Z118a Reconstructing the Primordial Density Field with Differentiable N-body Simulations

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Machine learning progresses in scientific discovery by providing new approaches to fundamental challenges in cosmology. In this study, we address the problem of reconstructing the initial density field of the universe by applying differentiable simulation techniques. More precisely, we implement pmwd (Particle-Mesh with Derivatives), an adjoint-based differentiable N-body framework, to recover the primordial density field from evolved large-scale structures at redshift z = 0 obtained from the Indra simulation. Our reconstructions show excellent agreement with target fields derived from the WMAP7 cosmological model. Moreover, through reverse time integration, we recover the density field at higher redshifts (z = 10, z = 80), revealing meaningful similarities to the expected initial conditions. With iterative refinement of initial conditions, we improve the accuracy of the forward simulations, which leads to a closer alignment with the observed density field. These results demonstrate the capability of differentiable programming in cosmological analysis and the viability of using machine learning and gradient-based optimization to extract precise initial conditions from large-scale structure data, illustrating the revolutionary role that differentiable techniques can play in advancing differentiable astronomy field.