DSFD 2026

35th International Conference on Discrete Simulation of Fluid Dynamics

Balneário Camboriú, Brazil

June 29 - July 3, 2026

UDESC UNIVERSIDADE DO ESTADO DE SANTA CATARINA

GEOENERGIA LAB

PETROBRAS

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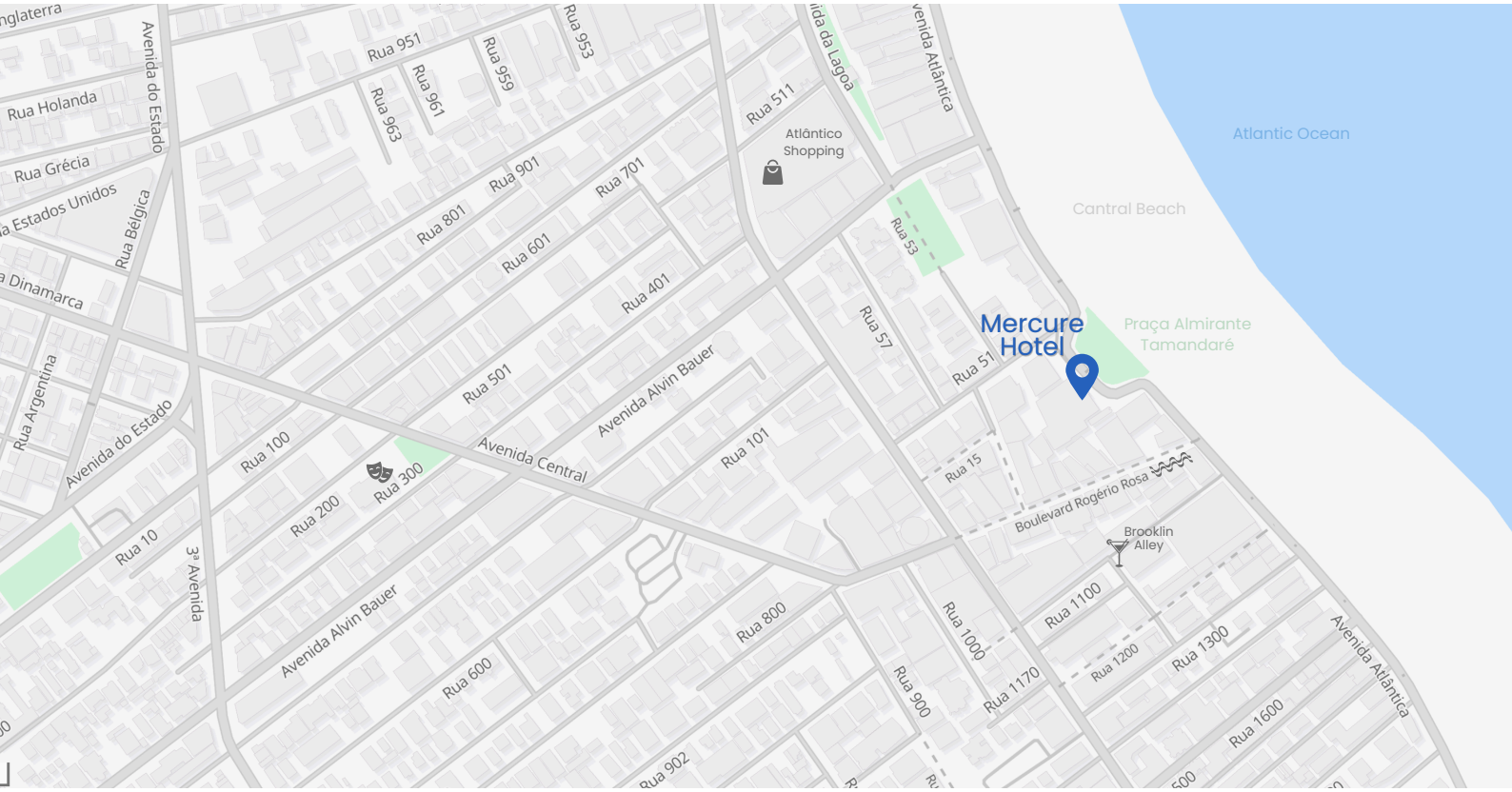
EVENT VENUE

Mercure Hotel
Av. Atlântica, 2010
Centro, Balneário Camboriú, SC 88330-012, Brazil



Wi-fi access (main room):
Network: DSFD2026
Password: 35thdsfd

Conference banquet
Paris 6 Bistrô
On the ground floor of the hotel
July 1, 19:00 onwards

GENERAL PROGRAM

June 29, Monday	
8:00 - 9:00	Registration/check in
9:00 - 9:20	Opening
9:20 - 10:10	INVITED **Alejandro L. Garcia**
10:10 - 10:40	Coffee break
10:40 - 12:00	**Session I** Mathematical modelling
12:00 - 14:00	Lunch (on your own)
14:00 - 14:50	INVITED **Seyed Ali Hosseini**
14:50 - 15:50	**Session II** Numerical analysis I
15:50 - 16:20	Coffee break
16:20 - 17:10	TUTORIAL **Mathias J. Krause**
17:10 - 17:50	**Session III** Numerical analysis II

June 30, Tuesday	
9:00- 9:50	TUTORIAL **Paulo C. Philippi**
9:50 - 10:20	Coffee break
10:20 - 12:00	**Session IV** Multiphase flows I
12:00 - 14:00	Lunch (on your own)
14:00 - 14:50	INVITED **José D. Muñoz**
14:50 - 15:50	**Session V** MHD
15:50 - 16:20	Coffee break
16:20 - 17:10	INVITED **Adriano Tiribocchi**
17:10 - 17:50	**Session VI** HMT and machine learning

July 1, Wednesday	
8:30 - 9:20	INVITED **Goncalo Silva**
9:20 - 10:00	**Session VII** Multiphase flows II
10:00 - 10:30	Coffee break
10:30 - 11:20	INVITED **Taehun Lee**
11:20 - 12:00	**Session VIII** Multiphase flows III
12:00 - 14:00	Lunch (on your own)
14:00 - 14:50	INVITED **José S. Andrade Jr.**
14:50 - 15:50	**Session IX** Interfacial phenomena and porous media I
15:50 - 16:20	Coffee break
16:20 - 17:10	INVITED **Xuhui Li**
17:10 - 17:50	**Session X** Interfacial phenomena and porous media II
19:00	Conference banquet

July 2, Thursday	
9:00- 9:50	INVITED **Moritz Lehmann**
9:50 - 10:20	Coffee break
10:20 - 12:00	**Session XI** High-performance computing
12:00 - 14:00	Lunch (on your own)
14:00	Excursion

July 3, Friday	
9:00- 9:50	INVITED **Felix Sharipov**
9:50 - 10:20	Coffee break
10:20 - 12:00	**Session XII** Turbulence, FSI and others
12:00 - 14:00	Lunch (on your own)
14:00 - 14:50	TUTORIAL **Jens Harting**
14:50 - 15:50	**Session XIII** Numerical Analysis III
15:50 - 16:20	Coffee break
16:20 - 17:10	TUTORIAL **Alexander Wagner**
17:10	Ending

THE CONFERENCE

The **International Conference on Discrete Simulation of Fluid Dynamics** (DSFD) is one of the longest-running scientific meetings dedicated to computational fluid dynamics based on discrete and kinetic approaches. The conference series originated in 1986 from a meeting coordinated by Gary D. Doolen at Los Alamos National Laboratory, USA, and has since been hosted by institutions across the Americas, Europe, and Asia. Over the years, DSFD has provided a forum for researchers in fluid dynamics, kinetic theory, statistical mechanics, and computational methods.

In the context of DSFD, the term “discrete” refers to approaches in which fluid behavior is described through the dynamics of discrete particles in space, time, and velocity, rather than through the direct discretization of continuum fluid equations. Many developments in discrete kinetic theory, particularly in lattice Boltzmann research, were first presented at DSFD conferences.

The **35th edition of DSFD** takes place in Balneário Camboriú, Santa Catarina, Brazil, from June 29 to July 3, 2026. The scientific program emphasizes multiphase flows and numerical analysis, while also covering mathematical modelling, interfacial phenomena, porous media, high-performance computing, turbulence, heat and mass transfer, magnetohydrodynamics, fluid–structure interaction, and machine-learning-assisted modelling. Contributions, invited lectures, and tutorials address advances in lattice Boltzmann methods and related kinetic approaches, including regularization strategies, boundary treatments, multicomponent and non-ideal fluid modelling, active matter, rarefied flows, and GPU-accelerated simulations.

We hope that your time at DSFD 2026 is productive, enjoyable, and filled with valuable discussions!

Luiz A. Hegele Jr.
On behalf of the DSFD 2026 Local Committee

DSFD timeline

- ☐ **1986** – Los Alamos, USA
- ☐ **1988** – Turin, Italy
- ☐ **1989** – Los Alamos, USA
- ☐ **1992** – Nice, France
- ☐ **1994** – Toronto, Canada
- ☐ **1996** – Boston, USA
- ☐ **1998** – Oxford, United Kingdom
- ☐ **1999** – Tokyo, Japan
- ☐ **2000** – Santa Fe, USA
- ☐ **2001** – Carghese, France
- ☐ **2002** – Shanghai, China
- ☐ **2003** – Beirut, Lebanon
- ☐ **2004** – Boston, USA
- ☐ **2005** – Kyoto, Japan
- ☐ **2006** – Geneva, Switzerland
- ☐ **2007** – Banff, Canada
- ☐ **2008** – Florianópolis, Brazil
- ☐ **2009** – Beijing, China
- ☐ **2010** – Rome, Italy
- ☐ **2011** – Fargo, USA
- ☐ **2012** – Bangalore, India
- ☐ **2013** – Yerevan, Armenia
- ☐ **2014** – Paris, France
- ☐ **2015** – Edinburgh, Scotland
- ☐ **2016** – Shenzhen, China
- ☐ **2017** – Erlangen, Germany
- ☐ **2018** – Worcester, USA
- ☐ **2019** – Bangalore, India
- ☐ **2020** – Viterbo, Italy (virtual)
- ☐ **2021** – Viterbo, Italy (virtual)
- ☐ **2022** – Suzhou, China
- ☐ **2023** – Albuquerque, USA
- ☐ **2024** – Zurich, Switzerland
- ☐ **2025** – Harbin, China
- ☑ **2026** – Balneário Camboriú, Brazil

A four-decade journey through DSFD

Which editions have you attended?

DSFD 2026

Hosted by

Santa Catarina State University (UDESC)
Geoenergia Lab

Conference Chair

Luiz A. Hegele Jr.
Santa Catarina State University (UDESC), Brazil

Local Organizing Committee

Diogo N. Siebert
Federal University of Santa Catarina (UFSC), Brazil

Huidan (Whitney) Yu
Purdue University in Indianapolis, USA

Luiz A. Hegele Jr.
Santa Catarina State University (UDESC), Brazil

Paulo C. Philippi
Pontifical Catholic University of Paraná (PUCPR), Brazil

Rodrigo C. V. Coelho
Brazilian Center for Physics Research (CBPF), Brazil

Scientific Committee

USEFUL INFORMATION

Balneário Camboriú is a compact and walkable city. Ride-sharing services such as Uber and 99 are widely available and provide an easy way to travel around the city.

The area surrounding the conference venue offers many restaurants, cafés, and bars. Participants are encouraged to **explore the local** cuisine and discover the city on their own.

While walking around the city, please be aware of bicycles, motorcycles, and electric scooters. Always look both ways before crossing streets.

DSFD 2026 will not feature parallel sessions. All presentations, tutorials, and invited talks will take place in the **main conference room**, allowing all participants to attend the full scientific program.

The conference **excursion** will take place on Thursday at Parque Unipraias. The meeting point is the cable car ("bondinho") boarding area, and participants should proceed directly to the site. One ticket will be provided to each participant, including the ascent to the Atlantic Forest Station, where participants may explore the preserved forest area and viewpoints, the descent to Laranjeiras Beach, and the return trip to Barra Sul Station.

Additional attractions are not included in the conference ticket and must be purchased separately. We particularly recommend the Super Gyro Tower, which offers panoramic views of Balneário Camboriú (approximately R$45, payable on site).

HELP & SUPPORT

Website
https://dsfd.org.br/

Support
support@dsfd.org.br

Emergency contacts in Brazil
Medical Emergency (SAMU): 192
Fire Department: 193
Police: 190

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Vinicius Czarnobay
Willian Pereira Teixeira
Zeina Kachkouche

COMPLETE PROGRAM

June 29, Monday

8:00- 9:00	Registration/check in
9:00- 9:20	Opening
9:20- 10:10	**INVITED** Hydrodynamic fluctuations – theory, simulations, and applications **Alejandro L. Garcia** | Chair: Alexander Wagner
10:10- 10:40	Coffee break
10:40 - 12:00	**Session I** - Mathematical modelling Chair: Alejandro L. Garcia
10:40 - 11:00	Flow-driven hysteresis in the transition boiling regime Alessandro Gabbana, Xander M. de Wit, Linlin Fei, Ziqi Wang, Daniel Livescu, and Federico Toschi
11:00 - 11:20	Chapman–Enskog analysis of modified second-order moments in regularized LBM Vinicius Czarnobay and Luiz A. Hegele Jr.
11:20 - 11:40	Lattice Boltzmann model for non-ideal compressible fluid dynamics Seyed A. Hosseini, and Ilya V. Karlin
11:40 - 12:00	Regularized boundary treatment for fluid nodes with missing directions in high-order LB stencils Bruno Y. dos Anjos and Luiz A. Hegele Jr.
12:00 - 14:00	Lunch (on your own)
14:00- 14:50	**INVITED** Modeling combustion and multispecies flows with the lattice Boltzmann method **Seyed Ali Hosseini** | Chair: Mathias Krause
14:50 - 15:50	**Session II** - Numerical analysis I Chair: Mathias Krause.
14:50 - 15:10	Controlled interspecies relaxation via drag-based coupling in LBM Shiladitya Patnaik, Alex Skillen, and Alessandro De Rosis
15:10 - 15:30	High Reynolds number turbulent jet simulation using a regularized LBM with GPU acceleration Leonardo D. Knippenberg, Gustavo Choaire, Vinicius Czarnobay, Huidan (Whitney) Yu, and Luiz A. Hegele Jr.
15:30 - 15:50	A kinetic theory-based lattice Boltzmann model for multicomponent systems with non-unitary molecular mass ratios. Maria R. Lisboa, Ricardo L. M. Bazarin, and Paulo C. Philippi
15:50 - 16:20	Coffee break
16:20 - 17:10	**TUTORIAL** Lattice Boltzmann methods for applications **Mathias J. Krause** | Chair: Seyed Ali Hosseini
17:10 - 17:50	**Session III** - Numerical analysis II Chair: Seyed Ali Hosseini
17:10 - 17:30	A moment-based regularized LBM with triangular sub-cells for inclined and curved boundaries Sakthivel Munikrishnan and Luiz A. Hegele Jr.
17:30 - 17:50	Conservative volumetric regularized boundary conditions for LBM modelling of internal compressible aerodynamic flow. Wilfred Bessem, I. Tsetoglou, H. Merley, S. Zhao, E. Serre, and P. Boivin

June 30, Tuesday

9:00- 9:50	**TUTORIAL** Kinetic models for non-ideal mixtures **Paulo C. Philippi** | Chair: Luiz A. Hegele Jr.
9:50- 10:20	Coffee break
10:20 - 12:00	**Session IV** - Multiphase flows I Chair: Rodrigo C. V. Coelho
10:20 - 10:40	A lattice Boltzmann approach to the one-fluid formulation of multiphase flow Snehil Srivastava, Timothy Reis, and Tim Phillips
10:40 - 11:00	Effective stresses analyses in unsaturated granular material via multifluid LBM-DEM coupling Clara M. Toffoli, Sina Sadeghi, Reihaneh Hosseini, and Jürgen Grabe
11:00 - 11:20	Dual roles of microbubbles in modulating slip on lubricated surfaces Sheng Li and Halim Kusumaatmaja
11:20 - 11:40	Bimodal drop motion Aqib Asif, A. Naga, G. McHale, and H. Kusumaatmaja
11:40 - 12:00	Artificial slip in the bounce-back boundary method: where does it come and can it be eliminated? Junfeng Zhang
12:00 - 14:00	Lunch (on your own)
14:00- 14:50	**INVITED** Acoustics and electrodynamics by lattice Boltzmann **José D. Muñoz** | Chair: Adriano Tiribocchi
14:50 - 15:50	**Session V** - MHD Chair: Adriano Tiribocchi
14:50 - 15:10	A mesoscopic Lorentz-force formulation for lattice Boltzmann MHD Diogo N. Siebert, Eduardo C. da Silva, Juan P. L. C. Salazar, and Luis O. E. dos Santos
15:10 - 15:30	A low-cost Gauss-Hermite quadrature implementation for mhddugksFoam Diogo N. Siebert, Garbriel M. F. Roberto, Juan P. L. C. Salazar, and Luis O. E. dos Santos
15:30 - 15:50	Relaminarization patterns in magnetohydrodynamic pipe flows using a simplified LB approach Hugo S. Tavares, Rodrigo Pereira, Luca Moriconi, and Juliana B. R. Loureiro
15:50 - 16:20	Coffee break
16:20 - 17:10	**INVITED** Active droplets: motion, confinement and topology **Adriano Tiribocchi** | Chair: José D. Muñoz
17:10 - 17:50	**Session VI** - HMT and machine learning Chair: José D. Muñoz
17:10 - 17:30	Using lattice Boltzmann to inform graph diffusion networks for aerodynamic design exploration Archie Dobson, Alistair Revell, and Alex Skillen

