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Exploratory computation of statistical Navier–Stokes solutions

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Global well-posedness for three-dimensional fluid flow equations remains a profound open problem. Recent efforts have shifted toward statistical solutions as a robust framework for describing turbulence, yet efficient computational tools to explore these solutions in three dimensions are scarce.

We develop novel stochastic numerical schemes to compute and analyze statistical solutions for three-dimensional incompressible flows. We combine entropy-stable lattice Boltzmann methods with Monte Carlo and stochastic Galerkin methods. By leveraging platform-agnostic development on heterogeneous high-performance computing systems, we efficiently target application-relevant flow configurations.

We present numerical results demonstrating the computational exploration of statistical solutions and their associated observables, including energy spectra, structure functions, and Wasserstein distances. Our goal is to validate the convergence of these statistical measures in regimes where deterministic simulations are nonunique. All developed methodologies are implemented in the open-source framework OpenLB to ensure public accessibility and sustainable reusability, including applications in training generative diffusion models and addressing complex engineering problems.

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