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Applications of the Lattice Boltzmann Method to Complex and Turbulent Flows

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High Performance Computing and Applications Oxford University Press
Nature continuously presents a huge number of complex and multi-scale phenomena, which in many cases, involve the presence of one or more fluids flowing, merging and evolving around us. Since its appearance on the surface of Earth, Mankind has tried to exploit and tame fluids for their purposes, probably starting with Hero's machinery to open the doors of the Temple of Serapis in Alexandria to arrive to modern propulsion systems and actuators. Today we know that fluid mechanics lies at the basis of countless scientific and technical applications from the smallest physical scales (nanofluidics, bacterial motility, and diffusive flows in porous media), to the largest (from energy production in power plants to oceanography and meteorology). It is essential to deepen the understanding of fluid behaviour across scales for the progress of Mankind and for a more sustainable and efficient future. Since the very first years of the Third Millennium, the Lattice Boltzmann Method (LBM) has seen an exponential growth of applications, especially in the fields connected with the simulation of complex and soft matter flows. LBM, in fact, has shown a remarkable versatility in different fields of applications from nanoactive materials, free surface flows, and multiphase and reactive flows to the simulation of the processes inside engines and fluid machinery. LBM is based on an optimized formulation of Boltzmann's Kinetic Equation, which allows for the simulation of fluid particles, or rather quasi-particles, from a mesoscopic point of view thus allowing the inclusion of more fundamental physical interactions in respect to the standard schemes adopted with Navier-Stokes solvers, based on the continuum assumption. In this book, the authors present the most recent advances of the application of the LBM to complex flow phenomena of scientific and technical interest with particular focus on the multi-scale modeling of heterogeneous catalysis within nano-porous media and multiphase, multicomponent flows.
Lattice Boltzmann Method Bentham Science Publishers
Certain forms of the Boltzmann equation, have emerged, which relinquish most mathematical complexities of the true Boltzmann equation. This text provides a detailed survey of Lattice Boltzmann equation theory and its major applications.
Accelerated Lattice Boltzmann Model for Colloidal Suspensions Springer Science & Business Media
In this dissertation, we explore direct-forcing immersed boundary methods (IBM) under the framework of the lattice Boltzmann method (LBM), which is called the direct-forcing immersed boundary-lattice Boltzmann method (IB-LBM). First, we derive the direct-forcing formula based on the split-forcing lattice Boltzmann equation, which recovers the Navier-Stokes equation with second-order accuracy and enables us to develop a simple and accurate formula due to its kinetic nature. Then, we assess the various interface schemes under the derived direct-forcing formula. We consider not only diffuse interface schemes but also a sharp interface scheme. All tested schemes show a second-order overall accuracy. In the simulation of stationary complex boundary flows, we can observe that the sharper the interface scheme is, the more accurate the results are. The interface schemes are also applied to moving boundary problems. The sharp interface scheme shows better accuracy than the diffuse interface schemes but generates spurious oscillation in the boundary forcing terms due to the discontinuous change of nodes for the interpolation. In contrast, the diffuse interface schemes show smooth change in the boundary forcing terms but less accurate results because of discrete delta functions. Hence, the diffuse interface scheme with a corrected radius can be adopted to obtain both accurate and smooth results. Finally, a direct-forcing immersed boundary method (IBM) for the thermal lattice Boltzmann method (TLBM) is proposed to simulate non-isothermal flows. The direct-forcing IBM formulas for thermal equations are derived based on two TLBM models: a double-population model with a simplified thermal lattice Boltzmann equation (Model 1) and a hybrid model with an advection-diffusion equation of temperature (Model 2). The proposed methods are validated through natural convection problems with stationary and moving boundaries. In terms of accuracy, the results obtained from the IBMs based on both models are comparable and show a good agreement with those from other numerical methods. In contrast, the IBM based on Model 2 is more numerically efficient than the IBM based on Model 1. Overall, this study serves to establish the feasibility of the direct-forcing IB-LBM as a viable tool for computing various complex and/or moving boundary flow problems.