July 1, Wednesday

8:30- 9:20	**INVITED** A lattice Boltzmann formulation for thermo-hydrodynamic slip-flow theory **Goncalo Silva** | Chair: Xuhui Li
9:20 - 10:00	**Session VII** - Multiphase flows II Chair: Xuhui Li
9:20 - 9:40	Spontaneous rotation and propulsion of suspended capsules in active nematics Rodrigo C. V. Coelho
9:40 - 10:00	A Digital Twin of Subsea Mechanical Dispersion Experiment Swayam Lotake, Pedro Granados, Aníbal A. C. Bonilla, Luiz A. Hegele Jr., and Huidan (Whitney) Yu
10:00- 10:30	Coffee break
10:30 - 11:20	**INVITED** Spectral element lattice Boltzmann methods (NekLBM) for complex and multiphase flows at the exascale. **Taehun Lee** | Chair: Huidan (Whitney) Yu
11:20- 12:00	**Session VIII** - Multiphase flows III Chair: Huidan (Whitney) Yu
11:20 - 11:40	Mapping an Ising model onto lattice Boltzmann Alexander J. Wagner, Vinicius Akyo Matsuda, and Luben Cabezas-Gómez
11:40 - 12:00	A low-memory phase-field moment representation LBM for multiphase flows with large density and viscosity contrasts. Breno V. Gemelgo and Luiz A. Hegele Jr.
12:00 - 14:00	Lunch (on your own)
14:00- 14:50	**INVITED** Morphological and statistical-physics signatures of stationary two-phase flow regimes in disordered porous media. **José S. Andrade Jr.** | Chair: Jens Harting
14:50 - 15:50	**Session IX** - Interfacial phenomena and porous media I Chair: Jens Harting
14:50 - 15:10	Lattice Boltzmann simulations of capillary invasion Luís O. E. dos Santos, Diogo N. Siebert, and Ricardo L. M. Bazarin
15:10 - 15:30	A Brinkman penalization LBM simulation of the flow over a porous backward-facing step Léo Roussel, Chloé Mimeau, and Simon Marié
15:30 - 15:50	Influence of voxelization on hydraulic properties in DEM-LBM modeling of tropical granular soil Lucas V. Dias, Ana C. Caetano, Bruno F. Porto, Felipe B. de Souza
15:50 - 16:20	Coffee break
16:20 - 17:10	**INVITED** Multiple-relaxation-time regularized LB model and some hydrodynamic applications **Xuhui Li** | Chair: José S. Andrade Jr.
17:10 - 17:50	**Session X** - Interfacial phenomena and porous media II Chair: José S. Andrade Jr.
17:10 - 17:30	Predicting relative permeability curves using single-phase lattice Boltzmann method Luís O. E. dos Santos, Bernardo Gehlen, Ricardo L. M. Bazarin, and Diogo N. Siebert
17:30 - 17:50	Lattice Boltzmann model for free-fluid/heterogeneous-porous-media coupled systems using a mesoscopic-scale one-domain approach. Nikita O. Gusev, and Ilya V. Karlin
19:00	Conference banquet | **Paris 6 Bistrô** (on the ground floor of the hotel)

July 2, Thursday

9:00- 9:50	**INVITED** The challenges to move research CFD software into production **Moritz Lehmann** | Chair: Diogo N. Siebert
9:50- 10:20	Coffee break
10:20 - 12:00	**Session XI** - High-performance computing Chair: Moritz Lehmann
10:20 - 10:40	Moment-based GPU implementation for lattice Boltzmann simulation of non-newtonian fluids Marco A. Ferrari, Rodrigo S. Romanus, Ricardo de Souza, Alan Lugarini, Luiz A. Hegele, and Admilson T. Franco
10:40 - 11:00	Just-in-time computational fluid dynamics with lattice Boltzmann methods and OpenLB Mathias J. Krause, Adrian Kummerländer
11:00 - 11:20	Multi-GPU streaming with the moment representation lattice Boltzmann method Nathan Duggins and Luiz A. Hegele Jr.
11:20 - 11:40	Efficient single-precision simulations of nematohydrodynamics Rodrigo C. V. Coelho
11:40 - 12:00	Multiscale finite-volume kinetic modeling of compressible flows with arbitrary Prandtl number and specific heat ratio. Ruben M. Strässle, Seyed A. Hosseini, and Ilya V. Karlin
12:00 - 14:00	Lunch (on your own)
14:00	Excursion **Parque Unipraias** Av. Atlântica, 6006 - Centro, Balneário Camboriú Suggested restaurant after the excursion: Casa da Lagosta (Avenida Atlântica, 5600). Dinner on your own.

July 3, Friday

9:00- 9:50	**INVITED** *Ab initio* modelling of rarefied gas flows **Felix Sharipov** | Chair: Goncalo Silva
9:50- 10:20	Coffee break
10:20 - 12:00	**Session XII** - Turbulence, FSI and others Chair: Juan P. L. C. Salazar
10:20 - 10:40	Turbulent kinetic energy budget in lid-driven cavity flow using the lattice Boltzmann method Gustavo Choaire, Andrea Scagliarini, Huidan (Whitney) Yu, Marco Ferrari, Admilson T. Franco, and Luiz A. Hegele Jr
10:40 - 11:00	Direct numerical simulations of viscoplastic turbulent flow Alan Lugarini, Marco A. Ferrari, Rodrigo S. Romanus, Felipe O. Basso, and Admilson T. Franco
11:00 - 11:20	A comparative study of lattice Boltzmann methods for structural mechanics Florian Kaiser, Fedor Bukreev, Adrian Kummerländer, and Mathias J. Krause
11:20- 12:10	**TUTORIAL** Particle-laden (multi-)phase flows: from hard to soft **Jens Harting** | Chair: Luiz A. Hegele Jr.
12:10- 14:00	Lunch (on your own)
14:00- 15:00	**Session XIII** - Numerical analysis III Chair: Taehun Lee
14:00- 14:20	Constant-flux boundary condition in periodic domains for the lattice Boltzmann method Ricardo L. M. Bazarin, Maria R. Lisboa, and Diogo N. Siebert
14:20 - 14:40	Multicomponent turbulent jet simulations using the color-gradient lattice Boltzmann method Juan F. Aristizabal Aldana and Luiz A. Hegele Jr.
14:40 - 15:00	Finite-difference structure of TRT lattice Boltzmann schemes for steady advection–diffusion–reaction problems. Goncalo Silva
15:00 - 15:50	**TUTORIAL** Derivation of lattice Boltzmann from first principles: procedure for mapping microscopic models to mesosccopic lattice Boltzmann methods. **Alexander Wagner** | Chair: Taehun Lee
15:50	Ending
16:00-16:30	Coffee break

INVITED TALKS & TUTORIALS

INVITED TALK

June 29, Monday, 9:00 - 9:50

Hydrodynamic fluctuations – theory, simulations, and applications

Alejandro L. Garcia

San Jose State University & Berkeley Lab, USA

The intrinsic thermal motion of the molecules in a fluid result in hydrodynamic fluctuations. From Einstein's theory of Brownian motion to the recent Fluctuation Theorems of Evans, Searles, Crooks, and others, the study of hydrodynamic fluctuations has been a seminal topic in statistical mechanics. Practical applications for modeling the stochastic nature of fluids range from pharmaceutical nanotechnology to thermal management in quantum computers.

While standard coarse-grained representations, such as the deterministic Navier-Stokes equations, fail to capture these stochastic dynamics, discrete simulations of fluids are ideally positioned for studying hydrodynamic fluctuations. These fluctuations occur naturally in particle simulations, such as molecular dynamics (MD) and Direct Simulation Monte Carlo (DSMC), where there is a direct mapping from physical molecules to computational particles. Discrete simulation algorithms with continuous fields, such as the Lattice Boltzmann method (LBM) and fluctuating hydrodynamics (FHD), incorporate stochastic elements based on the fluctuation-dissipation theorem.

The talk will review these discrete numerical methods for simulating hydrodynamic fluctuations. First, the basic statistical mechanics theory will be illustrated using the one dimensional stochastic heat equation, which can be solved analytically. These theoretical concepts then inform the development of robust numerical models for stochastic transport. Finally, a selection of examples will be discussed including gas-phase membranes, electrolyte solutions, wetting instabilities, and turbulence.

INVITED TALK

June 29, Monday, 14:00 - 14:50

Modeling combustion and multispecies flows with the lattice Boltzmann method

Seyed Ali Hosseini
ETH Zürich, Switzerland

Multispecies flows are ubiquitous in industrial applications and are characterized by complex physical interactions and high computational cost, particularly in the case of combustion. These challenges have motivated sustained interest within the lattice Boltzmann community. Early efforts, dating back to the late 1990s, relied on simplifying assumptions such as cold-flame approximations, Fickian diffusion, and reduced one-step chemical kinetics. Despite these initial studies, progress remained limited for over a decade.

Renewed momentum emerged in the mid-2010s, driven in part by advances in compressible lattice Boltzmann formulations. In this talk, we revisit the historical development of lattice Boltzmann approaches to combustion and multispecies flows, highlighting key milestones and limitations. We then discuss fundamental challenges inherent to modeling reactive, compressible, and thermally coupled flows within the lattice Boltzmann framework.

Finally, we review recent numerical developments and assess the current state of the art, including capabilities, limitations, and performance. Particular emphasis is placed on evaluating whether lattice Boltzmann methods offer tangible advantages over conventional computational fluid dynamics approaches for reactive flow simulations.

TUTORIAL

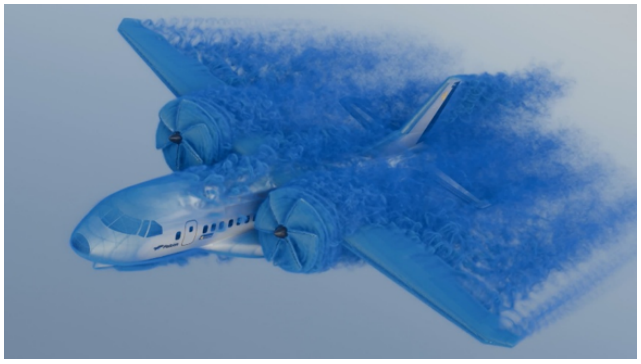
June 29, Monday, 16:00 - 16:20

Lattice Boltzmann methods for applications

Mathias J. Krause

Lattice Boltzmann Research Group, Institute for Applied and Numerical Mathematics, Karlsruhe Institute of Technology (KIT), Germany

An overall strategy for numerical simulations and optimization of fluid flows for industrial applications is introduced. The integrative approach takes advantage of numerical simulation strategies and newly developed mathematical optimization techniques, which are all based on kinetic model descriptions and on Lattice Boltzmann Methods (LBM) as discretization strategies [1]. Thereby, the resulting algorithms were implemented in a highly generic way in the open-source framework OpenLB [2]. In the talk, particular focus is placed on the design and application of the approach in order to face contemporary challenges in Computational Fluid Dynamics (CFD) [3, 4]. Further, the consideration of LBM as a generic technique for the approximation of Partial Differential Equations (PDE) [5] and its implementation for heterogeneous high-performance computing (HPC) platforms are highlighted. The presented approaches and realizations are illustrated by means of various fluid flow simulation and optimization examples in many different engineering fields, where specific aspects are discussed for the simulation of particulate [6] and turbulent flows [7] as well as optimal control and optimization problems.



[1] Krause, M.J. Fluid flow simulation and optimisation with lattice Boltzmann methods on high performance computers - application to the human respiratory system (2010).

[2] Krause, M.J., et al. OpenLB — open source lattice Boltzmann code, Computers & Mathematics with Applications, 81, 258–288, 2021.

[3] Slotnick, J. et al., CFD Vision 2030 study: a path to revolutionary computational aerosciences, NASA Technical Report NASA/CR-2014-218178, 2014.

[4] Kwak, D., Kiris, C. and Kim, C.S., Computational challenges of viscous incompressible flows, Computers & Fluids, 34, 283–299, 2005.

[5] Simonis, S., Frank, M. and Krause, M.J., On relaxation systems and their relation to discrete velocity Boltzmann models for scalar advection–diffusion equations, Philosophical Transactions of the Royal Society A, 378, 20190400, 2020.

[6] Trunk, R. et al., Revisiting the homogenized lattice Boltzmann method with applications on particulate flows, Computation, 9, 11, 2021.

[7] Haussmann, M. et al., Evaluation of a near-wall-modeled large eddy lattice Boltzmann method for the analysis of complex flows relevant to IC engines, Computation, 8, 43, 2020.

TUTORIAL

June 30, Tuesday, 9:00 - 9:50

Kinetic models for non-ideal mixtures

Paulo C. Philippi

Pontifical Catholic University of Paraná (PUCPR), Brazil

In fluid mechanics, multicomponent fluid systems are generally treated either as homogeneous solutions or as completely immiscible parts of a multiphasic system. In immiscible systems, the main task in numerical simulations is to find the location of the interface evolving over time, driven by normal and tangential surface forces. The lattice-Boltzmann method (LBM), on the other hand, is based on a mesoscopic description of the multicomponent fluid systems, and appears to be a promising framework that can lead to realistic predictions of segregation in non-ideal mixtures of partially miscible fluids. In fact, the driving forces in segregation are of a molecular nature: there is competition between the intermolecular forces and the random thermal motion of the molecules. Since these microscopic mechanisms are not accessible from a macroscopic standpoint, the LBM can provide a bridge linking the microscopic and macroscopic domains. To this end, the first purpose of this article is to present the kinetic equations in their continuum forms for the description of the mixing and segregation processes in mixtures. Discretization of the kinetic equations leads to evolution equations, written in LBM variables, directly amenable to numerical simulations. Here, the dynamics of the kinetic model equations is demonstrated with numerical simulations of a spinodal decomposition problem with dissolution. Finally, some simplified versions of the kinetic equations suitable for immiscible flows are discussed.

INVITED TALK

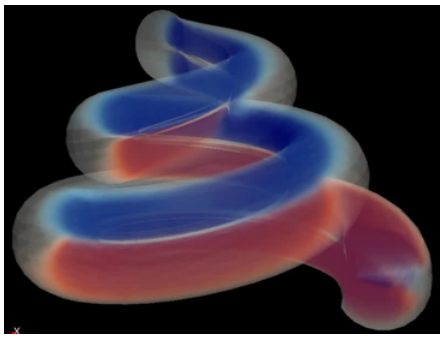
June 30, Tuesday, 14:00 - 14:50

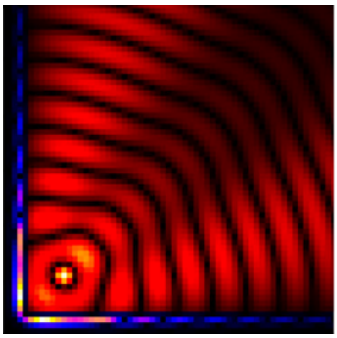
Acoustics and electrodynamics by lattice Boltzmann

José D. Muñoz

Department of Physics, National University of Colombia, Colombia

Lattice-Boltzmann methods (LBM) can also be engineered to simulate waves [1] and Maxwell equations [2]. Information travels from cell to cell and collides driven by a Boltzmann transport equation, as usual, but the conservative laws it reproduces are different, opening exciting possibilities. Hereby we show how a LBM for waves can be used to simulate the acoustic radiating forces in acoustic tweezers [3] and the acoustic response of a concert hall. We will also illustrate how to modify this LBM to work on curvilinear grids [4], employing it to reproduce the travelling sound waves inside the human cochlea. In addition, we will explain how an LBM for electrodynamics works, and how it can be employed to simulate antennas, with an example code that will be set at disposal for the audience. Those examples illustrate how the high parallelization advantages of LBM can be extended to the fields of acoustics and electrodynamics.





