

Application Of Lattice Boltzmann Method Thermal Multiphase Fluid Dynamics

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

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.

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.

On the Lattice Boltzmann Method

Multiphase Lattice Boltzmann Methods

Application of the Lattice Boltzmann Method to Thermal Explosion Development

Development and Application of Lattice Boltzmann Method for Complex Axisymmetric Flows

Simplified And Highly Stable Lattice Boltzmann Method: Theory And Applications

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.

This book begins by introducing the reader to Lattice Boltzmann Method (LBM), covering the fundamental principles of the method, while also outlining the potential problems involved. It provides a detailed description to build the thermal multiphase LBM (TMLBM) which includes the effects of interfacial tension and its dependence on temperature by a hybrid scheme. It also describes how a nearest-neighbor molecular interaction force is introduced into LB equation to model the adhesive forces between the fluid and solid surface. Some example simulations, e.g., two-phase Rayleigh-Benard convection, vibration-induced thermal convection in a two-layer fluid system, micron-scale fluid droplet on a heterogeneous surface, are included. The method has a remarkable ability to simulate a rich of behaviors, including single- and multiphase with or without thermal problem, phase separation, buoyancy, and the interactions with solid surfaces. This book may be used as a reference for science and engineers, and a textbook for graduates in engineering sciences such as materials, mechanical, biomedical engineering.

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.

Analysis and Applications of Lattice Boltzmann Simulations

Fundamentals and Engineering Applications with Computer Codes

A Coupled Bonded Particle and Lattice Boltzmann Method with Its Application to Geomechanics

Application of Lattice Boltzmann Equation Method for Fluid Flow and Heat Transfer

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Application of the Lattice Boltzmann Method to Issues of Coolant Flows in Nuclear Power Reactors

We briefly review the method of the lattice Boltzmann equation (LBE). We show three-dimensional LBE simulation results for a non-spherical particle in Couette flow and 16 particles in sedimentation in fluid. We compare the LBE simulation of the three-dimensional homogeneous isotropic turbulence flow in a periodic cubic box of the size 128³ with the pseudo-spectral simulation, and find that the two results agree well with each other but the LBE method is more dissipative than pseudo-spectral method in small scales, as expected. Luo, Li-Shi and Qi, Dewei and Wang, Lian-Ping and Bushnell, Dennis M. (Technical Monitor) Langley Research Center NASA/CR-2002-211659, NAS 1.26:211659, ICASE-2002-19

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.

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 solutions 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.

An Introduction for Geoscientists and Engineers

Principles and Practice

High Performance Computing and Applications

Application of Lattice Boltzmann Method in Electrodynamics with Adaptive Mesh Refinement

Theory and Application

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. 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.

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.

Application of the Lattice-Boltzmann Method to Multiphase Flows

Special Issue

Application of the Lattice Boltzmann Method for Analysing the Detachment of Micro-sized Drug Particles from a Carrier Particle

Lattice Boltzmann And Gas Kinetic Flux Solvers: Theory And Applications

The Lattice Boltzmann Methods and Their Applications to Fluid Flows

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. Lattice Boltzmann Method And Its Application In EngineeringWorld Scientific

In the past years, the Lattice Boltzmann Method (LBM) has been widely used by the scientific community as an alternative to the conventional numerical solvers for the Navier-Stokes (NS) equations. The present work in this thesis aims at studying the LBM for fluid dynamics. The main topics are concentrated in three aspects: the description of the model, the validation of this model, and the application of this model to an engineering case. In the first part the model is defined. Therefore, the Boltzmann equation and the Boltzmann distribution are defined. Also, the explanation of the framework where this method works is included. Then, the BGK-Approximation and the discretization of the Boltzmann equation are introduced. The algorithm needed to apply the model will also be explained together with numerical stability issues that one must take into account when it is

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implemented. An explanation of the different boundary conditions will also be summarized. In chapter 3 the LBM will be applied to different 3D cases to test its accuracy and validate the model. The Poiseuille and Couette flow will be studied and compared analytically. Lid driven cavity and the flow around an obstacle will also be simulated. In chapter 4, after the model has been validated, the LBM is used to simulate a complex situation to simulate the flow pattern in a lower plenum of a PWR reactor core, taking into account several simplifications, to understand the possibilities of the LBM implemented. To be able to perform chapter 3 and 4 an implementation in C++ has been developed.

