The Lattice Boltzmann Equation For Fluid Dynamics And Beyond Numerical Mathematics And Scientific Computation By Succi Sauro 2013 Paperback

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Lattice Boltzmann Method - A. A. Mohamad 2019-05-07

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 Method for Fluid Flow - Amine Abdellah-El-Hadj 2014

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.

Discrete Models of Fluid

Dynamics - A S Alves 1991-04-30 Recent developments of discrete methods of fluid dynamics, particularly the two most relevant aspects: the “half” discrete case — discrete Boltzmann equation; and the “totally” discrete one — lattice gas were discussed. Both the conceptual and numerical significance of these discrete models were covered as well as the mathematical problems which arise from them. This Colloquium is the third of a series initiated in Santa Fe (USA 1986) the second having taken place in Torino (Italy 1988). Contents: A Class of Lattice Gas Automata for Ginzburg-Landau Type Equations (J P Boon & D Dab)Temperature and Heat Conductivity in Cellular Automata Fluids (M H Ernst)On the Decomposition of Domains in Non-Linear Discrete Kinetic Theory (L Preziosi & E Longo)Macroscopic Variables in Discrete Kinetic Theory (Ph Chauvat & R Gatignol)The Trend to Equilibrium in Discrete and Continuous Kinetic Theory: A Comparison (C Cercignani)Lattice Gas Simulations of One and Two-Phase Fluid Flows Using the Connection Machine-2 (S Chen et al.)The Discrete Boltzmann Equation for Gases with Bi-Molecular Chemical Reactions (E Gabetta & R Monaco)Asymptotic Behavior of Solutions to the Discrete Boltzmann Equation (S Kawashima)Some Rigorous Results on Phase Segregation for Stochastic Cellular Automata (E Orlandi & E Presutti)On a Boundary Value Problem for the Carleman Model of the Boltzmann Equation (T Platkowski)Full Time Dependence of the VACF in CA-Fluids: Theory and Simulations (T Naitoh & M H Ernst)Simulation of River-Discharge Fronts with Lattice Gas Automata (Ch F Kougias et al.)and other papers Readership:

Applied mathematicians.

The Lattice Boltzmann Method - Timm Krüger 2016-11-07

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 Dynamics - Jeffrey Yepez 1995

The theory and computation of lattice gas dynamics for viscous fluid hydrodynamics is presented. Theoretical analysis of these exactly conserved, discrete models is done using the Boltzmann approximation, a mean-field theoretical treatment. Theoretical results are then compared to numerical data arrived by exactly computed simulations of simple lattice-gas systems. The numerical simulations presented were carried out on a prototype lattice-gas machine, the CAM-8, which is a virtual finegrained paralled mesh architecture suitable for discrete modeling in arbitrary dimensions. Single speed and multi-speed lattice gases are treated. The new contribution is an integer lattice gas with many particles per momentum state. Comparisons are made between the mean-field theory and numerical experiments for shear viscosity transport coefficient.

Progress in Computational Physics Volume 3: Novel Trends in Lattice-Boltzmann Methods - Matthias Ehrhardt 2013-06-18

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.

Development of a Prototype Lattice Boltzmann Code for CFD of Fusion Systems - 2007