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INVITED TALK

June 30, Tuesday, 16:20 - 17:10

Active droplets: motion, confinement and topology

Adriano Tiribocchi

Institute for Applied Mathematics "Mauro Picone" (IAC-CNR), Italy

Active fluid droplets are an intriguing example of bio-mimetic self-propelled ystem whose motion is driven by a self-assembled active gel [1,2]. Examples of active gels include actomyosin solutions and networks of extensile microtubule bundles plus kinesin, often modeled as orientationally ordered fluids comprising force dipoles.

In this talk I will describe, using lattice Boltzmann simulations, the physics of active fluid droplets containing nematic and polar fluids. In the former, I will discuss recent results about the dynamics of an active double emulsion, where one or two passive small droplets are encapsulated in a larger active droplet and the layer consists of an active nematic fluid [3]. While a double emulsion containing a single droplet becomes a self-motile object displaying translational and rotational motion, the presence of a pair of particles nucleates one or more disclination loops, with conformational dynamics resembling a rotor or chaotic oscillator, which can accessed by tuning activity. In the latter, I will consider polar active droplets navigating across microchannels, whose design resembles physiological conditions of cell migration [4,5,6]. Our results show that varying active stress, elasticity and degree of confinement leads to a variety of shapes and motile regimes, ranging from worm-like droplets displaying oscillatory behaviour within wider channels to bullet-shaped droplets exhibiting rectilinear motion in narrower slits. Overall, these findings highlight how topology and geometrical confinement shape the emergent dynamics of active droplets, with potential implications for the design of biomimetic microswimmers and synthetic active materials.

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INVITED TALK

July 1, Wednesday, 8:30 - 9:20

A lattice Boltzmann formulation for thermo-hydrodynamic slip-flow theory

Goncalo Silva

University of Évora, Portugal

Many gas microflows operate in the slip-flow regime, where accurate modelling demands proper treatment of velocity slip, thermal creep, temperature jump, and near-wall rarefaction effects. Sone's generalized slip-flow theory [1] offers a rigorous macroscopic framework for this regime, derived from the Boltzmann equation, that couples fluid-dynamic equations with asymptotically consistent slip/jump boundary conditions and Knudsen-layer corrections. This work presents a unified implementation of this thermo-hydrodynamic framework within the lattice Boltzmann method (LBM), restricted to the linear (Stokes-flow) regime. Despite being frequently advocated as a natural CFD tool for rarefied microflows, LBM is susceptible to numerical artefacts whenever boundary treatments lack proper consistency [2]. The central challenge is to reproduce, at the discrete level, the asymptotic structure underlying slipflow theory. Meeting this challenge requires two ingredients: (i) a consistent closure relation within LBM boundary schemes [2], interpreted as a Taylor-type approximation of the physical boundary condition; and (ii) a correct handling of directionality [3], whereby distinct conditions are enforced along the wall-normal and wall-tangential directions for both velocity and temperature fields. A new formulation is proposed that addresses both requirements by combining link-wise and node-wise operations within a single framework. Slip and jump boundary conditions are cast as Robin-type constraints — linear combinations of Dirichlet and Neumann contributions. The Dirichlet component is imposed through a standard link-wise construction that enforces impermeability at the wall [2, 3], while the Neumann component — encoding velocity slip, thermal creep, and temperature jump — is introduced via a local node-wise procedure [4]. This construction allows derivative information to be reconstructed locally and ensures consistency with Sone's first-order asymptotic boundary conditions [1]. In parallel, Knudsen-layer corrections are embedded directly into the LBM solution through Taylor-type representations of wall shear stress and heat flux, so that the asymptotic near-wall structure is captured within the same computational framework. The formulation is validated on benchmark problems involving planar and curved boundaries with coupled momentum and heat transfer. Results confirm that the proposed approach provides a simple, accurate, and physically consistent route for embedding thermo-hydrodynamic slip-flow theory into LBM, without recourse to external modelling strategies or more complex higher-order lattice formulations.

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INVITED TALK

July 1, Wednesday, 10:30 - 11:20

Spectral element lattice Boltzmann methods (NekLBM) for complex and multiphase flows at the exascale

Taehun Lee

City College of New York (CCNY), USA

This talk presents recent advancements in the Spectral Element Lattice Boltzmann Method (NekLBM), a high-order, highly scalable framework designed for complex fluid dynamics. By adopting an Eulerian description of the LBM streaming process, we utilize spectral element spatial discretization coupled with strong stability-preserving Runge-Kutta (SSPRK) time integration. To accurately handle complex boundaries on unstructured meshes, we introduce a novel Flux Bounce-Back (FBB) scheme. Combined with explicit filtering, this framework provides robust, high-fidelity predictions for single-phase flows, including isotropic turbulence and fully developed turbulent pipe flows.

We further extend NekLBM to model multiphase flows by incorporating a non-ideal gas phase-field model with a potential form of surface tension. By employing a force-splitting approach and our FBB scheme alongside a general wetting boundary condition, the method effectively resolves normal vector inconsistencies and captures partial wetting on curved geometries. Notably, this formulation reduces parasitic currents to near machine-precision levels. Finally, we demonstrate the extreme scalability of NekLBM on the Aurora supercomputer. Leveraging up to 8,192 nodes (49,152 GPUs) for high-order Taylor-Green vortex simulations, the solver achieves outstanding parallel efficiency, positioning NekLBM a s a powerful tool for next-generation high-performance computational fluid dynamics.

INVITED TALK

July 1, Wednesday, 14:00 - 14:50

Morphological and statistical-physics signatures of stationary two-phase flow regimes in disordered porous media

José S. Andrade Jr.

Department of Physics, Federal University of Ceará (UFC), Brazil

Immiscible displacement in disordered porous media exhibits a wide range of interfacial morphologies whose emergence reflects the complex interplay among viscous, capillary, and inertial forces. Yet, how pore-space morphology and collective interfacial organization shape stationary two-phase flow remains a scientific challenge. Here, we perform direct numerical simulations of the Navier–Stokes equations in a disordered porous matrix with periodic boundary conditions, enabling statistically stationary two-phase flow over several decades in the Capillary (Ca) and Forchheimer (Fo) numbers. We identify three robust stationary morphologies, namely, bubbles, stripes, and mixed flows, which organize into a compact (Fo,Ca) regime diagram with reproducible crossovers. Despite these pronounced morphological reorganizations, macroscopic transport varies smoothly: stripe and mixed-flow regimes follow a Forchheimer-like velocity–forcing relation, whereas bubble regimes deviate systematically due to recirculation and reduced connectivity. To characterize the collective organization underlying these morphologies, we coarse-grain the flow configurations into binary fields and infer pairwise maximum-entropy (Ising-like) models. Across the full control space, the inferred Hamiltonians reproduce the imposed first- and second-order statistics and, moreover, near morphological crossovers, accurately predict higher-order correlations that were not used during inference. Thermodynamic probing of the inferred models near these crossovers reveals systematic shifts in the effective distance to criticality, suggesting that morphological transitions are accompanied by substantial reorganization of the underlying interaction structure. Together, the hydrodynamic regime map and the maximum-entropy representation establish a unified, dimensionless framework linking pore-space morphology, interfacial organization, macroscopic transport, and collective structure in stationary two-phase flows in porous media.

INVITED TALK

July 1, Wednesday, 16:20 - 17:10

Multiple-relaxation-time regularized LB model and some hydrodynamic applications

Xuhui Li

Harbin Engineering University, China

Improving the numerical stability and accuracy of collision models of lattice Boltzmann methods has been a problematic issue and hotspot in this field for nearly 40 years. Except for the numerical challenges similar to those in traditional computational fluid dynamics methods, the essence of numerical instability and accuracy issues in lattice Boltzmann methods owns its unique characteristics. In this work, the multiple-relaxation-time(MRT) regularized lattice Boltzmann (RLB) collision model[1-3] and the connections among different regularized models will be briefly introduced[4]. Furthermore, the following applications of MRT-RLB collision models will be reported in detail:1) turbulence/wake with DNS/iLES and wall turbulence with WRLES/WMLES; 2) moving boundary treatment with both overset mesh technique and immersed boundary method; 3) wave-body interactions with phase-field model re-derived by MRT-RLB operator; 4) cavitation with Shan-Chen model re-derived by MRT-RLB operator. All simulations are conducted with multiple-GPU CUDA codes on GPU clusters with V100S/A100/A800 GPU cards.

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INVITED TALK

July 2, Thursday, 9:00 - 9:50

The challenges to move research CFD software into production

Moritz Lehmann

Intel & OpenCL Advisory Panel, Germany

Research groups often face new problems that existing software, be it open or commercial, cannot solve. So they create their own software in-house, written by students, for active development on new numerical methods. While at the forefront of computational science and without doubt valuable for a wider audience, such codes tend to lack in performance, portability, usability and robustness. With the end of the academic career, the software is often left behind in bad shape, and the next generation of researchers, although equipped with new methodological knowledge, have to start from zero on the software engineering side.

The transition from research software used only within a research group, to distributing it as production-grade software across much wider audiences, is a difficult undertaking. On the example of my FluidX3D CFD software, I share insights into this transition, its challenges, pitfalls and learnings. I want to encourage and prepare researchers to go the extra mile and make their software not just a one-time use item but a tool for generations to come.

INVITED TALK

July 3, Friday, 9:00 - 9:50

Ab initio modelling of rarefied gas flows

Felix Sharipov

Federal University of Paraná, Brazil

The equations of continuum gas dynamics are not valid when a characteristic length scale of the gas flow becomes comparable to the molecular mean free path. Under such conditions, methods of rarefied gas dynamics must be employed. These methods can be divided into two groups: deterministic and probabilistic approaches [1]. Deterministic methods are generally based on the kinetic Boltzmann equation, which is commonly solved using the discrete ve locity method. Probabilistic methods, in contrast, rely on the direct simulation of molecular motion and collisions. The most widely used probabilistic technique is the Direct Simulation Monte Carlo (DSMC) method. The principal idea of DSMC consists in discretizing the com putational domain into cells and decoupling molecular motion from intermolecular collisions. Macroscopic quantities are then evaluated as cell-averaged values. Both deterministic and prob abilistic methods require detailed information about the intermolecular potential. In practice, phenomenological molecular models such as hard spheres, variable hard spheres, variable soft spheres, and Lennard–Jones potentials are commonly used. However, all these models contain adjustable parameters that are often not uniquely determined and may vary depending on the experimental data used for their calibration. Recently, so-called ab initio potentials have been reported for noble and diatomic gases. These potentials are derived without relying on exper imentally fitted parameters. The purpose of the present work is to review numerical results obtained using both deterministic and probabilistic methods based on ab initio interaction po tentials. Results for several classical fluid-mechanics problems, including Couette flow [2], heat transfer [3], shock-wave structure [4], and slip coefficients [5], will be presented. In addition, reliable data on transport coefficients for gas mixtures will be discussed. A comparison between results obtained using *ab initio* potentials and those based on the hard-sphere model demon strates that the influence of the intermolecular potential on transport phenomena depends on many factors. Finally, recommendations regarding the practical use of different interaction potentials will be provided.

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TUTORIAL

July 3, Friday, 11:20 - 12:10

Particle-laden (multi-)phase flows: from hard to soft

Jens Harting

Helmholtz Institute Erlangen-Nürnberg (HI ERN), Germany

In this tutorial, I will provide a historical review of how to couple a lattice Boltzmann flow solver with the discrete element or immersed boundary method to describe the motion of suspended objects in flow. After introducing algorithmic and implementation details, I will focus on specific pros and cons of the different approaches and detail selected applications, ranging from the rheology of simple hard-sphere suspensions to biological cells and capsules. I will then move to the effect of fluid inertia on the migration and ordering of particles and report on the application of these methods to particle-stabilized emulsions and drying suspension droplets.

TUTORIAL

July 3, Friday, 16:20 - 17:10

Derivation of lattice Boltzmann from first principles: procedure for mapping microscopic models to mesosccopic lattice Boltzmann methods

Alexander Wagner

North Dakota State University, USA

Lattice Boltzmann methods were traditionally derived from lattice gas methods, as a specific Boltzmann limit. We will explain in this tutorial how to coarse-graini other microscopic models like Molecular Dynamics simulations or the Ising model onto corresponding lattice Boltzmann methods, which provides an interesting fundamental alternative for the derivation of lattice Boltzmann methods.

ABSTRACTS

35th International Conference on Discrete Simulation of Fluid Dynamics
June 29 – July 3, 2026
Balneário Camboriú, Brazil

Flow-driven hysteresis in the transition boiling regime

Alessandro Gabbana[1], Xander de Wit[2], Linlin Fei[3], Ziqi Wang[2], Daniel Livescu[4], and Federico Toschi[2]

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[2]Eindhoven University of Technology, 5600 MB Eindhoven, Netherlands
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Classification: 01-I Lattice Boltzmann Methods, Multiphase Flows
Keywords: Transition Boiling; Hysteresis; Pool Boiling.

Boiling plays a critical role in various natural and industrial processes. Despite its ubiquity, accurately modeling boiling remains a significant challenge due to the broad range of spatial and temporal scales involved. In this study, we focus on transition boiling, an intermediate regime that occurs between nucleate boiling, where bubbles effectively transfer heat from the surface, and film boiling, where a vapor layer forms over the surface, insulating it and reducing heat transfer. This regime is inherently unstable and occurs near the boiling crisis, where the system approaches its maximum heat flux, leading to a sharp decline in heat removal efficiency. Transition boiling has critical implications for industrial cooling systems and nuclear reactor safety, as entering this regime can sharply reduce heat removal, potentially leading to overheating or component damage.

Employing GPU-accelerated Lattice Boltzmann simulations [1], we perform large-scale, high-resolution three-dimensional pool boiling simulations (see Fig. 1) to investigate transition boiling with unprecedented detail. Our results show that transition boiling exhibits hysteresis, even under idealized conditions on smooth surfaces with constant temperature [2]. Additionally, we observe distinct asymmetries in the transition process: while the heating branch leads to a sudden, memoryless shift to film boiling, the cooling branch shows a metastable coexistence of nucleate and film boiling states, which slows the recovery of efficient heat transfer.

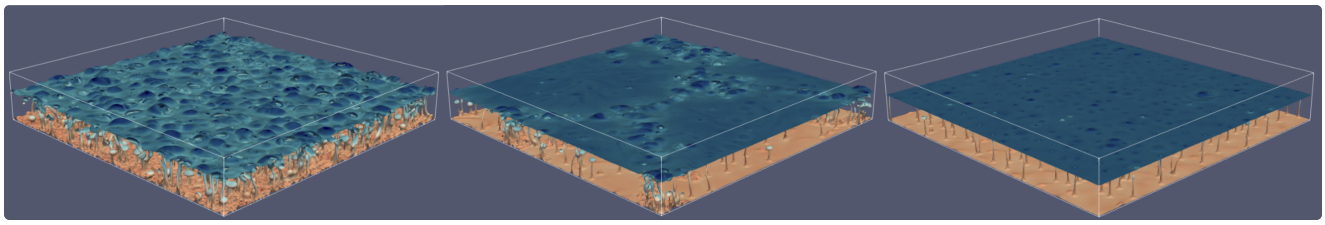

Figure 1: Snapshots from pool boiling simulations, showing, from left to right, the nucleate boiling regime, metastable coexistence of nucleate and film boiling, and film boiling regime.

References

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35th International Conference on Discrete Simulation of Fluid Dynamics
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Chapman–Enskog analysis of modified second-order moments in regularized lattice Boltzmann methods

Vinicius Czarnobay[1] and Luiz A. Hegele Jr.[1]

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Classification: 01-A Lattice Boltzmann Methods, Mathematical Modelling
Keywords: Chapman–Enskog expansion; Lattice Boltzmann method; Regularization; Second-order moments.