Theory and Applications of the Lattice Boltzmann Method

The Lattice Boltzmann Equation

Lattice Boltzmann Method And Its Application In Engineering

The Finite-difference Lattice Boltzmann Method and Its Application in Computational Aero-acoustics

Recent Advances in Lattice Boltzmann Methods

Introducing the Lattice Boltzmann Method in a readable manner, this book provides detailed examples with complete computer codes. It avoids the most complicated mathematics and physics without sacrificing the basic fundamentals of the method.

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 from 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.

This book constitutes the thoroughly refereed post-conference proceedings of the Second International Conference on High Performance Computing and Applications, HPCA 2009, held in Shangahi, China, in August 2009. The 71 revised papers presented together with 10 invited presentations were carefully selected from 324 submissions. The papers cover topics such as numerical algorithms and solutions; high performance and grid computing; novel approaches to high performance computing; massive data storage and processing; and hardware acceleration.

Lattice Boltzmann Modeling

Lattice-Gas Cellular Automata and Lattice Boltzmann Models

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

Application of Lattice Boltzmann Method

In this paper, the authors briefly present the basic principles of lattice Boltzmann method and summarize recent advances of the method, including the application of the lattice Boltzmann method for fluid flows in MEMS and simulation of the multiphase mixing and turbulence.

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.

The lattice Boltzmann method (LBM) is a modern numerical technique, very efficient, flexible to simulate different flows within complex/varying geometries. 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 microscopic picture of particles movement in an extremely simplified way, and on the macroscopic level it gives a correct average description of a fluid. The averaged 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.

Second International Conference, HPCA 2009, Shanghai, China, August 10-12, 2009, Revised Selected Papers

Implementation and Applications

Theories and Applications

Thermal Multiphase Fluid Dynamics

An Introduction

This book is an introduction to the theory, practice, and implementation of the Lattice Boltzmann (LB) method, a powerful computational fluid dynamics method that is steadily gaining attention due to its simplicity, scalability, extensibility, and simple handling of complex geometries. The book contains chapters on the method's background, fundamental theory, advanced extensions, and implementation. To aid beginners, the most essential paragraphs in each chapter are highlighted, and the introductory chapters on various LB topics are front-loaded with special "in a nutshell" sections that condense the chapter's most important practical results.

Together, these sections can be used to quickly get up and running with the method. Exercises are integrated throughout the text, and frequently asked questions about the method are dealt with in a special section at the beginning. In the book itself and through its web page, readers can find example codes showing how the LB method can be implemented efficiently on a variety of hardware platforms, including multi-core processors, clusters, and graphics processing units. Students and scientists learning and using the LB method will appreciate the wealth of clearly presented and structured information in this volume.

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. 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.

*Applications of the Lattice Boltzmann Method to Model Fluid Flow in Microchannels
Lattice Boltzmann Modeling of Complex Flows for Engineering Applications*

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Application of Lattice Boltzmann Method in Fluid Flow and Heat Transfer

Lattice Boltzmann Method and Its Applications in Engineering

Application and Assessment of the Lattice Boltzmann Method for Fluid Flow Modeling in Porous Rocks

The history of the Lattice Boltzmann Method and its application to fluid mechanics are investigated here. Detailed formulations are provided to form a basis for the Lattice Boltzmann Method and its many variations. These variations are designed to overcome shortcomings in the standard single relaxation time Lattice Boltzmann model. Presented here are: a model that utilizes the non-equilibrium parts of the stress tensor, the Regularized Lattice Boltzmann model; a model that converts over to momentum space, the Multi-Relaxation Time Lattice Boltzmann model; and a model that corrects itself using the entropy equation, the entropic Lattice Boltzmann model. Extensions for the Lattice Boltzmann method are derived that include: external forces, multiphase flows, and thermal flows. Various types of boundary conditions are modeled using different approaches. A detailed explanation on extracting common macroscopic flow properties in physical units is provided. These extracted properties can be used to check temporal and spatial convergence. A two dimensional, nine velocity model and a three dimensional, fifteen velocity model are used to provide examples of a number of the approaches mentioned. A two dimensional and three dimensional lid-driven cavity flow is used to illustrate these methods.

The Lattice Boltzmann Method

The Lattice Boltzmann Equation: For Complex States of Flowing Matter

Lattice Boltzmann Method in Scientific and Engineering Applications

Application of the Lattice-Boltzmann Method to Study Flow and Dispersion in Channels with and Without Expansion and Contraction Geometry

Applications of the Lattice Boltzmann Method to Complex and Turbulent Flows