Designs of proposed fusion reactors, such as the ITER project, typically involve the use of liquid metals as coolants in components such as heat exchangers, which are generally subjected to strong magnetic fields. These fields induce electric currents in the fluids, resulting in magnetohydrodynamic (MHD) forces which have important effects on the flow. The objective of this SBIR project was to develop computational techniques based on recently developed lattice Boltzmann techniques for the simulation of these MHD flows and implement them in a computational fluid dynamics (CFD) code for the study of fluid flow systems encountered in fusion engineering. The code developed during this project, solves the lattice Boltzmann equation, which is a kinetic equation whose behaviour represents fluid motion. This is in contrast to most CFD codes which are based on finite difference/finite volume based solvers. The lattice Boltzmann method (LBM) is a relatively new approach which has a number of advantages compared with more conventional methods such as the SIMPLE or projection method algorithms that involve direct solution of the Navier-Stokes equations. These are that the LBM is very well suited to parallel processing, with almost linear scaling even for very large numbers of processors. Unlike other methods, the LBM does not require solution of a Poisson pressure equation leading to a relatively fast execution time. A particularly attractive property of the LBM is that it can handle flows in complex geometries very easily. It can use simple rectangular grids throughout the computational domain -- generation of a body-fitted grid is not required. A recent advance in the LBM is the introduction of the multiple relaxation time (MRT) model; the implementation of this model greatly enhanced the numerical stability when used in lieu of the single relaxation time model, with only a small increase in computer time. Parallel processing was implemented using MPI and demonstrated the ability of the LBM to scale almost linearly. The equation for magnetic induction was also solved using a lattice Boltzmann method. This approach has the advantage that it fits in well to the framework used for the hydrodynamic equations, but more importantly that it preserves the ability of the code to run efficiently on parallel architectures. Since the LBM is a relatively recent model, a number of new developments were needed to solve the magnetic induction equation for practical problems. Existing methods were only suitable for cases where the fluid viscosity and the magnetic resistivity are of the same order, and a preconditioning method was used to allow the simulation of liquid metals, where these properties differ by several orders of magnitude. An extension of this method to the hydrodynamic equations allowed faster convergence to steady state. A new method of imposing boundary conditions using an extrapolation technique was derived, enabling the magnetic field at a boundary to be specified. Also, a technique by which the grid can be stretched was formulated to resolve thin layers at high imposed magnetic fields, allowing flows with Hartmann numbers of several thousand to be quickly and efficiently simulated. In addition, a module has been developed to calculate the temperature field and heat transfer. This uses a total variation diminishing scheme to solve the equations and is again very amenable to parallelisation. Although, the module was developed with thermal modelling in mind, it can also be applied to passive scalar transport. The code is fully three dimensional and has been applied to a wide variety of cases, including both laminar and turbulent flows. Validations against a series of canonical problems involving both MHD effects and turbulence have clearly demonstrated the ability of the LBM to properly model these types of flow. As well as applications to fusion engineering, the resulting code is flexible enough to be applied to a wide range of oth ...

Lattice Boltzmann Modeling - Michael C. Sukop 2007-04-05 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.

The Lattice Boltzmann Equation

- Sauro Succi 2018

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.

Lattice Boltzmann Simulations of Environmental Flow Problems in Shallow Water Flows - Yong Peng 2012

The lattice Boltzmann method (LBM) proposed about decades ago has been developed and applied to simulate various complex fluids. It has become an alternative powerful method for computational fluid dynamics (CFD). Although most research on the LBM focuses on the Navier-Stokes equations, the method has also been developed to solve other flow equations such as the shallow water equations. In this thesis, the lattice Boltzmann models for the shallow water equations and solute transport equation have been improved and applied to different flows and environmental problems, including solute transport and morphological evolution. In this work, both the single-relaxation-time and multiple-relaxation-time models are used for shallow water equations (named LABSWE and LABSWEMRT, respectively), and the large eddy simulation is incorporated into the LABSWE (named LABSWETM) for turbulent flow. The capability of the LABSWETM was firstly tested by applying it to simulate free surface flows in rectangular basins with different length - width ratios, in which the characteristics of the asymmetrical flows were studied in details. The LABSWEMRT was then used to simulate the one- and two-dimensional shallow water flows over discontinuous beds. The weighted centred scheme for force term, together with the bed height for a bed slope, was incorporated into the model to improve the simulation of water flows over a discontinuous bed. The resistance stress was also included to investigate the effect of the local head loss caused by flows over a step. Thirdly, the LABSWEMRT was extended to simulate a moving body in shallow water. In order to deal with the moving boundaries, three different schemes with second-order accuracy were tested and compared for treating curved boundaries. An additional momentum term was added to reflect the interaction between the following fluid and the solid, and a refilled method was proposed to treat the wetted nodes moving out from the solid nodes. Fourthly, both LABSWE and LABSWEMRT were used to investigate solute transport in shallow water. The flows are solved using LABSWE and LABSWEMRT, and the advection-diffusion equation for solute transport was solved with a LBM-BGK model based on the D2Q5 lattice. Three cases: open channel flow with a side discharge, shallow recirculation flow and flow in a harbour, were simulated to verify the methods. In addition, the performance of LABSWEMRT and LABSWE were compared, and the results showed that the LABSWMRT has better stability and can be used for flow with high Reynolds number. Finally, the lattice Boltzmann method was used with the Euler-WENO scheme to simulate morphological evolution in shallow water. The flow fields were solved by the LABSWEMRT with the improved scheme for the force term, and the fifth order Euler-WENO scheme was used to solve the morphological equation to predict the morphological evolution caused by the bed-load transport.