A Chapman–Enskog analysis for generalized second-order moment modifications in regularized lattice Boltzmann methods is presented. The proposed formulation introduces explicit corrections into the second-order moment tensor during the regularization procedure according to

$$m^*_{\alpha\beta} = m_{\alpha\beta} + \Delta\tilde{m}_{\alpha\beta}, \tag{1}$$

where $m_{\alpha\beta}$ is the second-order moment tensor and $\Delta\tilde{m}_{\alpha\beta}$ denotes a generic correction applied at the kinetic level. Starting from a modified BGK collision operator, the asymptotic expansion is performed up to second order in the Knudsen number, leading to corrected expressions for the non-equilibrium moments, strain-rate tensor, and recovered hydrodynamic equations. In particular, the Chapman–Enskog analysis yields the strain-rate tensor

$$S_{\alpha\beta} = \frac{a_s^2}{2\tau}\left((u_\alpha u_\beta - m_{\alpha\beta}) - \Delta\tilde{m}_{\alpha\beta}\left(1 - \frac{\tau}{\Delta t}\right)\right), \tag{2}$$

where τ is the relaxation time, and a_s is the lattice scaling factor. The resulting expression shows that the recovered transport coefficients depend explicitly on both the imposed second-order corrections and the relaxation time through the factor $(1 - \tau/\Delta t)$. Using this framework, isotropic modifications associated with isothermal and incompressible formulations are investigated regarding their implications for compressibility constraints and bulk viscosity effects. The resulting framework provides a systematic formulation for constructing modified regularized lattice Boltzmann models while preserving mass and momentum conservation within the Chapman–Enskog expansion.

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Lattice Boltzmann model for non-ideal compressible fluid dynamics

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Classification: 01-07-A-K-L
Keywords: Lattice Boltzmann; Non-ideal fluids; Compressible flows.

We present a lattice Boltzmann formulation for the simulation of compressible, non-ideal fluid flows. The method employs first-neighbor lattices and introduces a consistent set of correction terms through quasi-equilibrium attractors, ensuring positive-definite and Galilean-invariant Navier–Stokes dissipation rates. This construction circumvents the need for extended stencils or ad hoc regularization, while maintaining numerical stability and thermodynamic consistency across a broad range of flow regimes. The resulting model accurately reproduces both Euler- and Navier–Stokes-level hydrodynamics. As a stringent validation, we demonstrate, for the first time within a lattice Boltzmann framework, quantitatively accurate simulations of drop–shock interactions at Mach numbers up to 1.47. The proposed approach thus extends the applicability of lattice Boltzmann methods to high-speed, non-ideal compressible flows with a minimal kinetic stencil.

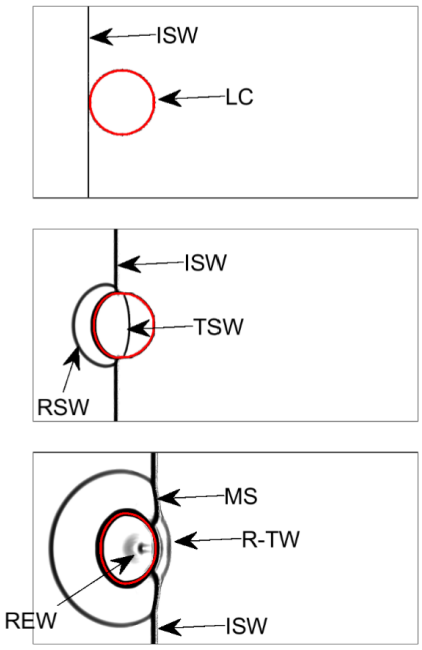

Figure 1: Schlieren images of shock/liquid column interaction case at (top to bottom): $t/t_0 = 0$, $t/t_0 = 0.3$ and $t/t_0 = 0.7$. Schlieren images are generated as $\phi = \exp\left(-a\frac{||\nabla\rho||}{\max(||\nabla\rho||)}\right)$ with $a = 100$. ISW: Incident Shock Wave, LC: Liquid Column, TSW: Transmitted Shock Wave, RSW: Reflected Shock Wave, MS: Mach Stem, R-TW: Re-transmitted Wave and REW: Reflected Expansion Wave.

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35th International Conference on Discrete Simulation of Fluid Dynamics
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Regularized Boundary Treatment for Fluid Nodes with Missing Directions in High-Order Lattice Boltzmann Stencils

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Classification: 01-A Lattice Boltzmann Methods, Numerical Analysis
Keywords: High-order stencils; Moment reconstruction; Regularized boundary conditions.

Boundary treatment is a challenge in high-order Lattice Boltzmann formulations, particularly for velocity sets involving extended lattice connections and incomplete neighbor availability near solid boundaries. In high-order stencils, fluid nodes located close to walls may contain missing lattice directions associated with distant neighbors outside the computational domain. In such cases, the missing directional populations must be treated as boundary populations, since the standard regularization procedure cannot be directly applied to incomplete distribution sets. In this context, we propose an extension of the regularized boundary condition (RBC) formulation introduced by Hegele Jr. et al. (2018) for high-order lattice structures with missing directional populations. We employ a moment-based incompressible Lattice Boltzmann formulation combined with the Bhatnagar-Gross-Krook collision operator and second-order regularization procedures. The proposed methodology is applied to the D2V17 and D2V32 velocity sets. The boundary treatment is formulated as a system of equations for the reconstruction of the unknown moments required by the regularization procedure. Mass conservation is imposed by matching incoming populations and collided outgoing populations, following the original RBC formulation. The reconstruction of the second-order moments is obtained by imposing consistency between the incoming populations and the regularized distributions projected onto the second-order Hermite basis. In addition, we introduce a reconstruction condition for the first-order moments associated with momentum transport by enforcing equivalence between the incoming populations and the reconstructed regularized populations. This additional constraint becomes necessary at fluid nodes containing missing directional information, where the velocity field is not prescribed as in Dirichlet boundary conditions. The resulting formulation produces a closed system with six equations and six unknowns, allowing the reconstruction of the required moments and the subsequent application of the regularization procedure. We assess the formulation for the lid-driven square cavity problem, and the obtained results present agreement with reference solutions for the evaluated flow configurations.

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Controlled interspecies relaxation via drag-based coupling in LBM

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Classification: 01-B Lattice Boltzmann Methods, Numerical Analysis
Keywords: multispecies flows; interspecies coupling; drag-based forcing.

In existing lattice Boltzmann formulations for multispecies flows, each species is represented by its own distribution function, and interspecies coupling is typically introduced through equilibrium-based approaches [1], where relaxation of relative velocity is fixed by construction. The barycentric velocity equilibrium enforces velocity alignment by modifying the equilibrium velocity, but does not allow independent control over the relaxation timescale.

To address this, a collision frequency-based (rate controlled) drag formulation is introduced as an explicit momentum-exchange forcing. It is implemented within a non-orthogonal central-moments framework [2], but is equally applicable to BGK formulations. The forcing is defined as a pairwise symmetric exchange between two species, s and s',

$$\mathbf{F}_s = \sum_{s'} \frac{2\rho_s\rho_{s'}}{\rho_s + \rho_{s'}} \nu_{ss'} \left(\mathbf{u}_{s'} - \mathbf{u}_s\right), \tag{1}$$

which conserves total momentum while directly parameterising coupling strength via the collision frequency. ρ and $\mathbf{u}$ denote fluid mass density and flow momentum, respectively. This provides explicit control over interspecies slip and yields a well-defined exponential relaxation governed by the collision frequency, independent of the collision operator.

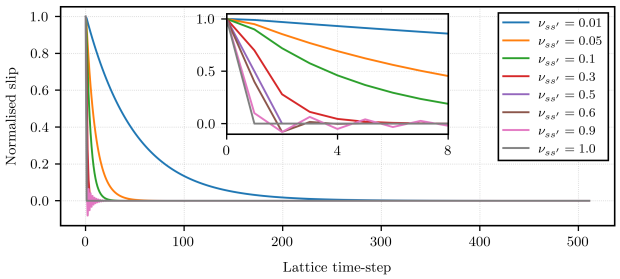

Figure 1: Normalised slip between species for different collision frequencies $\nu_{ss'}$.

Slip decays exponentially with a timescale set by the collision frequency, consistent with the predicted relaxation behaviour. With velocity gradients, an initial coupling-controlled decay is followed by a transport-driven stage. Under an imposed electric field, the drag formulation permits higher maximum stable field strengths than the barycentric equilibrium approach, but only above a coupling threshold, where increased coupling suppresses slip-driven instability.

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High Reynolds Number Turbulent Jet Simulation Using a Regularized Lattice Boltzmann Method with GPU Acceleration

Leonardo D. Knippenberg[1], Gustavo Choaire[1], Vinicius Czarnobay[1], Huidan (Whitney) Yu[2], and Luiz A. Hegele Jr.[1]

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Classification: 01-B Lattice Boltzmann Methods, Numerical analysis
Keywords: Lattice Boltzmann method; CFD; Turbulent jet.

We present simulations of a turbulent single-phase jet flow using the lattice Boltzmann method (LBM). We employ a regularized version of the lattice Boltzmann equation that incorporates a formulation for the Bhatnagar-Gross-Krook (BGK) collision operator. The reconstruction of regularized particle populations is based on incomplete second-order moments of the distribution function based on the application of Hermite polynomials. Our approach reconstructs unknown moments by means of known particle populations at the boundaries, leading to a system of equations solved according to the chosen stencil. The three-dimensional stencils D3Q19 and D3Q27 using a second-order model are considered for the solution of the jet flow. Comparison with experimental results validates the effectiveness of the proposed method. Then, we use a high-order model to model the flow with $\mathrm{Re} = 2000$. The proposed model makes it possible to carry out a high-performance simulation to test the processing capacity of a GPU and obtain accurate results in a relatively short period of time compared to other methods for simulating the flow of a fluid. The mesh used for the simulation has $384 \times 1152 \times 384$ grid points.

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A kinetic theory-based lattice Boltzmann model for multicomponent systems with non-unitary molecular mass ratios

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Classification: 01-B Lattice Boltzmann Methods, Numerical Analysis
Keywords: Multicomponent flow; Non-unitary molecular mass ratios;

In multicomponent systems, pressure and momentum are governed by distinct physical densities. While pressure depends on number density and temperature, the resulting acceleration is determined by mass density. Although number-density ratios have been extensively studied within the Lattice Boltzmann Method (LBM), the introduction of mass ratios between fluids has generally been treated heuristically in the literature. From a kinetic-theory perspective, particle velocity distributions depend on both temperature and molecular mass, and these dependencies must be consistently incorporated into the LBM framework.

Two main strategies have been proposed: Different Lattice Speeds (DLS) and Same Lattice Speeds (SLS) [1]. DLS approaches employ multiple discrete velocity sets, but require temporal or spatial interpolation, thereby introducing additional numerical errors. In contrast, existing SLS models typically rely on ad hoc modifications of the equilibrium distribution, achieving high density ratios by tuning the population of rest particles to effectively alter the speed of sound [2].

In this work, we demonstrate that a kinetic-theory-based LBM, employing abscissa-prescribed quadrature [3] of the Maxwell–Boltzmann equilibrium distribution, enables the systematic and physically consistent introduction of non-unity mass ratios in multicomponent simulations. By using a full Hermite expansion of the D2Q9 lattice Boltzmann equation up to fourth order, mass effects are consistently incorporated into higher-order moments [4, 5]. Coupled with an order-parameter model for the segregation of immiscible fluids, the proposed approach is validated in layered Poiseuille flow, achieving stable density ratios of up to 10^6, as well as in simulations of the Rayleigh–Taylor instability.

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35th International Conference on Discrete Simulation of Fluid Dynamics
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A moment-based regularized lattice Boltzmann method with triangular sub-cells for inclined and curved boundaries

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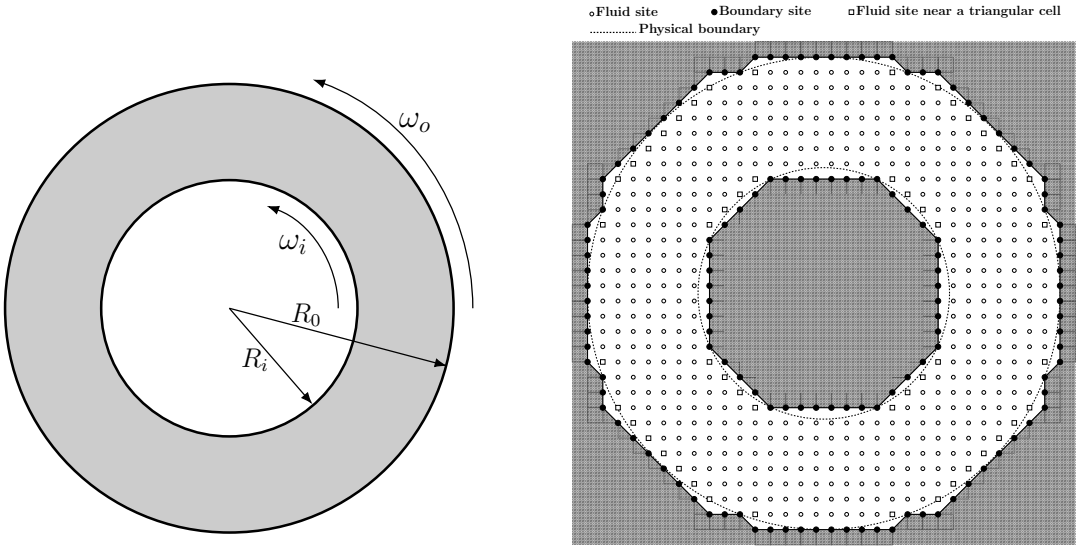
Classification: 01-B Lattice Boltzmann Methods, Numerical Analysis
Keywords: Boundary conditions; Curved boundaries; Moment-based regularization.

In the standard D2Q9 lattice Boltzmann formulation, lattice sites are associated with Cartesian quadrants possessing complete lattice connectivity. For inclined or curved geometries, however, this Cartesian construction inherently produces a staircase-like boundary representation. We develop a moment-based regularized lattice Boltzmann method that departs from this conventional description by introducing triangular sub-cells at boundary-adjacent sites. Replacing the staircase-like Cartesian cells near the boundary with triangular sub-cells significantly reduces geometric discretization errors while preserving consistency with the underlying D2Q9 lattice structure. In addition, following the boundary treatment introduced in our previous work [1], the local wall inclination is explicitly incorporated into the boundary conditions, allowing the imposed hydrodynamic constraints to reflect the actual boundary orientation rather than its Cartesian approximation. Because fluid sites adjacent to the boundary are associated with triangular sub-cells, they may exhibit incomplete lattice connectivity due to missing neighboring sites. Nevertheless, the hydrodynamic state at these sites is consistently reconstructed from the available stencil information through a moment-based regularization procedure, preserving both accuracy and numerical stability.



(a) (b)

Figure 1: Computational setup for Taylor–Couette flow in a concentric annulus: (a) schematic representation of the annulus geometry and (b) Cartesian grid showing the piecewise-linear representation of the curved boundaries.

The resulting formulation provides a near-wall treatment that is consistent with the actual boundary geometry and with the underlying physics, improving the prediction of boundary-sensitive quantities such as surface forces, wall shear stresses, and boundary-layer dynamics. The accuracy and robustness of the method are assessed using a hierarchy of benchmark problems. For inclined planar Couette flow, the method accurately recovers the analytical velocity and pressure distributions, as well as the wall shear stress. For Taylor–Couette flow in a concentric annulus, it accurately reproduces the principal flow characteristics in a curved geometry. The computational setup for this problem is presented in Fig. 1: the annulus geometry is shown in Fig. 1a, while the corresponding Cartesian grid and the piecewise-linear representation of the curved boundaries are shown in Fig. 1b. Finally, for external flow past a circular cylinder, the predicted drag and lift coefficients are in close agreement with reference data. The numerical results demonstrate that the proposed method retains second-order accuracy while substantially reducing the geometric errors associated with staircase boundary representations.

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35th International Conference on Discrete Simulation of Fluid Dynamics
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Conservative Volumetric Regularized Boundary Conditions for LBM modelling of Internal Compressible Aerodynamic Flow

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Classification: 01-K Lattice Boltzmann Methods, Compressible Flows
Keywords: Lattice Boltzmann Methods (LBM); Boundary conditions; mass conservation.

