Fast and Accurate Non-Linear Predictions of Universes with Deep Learning

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Motivation

✓ NN can indeed learn from fast approximation methods the evolution of dark matter particles outperforming analytical methods.

Goal

✓ Improvement of this methodology by using high resolution and full N-body simulations for universes with different cosmological parameters.

Types of cosmological simulations

✓ N-body
  ▪ Brute force method;
  ▪ Computationally expensive.
✓ Linear Theory
  ▪ ZA, 2LPT;
  ▪ Ideal for large-scales, small matter density.
✓ Fast Approximations
  ▪ Resolves well small-scale issues;
  ▪ COLA, L-PICOLA.
✓ Neural Networks
  ▪ Outperform Linear Theory and Fast Approximations;
  ▪ Need a dataset for training.

The Model

Inputs
Linear displacement field from initial conditions of N-body simulations.

Loss
Combination of Displ. and Density field

Targets
N-body displacement field after non-linear evolution of particles from Qijie Saito

Outputs
Neural Net: U/V-Net like

Fig. 1: Slice density δ distribution of dark matter particles in a box of 1 Gpc.

Motivation

Fig. 2: The first line are slices of displacements of particles and in the second line we show density slices. Can you spot any difference between these simulations by eye? From left to right: Linear, N-Body (truth), Fast. Approx., and NN.

Metrics Used

✓ Power Spectrum P of Ψ and δ;
✓ Transfer function:
  \[ T(k) = \frac{P_{\text{pred}}(k)}{P_{\text{true}}(k)} \]
✓ Cross-Correlation:
  \[ r(k) = \frac{P_{\text{pred}x\text{true}}(k)}{\sqrt{P_{\text{pred}}(k)P_{\text{true}}(k)}} \]

Results

Fiducial Universes

✓ Same set of cosmological parameters: \{Ω_m, Ω_b, Ω_Λ, σ_8, h, n_s\}

Fig. 3: Metrics for NN and fast approximator model compared with N-body sims.

Other Universes

✓ Tested on 2000 types of universes

Fig. 4: Accuracy comparison between predictions by the fast approximator (blue dot-dashed) and our NN (green dashed) for universes with different cosmological parameters used in training.

References in hyperlinks | fisica.renan@gmail.com