Lattice Boltzmann Method for 3-D Flows with Curved Boundary - Renwei Mei 2002

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.

Analysis of Lattice-Boltzmann Methods - Martin Rheinländer 2007

Doctoral Thesis / Dissertation from the year 2007 in the subject Mathematics - Analysis, University of Constance (Fachbereich Mathematik & Statistik), 69 entries in the bibliography, language: English, abstract: Lattice-Boltzmann algorithms represent a quite novel class of numerical schemes, which are used to solve evolutionary partial differential equations (PDEs). In contrast to other methods (FEM, FVM), lattice-Boltzmann methods rely on a mesoscopic approach. The idea consists in setting up an artificial, grid-based particle dynamics, which is chosen such that appropriate averages provide approximate solutions of a certain PDE, typically in the area of fluid dynamics. As lattice-Boltzmann schemes are closely related to finite velocity Boltzmann equations being singularly perturbed by special scalings, their consistency is not obvious. This work is concerned with the analysis of lattice-Boltzmann methods also focusing certain numeric phenomena like initial layers, multiple time scales and boundary layers. As major analytic tool, regular (Hilbert) expansions are employed to establish consistency. Exemplarily, two and three population algorithms are studied in one space dimension, mostly discretizing the advection-diffusion equation. It is shown how these model schemes can be derived from two-dimensional schemes in the case of special symmetries. The analysis of the schemes is preceded by an examination of the singular limit being characteristic of the corresponding scaled finite velocity Boltzmann equations. Convergence proofs are obtained using a Fourier series approach and alternatively a general regular expansion combined with an energy estimate. The appearance of initial layers is investigated by multiscale and irregular expansions. Among others, a hierarchy of equations is found which gives insight into the internal coupling of the initial layer and the regular part of the solution. Next, the consistency of the model algorithms is considered followed by

Direct Modeling for Computational Fluid Dynamics - Kun Xu 2014-12-23

Computational fluid dynamics (CFD) studies the flow motion in a discretized space. Its basic scale resolved is the mesh size and time step. The CFD algorithm can be constructed through a direct modeling of flow motion in such a space. This book presents the principle of direct modeling for the CFD algorithm development, and the construction unified gas-kinetic scheme (UGKS). The UGKS accurately captures the gas evolution from rarefied to continuum flows. Numerically it provides a continuous spectrum of governing equation in the whole flow regimes. Contents:Direct Modeling for Computational Fluid DynamicsIntroduction to Gas Kinetic TheoryIntroduction to Nonequilibrium Flow SimulationsGas Kinetic SchemeUnified Gas Kinetic SchemeLow Speed Microflow StudiesHigh Speed Flow StudiesUnified Gas Kinetic Scheme for Diatomic GasConclusion Readership: Undergraduate and graduate students, researchers and professionals interested in computational fluid dynamics. Key Features:Direct modeling for CFD is self-contained and unified in presentationIt may be used as an advanced textbook by graduate students and even ambitious undergraduates in computational fluid dynamicsIt is also suitable for experts in CFD who wish to have a new understanding of the fundamental problems in the subject and study alternative approaches in CFD algorithm development and applicationThe explanations in the book are detailed enough to capture the interest of the curious reader, and complete enough to provide the necessary background material needed to go further into the subject and explore the research literatureKeywords:Direct Modeling;Unified Gas Kinetic Scheme;Boltzmann Equation;Kinetic Collision Model;Asymptotic Preserving Method

Lattice Gas Methods - Gary D. Doolen 1991

This volume focuses on progress in applying the lattice gas approach to partial differential equations that arise in simulating the flow of fluids.Lattice gas methods are new parallel, high-resolution, high-efficiency techniques for solving partial differential equations. This volume focuses on progress in applying the lattice gas approach to partial differential equations that arise in simulating the flow of fluids. It introduces the lattice Boltzmann equation, a new direction in lattice gas research that considerably reduces fluctuations.The twenty-seven contributions explore the many available software options exploiting the fact that lattice gas methods are completely parallel, which produces significant gains in speed. Following an overview of work done in the past five years and a discussion of frontiers, the chapters describe viscosity modeling and hydrodynamic mode analyses, multiphase flows and porous media, reactions and diffusion, basic relations and long-time correlations, the lattice Boltzmann equation, computer hardware, and lattice gas applications.Gary D. Doolen is Acting Director of the Center for Nonlinear Studies at Los Alamos National Laboratory.

