Chair of Aerodynamics and Fluid Mechanics
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Data-driven turbulence modeling with JAX-SPH

Semester Thesis/Master's Thesis

The emergence of powerful automatic differentiation (AD) libraries like TensorFlow, PyTorch, and JAX has motivated the development of differentiable computational fluid dynamics (CFD) frameworks (e.g., JAX-CFD, PhiFlow, JAX-Fluids). In scientific machine learning (ML), AD allows the discovery of novel physical and numerical models by propagating gradient information through entire numerical algorithms, i.e., ML models can be optimized *end-to-end*.

Smoothed Particle Hydrodynamics (SPH) is a Lagrangian discretization scheme for the compressible and incompressible Navier-Stokes equations (Morris et al. 1997). Although being originally devised for applications in astrophysics, SPH has gained traction in recent years as a versatile framework for simulating complex physics. Given the need for a differentiable SPH code, we have developed a high-fidelity SPH framework based on the differentiable particle simulator JAX-MD. Following this naming convection of JAX-derived codes, our AD framework is entitled JAX-SPH.

Despite the increasing popularity of SPH, turbulence modeling in SPH is not as explored as compared to mesh-based methods. However, certain SPH discretizations function as implicit subgrid-scale (SGS) models (Adami et al. 2012) and SPH exhibits statistics of turbulent flows (Ellero et al. 2010 and Borreguero et al. 2019). In this work, we want to make use of the AD capabilities of JAX-SPH and learn explicit SGS closure models for turbulent flows. Considering canonical turbulent flows, we want to explore how turbulent dynamics can be captured by data-driven methods. Especially, we are interested in what network architectures are suitable to model unresolved turbulent motions in SPH.

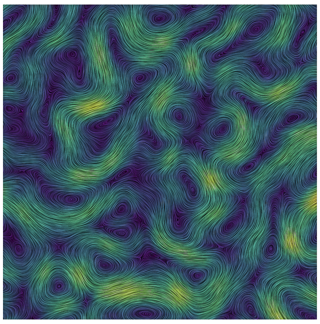

Figure 1: Two-dimensional decaying turbulence with $\mathrm{Re} = \infty$ generated with the JAX-SPH CFD code.

Tasks

- Familiarize yourself with the JAX-SPH code.
- Conduct simulations of canonical turbulent flows.
- Implement and train neural networks for data-driven SGS modeling.

Requirements

- Programming experience in Python.
- Interest in computational fluid dynamics/numerical solution of partial differential equations.
- Beneficial: Gas Dynamics, Applied CFD, Turbulent Flows, Numerical Methods for Conservation Laws.

Contact

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