6-MONTHS M2 INTERNSHIP PROPOSAL

Generative AI for reconstructing Eulerian turbulent fields from Lagrangian trajectories

Keywords : Turbulence ; Neural Networks ; Lagrangian Particles ; Generative AI; Multiscale analysis ;

1. Scientific context

Turbulence is an omnipresent phenomenon in nature, influencing a wide range of processes, such as chemical reactions, atmospheric and oceanic flows, and galactic dynamics. However, due to its multiscale and nonlinear behavior, leading to long-range correlations, non-Gaussian statistics at small scales, and intermittency, turbulence remains a significant challenge for science.

Lagrangian formalism is a promising approach to understand turbulence. It involves the analysis of the movement of fluid parcels in the flow [1]. One of the fundamental challenges in this context is that, given a set of trajectories, there are multiple possible Eulerian fields that could generate these trajectories. This ambiguity makes it essential to identify which field is most compatible with the observed data.

Today, Neural Networks are used in a wide variety of applications, including super-resolution, forecasting, and data generation. The ability of these models to capture nonlinearities and complex behaviors makes them a powerful tool for estimating the most compatible Eulerian field from trajectory data. In particular, we propose using Generative AI architecture like the Energy-Based Models [2-3] to navigate the large space of possible fields and estimate the one that best aligns with the observed trajectories, ensuring a more physically plausible reconstruction. This approach can leverage state-of-the-art neural architectures, such as transformers with self-attention mechanisms, to capture intricate multiscale interactions inherent in turbulent flows.

An application of this approach is in oceanography, where data from ocean drifters can be used to reconstruct the most compatible Eulerian fields, providing insights into ocean turbulence.

2. Specific Objectives

1. Lagrangian to Eulerian Reconstruction: Develop deep learning methods to address the challenging inverse problem of reconstructing a complete Eulerian velocity field from sparse Lagrangian observations. This involves using limited trajectory data from moving particles to estimate the full, fixed spatial flow field.

2. Estimation of Uncertainties: Use ensemble realizations and Energy-Based Models to quantify the uncertainties associated with the reconstructed Eulerian field, providing insights into the confidence and reliability of the reconstruction.

3. Eligibility Criteria

Candidates are required to be in the Master 2 (or third year engineering school) level education in the field of either applied mathematics or physics. Good knowledge of Python programming language with previous experiences in programming is required, as well as previous experience in machine learning and deep learning especially using pytorch library. Background in fluid dynamics and/or turbulence will be a plus.

4. Supervision

The internship will be advised by Carlos Granero-Belinchon and Eugenio Cutolo from IMT Atlantique and Aurelien Ponte from Ifremer. Motivated students should send a CV and a motivation letter to : carlos.granero-belinchon@imt-atlantique.fr.

References

[1] Li, T., Biferale, L., Bonaccorso, F. et al. Synthetic Lagrangian turbulence by generative diffusion models. Nat Mach Intell 6, 393–403 (2024)

[2] Granero-Belinchon, C. and Cabeza-Gallucci, M. A multiscale and multicriteria Generative Adversarial Network to synthesize 1-dimensional turbulent fields. Mach. Learn.: Sci. Technol. 5, 025032 (2024)

[3] Xie, S. -C. Zhu and Y. N. Wu, "Learning Energy-Based Spatial-Temporal Generative ConvNets for Dynamic Patterns," in *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 43, no. 2, pp. 516-531, 1 Feb. 2021,