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InPore: Image-based and GPU-Accelerated Volumetric Lattice Boltzmann Method for Pore-Scale Porous-media Flows with Applications

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Recently developed image-based computational fluid dynamics (ICFD) techniques have revolutionized the study of pore-scale porous media flows (PSPMFs) by allowing for simulations within realistic porous structures extracted directly from images. Pore-scale fluid dynamics delve into the fundamental physics governing flow, transport, reaction, adsorption, and deformation within heterogeneous porous materials, marking a significant leap towards establishing heterogeneous porous media flow as a standard analytical tool. The applications of this advancement are diverse and far-reaching, encompassing scenarios such as tracking chemical contaminant propagation in underground reservoirs, understanding ink permeation dynamics, modelling sedimentation processes, optimizing hazardous waste storage, and predicting fluid flow behaviours in oil reservoirs and biological tissues. Traditionally, porous media flow was approached through temporally and spatially averaged models, relying on phenomenological and empirically derived equations such as Darcy's law. However, these conventional methods often fell short in capturing the intrinsic complexity of porous media due to the lack of suitable research tools. In this context, we present InPore, a groundbreaking computational platform that employs a kinetic-based volumetric lattice Boltzmann method to solve PSPMFs within image-derived porous structures. InPore stands out for its integrated modelling approach, seamlessly combining image extraction and fluid dynamics simulation, thereby eliminating the need for additional grid or mesh generation steps and simplifying data transfer across software packages. Furthermore, InPore leverages state-of-the-art GPU (Graphic Processing Units) parallel computing technology to enable rapid and localized computations, facilitating high-fidelity simulations. During our presentation, we will showcase InPore's capabilities through application studies and discuss its integration with supplemental mechanisms such as mass/heat transfer, interfacial dynamics, and chemical reactions. These enhancements aim to broaden InPore's functionality for tackling real-world porous media flows, thereby advancing our understanding of intricate phenomena within porous materials.

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