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Emulating Proton-Proton Pile-up Interactions in Particle Detectors with Conditional Flow Matching

At the Large Hadron Collider (LHC) [1] high energy proton-proton (pp) interactions, known as \textit{hard scatters}, are produced in contrast to low energy inelastic proton-proton collisions, referred to as \textit{pile-up}. From the perspective of experimental measurements, hard scatter events are processes of interest, whilst pile-up is conceptually no different from noise. Experiments, such as ATLAS [2], therefore employ an array of noise reduction techniques [3] when performing measurements. However, as the High Luminosity LHC era [4] approaches, the number of pile-up events per bunch crossing increases from 60 to approximately 200. Given that current simulations struggle to accurately model this 'noise', this miss-modelling is expected to be exponentially worse at the HL-LHC. In order to address this, \textit{Deep Generative models for fast and precise physics Simulations} (DeGeSim) endeavours to utilise deep generative image synthesis techniques to emulate calorimeter images of 'real' pile-up data collected by ATLAS at the LHC.

In this work we present the use of Conditional Flow Matching (CFM) [5] as a generative method to synthesizing calorimeter images. However, instead of seeding the generation process from Gaussian noise, Monte Carlo simulated images of pile-up are used. This is achieved by Conditional Variable Flow Matching [6], an adaption of normal CFMs, in which a Wasserstein based optimal transport solution is used to map conditioned probability paths in the flow model from one image to another. The goal is to demonstrate that Monte Carlo calorimeter images of pile-up can be changed in a minimal way to resemble real pile-up data, using image-to-image translation methods. A demonstrator will be presented using the open-source JetNet/JetClass data [7,8].

References

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Significance

This work represents the application of CVFM to ATLAS based collider physics as an image-to-image translation problem.

References

Experiment context, if any

LHC Collider Physics

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