Proposition de stage 2024/2025

Deep learning of scale free processes

THEME: Machine learning and statistical physics
RESPONSABLE: Sergio Chibbaro, Cyril Furtlehner and François Landes
LABORATOIRE: LISN
ADRESSE: Université Paris-Saclay, 91405 Orsay Cedex
MAIL: sergio.chibbaro@universite-paris-saclay.fr, cyril.furtlehner@inria.fr, francois.landes.pro@gmail.com

1 ML and Physics Context

Machine learning models, in particular deep neural networks have shown spectacular successes in various scientific domains. In the statistical physics context many problems of interest, related to critical phenomena are associated to fractal structures, containing information at all scales. This results in notoriously difficult data to capture with standard ML methods. Determining for instance on which side of a second order phase transition is a given critical system, requires to decipher subtile signatures over a large spectrum of scales. Considering for instance 2D percolation, which is known to exhibit a phase transition at some critical density p_c, it has been observed that standard tools of image recognition are unable to reliably detect a spanning cluster close to transition for finite systems.

We see two possible reasons for this: (i) the first one is that learning a model on data which are scale free constitutes a badly conditionned optimization problem, because parameters responsible for small scale or large scale features of the model are expected to have different learning time scale, namely they should be given different learning rates; (ii) the second and non-excludive possible reason is that the detection of a spanning cluster is in principle the result of a difficult coarse-graining procedure (typically hierachical clustering) that standard NN are not able to perform automatically. In order to adress the first problem, as is usual for badly conditionned optimization problem, we could try to replace the standard gradient descent by a natural gradient one which is in principle computationally expensive, but for which there exists a simple an efficient low rank version[2]. The specificity of the coarse grained procedure is intimately related to the properties of the renormalization group (RG) procedure able to characterize the fluctuations of the critical state associated to the percolation transition. From the practical point of view, this amount to learn how the different scales are interdependant and a generative model like similar in spirit to the top-down auto-regressive model developped in [3] could offer consistent representation of the various scales, compatible with the RG procedure, which in turn could be used to make some predictions.

2 Objectives

The objective of the internship is to investigate the validity of this interpretation. Using in a first step the percolation problem as a study case the task will consist to regress from images of percolation states the size of the maximal cluster and whether it is a spanning cluster. The two advocated reasons for failure of standards NN architecture can be investigated independently.

- implement and test ANaGRAM with standard CNN architectures like U-Net or ResNet models on the percolation problem.
- learn an RG like model similar to [3] able generate the map of the maximal percolation cluster

A second and related task would be to consider different 2D conformal field theory, characterized by some fractal exponents ot their central charge and then perform the task of regression of these critical signatures from the input map of such randomly generated critical samples.

3 Practical conditions of the Internship

The stage will take place in the context of a collaboration between Ladhyx and LISN, the intern will be indifferently located at LISN or at Ladhyx.

Further reading

[1] Bayo,Honecker and Römer,"Machine Learning the 2D percolation model",journal of Physics: Conference on computational Physics (2022)

[2] Schwencke,Furtlehner, "ANaGRAM: A Natural Gradient Method for efficient PINNs learning", submitted (2024)

[3] Marchand,Ozawa,Biroli,Mallat, "Multiscale Data-Driven Energy Estimation and Generation", Phys.Rev.X (2023)