Accurate wall treatment remains a major challenge in lattice Boltzmann method (LBM) simulations of internal flows, particularly for complex geometries. Nodal approaches, where near-wall density is updated using bounce-back–equivalent schemes, although mass-conservative [1], are generally limited to configurations with prescribed zero wall velocities and weak near-wall gradients, which makes their extension to wall-law modelling difficult due to the lack of consistent near-wall stress and velocity reconstruction. High velocities in these regions lead to spurious pressure oscillations and reduced accuracy. In this work, we propose a conservative volumetric regularized boundary condition (VRBC), which departs from traditional nodal formulations by introducing a volumetric density treatment for nodes associated with boundary-cut cells. Mass conservation is ensured through a volumetric reconstruction of mass fluxes inspired by volumetric LBM formulations [2]. This approach is combined with a consistent reconstruction of equilibrium and non-equilibrium distribution functions to control shear stress near the wall. The method significantly reduces spurious oscillations in density and velocity fields and mitigates the staircase effect in complex geometries. Validation on isothermal test cases, including inclined Poiseuille and Couette flows, demonstrates improved accuracy and stability of macroscopic fields compared to bounce-back–equivalent schemes (Fig. 1), especially under strong wall-induced gradients. Finally, the approach is intended to be extended to compressible flows using a hybrid lattice Boltzmann–finite volume (LBM–FV) formulation for total energy conservation.

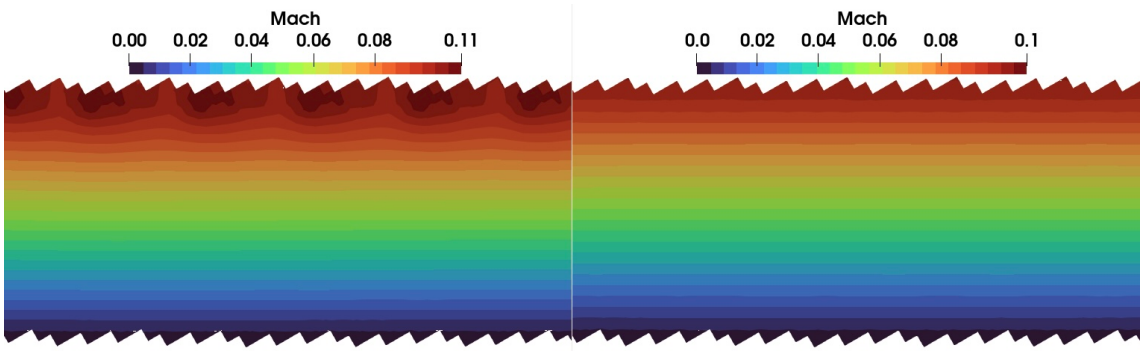

Figure 1: Mach number field of 30° inclined Couette. **Left** is the base scheme, **right** is VRBC.

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A Lattice Boltzmann Approach to the One-Fluid Formulation of Multiphase Flow

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Classification: 01-I Lattice Boltzmann Methods, Multiphase Flows
Keywords: Lattice Boltzmann, Galilean invariance, multiphase flow, One-fluid model

The lattice Boltzmann method (LBM) has become a widely adopted computational framework for simulating multiphase flows, offering algorithmic simplicity, natural parallelism, and an efficient treatment of interfacial dynamics. Despite its success, standard LBM formulations on common discrete velocity lattices exhibit well-known deficiencies that can compromise the accuracy and physical fidelity of simulations, particularly at finite Mach numbers and in the presence of moving interfaces. Addressing these deficiencies is essential for extending the reliability and applicability of the method to a broader class of practically relevant flow configurations.

This work builds upon the lattice Boltzmann formulation of the one-fluid model proposed by Reis [1], in which surface tension is encoded through a capillary tensor embedded directly in the equilibrium momentum flux. This construction ensures that the interfacial physics, described through a continuum surface force approach, enters naturally at the kinetic level rather than as an external forcing term. Under the Chapman–Enskog expansion, the model recovers the multiphase Navier–Stokes equations together with an equation governing the evolution of the phase field, providing a thermodynamically consistent and computationally efficient description of two-phase flow.

Building on this foundation, the present work is concerned with the systematic investigation and improvement of the framework, with the dual aim of reducing numerical artefacts and improving the frame-independence of the simulated flow. Motivated by theoretical analysis of the recovered hydrodynamic equations, we identify the origins of key error sources in the model and develop targeted modifications to address them. The effectiveness of these modifications is assessed through carefully designed benchmark tests that isolate specific aspects of the model's behaviour and allow rigorous quantitative comparison between formulations.

The broader goal of this work is to contribute towards a more accurate, robust, and physically consistent multiphase LBM, with relevance to applications involving droplet dynamics and interfacial flows.

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35th International Conference on Discrete Simulation of Fluid Dynamics
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Effective stresses analyses in unsaturated granular material via multifluid LBM-DEM coupling

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Classification: 01-I Lattice Boltzmann Methods, Multiphase Flows
Keywords: Multiphase LBM-DEM; unsaturated soils; effective stress.

Building on previous work comparing multiphase Lattice Boltzmann Method (LBM) models for unsaturated granular materials [1], we develop a coupled LBM–Discrete Element Method (DEM) framework to investigate effective stress in partially saturated granular systems. The gas and liquid phases are modeled using an in-house multiphase Shan–Chen LBM, while particle dynamics are resolved using the open-source DEM solver Yade [2]. Two-way coupling is achieved using a momentum exchange method, with particles initially represented as spherical. The framework enables direct resolution of fluid distribution within the pore space, allowing computation of capillary forces arising from surface tension and suction (defined as the difference between gas and liquid pressures, respectively u_a and u_w). These forces play a central role in the effective stress (σ') of unsaturated soils, where Bishop's parameter χ [3] is commonly introduced, as shown in Eq. 1. This term is employed specifically for unsaturated media, not being present for fully saturated materials, context in which the concept of subtracting water pore-pressure (u_w) from total stress (σ) was initially developed. Because of that, Bishop's factor remains poorly understood in terms of its dependence on saturation, permeability, and grain-scale properties.

$$\sigma' = \sigma - u_a + \chi(u_a - u_w) \tag{1}$$

Preliminary results of this study demonstrate stable coupling between the methods and consistent fluid–particle interaction. The ongoing work focuses on quantitative analysis of capillary effects and their contribution to effective stress, in an environment in which grains are allowed to move. The proposed approach provides a pore-scale numerical tool for investigating unsaturated granular materials, with future applications in unsaturated geotechnical systems such as slopes, pavements, and tailings storage facilities.

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Dual Roles of Microbubbles in Modulating Slip on Lubricated Surfaces

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Classification: 01-I Lattice Boltzmann Methods, Multiphase Flows
Keywords: Slip Length; Lubricated Surface; Microbubble; Lattice Boltzmann Simulation.

Reducing fluid–solid friction has emerged as a prominent research topic in recent years, and a key idea is to introduce microbubbles that can be trapped at surface corrugations. In particular, recent studies have shown that entrained microbubbles can markedly enhance the slip length of lubricated surfaces [1], providing new insights into natural drag reduction and guiding advanced engineering applications. Here, however, we demonstrate that such enhancement is not guaranteed.

Using a ternary color-gradient lattice Boltzmann method [2], we identify five types of equilibrium morphologies of microbubble-laden lubricated surfaces, depending on interfacial tension states, microbubble contact angles, and initial system configurations. When the interface between the working fluid and the lubricated surface develops appreciable roughness, the slip length (l_s) can become extremely small, as shown in Figure. 1(a). By introducing an interface roughness parameter I_r [Figure. 1(b)], we uncover a robust correlation between l_s and I_r over a broad range of hydrodynamic parameters. An explicit theoretical model that accounts for the additional resistance induced by the bulged interface is then derived, providing a quantitative explanation for the observed l_s-I_r correlation. Our findings reveal the dual role of gas components and provide important guidelines for the design of slippery lubricated surfaces.

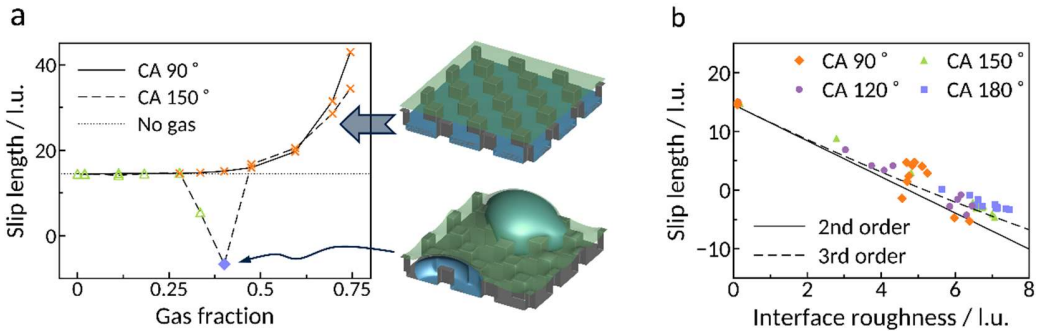

Figure 1: (a) Slip length vs gas volume fraction; gas-free case included. Insets show flat/rugged lubricated interfaces. (b) Simulation vs derived second/third-order theoretical solutions.

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Bimodal drop motion

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Classification: 01-I Lattice Boltzmann Methods, Multiphase flows
Keywords: Wetting; Heterogeneous surfaces; drop Dynamics.

Drop motion on solid surfaces is governed by capillary and viscous forces. Both of these forces are strongly influenced by surface heterogeneities, making it difficult to predict the speed at which the drop moves. Surface heterogeneity is a property that can be designed for, whether it is topographical to enhance hydrophobicity [1] or chemical and/or topographical to control drop motion [2]. An important consequence of surface heterogeneity is the different wetting states a drop can adopt. It was recently suggested by Laroche et al. [1] that modifying drop shape, and consequently the wetting state, on topographically patterned surfaces alters the static friction for drops, while the dynamic friction always converges to the same behaviour independent of the drop history.

In contrast, here we show that drop dynamic friction is not unique and is dependent on the drop dynamic state. To demonstrate this, we investigate drop motion on chemically patterned surfaces composed of hydrophilic and hydrophobic patches using a well-balanced lattice Boltzmann scheme, which benefits from low spurious velocity at the interface [3]. By varying the initial drop configurations, we get different wetting states and these states then evolve dynamically in a symmetric or asymmetric mode as shown in Figure 1.(a, b) respectively. For drops of equal volume, we show that the drop speed can vary significantly as shown in Figure 1.(c), with the symmetry of the drop motion emerging as the key determiner of how fast the drop moves. In particular, drops exhibiting symmetric motion travel significantly further than those exhibiting asymmetric dynamics as shown in Figure 1.(c). These results demonstrate that drop dynamic friction is multimodal and history dependent. They also provide insights why seemingly identical drops can exhibit different velocities on the same surface.

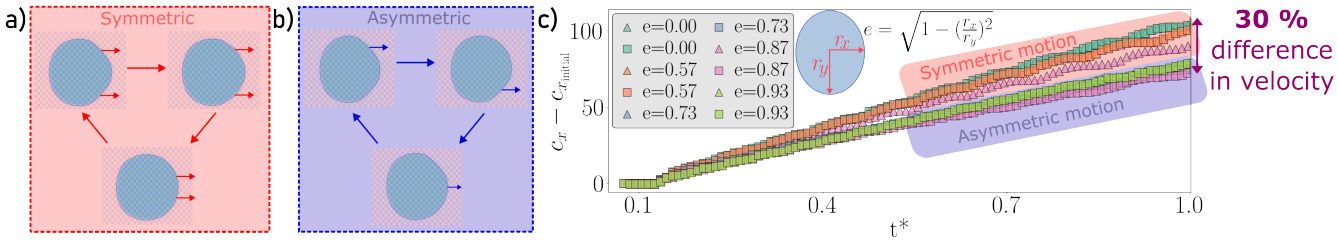

Figure 1: Schematic of drop configurations and displacement over time. (a) Symmetric drop motion cycle, (b) asymmetric drop motion cycle, and (c) displacement of centre of mass along x-axis over time for different wetting states.

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Artificial Slip in the Bounce-Back Boundary Method: Where Does It Come and Can It be Eliminated?

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Classification: 01-A/B Lattice Boltzmann Methods, Mathematical Modeling, Numerical Analysis
Keywords: LBM, BGK, Bounce-back, Boundary Slip, Channel Flow

The artificial slip of simulated flows over boundaries has been well noticed in lattice Boltzmann calculations with the classical bounce-back boundary method. Extensive research has been conducted to investigate this phenomenon and explore the relationship between the slip magnitude and the simulation parameters (especially the relaxation time τ). In this study, we derive the bounce-back formulation based on the collision and propagation processes in the lattice Boltzmann method (LBM), and point out the assumptions involved during this derivation process. By re-introducing the neglected terms back with these assumptions removed, the artificial velocity slip in a demonstration channel flow can be gradually eliminated, and the simulated velocity profile can match the theoretical solution perfectly (subjected to the machine precision), even with the relation time τ up to 10 times of the simulation time step Δt. Furthermore, those neglected terms in the bounce-back method are also responsible for the mass leakage and non-physical velocity in a hydrostatic system. Regretfully, including these neglected terms causes numerical instability in realistic simulations and thus is not practical useful. Nevertheless, the analysis and demonstrations could be interesting for future development or improvement of LBM boundary methods.

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A Mesoscopic Lorentz-Force Formulation for Lattice Boltzmann MHD

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Classification: 01-G Lattice Boltzmann Methods, Electromagnetic Hydrodynamics
Keywords: High-Order Lattice Boltzmann; Magnetohydrodynamics; Transport Coefficients; Plasma Physics.

Although plasma consists of an ionized gas, its behavior can differ significantly from that of conventional fluids. Depending on the ratio between the mean free path and the Larmor radius, different transport regimes may arise [1]. In strongly magnetized regimes, where the Larmor radius becomes comparable to or smaller than the mean free path, the electromagnetic field influences not only the macroscopic dynamics through the Lorentz force, but also the microscopic transport of momentum and energy. In particular, transport coefficients such as viscosity and thermal conductivity become anisotropic and depend explicitly on the magnetic field strength [2]. In this work, we propose a numerical method for an ionized gas in the magnetic regime based on the high-order multispeed Lattice-Boltzmann approach proposed by Surmas *et al.* [3].The model is developed from the Boltzmann-BGK equation through a third-order expansion of the force term in the peculiar velocity and a suitable quadrature-based discretization combined with a semi-implicit time integration scheme [4, 5]. Owing to the velocity dependence of the magnetic force term, the semi-implicit formulation results in an implicit linear system for the macroscopic velocity, which is analytically inverted to obtain an explicit expression for the velocity. The resulting Lattice-Boltzmann equation is analyzed via a Taylor series expansion, demonstrating that both viscosity and thermal conductivity depend on the applied magnetic field. This dependence is verified through simulations of the shear wave, and the method's robustness is further confirmed by simulations of the Orszag-Tang vortex and Hartmann flow.

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A low-cost Gauss-Hermite Quadrature Implementation for mhddugksFoam

Diogo N. Siebert[1], Garbriel M. F. Roberto[1], Juan P. L. C. Salazar[1], and Luis O. E. dos Santos[1]

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Classification: 07-G Gas-Kinetic Schemes and Traditional CFD, Numerical Analysis
Keywords: Discrete Unified Gas Kinetic Scheme; Magnetohydrodynamics; Gauss-Hermite quadrature.

The Discrete Unified Gas Kinetic Scheme (DUGKS) was first proposed for low-speed isothermal flows [1] and later extended to compressible flows [2]. Recently we enhanced an existing OpenFOAM implementation (dugksFoam) [3] to enable the simulation of MHD flows, by adding a force term to the Boltzmann-BGK equation, which when integrated over the second order moment yields the Maxwell stress tensor. The induction equation for the magnetic field is solved using the macroscopic velocity and density field values computed by the DUGKS algorithm. This approach is implemented in a new solver (mhddugksFoam), which allows us to simulate the one-fluid, one-temperature plasma model over the entire Knudsen number regime. In addition, we now implement a more efficient quadrature-based discretization in velocity space based on previous work [4]. Gains in computational cost over the existing discretization are quantified for cases in both continuum and rarefied regimes, showing that there is no loss in accuracy.

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Relaminarization patterns in magnetohydrodynamic pipe flows using a simplified lattice Boltzmann approach

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Classification: 01-G Lattice Boltzmann Methods, Electromagnetic Hydrodynamics
Keywords: Magnetohydrodynamics; Relaminarization; Lattice Boltzmann method.

