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Next-Generation CFD for Porous Media Flows: GPU Acceleration and Physics-Informed Neural Networks

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Abstract

Porous media flows are central to a broad range of engineering and energy applications, including geothermal energy, carbon capture and storage, hydrogen technologies, fuel cells, filtration, and advanced thermal management. Despite significant advances in computational fluid dynamics (CFD), high-fidelity modelling of these systems remains computationally demanding due to complex pore-scale geometries, multiscale transport phenomena, and strongly coupled nonlinear physics. This plenary talk explores how recent developments in GPU acceleration and physics-informed neural networks (PINNs) are opening new pathways for the simulation and prediction of flow and heat transfer in porous media. GPU-enabled CFD exploits massively parallel computing architectures to substantially accelerate numerical solvers, enabling increasingly detailed pore-scale simulations and large-scale parametric studies that were previously computationally prohibitive. In parallel, PINNs incorporate governing conservation equations, constitutive relations, boundary conditions, and available data directly into machine-learning frameworks, offering promising capabilities for forward modelling, inverse problems, parameter estimation, and rapid surrogate prediction. Particular attention will be given to hybrid computational strategies that integrate high-fidelity GPU-accelerated CFD with physics-informed learning. The talk will discuss current limitations, including computational scalability, training robustness, generalisation, and physical consistency, and highlight future opportunities for developing faster, scalable, and predictive computational frameworks for next-generation porous-media flow and thermal systems.