



Kinetic Simulation of Turbulent Multifluid Flows

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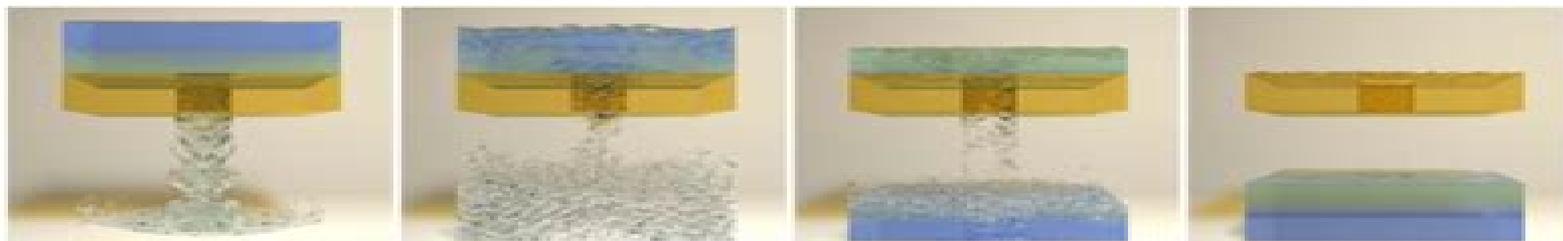


Fig. 1. **Gurgling with Rayleigh-Taylor instability:** Our multiphase solver produces gurgling for two-colored immiscible fluids in the transparent upper container and air in the bottom one (water-air with density ratios 100:100:1), with a square conduit in between. The two fluids are initially arranged with the heavier fluid (blue) on top of the lighter fluid (cyan), thus forming Rayleigh-Taylor instabilities early on, before flowing down and exhibiting splashes, bubbles and wetting, and ending up in stable layers based on their densities.

Despite its visual appeal, the simulation of separated multiphase flows (i.e., streams of fluids separated by interfaces) faces numerous challenges in accurately reproducing complex behaviors such as gurgling, wetting, or bubbling. These difficulties are especially pronounced for high Reynolds numbers and large density variations between fluids, most likely explaining why they have received comparatively little attention in Computer Graphics compared to single- or two-phase flows. In this paper, we present a full LBM solver for multifluid simulation. We derive a conservative phase field model with which the spatial presence of each fluid or phase is encoded to allow for the simulation of miscible, immiscible and even partially-miscible fluids, while the temporal evolution of the phases is performed using a D3Q27 lattice-Boltzmann discretization. The velocity field, handled through the recent high-order moment-encoded LBM (HOME-LBM) framework to minimize its memory footprint, is simulated via a velocity-based distribution stored on a D3Q27 or D3Q19 discretization to offer accuracy and stability to large density ratios even in turbulent scenarios, while coupling with the phases through pressure, viscosity, and interfacial forces is achieved by leveraging the diffuse encoding of interfaces. The resulting solver addresses a number of limitations of kinetic methods in both computational fluid dynamics and computer graphics: it offers a fast, accurate, and low-memory fluid solver enabling efficient turbulent multifluid simulations free of the typical oscillatory pressure behavior near boundaries. We present several

numerical benchmarks, examples and comparisons of multiphase flows to demonstrate our solver's visual complexity, accuracy, and realism.

CCS Concepts: • Computing methodologies → Physical simulation.

Additional Key Words and Phrases: Lattice Boltzmann method, velocity moments, turbulent flows, large density ratio, multifluid flows.

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1 INTRODUCTION

Fluid simulation in graphics has been studied for decades now, as the visual intricacy of fluid motions remains highly sought after. While airflow simulation has reached an impressive level of realism, real-world flows often involve multiple fluids (of various densities, viscosities, etc.) and air. This type of “multiphase flows” presents challenges for both Computational Fluid Dynamics (CFD) and Computer Graphics (CG), since modeling the equations of motion for mixtures of oil, gas, and water in engineering or realistically simulating bubbling and splashing for multiple fluids in visual effects remains difficult. In particular, the rare works dedicated to multiphase flow simulation in CG all come with strong limitations: current solvers often cannot efficiently handle fluids with large density ratios [Losasso et al. 2006; Mihaljeff et al. 2007; Kim 2010; Premidor et al. 2003; Müller et al. 2005; Ren et al. 2014], introduce too much numerical dissipation to handle turbulence at high Reynolds numbers [Yan et al. 2018; Yan and Ren 2023], or only apply to two-phase flows [Hong and Kim 2005; Ando et al. 2015; Li et al. 2021, 2022; Li and Desbrun 2023].

In this work, we introduce a multifluid flow simulation approach offering a unified n -phase treatment of a large variety of (im)miscible

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Advances In Multifluid Flows

Thomas Griffiths



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