Lattice Boltzmann Modeling of Complex Flows for Engineering Applications - Andrea Montessori 2018-02-20

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.

Application of the Lattice Boltzmann Method to Issues of Coolant Flows in Nuclear Power Reactors - Adrià Carrasco Boix 2013

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 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.

Finite Difference of Thermal Lattice Boltzmann Scheme for the Simulation of Natural Convection Heat Transfer - Siti Aishah-Awanis Mohd Yusoff 2009

In this thesis, a method of lattice Boltzmann is introduced. Lattice Boltzmann method (LBM) is a class of computational fluid dynamics (CFD) methods for fluid simulation. Objective of this thesis is to develop finite difference lattice Boltzmann scheme for the natural convection heat transfer. Unlike conventional CFD methods, the lattice Boltzmann method is based on microscopic models and macroscopic kinetic equation. The lattice Boltzmann equation (LBE) method has been found to be particularly useful in application involving interfacial dynamics and complex boundaries. First, the general concept of the lattice Boltzmann method is introduced to understand concept of Navier-Strokes equation. The isothermal and thermal lattices Boltzmann equation has been directly derived from the Boltzmann equation by discretization in both time and phase space. Following from this concept, a few simple isothermal flow simulations which are Poiseulle flow and Couette flow were done to show the effectiveness of this method. Beside, numerical result of the simulations of Porous Couette flow and natural convection in a square cavity are presented in order to validate these new thermal models. Lastly, the discretization procedure of Lattice Boltzmann Equation (LBE) is demonstrated with finite difference technique. The temporal discretization is obtained by using second order Rungge-

Kutta (modified) Euler method from derivation of governing equation. The discussion and conclusion will be presented in chapter five.

The Lattice Boltzmann Equation - S. Succi 2018

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.

Lattice Boltzmann Method for 3-D Flows with Curved Boundary - National Aeronautics and Space Administration (NASA) 2018-06-19

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 athermal 3-D LBE models (D3QI5, D3Ql9, and D3Q27) are studied and compared in terms of efficiency, accuracy, and robustness. The boundary treatment recently developed by Filippova and Hanel and Met 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 (D3Ql5) model is more prone to numerical instability and the D3Q27 is more computationally intensive, the 63Q19 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. Mei, Renwei and Shyy, Wei and Yu, Dazhi and Luo, Li-Shi Langley Research Center NASA/CR-2002-211657, NAS 1.26:211657, ICASE-2002-17

Introduction To The Lattice Boltzmann Method, An: A Numerical Method For Complex Boundary And Moving Boundary Flows - Takaji Inamuro 2021-11-19

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.

Multiphase Lattice Boltzmann Methods - Haibo Huang 2015-06-08

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 - Liming Yang 2020-07-13

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.

Lattice Boltzmann Methods for Shallow Water Flows - Jian Guo Zhou 2013-03-14

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.

Numerical Investigation of the Cascaded Lattice Boltzmann Method - Yang Ning 2011

Lattice Boltzmann methods (LBM) are a class of computational fluid dynamics techniques based on kinetic theory. The method is characterized by a Lagrangian streaming step followed by a local collision step, with the specification of the latter having profound influence on its physical fidelity and numerical stability. More recently, a new formulation known as the Cascaded LBM has been developed, in which the collision process is performed in a local moving frame of reference. Moreover, different physical quantities characterized in terms of central moments relax at different rates during the collision step, which are designed in such a way as to recover the Navier-Stokes equations. This naturally enforces Galilean invariance, an important physical property of fluid flows, and is expected to enhance the numerical stability considerably. In the first part of this thesis, the numerical properties of a two-dimensional Cascaded LBM are investigated including accuracy, stability and convergence for a set of benchmark problems. Numerous fluid flow problems exist that can be characterized as axisymmetric in nature. In this thesis, a new cascaded LBM is developed in cylindrical coordinates, which would enable more efficient simulations. This axisymmetric Cascaded LBM is derived directly from the continuous Boltzmann equation rather than starting from the macroscopic hydrodynamic equations, i.e. in a bottom-up approach. As a result, it retains the advantages of kinetic theory, while inheriting the various properties of the Cascaded formulation. Meridional and azimuthal components are derived individually, which gives the ability to simulate flows dominated by either meridional or azimuthal velocity as desired. The new approach is validated for a set of axisymmetric benchmark problems.

