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Solving inverse problems of Type IIB flux vacua with conditional generative models

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We address the inverse problem in Type IIB flux compactifications of identifying flux vacua with targeted phenomenological properties such as specific superpotential values or tadpole constraints using conditional generative models. These machine learning techniques overcome computational bottlenecks in traditional approaches such as rejection sampling and Markov Chain Monte Carlo (MCMC), which struggle to generate rare, finely-tuned vacua. As a proof of concept, we demonstrate that conditional generative models provide a more efficient alternative, specifically using conditional variational autoencoders (CVAEs). We introduce a CVAE framework tailored to flux compactifications, incorporating physical constraints directly into the loss function —enabling the generation of physically consistent vacua beyond the training set. Our experiments on conifold and symmetric torus background geometries show that the CVAE achieves a speedup of about O(10ˆ3) compared to Metropolis sampling, particularly in narrow target ranges for superpotential values. Additionally, the CVAE generates novel, distinct flux configurations beyond the training data, highlighting its potential for probing computationally challenging regions of the string landscape. Our results establish conditional generative models as a powerful and scalable tool for targeted flux vacua generation, opening new pathways for model building in regions of the landscape previously inaccessible by traditional model building techniques.

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