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

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

The generalized hydrodynamics (the wave vector dependence of the transport coefficients) of a generalized lattice Boltzmann equation (LBE) is studied in detail. The generalized lattice Boltzmann equation is constructed in moment space rather than in discrete velocity space. The generalized hydrodynamics of the model is obtained by solving the dispersion equation of the linearized LBE either analytically by using perturbation technique or numerically. The proposed LBE model has a maximum number of adjustable parameters for the given set of discrete velocities. Generalized hydrodynamics characterizes dispersion, dissipation (hyper-viscosities), anisotropy, and lack of Galilean invariance of the model, and can be applied to select the values of the adjustable parameters which optimize the properties of the model. The proposed generalized hydrodynamic analysis also provides some insights into stability and proper initial conditions for LBE simulations. The stability properties of some 2D LBE models are analyzed and compared with each other in the parameter space of the mean streaming velocity and the viscous relaxation time. The procedure described in this work can be applied to analyze other LBE models. As examples, LBE models with various interpolation schemes are analyzed. Numerical results on shear flow with an initially discontinuous velocity profile (shock) with or without a constant streaming velocity are shown to demonstrate the dispersion effects in the LBE model; the results compare favorably with our theoretical analysis. We also show that whereas linear analysis of the LBE evolution operator is equivalent to Chapman-Enskog analysis in the long wave-length limit (wave vector $k = 0$), it can also provide results for large values of k. Such results are important for the stability and other hydrodynamic properties of the LBE method and cannot be obtained through Chapman-Enskog analysis.Lallemand, Pierre and Luo, Li-ShiLangley Research CenterBOLTZMANN TRANSPORT EQ

This open access book, published in the Soft and Biological Matter series, presents an introduction to selected research topics in the broad field of flowing matter, including the dynamics of fluids with a complex internal structure -from nematic fluids to soft glasses- as well as active matter and turbulent phenomena. Flowing matter is a subject at the crossroads between physics, mathematics, chemistry, engineering, biology and earth sciences, and relies on a multidisciplinary approach to describe the emergence of the macroscopic behaviours in a system from the coordinated dynamics of its microscopic constituents. Depending on the microscopic interactions, an assembly of molecules or of mesoscopic particles can flow like a simple Newtonian fluid, deform elastically like a solid or behave in a complex manner. When the internal constituents are active, as for biological entities, one generally observes complex large-scale collective motions. Phenomenology is further complicated by the invariable tendency of fluids to display chaos at the large scales or when stirred strongly enough. This volume presents several research topics that address these phenomena encompassing the traditional micro-, meso-, and macro-scales descriptions, and contributes to our understanding of the fundamentals of flowing matter. This book is the legacy of the COST Action MP1305 “Flowing Matter”.

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.

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.

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

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.

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.

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

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.

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.

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.

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.

The Reviews in Computational Chemistry series brings together leading authorities in the field to teach the newcomer and update the expert on topics centered on molecular modeling, such as computer-assisted molecular design (CAMD), quantum chemistry, molecular mechanics and dynamics, and quantitative structure-activity relationships (QSAR). This volume, like those prior to it, features chapters by experts in various fields of computational chemistry. Topics in Volume 31 include: Lattice-Boltzmann Modeling of Multicomponent Systems: An Introduction Modeling Mechanochemistry from First Principles Mapping Energy Transport Networks in Proteins The Role of Computations in

Catalysis The Construction of Ab Initio Based Potential Energy Surfaces Uncertainty Quantification for Molecular Dynamics

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 processsing; and hardware acceleration.

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.

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.

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

The first detailed survey of the Lattice Boltzmann Equation theory and its major applications to date. This book is accessible to a range of scientists dealing with complex system dynamics, the book also portrays future developments in allied areas of science (material science, biology etc.) where fluid motion plays a distinguished role.

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.

We construct a multi-relaxation lattice Boltzmann model on a two-dimensional rectangular grid. The model is partly inspired by a previous work of Koelman to construct a lattice BGK model on a two-dimensional rectangular grid. The linearized disperson equation is analyzed to obtain the constraints on the isotropy of the transport coefficients and Galilean in variance for various wave propagations in the model. The linear stability of the model is also studied. The model is numerically tested for three cases: (a) a vortex moving with a constant velocity on a mesh periodic boundary conditions: (b) Poiseuille flow with an arbitrary inclined angle with respect to the lattice orientation; and (c) a cylinder asymmetrically placed in a channel. The numerical results of these tests are compared with either analytic solutions or the results obtained by other methods. Satisfactory results are obtained for the numerical simulations.

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

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.

The Lattice Boltzmann equation (LBE) was used to perform direct numerical simulations (DNS) and large-eddy simulations (LES) of benchmark problems in turbulence, scalar mixing, and reaction. The most important contribution was the development of LBE theory for binary mixing, which can be extended in a straight-forward manner to multi-scalar mixing. Computational simulations were performed to verify that the desired diffusive effects could be achieved in classical mixing problems. It was demonstrated that the shape of the probability density functions during binary mixing from non-premixed initial conditions was captured precisely. The technique for handling reactions in the LBE context also was demonstrated. In the standard one-dimensional flame propagation problem, the burning rate was captured accurately. The third significant contribution was the adaptation of the multi-time-scale relaxation technique to LES. Several DNS and LES calculations of benchmark turbulent flows (decaying isotropic and homogeneous shear, square jet) were performed to establish the effectiveness and efficiency of LBE. The decay exponent in decaying turbulence, the equilibrium anisotropies in homogeneous turbulence, and the spread rates in square jets were calculated accurately.

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.

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

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.

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, comment: Die Arbeit wurde mit 1 (magna cum laude bewertet) und enthalt farbige Abbildungen., 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 par

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.

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

In the lattice Boltzmann equation, continuous particle velocity space is replaced by a finite dimensional discrete set. The number of linearly independent velocity moments in a lattice Boltzmann model cannot exceed the number of discrete velocities. Thus, finite dimensionality introduces linear dependencies among the moments that do not exist in the exact continuous theory. Given a discrete velocity set, it is important to know to exactly what order moments are free of these dependencies. Elementary group theory is applied to the solution of this problem. It is found that by decomposing the velocity set into subsets that transform among themselves under an appropriate symmetry group, it becomes relatively straightforward to assess the behavior of moments in the theory. The construction of some standard two- and three-dimensional models is reviewed from this viewpoint, and procedures for constructing some new higher dimensional models are suggested.

Statistical mechanics may be naturally divided into two branches, one dealing with equilibrium systems, the other with nonequilibrium systems. The equilibrium properties of macroscopic systems are defined in principle by suitable averages in well-defined Gibbs's ensembles. This provides a frame work for both qualitative understanding and quantitative approximations to equilibrium behaviour. Nonequilibrium phenomena are much less understood at the present time. A notable exception is offered by the case of dilute gases. Here a basic equation was established by Ludwig Boltzmann in 1872. The Boltzmann equation still forms the basis for the kinetic theory of gases and has proved fruitful not only for a study of the classical gases Boltzmann had in mind but also, properly generalized, for studying electron transport in solids and plasmas, neutron transport in nuclear reactors, phonon transport in superfluids, and radiative transfer in planetary and stellar atmospheres. Research in both the new fields and the old one has undergone a considerable advance in the last thirty years.

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.

The Lattice Boltzmann EquationFor Complex States of Flowing MatterOxford University Press