Magnetohydrodynamics (MHD) governs electrically conducting fluids and plasmas in natural and industrial contexts. In industrial applications, the magnetic Reynolds number R_m is typically below 10^{-2}. For lattice Boltzmann simulations, numerical difficulties have restricted most studies to magnetic Prandtl numbers near unity, where magnetic and kinetic time scales are comparable. This work uses a simplified lattice Boltzmann approach [1] combined with an explicit immersed boundary method to simulate MHD flows with curved boundaries over a range of magnetic Prandtl numbers. GPU-based parallel simulations are performed to reach fully developed turbulent pipe flow. The effect of the magnetic Prandtl number on the energy balance is examined under uniform and non-uniform magnetic fields. The non-uniform configuration is relevant to limescale formation in oil industry applications and is described in detail. The objective is to quantify the influence of varying magnetic Prandtl numbers and non-uniform fields on the process of relaminarization (shown in Figure 1) and on coherent structure formation. The proposed method is a suitable tool for this analysis.

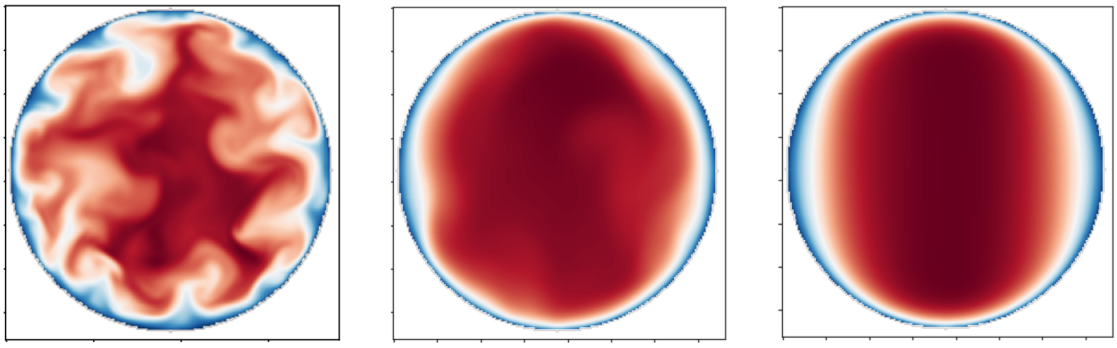

Figure 1: Cross-sectional velocity fields in a pipe flow under a transverse magnetic field for Hartmann numbers $Ha = 0$, $Ha = 15$, and $Ha = 20$ (from left to right). Complete relaminarization of the flow is observed as Ha increases.

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Using Lattice Boltzmann to Inform Graph Diffusion Networks for Aerodynamic Design Exploration

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Classification: 01-M Lattice Boltzmann Methods, Machine Learning for Fluid Mechanics
Keywords: Graph neural networks; Diffusion models; Aerodynamic Shape Optimisation; Surrogate Modelling; Lattice Boltzmann Method.

High-fidelity aerodynamic shape optimisation is limited by the computational cost of repeated CFD evaluations. We present a graph-based generative framework for inverse aerodynamic design, trained on data produced by Lattice Boltzmann Method (LBM) simulations.

Aerodynamic meshes are represented as graphs $\mathcal{G} = (V, E)$, where nodes encode geometric and flow-state features and edges encode spatial connectivity. This representation mirrors the mathematical structure of LBM: the streaming step propagates distribution functions along discrete velocity directions, a local neighbourhood operation formally equivalent to GNN message passing, while the BGK collision step maps directly onto a GNN node update function.

Building on this correspondence, a Diffusion Graph Network (DGN) adapted from Lino et al. [1] models the joint distribution of flow fields and design geometries using a denoising diffusion probabilistic model (DDPM) parameterised by a multi-scale GNN. The LBM solver provides efficient, high-resolution training data across a broad design parameter space. Conditioning on target freestream parameters and aerodynamic performance enables stochastic sampling of novel candidate geometries, performing inverse design without repeated high-fidelity solver evaluations.

The poster aims to demonstrate accurate in-distribution sampling of flow fields and geometries, see Figure 1, as well as discuss the use of GNNs coupled with LBM for design exploration.

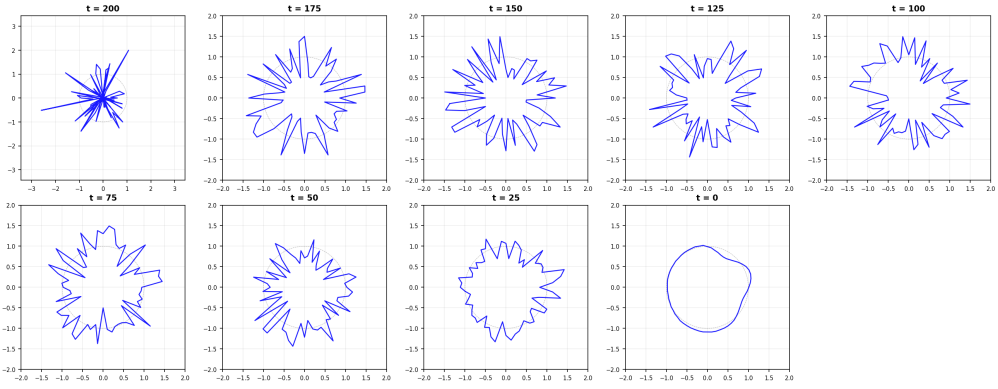

Figure 1: Overview of the reverse graph diffusion process: from random noise, to in distribution design.

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Spontaneous rotation and propulsion of suspended capsules in active nematics

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Classification: 01-I Lattice Boltzmann Methods, Multiphase Flows

We investigate the dynamics of elastic capsules suspended in two-dimensional active nematic fluids using lattice Boltzmann simulations. The capsules, modeled as flexible membranes enclosing active internal regions, exhibit a rich variety of behaviors shaped by their geometry and the interplay between internal and external activity. Circular capsules with active interiors undergo persistent rotation driven by internally confined $+1/2$ topological defects. Axisymmetric capsules, such as boomerangs, develop directed motion along their axis of symmetry due to unbalanced active forces generated by defect distributions near their boundaries. We further show that capsule flexibility suppresses motility and rotation, as active stresses are dissipated into shape deformations. These findings reveal how shape, deformability, and defect dynamics cooperate to produce emergent motility in soft active matter, with potential applications in the design of microswimmers and drug delivery vehicles.

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A Digital Twin of Subsea Mechanical Dispersion Experiment

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Classification: 09-I Others, Multiphase Flows
Keywords: Digital twin; oil spill; subsea mechanical dispersion; multiphase flow; numerical simulation.

Laboratory experiments are fundamental for advancing the understanding of subsea mechanical dispersion (SSMD), enabling controlled investigation of droplet breakup, turbulence-driven mixing, and near-field plume behavior under reproducible conditions. To enhance the scientific value and interpretability of these experiments, this study presents a digital twin of the SSMD experiment, explicitly designed to operate in parallel with laboratory measurements and evolve continuously as data are acquired. The digital twin concept is illustrated in Fig. 1, which depicts the bidirectional data bridge between the Physical SSMD experiment and its Computational SSMD counterpart.

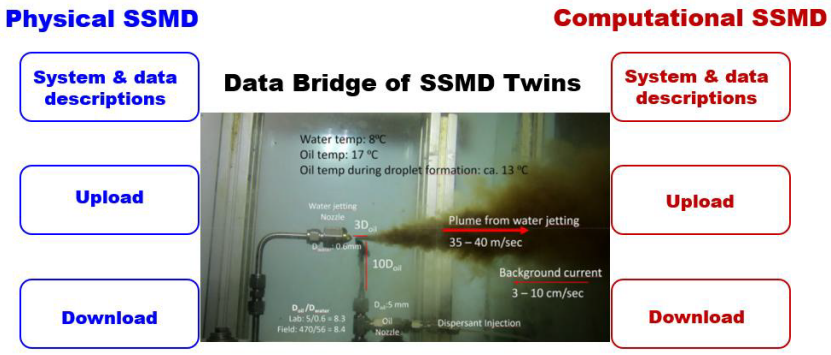

Figure 1: Conceptual illustration of digital twin technology applied to a SSMD experiment [1]. A physical laboratory experiment and its computational counterpart are connected through continuous data exchange, enabling real-time interaction between observations and simulations.

On the physical side, the laboratory system is fully characterized through system and data descriptions, including release geometry, fluid properties, flow rates, temperature conditions, and mechanically induced turbulence. High-resolution experimental data — such as droplet size distributions, plume morphology, jet velocities, and background currents — are acquired using optical imaging and flow diagnostics and are uploaded to the digital twin in near-real time. Within the computational SSMD, these data streams are assimilated into physics-based multiphase flow and breakup models that reproduce laboratory conditions with explicit representation of mechanical energy input and turbulence scales. Model outputs, including predicted droplet sizes, plume spreading rates, and mixing efficiencies, are then downloaded back to the experimental domain for direct comparison with observations. This continuous upload–download cycle establishes an operational data bridge that synchronizes the physical experiment and its digital representation. A key contribution of this laboratory-focused digital twin framework is its role as an experimental companion rather than a post-processing tool. Discrepancies between measured and simulated behavior are identified as experiments progress, enabling real-time model calibration, uncertainty quantification,

and informed adjustment of experimental parameters. The digital twin also supports experimental design by identifying sensitive variables, optimal operating ranges, and measurement gaps requiring higher resolution. By embedding digital twin technology directly into the laboratory workflow, the proposed framework transforms traditional mechanical dispersion experiments into adaptive, data-rich systems. The approach strengthens reproducibility, accelerates model validation, and provides a scalable pathway for translating laboratory results to field-relevant subsea scenarios. More broadly, the work demonstrates how tightly coupled physical–computational twins can advance experimental fluid mechanics and multiphase flow research in controlled laboratory environments.

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Mapping an Ising model onto lattice Boltzmann

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Classification:
08 Hybrid Methods I Multiphase Flows
Keywords: Ising Model; Lattice Boltzmann; Lattice Gas; Coarse Graining.

The Ising model is the simplest system in statistical mechanics that shows phase separation. We are here concerned by its incarnation as a lattice gas, i.e. a system in which particles are conserved. It consists of particles that reside on a lattice with at most single occupancy for each lattice site and an interaction between particles that are on neighboring lattice sites. This model can be considered a fundamental model for phase-separating systems.

It was originally designed to anlyze the equilibrium behavior of such a system, but it also allows to examine dynamics from an initial state, by defining a dynamics that is consistent with the correct equilibrium behavior. A typical example of such an evolution is given by picking particles at random and attempting to move them to a neighboring site. If such moves are accepted when it reduces the energy or with a probability given by the Boltzmann factor it can be show to recover the correct equilibrium behavior.

Since such updates are inherently sequential it is not obvious how to represent this evolution as a lattice gas, or the average evolution as a lattice Boltzmann method. Here we show a first approach to map the Ising model onto a lattice gas, an approach very similar in concept to the MDLG approach [1]. The key to developing a correct lattice Boltzmann collision operator is to understand the probability for the displacement of particles. Doing so we were able to derive a novel lattice Boltzmann approach for the Ising model.

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A low-memory phase-field moment representation lattice Boltzmann method for multiphase flows with large density and viscosity contrasts

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Classification: 01-I Lattice Boltzmann Methods, Multiphase Flows
Keywords: Multiphase lattice Boltzmann method; Moment representation; Conservative Allen–Cahn;

We present a memory-efficient phase-field lattice Boltzmann framework for incompressible immiscible two-phase flows with large density and viscosity contrasts. The proposed method is a cross-fertilization between a velocity-based conservative Allen–Cahn lattice Boltzmann formulation for interface capturing [1] and the moment representation lattice Boltzmann method [2], in which the hydrodynamic state is encoded in low-order moments, enabling a low-storage formulation where regularized distribution functions are reconstructed on demand rather than stored as primary variables.

Hydrodynamics are described in terms of the zeroth-, first-, and second-order moments, which constitute the fundamental variables of the method and from which second-order regularized distribution functions are locally reconstructed to recover the kinetic dynamics. These moments correspond to the pressure, velocity, and stress contributions of the underlying populations f_i, with the hydrodynamic velocity obtained through a half-force correction.

The interface is represented by a phase field $\phi \in [0, 1]$, defined as the zeroth-order moment of a second population set g_i and evolved through a conservative Allen–Cahn formulation combining advection–diffusion with a conservative compressive term to counteract interfacial smearing. By relaxing the non-equilibrium part of g_i with unit relaxation time, ϕ becomes the only additional state variable required for the phase-field dynamics, as advection is driven by the hydrodynamic velocity field. The phase field provides the local density and kinematic viscosity through affine interpolation between bulk-phase values. The body force is decomposed into capillary, pressure-recovery, variable-viscosity, and, when applicable, buoyancy contributions. The capillary term represents surface tension forces and is obtained from the phase field through the chemical potential, whereas the remaining terms arise from the hydrodynamic formulation.

Validation was carried out using three-dimensional benchmark problems. The static droplet test assesses Laplace pressure recovery and spurious currents, while the Rayleigh–Taylor instability probes interface evolution across different Reynolds and Weber numbers.

Memory requirements were shown to be significantly reduced relative to conventional multiphase lattice Boltzmann formulations, owing to the minimal-state structure inherited from the moment representation and preserved in the present phase-field extension.

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Lattice Boltzmann simulations of capillary invasion

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Classification: 01-B Lattice Boltzmann Methods, Interfacial Phenomena
Keywords: Lattice Boltzmann Method; Capillary invasion; Wetting dynamics.

Capillary invasion in cylindrical tubes is a classical benchmark for studying wetting-driven flows and remains highly relevant for the validation of pore-scale numerical methods. In this work, the capillary invasion process is investigated by means of the Lattice Boltzmann Method (LBM), with emphasis on the transient evolution of the invading meniscus. The simulations are used to evaluate the ability of LBM to reproduce the dynamics of spontaneous invasion under conditions in which capillary, viscous, and inertial effects compete.

The numerical results are compared with predictions obtained from the Bosanquet equation[1], which provides a simplified theoretical description of capillary penetration by accounting for both inertial and viscous contributions. Particular attention, however, is devoted to comparison with experimental data available in the literature[2],[3], which constitutes the main reference for assessing the physical consistency of the simulations. This combined analysis allows the identification of regimes in which the Bosanquet model is adequate and of situations in which deviations arise due to interfacial effects not captured by simplified analytical approaches.

A central aspect of the study is the dynamic variation of the contact angle during the invasion process. Instead of assuming a constant static contact angle, the work investigates how the apparent contact angle evolves in time and how this variation influences the invasion rate and the meniscus position. The results indicate that dynamic contact-angle effects may play a decisive role in reconciling numerical predictions with experimental observations, especially during the early and intermediate stages of invasion.

By combining LBM simulations, Bosanquet-based analysis, and experimental data from the literature, this work contributes to a better understanding of capillary invasion dynamics and to the validation of LBM as a reliable tool for the study of wetting-controlled flows in capillary systems.

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A Brinkman penalization Lattice Boltzmann Method simulation of the flow over a porous backward-facing step

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Classification: 01-E Lattice Boltzmann Methods, Flows in Porous Media
Keywords: Brinkman penalization; Turbulence; Backward-facing step.

Flows at the interface of a porous medium are commonly found in nature and thus make up for numerous applications in areas such as geophysics, chemical engineering and meteorology. However, this kind of flows is particularly difficult to study because of the large range of scales involved, which lead to a significant computational cost if all scales down to the pore size are to be resolved. Instead, upscaling methods can be used that only consider the flow on a macroscopic, pore-averaged scale. In the one-domain approach, or Brinkman penalization method, one considers a single equation in the whole domain by introducing a forcing term in the porous region, which can readily be implemented in a Lattice Boltzmann Method (LBM) framework [1]. The LBM is a particularly attractive candidate as a Brinkman penalization solver, thanks to its efficiency for massively parallel computing. In addition, its inherent weakness in the difficulty to resolve high velocity gradients, as a result of a homogeneous cartesian mesh, is also irrelevant for upscaled approaches which smooth out the boundary layers forming on the porous matrix. In this work, an in-house LBM solver working on CPU and GPU architectures is used to simulate the flow past a porous backward-facing step (BFS). A parametric study is carried out to evaluate the dependence in Reynolds number and porous medium permeability. The results are validated against the experimental data of [2] for the transitional regime. Further investigations are carried out in the turbulent regime at $\mathrm{Re} = 1150$ to characterize the influence of the porous step.