Numerical Solution of Partial Differential Equations on Parallel Computers - Are Magnus Bruaset 2006-03-05

Since the dawn of computing, the quest for a better understanding of Nature has been a driving force for technological development. Groundbreaking achievements by great scientists have paved the way from the abacus to the supercomputing power of today. When trying to replicate Nature in the computer's silicon test tube, there is need for precise and computable process descriptions. The scienti?c ?elds of Ma- ematics and Physics provide a powerful vehicle for such descriptions in terms of Partial Differential Equations

(PDEs). Formulated as such equations, physical laws can become subject to computational and analytical studies. In the computational setting, the equations can be discreti ed for ef?cient solution on a computer, leading to valuable tools for simulation of natural and man-made processes. Numerical so-tion of PDE-based mathematical models has been an important research topic over centuries, and will remain so for centuries to come. In the context of computer-based simulations, the quality of the computed results is directly connected to the model's complexity and the number of data points used for the computations. Therefore, computational scientists tend to ?ll even the largest and most powerful computers they can get access to, either by increasing the si e of the data sets, or by introducing new model terms that make the simulations more realistic, or a combination of both. Today, many important simulation problems can not be solved by one single computer, but calls for parallel computing.

Analysis and Applications of Lattice Boltzmann Simulations - Valero-Lara, Pedro 2018-05-04

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 Applications in Engineering - Zhaoli Guo 2013

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.

Lattice Gas Methods For Partial Differential Equations - Gary Doolen 2019-03-01

Although the idea of using discrete methods for modeling partial differential equations occurred very early, the actual statement that cellular automata techniques can approximate the solutions of hydrodynamic partial differential equations was first discovered by Frisch, Hasslacher, and Pomeau. Their description of the derivation, which assumes the validity of the Boltzmann equation, appeared in the Physical Review Letters in April 1986. It is the intent of this book to provide some overview of the directions that lattice gas research has taken from 1986 to early 1989.

Development of an Innovative Algorithm for Aerodynamics-Structure Interaction Using Lattice Boltzmann Method - National Aeronautics and Space Administration (NASA) 2018-06-15

The lattice Boltzmann equation (LBE) is a kinetic formulation which offers an alternative computational method capable of solving fluid dynamics 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 the algorithm is natural to parallelize. In this final report, we summarize the works accomplished in the past three years. Since most works have been published, the technical details can be found in the literature. Brief summary will be provided in this report. In this project, a second-order accurate treatment of boundary condition in the LBE method is developed for a curved boundary and tested successfully in various 2-D and 3-D configurations. To evaluate the aerodynamic force on a body in the context of LBE method, several force evaluation schemes have been investigated. A simple momentum exchange method is shown to give reliable and accurate values for the force on a body in both 2-D and 3-D cases. Various 3-D LBE models have been assessed in terms of efficiency, accuracy, and robustness. In general, accurate 3-D results can be obtained using LBE methods. The 3-D 19-bit model is found to be the best one among the 15-bit, 19-bit, and 27-bit LBE models. To achieve desired grid resolution and to accommodate the far field boundary conditions in aerodynamics computations, a multi-block LBE method is developed by dividing the flow field into various blocks each having constant lattice spacing. Substantial contribution to the LBE method is also made through the development of a new, generalized lattice Boltzmann equation constructed in the moment space in order to improve the computational stability, detailed theoretical analysis on the stability, dispersion, and dissipation characteristics of the LBE method, and computational studies of high Reynolds number flows with singular gradients. Finally, a finite difference-based lattice Boltzmann method is developed

Introduction to the Lattice Boltzmann Method, An: A Numerical Method for Complex Boundary and Moving Boundary Flows - Takaji Inamuro 2021-12-23

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 - Sauro Succi 2001-06-28

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.