Numerical Prediction of Jet Noise Using Compressible Lattice Boltzmann Method IGI Global
This book introduces readers to 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, together with applications and examples, and complete computer codes accompany the sections on single and multi-relaxation-time methods. The codes are written in MatLab. However, the codes are written in a way that can be easily converted to other languages, such as FORTRANm Python, Julia, etc. The codes can also be extended with little effort to multi-phase and multi-physics, provided the physics of the respective problem are known. The second edition of this book adds new chapters, and includes new theory and applications. It discusses a wealth of practical examples, and explains LBM in connection with various engineering topics, especially the transport of mass, momentum, energy and molecular species. This book offers a useful and easy-to-follow guide for readers with some prior experience with advanced mathematics and physics, and will be of interest to all researchers and other readers who wish to learn how to apply LBM to engineering and industrial problems. It can also be used as a textbook for advanced undergraduate or graduate courses on computational transport phenomena
Lattice Boltzmann Modeling World Scientific
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.
Immersed Boundary Methods in the Lattice Boltzmann Equation for Flow Simulation John Wiley & Sons
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 Method and Its Applications in Engineering Lattice Boltzmann Method and Its Applications in EngineeringWorld Scientific
An Introduction for Geoscientists and Engineers World Scientific
The book introduces the fundamentals and applications of the lattice Boltzmann method (LBM) for incompressible viscous flows. It is written clearly and easy to understand for graduate students and researchers.The book is organized as follows. In Chapter 1, the SRT- and MRT-LBM schemes are derived from the discrete Boltzmann equation for lattice gases and the relation between the LBM and the Navier-Stokes equation is explained by using the asymptotic expansion (not the Chapman-Enskog expansion). Chapter 2 presents the lattice kinetic scheme (LKS) which is an extension method of the LBM and can save memory because of needlessness for storing the velocity distribution functions. In addition, an improved LKS which can stably simulate high Reynolds number flows is presented. In Chapter 3, the LBM combined with the immersed boundary method (IB-LBM) is presented. The IB-LBM is well suitable for moving boundary flows. In Chapter 4, the two-phase LBM is explained from the point of view of the difficulty in computing two-phase flows with large density ratio. Then, a two-phase LBM for large density ratios is presented. In Appendix, sample codes (available for download) are given for users.
The Lattice Boltzmann Equation: for Complex States of Flowing Matter World Scientific
Lattice Boltzmann method (LBM) is a relatively new simulation technique for the modeling of complex fluid systems and has attracted interest from researchers in computational physics. Unlike the traditional CFD methods, which solve the conservation equations of macroscopic properties (i.e., mass, momentum, and energy) numerically, LBM models the fluid consisting of fictive particles, and such particles perform consecutive propagation and collision processes over a discrete lattice mesh.This book will cover the fundamental and practical application of LBM. The first part of the book consists of three chapters starting form the theory of LBM, basic models, initial and boundary conditions, theoretical analysis, to improved models. The second part of the book consists of six chapters, address applications of LBM in various aspects of computational fluid dynamic engineering, covering areas, such as thermo-hydrodynamics, compressible flows, multicomponent/multiphase flows, microscale flows, flows in porous media, turbulent flows, and suspensions.With these coverage LBM, the book intended to promote its applications, instead of the traditional computational fluid dynamic method.
Theory and Application Springer Science & Business Media
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 Method for Fluid Flow Springer
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 Coupled Bonded Particle and Lattice Boltzmann Method with Its Application to Geomechanics Independently Published
The Lattice Boltzmann Method (LBM) is a powerful technique for the computation of a wide variety of complex fluid flow problems including single and multiphase fluids in complex geometries. Historically, the Lattice Boltzmann equation for modeling hydrodynamics originated from the lattice gas cellular automata (LGCA), which are discrete models based on particles that move on a lattice. The LBM is different from traditional computational fluid dynamics (CFD) approaches, which solve the Navier-Stokes equations numerically. The LBM models the fluid with particle distributions, and assumes that these particles perform collision and steaming processes on a discrete lattice mesh. During the last decade, the LBM has been receiving increased attention. Great improvements have occurred not only in theoretical understanding but also in algorithmic development, and the method has been used more widely in computational fluid dynamics. The LBM are explicit time-integration approaches which are based on the Lattice Boltzmann Equation (LBE). They are notoriously inefficient for steady-state simulations or time-dependent problems which have large separations in relevant time and spatial scales. To solve this problem, a time-implicit multigrid LBE scheme is developed in this work. This scheme can solve the time dependent LBE problem more efficiently by using unconditionally large time step sizes. The improved efficiency and temporal accuracy of this implicit multigrid LBE scheme are demonstrated by numerical experiments and comparisons with the original explicit LBE approach.
