A Deep Learning Based Hierarchical Labeling and Generative Sampling Framework for Classifying Particle Jets for Generalizable Tagging

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Jet tagging is a classification problem in high-energy physics experiments that aims to identify the collimated sprays of subatomic particles, jets, from particle collisions and 'tag' them to their emitter particle. Advances in jet tagging present opportunities for searches of new physics beyond the Standard Model. Current approaches use machine-learning techniques to uncover hidden patterns in complex collision data. However, jet tagging research has primarily focused on developing classification techniques to address individual decay channels, which narrows the spectrum of jet labels. To enable more robust searches for new phenomena, there is a need to develop a generalized jet tagging model that can accurately identify a wide range of jet types under various experimental conditions. We propose a solution that utilizes a hierarchical labeling framework to leverage state-of-the-art classifiers for each jet type while achieving generalized classification. Our framework involves two labeling steps that separate jets first by their emitter particle and then by their end-state decay particles. This approach is motivated by the fact that jet production involves both the production and decay of particles and that the properties of jets can depend on both of these factors. We incorporate deep neural network and visual transformer architectures to tag the jets, preprocessing methods used by state-of-the-art models to achieve generalized jet tagging, and a novel data generation method based on Stable Diffusion and transformer architectures to expand the size of training datasets. This solution achieves performance metrics on par with state-of-the-art models seen in more specific classification tasks while expanding the scope of classification drastically.

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