Application of Lattice Boltzmann

Equation Method for Fluid Flow and Heat Transfer - Quan Liao 2008

Lattice-Gas Cellular Automata and Lattice Boltzmann Models - Dieter A. Wolf-Gladrow 2004-10-20

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.

Lattice Boltzmann Simulation to Study Single and Multi Bubble Dynamics - Amit Gupta 2007

In recent years, the lattice Boltzmann method (LBM) has emerged as a powerful tool that has replaced conventional macroscopic techniques like Computational Fluid Dynamics (CFD) in many applications. The LBM starts from meso- and microscopic Boltzmann's kinetic equation to determine macroscopic fluid dynamics. The origins of LBM can be drawn back to lattice gas cellular automata (LGCA); however it lacks Galilean invariance and creates statistical noise in the system. LBM on the other hand does away from these drawbacks of LGCA, and is easy to implement in complex geometries and can be used to study microscopic flow behavior in complex fluids/fluid mixtures. In this work, the LBM is used as a tool to study isothermal bubble dynamics of single and multiple bubbles in heavier fluids. Some benchmark problems have been solved to prove the effectiveness of LBM over conventional solvers and results have been compared to analytical/existing solutions. Flow behavior at different flow parameters have been recorded and presented. Bubble shape regimes have been classified based on the important two-phase flow parameters, namely the Eotvos number, Morton number, Reynolds number and the Weber number.

Numerical Methods for the Simulation of Multi-phase and Complex Flow - T. M. M. Verheggen 1992

The nine review articles contained here introduce the techniques required touse lattice gas methods for numerical simulations of complex flows. Furthermore, lattice Boltzmann models are studied together with classical numerical techniques. The editors have written an extensive introductionto this exciting new approach to solving practical problems in modelling andsimulating flows. The book addresses numerical analysts and engineers in fluid mechanics, but also graduate students.

Computational Fluid Dynamics - Oleg Minin 2011-07-05

This book is planned to publish with an objective to provide a state-of-art reference book in the area of computational fluid dynamics for CFD engineers, scientists, applied physicists and post-graduate students. Also the aim of the book is the continuous and timely dissemination of new and innovative CFD research and developments. This reference book is a collection of 14 chapters characterized in 4 parts: modern principles of CFD, CFD in physics, industrial and in castle. This book provides a comprehensive overview of the computational experiment technology, numerical simulation of the hydrodynamics and heat transfer processes in a two dimensional gas, application of lattice Boltzmann method in heat transfer and fluid flow, etc. Several interesting applications area are also discusses in the book like underwater vehicle propeller, the flow behavior in gas-cooled nuclear reactors, simulation odour dispersion around windbreaks and so on.

Lattice Boltzmann Method - A. A. Mohamad 2011-06-27

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.

Simplified And Highly Stable Lattice Boltzmann Method: Theory And Applications - Zhen Chen 2020-09-15

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.

Time-implicit Solution of the Lattice Boltzmann Equation - Jing Liu 2008

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.

Multiscale and Multiphysics Flow Simulations of Using the Boltzmann Equation - Jun Li 2019-08-28

This book provides a comprehensive introduction to the kinetic theory for describing flow problems from molecular scale, hydrodynamic scale, to Darcy scale. The author presents various numerical algorithms to solve the same Boltzmann-like equation for different applications of different scales, in which the dominant transport mechanisms may differ. This book presents a concise introduction to the Boltzmann equation of the kinetic theory, based on which different simulation methods that were independently developed for solving problems of different fields can be naturally related to each other. Then, the advantages and disadvantages of different methods will be discussed with reference to each other. It mainly covers four advanced simulation methods based on the Boltzmann equation (i.e., direct simulation Monte Carlo method, direct simulation BGK method, discrete velocity method, and lattice Boltzmann method) and their applications with detailed results. In particular, many simulations are included to demonstrate the applications for both conventional and unconventional reservoirs. With the development of high-resolution CT and high-performance computing facilities, the study of digital rock physics is becoming increasingly important for understanding the mechanisms of enhanced oil and gas recovery. The advanced methods presented here have broad applications in petroleum engineering as well as mechanical engineering , making them of interest to researchers, professionals, and graduate students alike. At the same time, instructors can use the codes at the end of the book to help their students implement the advanced technology in solving real industrial problems.