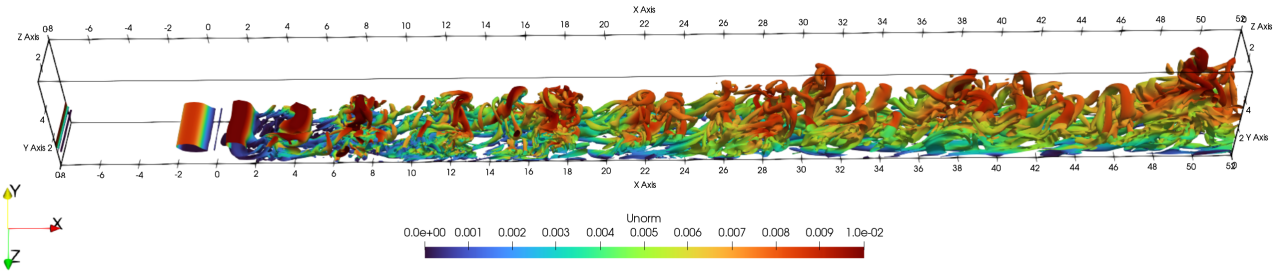

Figure 1: Iso-surfaces of λ_2-criterion colored by the norm of the velocity field at $\mathrm{Re} = 1150$. The porous insert is located at $-8 \leq x/h \leq 0$.

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Influence of Voxelization on Hydraulic Properties in DEM-LBM Modeling of Tropical Granular Soil

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Classification: 01-E Lattice Boltzmann Methods, Flows in Porous Media

Keywords: DEM; Lattice Boltzmann; voxelization; porous media; intrinsic permeability.

Intrinsic permeability and saturated hydraulic conductivity are fundamental properties governing flow in soils. Coupled modeling approaches combining the Discrete Element Method (DEM) and the Lattice Boltzmann Method (LBM) have been widely employed for flow analysis in complex porous media. In this context, voxelization resolution directly influences pore network representation and equivalent hydraulic properties, such as permeability and flow connectivity. In this work, the influence of voxelization resolution on DEM-LBM modeling of an *Ap* horizon of a medium-textured Red Latosol [1] was investigated. The granular medium was generated in the software YADE (v2022.02a) through gravitational deposition of coarse-grained particles representing sand, silt, and clay fractions, resulting in a stable packing with porosity of 0.432 and mean coordination number of 4.42. Intrinsic permeability and saturated hydraulic conductivity were evaluated in the vertical direction using voxel sizes of 1.5 mm, 1 mm, 0.5 mm, and 0.3 mm. LBM simulations were performed in the software Palabos (v2.3.0) using the D3Q19 model with the BGK collision operator, directly employing the DEM-derived voxelized geometry as a binary solid-fluid computational domain. Hydrodynamic solver validation was performed using the Hagen–Poiseuille problem in a three-dimensional channel [2]. Numerical velocity profiles showed agreement with the analytical solution for fully developed laminar flow, with errors on the order of 10^{-2} and correlation and determination coefficients close to 0.99, confirming the adequate hydrodynamic representation and boundary condition treatment by the LBM-BGK model with Bounce-Back boundary conditions. Simulations showed numerical stability and satisfactory convergence for all evaluated resolutions (dx = 0.0003, 0.0005, 0.001, and 0.0015 m), with nearly constant global porosity, low Mach numbers, and Reynolds numbers consistent with Darcy-dominated viscous flow. The results indicated high sensitivity of intrinsic permeability and saturated hydraulic conductivity to voxelization resolution, with permeability ranging from 10^{-11} to 10^{-10} m² and hydraulic conductivity from 10^{-4} to 10^{-3} m s^{-1}. Variations in pore network discretization directly modified pore-throat representation, hydraulic connectivity, and effective flow channel aperture, highlighting the strong influence of spatial resolution on the hydrodynamic response obtained through DEM-LBM modeling.

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Predicting Relative Permeability Curves Using Single-Phase Lattice Boltzmann Method

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Classification: 01-E Lattice Boltzmann Methods, Flows in Porous Media
Keywords: Lattice Boltzmann method; Relative permeability; Multiphase flow; Porous media.

Proper characterization of multiphase flow in porous media is fundamental for several applications, including enhanced oil recovery, aquifer management, and environmental engineering. Relative permeability is one of the key concepts among the phenomena, as it quantifies the mobility of a fluid in the presence of another. Conventional multiphase simulations using the Lattice Boltzmann Method (LBM), such as the Color and the Shan-Chen models, are computationally demanding. These methods require additional distribution functions to track interface evolution, significantly increasing memory demand and execution time compared to single-phase solvers. Furthermore, intrinsic pore-scale dynamics such as Haines jumps and snap-off can induce numerical instabilities that delay the convergence of effective permeability calculations.

This work proposes a D3Q19 single-phase LBM adaptation with Guo forcing scheme and BGK collision operator to predict relative permeability of known and converged saturation maps by applying a force normal to the fluid-fluid interface, cancelling velocity components in its direction. It operates under the assumption of a low capillary number ($Ca \to 0$). In this quasi-static limit, the interfacial configurations are primarily governed by surface tension and pore geometry, justifying the use of steady saturation maps as the basis for steady-state velocity field calculations. The proposed approach minimizes both the computational cost of multiphase simulations and the time required for convergence, while allowing for different viscosity ratios.

This application serves as a fast proxy for multiphase flow behavior, which is particularly advantageous for Representative Elementary Volume (REV) analyses. Since such studies require a large number of simulations across multiple subdomains, the reduced computational cost enables statistically meaningful REV assessments that would otherwise be prohibitive with conventional multiphase LBM. Saturation maps are obtained through the intersection between a morphology operator and the single-phase velocity field to maximize inlet-outlet phase connections. The normal vector is calculated using a Gaussian-filtered phase field to minimize the effects of the sharp and binarized morphological image, presenting good agreement with the diffuse phase field provided by the Color Model.

Preliminary results for 2D benchmark geometries show strong consistency between analytical or dynamic solutions and the proposed method across a wide range of viscosity ratios. The methodology significantly reduces computational overhead and eliminates time-step constraints associated with interface tracking. Ongoing work focuses on extending this framework to complex 3D digital rock samples, with further results on computational speed-up and performance in heterogeneous domains to be presented.

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Lattice Boltzmann model for free-fluid/heterogeneous-porous-media coupled systems using a mesoscopic-scale one-domain approach

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Classification: 01-E Lattice Boltzmann Methods, Flows in Porous Media
Keywords: Heterogeneous porous media; non-Darcian flow; Free-fluid/porous-medium system.

We propose a lattice Boltzmann model (LBM) on standard lattices for simulating multi-dimensional, weakly compressible, isothermal flows within and around isotropic heterogeneous porous media. The model incorporates Darcy–Forchheimer drag and a Brinkman-like effective viscous stress tensor. In the hydrodynamic limit, it recovers a generalized volume-averaged formulation valid in both free-fluid and porous-medium regions. By relying on a single kinetic equation and a monolithic LBM algorithm, the formulation provides a one-domain solver for free-fluid/porous-medium interactions.

Unlike previous LBM formulations for porous media, the proposed model recovers the correct porosity scaling of both the pressure and convective terms, while preserving the isotropy, and hence the Galilean invariance, of the viscous stress tensor. Linear and nonlinear drag, variable-porosity corrections, and additional body forces are incorporated through a consistent generalized forcing scheme. The model further allows the temperature, and therefore the speed of sound, to be specified independently, improving computational efficiency. In addition, it includes a freely tunable effective bulk viscosity that can be used to enhance numerical stability. Model performance was evaluated using 2D benchmark flow problems.

The ability of the proposed LBM model to simulate transport between free-fluid and heterogeneous porous regions within a one-domain framework enables a broad range of applications, particularly in early-stage, device-scale design studies of engineered porous structures with spatially varying porosity.

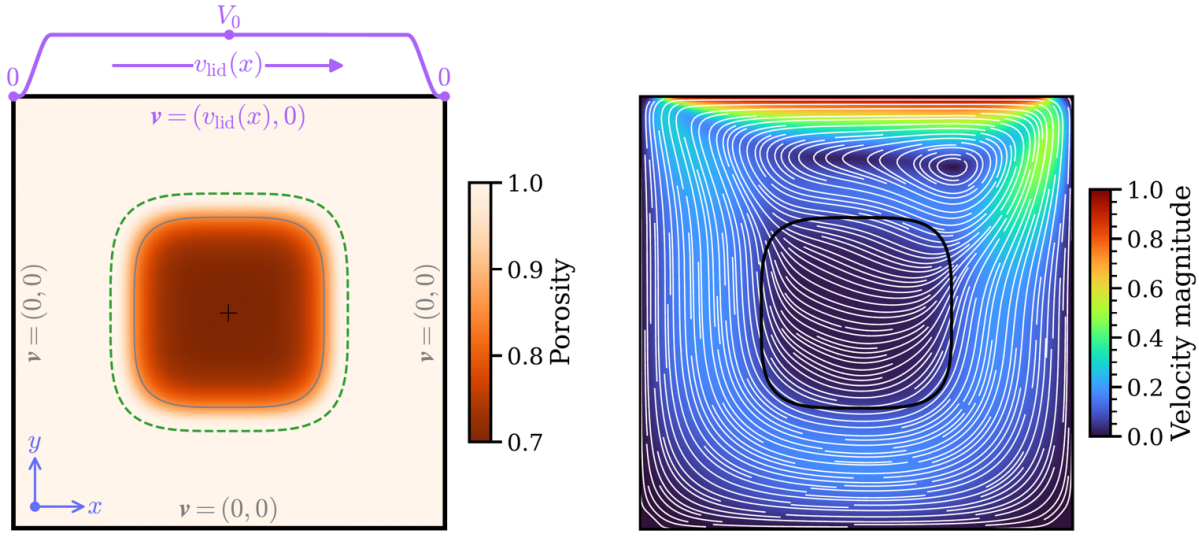

Figure 1: Lid-driven cavity flow with an internal superelliptic porous obstacle. Left: Domain geometry and boundary conditions; Right: Steady-state velocity field from simulation with proposed LBM model.

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Moment-Based GPU Implementation for Lattice Boltzmann Simulation of Non-Newtonian Fluids

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Classification: 01-B Lattice Boltzmann Methods, High-Performance Computation
Keywords: Lattice Boltzmann Method, Non-Newtonian Fluids, Advection-Diffusion Equations, GPU Computing.

Non-Newtonian fluids are present in both natural phenomena and industrial processes. Examples range from geophysical flows and biological fluids to applications in food processing, energy systems, chemical engineering, and additive manufacturing. In many of these systems, the macroscopic flow behavior is governed by the fluid's complex rheological properties. Understanding and predicting these flows therefore requires numerical tools capable of capturing nonlinear rheology across a wide range of flow conditions. Unlike Newtonian fluids, complex fluids exhibit constitutive behavior that depends on the local deformation history and/or microstructural dynamics. Such behavior appears in generalized Newtonian fluids with shear-dependent viscosity, viscoplastic materials exhibiting yield-stress behavior, thixotropic systems with time-dependent structural evolution, and viscoelastic fluids in which elastic stresses play an important role in flow dynamics. The resulting rheological effects introduce additional modeling and numerical challenges because of the coupling between the flow field and the material's internal structure.

In many cases, modeling these materials requires solving additional transport equations that describe the evolution of internal variables associated with the fluid microstructure. Examples include structural parameters in thixotropic models or conformation tensors in viscoelastic formulations. Such quantities are typically governed by advection-diffusion-reaction equations that must be solved consistently with the hydrodynamic field. Within the lattice Boltzmann method (LBM) framework, these equations can be incorporated via a double-distribution-function approach, in which separate distribution functions are used to evolve the hydrodynamic variables and the additional scalar or tensor fields. Additionally, stresses can be computed locally from moments of the distribution functions, without requiring explicit spatial derivatives or information from neighboring lattice sites. That locality is particularly desirable for GPU implementations, as it reduces memory access overhead and improves parallel efficiency.

Because multiple coupled equations must be solved simultaneously, efficient simulation of such systems is not merely advantageous but a practical requirement. Modern GPU architectures provide substantial computational throughput, yet remain constrained by memory bandwidth and capacity. Under these conditions, the use of a moment representation for the advection-diffusion equations offers an effective strategy for GPU implementations. Operating in moment space makes it possible to reduce memory usage and improve data locality, particularly on memory-constrained hardware, while preserving the flexibility required to incorporate complex rheological models.

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Just-in-time Computational Fluid Dynamics with Lattice Boltzmann Methods and OpenLB

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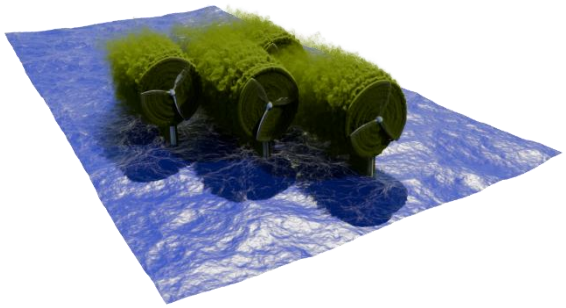
Classification: 01-L Lattice Boltzmann Methods, High Performance Computation
Keywords: Just-in-time simulations, GPU cluster; OpenLB



This talk introduces an integrated strategy for just-in-time numerical simulation and optimization of fluid flows. The approach takes advantage of kinetic model descriptions and Lattice Boltzmann Methods (LBM) as discretization strategies [1]. All resulting algorithms are implemented generically within the open-source framework OpenLB [2], enabling just-in-time simulation on hardware ranging from smartphones and workstations to the world's fastest supercomputers, such as the exascale Aurora system (Ranked #3 on TOP500, Argonne National Laboratory, USA).

We focus specifically on the design and application of these methods to address contemporary challenges in Computational Fluid Dynamics (CFD) [3]. Furthermore, we highlight LBM as a generic technique for approximating Partial Differential Equations (PDE) [4] and its implementation on heterogeneous high-performance computing (HPC) platforms. These approaches are illustrated through various fluid flow simulation and optimization examples across multiple engineering fields. Specific discussions include the simulation of particulate and turbulent flows, as well as optimal control and optimization problems.

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35th International Conference on Discrete Simulation of Fluid Dynamics
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Multi-GPU streaming with the moment representation lattice Boltzmann method

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Classification: 01-L Lattice Boltzmann Methods, High-Performance Computation
Keywords: Lattice Boltzmann; GPU acceleration; High performance computing; Parallel computing; CUDA

The Lattice Boltzmann Method (LBM) is a powerful tool for simulating complex fluid dynamics, particularly in fields like petroleum engineering. However, the computational demands of high-resolution, three-dimensional simulations necessitate high-performance computing (HPC) resources. This work details the adaptation of a moment-based LBM code [1] for execution on multiple GPUs, a crucial step for scaling to industrially relevant scales.

We focus on domain decomposition, a critical factor for parallel efficiency. Analysis of 1D slab, 2D pencil, and 3D brick decompositions shows that the 3D brick method provides the optimal asymptotic scaling. By partitioning along all three dimensions, the surface-to-volume ratio of each subdomain is minimized.

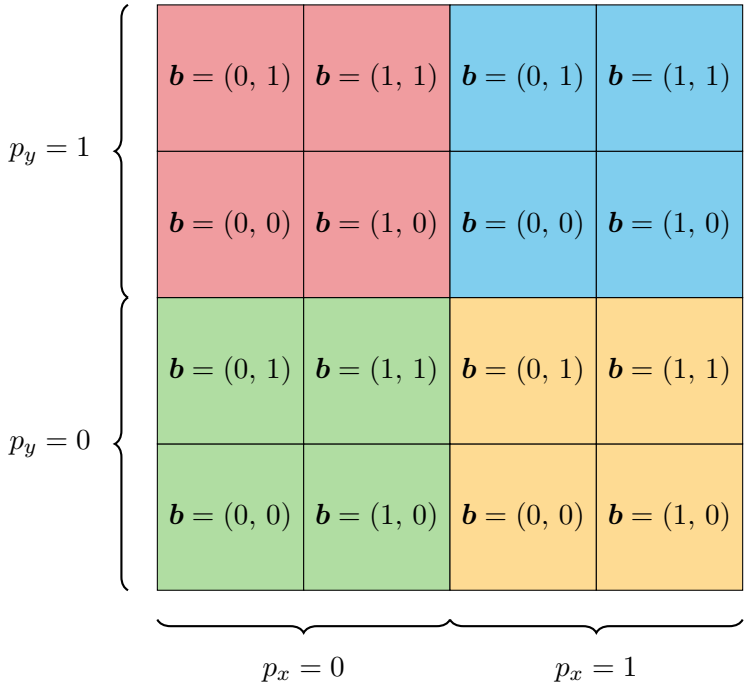

Figure 1: Multi-GPU block structure of the global lattice mesh, illustrated with a 2×2 block structure per GPU.