Theory of the Lattice Boltzmann Method: Lattice Boltzmann Models for Non-ideal Gases Co-Published with World Scientific
In the last few years, a rapid development in the method known as the Lattice Boltzmann Method (LBM) has been achieved. It demonstrated its ability to simulate hydrodynamic systems, multiphase and multicomponent fluids. The main advantages of the LBM are the parallelism of the method, the simplicity of programming and the capability of incorporating model interactions. The use of the LBM to understand the flow structure inside the Gas Diffusion Layer (GDL) of a fuel cell is a particular active topic, motivated by the need of finding alternative energy conversion devices. In the present work we developed a rigorous initial base of a flow solver based on the LBM, the BGK model is used to approximate the collision term in the Boltzmann equation. We used the bounce back scheme to simulate the boundary conditions and the flow solver is validated against three benchmarking cases. The process of applying the boundary conditions was automated to handle complicated flow structures. We simulated the flow in a 2D structure surface extracted from a 3D reconstructed GDL, using both non-parallel and parallel code. The results for a single phase flow show the flow structure expected, the convergence of the parallel code is faster and its parallelism is easier comparing to the traditional Navier-Stokes solver.
Lattice Boltzmann Method for 3-D Flows with Curved Boundary Oxford University Press
Colloids are ubiquitous in the food, medical, cosmetics, polymers, water purification, and pharmaceutical industries. The thermal, mechanical, and storage properties of colloids are highly dependent on their interface morphology and their rheological behavior. Numerical methods provide a convenient and reliable tool for the study of colloids. Accelerated Lattice Boltzmann Model for Colloidal Suspensions introduce the main building-blocks for an improved lattice Boltzmann–based numerical tool designed for the study of colloidal rheology and interface morphology. This book also covers the migrating multi-block used to simulate single component, multi-component, multiphase, and single component multiphase flows and their validation by experimental, numerical, and analytical solutions. Among other topics discussed are the hybrid lattice Boltzmann method (LBM) for surfactant-covered droplets; biological suspensions such as blood; used in conjunction with the suppression of coalescence for investigating the rheology of colloids and microvasculature blood flow. The presented LBM model provides a flexible numerical platform consisting of various modules that could be used separately or in combination for the study of a variety of colloids and biological flow deformation problems.
Lattice Boltzmann Method Springer Science & Business Media
An introductory textbook to Lattice Boltzmann methods in computational fluid dynamics, aimed at a broad audience of scientists working with flowing matter. LB has known a burgeoning growth of applications, especially in connection with the simulation of complex flows, and also on the methodological side.
Rheology and Interface Morphology John Wiley & Sons
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.
Springer
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.
Applications of the Lattice Boltzmann Method to Complex and Turbulent Flows World Scientific
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.
Special Issue Morgan & Claypool Publishers
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.
Multiphase Lattice Boltzmann Methods Springer Science & Business Media
The book introduces the fundamentals and applications of the lattice Boltzmann method (LBM) for incompressible viscous flows. It is written clearly and easy to understand for graduate students and researchers.The book is organized as follows. In Chapter 1, the SRT- and MRT-LBM schemes are derived from the discrete Boltzmann equation for lattice gases and the relation between the LBM and the Navier-Stokes equation is explained by using the asymptotic expansion (not the Chapman-Enskog expansion). Chapter 2 presents the lattice kinetic scheme (LKS) which is an extension method of the LBM and can save memory because of needlessness for storing the velocity distribution functions. In addition, an improved LKS which can stably simulate high Reynolds number flows is presented. In Chapter 3, the LBM combined with the immersed boundary method (IB-LBM) is presented. The IB-LBM is well suitable for moving boundary flows. In Chapter 4, the two-phase LBM is explained from the point of view of the difficulty in computing two-phase flows with large density ratio. Then, a two-phase LBM for large density ratios is presented. In Appendix, sample codes (available for download) are given for users.