Deep Learning extreme events in complex systems: getting dynamical systems with the right statistics

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Context In the last decade, machine learning, and more specifically deep neural networks, have thoroughly renewed the research perspectives in many fields like Natural Language Processing and Computer Vision. Acting nowadays as an army knife in countless situations, its unprecedented level of performance comes along with successful applications, making it a must-have in many engineering areas. Despite indisputable successes however, the introduction of ML approaches in physical systems remains a challenge to overcome the lack of confidence, acceptability, guarantees and explainability. This project aims at developing new Machine Learning techniques tailored to the modelling and inference of turbulence as a prototype of high-dimensional complex physical systems described by partial differential equations (PDEs).

Project For chaotic systems, instead of trying to make long-term predictions as accurate as possible on a given dataset of simulations (which does not make sense anyway given the chaotic nature of the dynamical system), we will try to **get at least the statistics correct**. That is, when generating many trajectories, do we **produce vortices at different spatial scales with the right probabilities**? Does our learned system **"look like" the real system in some statistical sense**?

This is a key point. Turbulence is multi-scale and that is reflected by a lack of self-similarity which leads to an increased probability of having very strong events at the smallest scales. We are interested notably in these rare events. The multiscale character of turbulence is clearly visible in Figure 1, where large scale vortices are present together much smaller structures within the blue "sea".

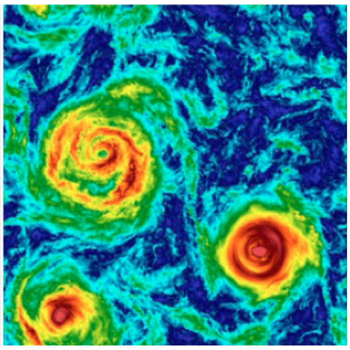

Figure 1: Slice of the velocity field extracted from a 3D turbulent stratified flow.

Challenges To tackle such an objective, we will face several challenges, including: (i) finding a suitable neural network architecture; (ii) properly designing a training criterion or ML procedure, to train toward predicting the right statistics. Indeed, making accurate short-term predictions is different

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from obtaining the right global statistics of the dynamical system, and consequently standard training criteria have to be revisited, in order to express a notion of global similarity between dynamical systems. We can we can leverage some important properties like symmetries and invariances to address these issues. The project eventually aims at developing novel architectures and structure for the machine learning of complex dynamical systems. This remains a problem yet out of reach, and its success would have an immediate impact.

The project is strongly interdisciplinary with an interplay of applied mathematics, statistical physics, fluid mechanics and informatics. Depending on the skills of the candidate, different tracks can be explored.