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On the accuracy of posterior recovery with neural network emulators

Neural network emulators or surrogates are widely used in astrophysics and cosmology to approximate expensive simulations, accelerating both likelihood-based inference and training for simulation-based inference. However, emulator accuracy requirements are often justified heuristically rather than with rigorous theoretical bounds. We derive a principled upper limit on the information loss introduced by an emulator with a given accuracy. This is quantified via the Kullback-Leibler divergence between the true posterior, which would be recovered using full simulations if computationally feasible, and the inferred posterior obtained with the emulator. Under assumptions of model linearity, uncorrelated noise, and a Gaussian likelihood, we show that accurate posterior recovery remains possible even when emulator errors reach 20% of the data noise level. We demonstrate the utility of this bound with an example from 21-cm cosmology, where neural networks are extensively used to constrain the astrophysics of the early universe with current observational limits.

AI keywords

Emulators, simulation-based inference, inference, information theory, Bayesian analysis

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