To support this decomposition, the global indexing scheme was fundamentally revised. The original single-GPU indexing, based on thread and block coordinates, was extended to incorporate the GPU's

position within a 3D grid of devices. The global mesh structure of a 4-device setup is illustrated in figure 1. This new scheme guarantees that each GPU's partition occupies a contiguous region in global memory, which is essential for efficient data transfers and file I/O. The generalized indexing function simplifies identically to the single-GPU case, ensuring backward compatibility.

Inter-GPU communication for the streaming step is managed through direct peer-to-peer memory transfers using `cudaMemcpyPeer`. This approach allows efficient halo exchange of boundary populations without host involvement, minimizing latency. While the initial implementation targets a single node with two GPUs using slab decomposition - where all methods are equivalent - this work lays the foundation for full 3D brick decomposition across multiple compute nodes, enabling large-scale, high-fidelity LBM simulations on modern supercomputing architectures.

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Efficient single-precision simulations of nematohydrodynamics

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Classification: 01-L Lattice Boltzmann Methods, High-Performance Computation

Simulations of nematohydrodynamics on graphics processing units (GPUs) are typically performed using double precision, which ensures accuracy but significantly increases computational cost. However, consumer-grade GPUs are optimized for single-precision calculations, making double-precision simulations inefficient on widely available hardware. In this work, we demonstrate that single-precision simulations can achieve the same accuracy as double-precision methods while delivering a 27-fold increase in the computational speed. To achieve this, we introduce two key improvements: (i) the shifted distribution function in the lattice Boltzmann method, which mitigates precision loss at low velocities, and (ii) the use of larger time steps in the finite-difference solver, which reduces numerical errors and improves the overall accuracy. We find that, unlike in double precision, accuracy in single-precision simulations follows a non-monotonic trend with respect to the finite-difference time step, revealing an optimal regime for precise computations. To illustrate the effectiveness of our approach, we simulate the dynamics of single and multiple skyrmionic tubes in Poiseuille flow. Our results confirm that optimized single-precision simulations enable fast and accurate modeling of complex nematohydrodynamic systems, making large-scale simulations feasible on standard gaming GPUs.

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Multiscale finite-volume kinetic modeling of compressible flows with arbitrary Prandtl number and specific heat ratio

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Classification: 01-07-A-K-L
Keywords: double-distribution; quasi-equilibrium; finite-volume kinetic method; parallel space-time adaptive refinement.

A consistent kinetic modeling strategy for compressible flows across all Prandtl numbers and specific heat ratios is developed using the quasi-equilibrium approach within two of the most widely used double-distribution frameworks. The methodology ensures accurate recovery of the Navier—Stokes—Fourier equations, including all macroscopic moments and dissipation rates, through detailed hydrodynamic limit analysis and careful construction of equilibrium and quasi-equilibrium attractors. Discretization is performed using high-order velocity sets with a static reference frame in a finite-volume discrete velocity Boltzmann context to isolate key modeling aspects such as strict conservation and the minimum necessary requirements on expansion and quadrature orders [1]. Extensions to high-Mach flows, strong discontinuities and hypersonic regimes are enabled by shifted and scaled reference frames. Furthermore, a space-time adaptive refinement methodology is implemented to provide high resolution where needed and reduce computational cost and memory usage in regions where coarser resolution is sufficient [2]. The methodology is complemented by local kinetic refinement sensors [3], to neatly target specific flow structures of interest, and overall ensures flexible application, full parallelism, scalability, and strict conservation.

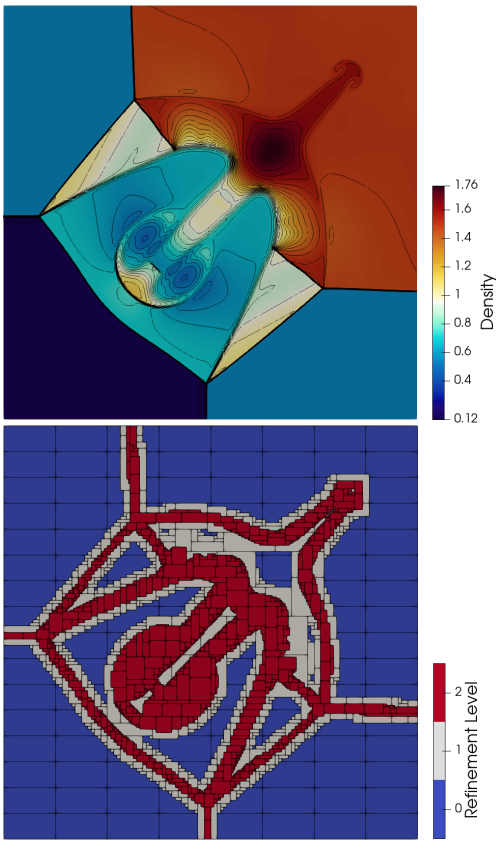

Fig.: Results of the Riemann problem No. 3 [Lax & Liu, SIAM J. Sci. Comput. (1998)] depicting density with contour lines (top) and the refinement levels in play (bottom).

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Turbulent kinetic energy budget in lid-driven cavity flow using the lattice Boltzmann method

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Classification: 01-O Lattice Boltzmann Methods, Turbulence
Keywords: LBM; Turbulent flow; High Reynolds numbers

We present a numerical study of turbulent flow dynamics in a cubic lid-driven cavity for Reynolds (Re) numbers up to 50,000, employing the moment representation lattice Boltzmann method (MR-LBM). The method is combined with incompressible regularized boundary conditions derived from second-order moment formulations, which enhances numerical stability and enables reliable simulations in high-Reynolds-number regimes where experimental data remain scarce. This framework enables a systematic assessment of the turbulent kinetic energy budget and vorticity balance, allowing a detailed examination of turbulence mechanisms and transitional flow behavior. Validation is performed through comparisons with benchmark experimental data and by verifying minimal residuals in both balance equations. The results indicate the presence of localized regions of negative turbulence production near the bottom wall, associated with complex shear-layer interactions, in agreement with previous studies. A transitional regime is identified around $Re \approx 25{,}000$, marked by an upward displacement of the peak turbulence production and dissipation toward the moving lid, along with a modification in the scaling of mean kinetic energy with Reynolds number. This behavior suggests a reorganization of energy transfer mechanisms and the strengthening of shear-driven turbulence near the lid. Within this regime, the flow displays a mixed behavior, combining features typically associated with wall-bounded turbulence and free-shear flows, which indicates a concurrent action of inertial and viscous effects.

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Direct Numerical Simulations of Viscoplastic Turbulent Flow

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Classification: 01-O Lattice Boltzmann Methods, Turbulence
Keywords: Lattice Boltzmann Method; Direct Numerical Simulation; Turbulent Flow; Viscoplastic Fluids.

We investigate the turbulent channel flow of an ideal viscoplastic fluid, a material that does not flow below a certain stress threshold, called yield stress. The ratio between the material's yield stress and the mean wall stress is kept fixed at 0.1, while the friction Reynolds number (Re_τ) varies in the range 180 to 360. A lattice Boltzmann scheme based on collision in the moment space was implemented in GPU. An outstanding characteristic of LBGK is the possibility of representing infinite viscosity by setting the relaxation frequency to zero, enabling the representation of the Bingham constitutive equation without artifacts, which produces yield surfaces with higher quality. We analyze many turbulent statistics, such as means, root mean square, Reynolds stresses, turbulent energy budgets and energy spectra, with the objective of interpreting how Re_τ may (or may not) bring the flow to a Newtonian-like behavior.

We show that unyielded portions of fluid travel along with the flow near the centerline, and we calculate the lifetime of these structures. The energy cascade decay of Newtonian fluid follows the classic $-5/3$ exponent, while the viscoplastic fluid at the same Re_τ decays at a steeper rate of $-7/2$. In general, the increase in Re_τ brings the flow statistics closer to Newtonian behavior. However, some viscoplastic features remain present in the core region, where the viscosity is very high.

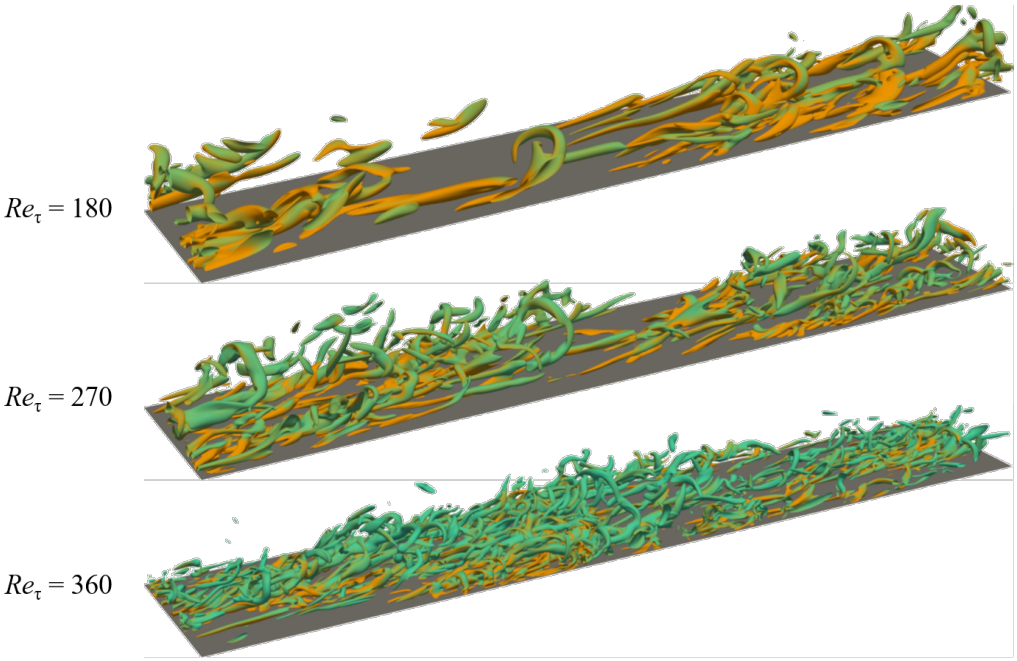

Figure 1: Isocontours of positive Q-criterion for viscoplastic turbulent flow.

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A Comparative Study of Lattice Boltzmann Methods for Structural Mechanics

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Classification: 01-P Lattice Boltzmann Methods, Fluid-Structure Interaction
Keywords: Lattice Boltzmann Method; Structural Mechanics; Linear Elasticity;

The lattice Boltzmann method (LBM) is well established in computational fluid dynamics and has recently been adapted for applications in structural mechanics. This development is motivated by LBM's inherent parallelism and its ability to handle complex geometries with comparatively low meshing effort.

While previous research has shown that the LBM can recover the governing equations of linear elasticity, the field has developed along two separate paths: displacement-based [1] and strain-based [2] formulations. This study provides the first direct comparison of these two branches. We rigorously evaluate their numerical accuracy and spatial convergence using the method of manufactured solutions (MMS). Furthermore, the formulations are validated against established two-dimensional benchmarks to assess practical performance, specifically looking at the dynamic loading of cantilever beams and the stress concentration in the plate with a hole test case compared against the exact analytical solution by [3].

All simulations are implemented in the C++ framework OpenLB [4] to ensure reproducibility. Our results show that LBM is a viable, scalable alternative for structural analysis, offering a roadmap for researchers looking for high-performance, open-source solvers.

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Constant-flux boundary condition in periodic domains for the lattice Boltzmann method

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Classification: 01-B Lattice Boltzmann Methods, Numerical Analysis
Keywords: Constant-Flux; Boundary Condition; Periodic Domain; Lattice Boltzmann method.

The present work proposes a periodic constant-flux boundary condition for the Lattice Boltzmann Method (LBM), designed to prescribe volumetric flow rates in simulations of single-phase and multiphase/multicomponent flows in complex geometries. The proposed approach combines periodic pressure formulation with the concept of volumetric flux imposition, both of which have been independently developed in the LBM literature [1, 2, 3]. This feature is particularly relevant for efficiently mimicking laboratory conditions in fluid flow experiments [4, 5], where the flow rate is controlled rather than the pressure or velocity distribution. The methodology is validated for both single-phase and immiscible two-phase flows, demonstrating consistency in maintaining the prescribed volumetric flux. Results for immiscible two-phase systems show that the approach effectively captures the interaction between viscous and capillary forces, ensuring physically meaningful flow behavior across a range of flow conditions.

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Multicomponent turbulent jet simulations using the color-gradient lattice Boltzmann method

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Classification: 01-B Lattice Boltzmann Methods, Numerical Analysis
Keywords: Turbulent multicomponent jets; Lattice Boltzmann method; Color-gradient model.

The behavior of turbulent jets has been widely studied, owing to their important role in many natural phenomena and engineering systems. When more than one component is involved, however, the flow becomes more complex than in the single-component case, owing to topological transitions driven by inertia, viscous stresses, surface tension, and buoyancy [1]. Such effects create a fragile interplay between the components, making analytical prediction extremely difficult and motivating numerical methods. Among CFD approaches, the lattice Boltzmann method (LBM) has attracted increasing attention because its mesoscopic formulation links microscopic interactions to macroscopic hydrodynamics, while its computational efficiency and natural parallelism make it suitable for large-scale simulations [2]. Nevertheless, the standard LBM still suffers from numerical instability and loss of accuracy at high Reynolds numbers, which limits its applicability to practical flows. To address these limitations, this work implements a turbulent multicomponent axisymmetric jet evolving in a quiescent immiscible environment using the color-gradient model [3] combined with a regularized BGK collision operator [4]. The simulations are performed at Re = 5000 and Weber numbers We = 10, 100, 500, and 2500, enabling the analysis of several regimes governed by the competition between inertial and capillary effects. TThe color-gradient model is adopted because of its fully mesoscopic formulation and its ability to represent immiscible fluids, while regularization enhances stability by retaining hydrodynamic nonequilibrium content and filtering higher-order numerical disturbances. Equilibrium and nonequilibrium distribution functions are reconstructed through Hermite polynomial expansions, and the formulation is coupled with a thread-safe GPU algorithm [5] in which post-collision populations are reconstructed locally from macroscopic fields. The main contributions are the development of a high-performance GPU framework and the investigation of the dynamics and breakup behavior of turbulent multicomponent jets over a wide range of flow regimes.

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A lattice Boltzmann formulation for thermo-hydrodynamic slip-flow theory

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Classification: 01-B Lattice Boltzmann Methods, Numerical Analysis
Keywords: Two-Relaxation-Time; Boundary Schemes; Slip-Flow Theory.

Many gas microflows operate in the slip-flow regime, where accurate modelling demands proper treatment of velocity slip, thermal creep, temperature jump, and near-wall rarefaction effects. Sone's generalized slip-flow theory [1] offers a rigorous macroscopic framework for this regime, derived from the Boltzmann equation, that couples fluid-dynamic equations with asymptotically consistent slip/jump boundary conditions and Knudsen-layer corrections. This work presents a unified implementation of this thermo-hydrodynamic framework within the lattice Boltzmann method (LBM), restricted to the linear (Stokes-flow) regime. Despite being frequently advocated as a natural CFD tool for rarefied microflows, LBM is susceptible to numerical artefacts whenever boundary treatments lack proper consistency [2]. The central challenge is to reproduce, at the discrete level, the asymptotic structure underlying slip-flow theory. Meeting this challenge requires two ingredients: (i) a consistent closure relation within LBM boundary schemes [2], interpreted as a Taylor-type approximation of the physical boundary condition; and (ii) a correct handling of directionality [3], whereby distinct conditions are enforced along the wall-normal and wall-tangential directions for both velocity and temperature fields. A new formulation is proposed that addresses both requirements by combining link-wise and node-wise operations within a single framework. Slip and jump boundary conditions are cast as Robin-type constraints — linear combinations of Dirichlet and Neumann contributions. The Dirichlet component is imposed through a standard link-wise construction that enforces impermeability at the wall [2, 3], while the Neumann component — encoding velocity slip, thermal creep, and temperature jump — is introduced via a local node-wise procedure [4]. This construction allows derivative information to be reconstructed locally and ensures consistency with Sone's first-order asymptotic boundary conditions [1]. In parallel, Knudsen-layer corrections are embedded directly into the LBM solution through Taylor-type representations of wall shear stress and heat flux, so that the asymptotic near-wall structure is captured within the same computational framework. The formulation is validated on benchmark problems involving planar and curved boundaries with coupled momentum and heat transfer. Results confirm that the proposed approach provides a simple, accurate, and physically consistent route for embedding thermo-hydrodynamic slip-flow theory into LBM, without recourse to external modelling strategies or more complex higher-order lattice formulations.

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