contributed by outstanding experts of modeling of physical problems. The series focuses on interdisciplinary computational perspectives of current physical challenges, new numerical techniques for the solution of mathematical wave equations and describes certain real-world applications. With the help of powerful computers and sophisticated methods of numerical mathematics it is possible to simulate many ultramodern devices, e.g. photonic crystals structures, semiconductor nanostructures or fuel cell stacks devices, thus preventing expensive and longstanding design and optimization in the laboratories. In this book series, research manuscripts are shortened as single chapters and focus on one hot topic per volume. Engineers, physicists, meteorologists, etc. and applied mathematicians can benefit from the series content. Readers will get a deep and active insight into state-of-the art modeling and simulation techniques of ultra-modern devices and problems. The third volume - Novel Trends in Lattice Boltzmann Methods - Reactive Flow, Physicochemical Transport and Fluid-Structure Interaction - contains 10 chapters devoted to mathematical analysis of different issues related to the lattice Boltzmann methods, advanced numerical techniques for physico-chemical flows, fluid structure interaction and practical applications of these phenomena to real world problems.

The Lattice Boltzmann Method for Complex Flows Independently Published

Flowing matter is all around us, from daily-life vital processes (breathing, blood circulation), to industrial, environmental, biological, and medical sciences. Complex states of flowing matter are equally present in fundamental physical processes, far remote from our direct senses, such as quantum-relativistic matter under ultra-high temperature conditions (quark-gluon plasmas). Capturing the complexities of such states of matter stands as one of the most prominent challenges of modern science, with multiple ramifications to physics, biology, mathematics, and computer science. As a result, mathematical and computational techniques capable of providing a quantitative account of the way that such complex states of flowing matter behave in space and time are becoming increasingly important. This book provides a unique description of a major technique, the Lattice Boltzmann method to accomplish this task. The Lattice Boltzmann method has gained a prominent role as an efficient computational tool for the numerical simulation of a wide variety of complex states of flowing matter across a broad range of scales; from fully-developed turbulence, to multiphase micro-flows, all the way down to nano-biofluidics and lately, even quantum-relativistic sub-nuclear fluids. After providing a self-contained introduction to the kinetic theory of fluids and a thorough account of its transcription to the lattice framework, this text provides a survey of the major developments which have led to the impressive growth of the Lattice Boltzmann across most walks of fluid dynamics and its interfaces with allied disciplines. Included are recent developments of Lattice Boltzmann methods for non-ideal fluids, micro- and nanofluidic flows with suspended bodies of assorted nature and extensions to strong non-equilibrium flows beyond the realm of continuum fluid mechanics. In the final part, it presents the extension of the Lattice Boltzmann method to quantum and relativistic matter, in an attempt to match the major surge of interest spurred by recent developments in the area of strongly interacting holographic fluids, such as electron flows in graphene.

Lattice Boltzmann Methods for Shallow Water Flows Springer Science & Business Media

This book is a printed edition of the Special Issue "Non-Linear Lattice" that was published in Entropy

Multiphase Lattice Boltzmann Methods Oxford University Press

This thesis presents the extension of the lattice Boltzmann equation (LBE) to several well-known flows. First, the flow over a cylinder is studied using the LBE and the numerical predictions are shown to compare well with those obtained using a stylised finite volume method. A clear and formal perturbation analysis of the generalised LBE is also presented. A LBE for axisymmetric flows is developed, the precise form of which is derived through a Chapman-Enskog analysis so that the additional axisymmetric contributions to the Navier-Stokes equation are furnished when written in the cylindrical polar coordinate system. Stokes' flow over a sphere is studied and excellent agreement is found between the numerical and analytical predictions. A lattice Boltzmann model for immiscible binary fluids with variable viscosities and density ratio is developed. In the macroscopic limit this model is shown to recover the Navier-Stokes equations for two phase flow. A theoretical expression for surface tension is determined. The validity of this analysis is confirmed by comparing numerical and theoretical predictions of surface tension as a function of density. A number of numerical simulations are presented and shown to be in good agreement with analytical results. Finally, an axisymmetric multiphase lattice Boltzmann model has been proposed. This model is easy to implement and some test cases have been performed to demonstrate its capabilities. A review of the extension of the lattice Boltzmann equation to viscoelasticity is also presented.

Lattice Boltzmann Equation on a 2D Rectangular Grid MDPI

Computational fluid dynamics (CFD) has been widely applied in a wide variety of industrial applications, including aeronautics, astronautics, energy, chemical, pharmaceuticals, power and petroleum.This unique compendium documents the recent developments in CFD based on kinetic theories, introducing flux reconstruction strategies of kinetic methods for the simulation of complex incompressible and compressible flows, namely the lattice Boltzmann and the gas kinetic flux solvers (LBFS or GKFS). LBFS and GKFS combine advantages of both Navier-Stokes (N-S) solvers and kinetic solvers.Detailed derivations, evaluations and applications of LBFS and GKFS, and their advantages over conventional flux reconstruction strategies are analyzed and discussed in the volume.The must-have reference text is useful for scholars, researchers, professionals and students who are keen in CFD methods and numerical simulations.