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Marginal likelihood-free cosmological parameter inference from type Ia supernovae

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Type Ia supernovae (SNIa) are standardisable candles that allow tracing the expansion history of the Universe and constraining cosmological parameters, particularly dark energy. State-of-the-art Bayesian hierarchical models scale poorly to future large datasets, which will mostly consist of photometric-only light curves, with no spectroscopic redshifts or SN typing. Furthermore, likelihood-based techniques are limited by their simplified probabilistic descriptions and the need to explicitly sample the high-dimensional latent posteriors in order to obtain marginals for the parameters of interest.
Marginal likelihood-free inference offers full flexibility in the model and thus allows for the inclusion of such effects as complicated redshift uncertainties, contamination from non-SNIa sources, selection probabilities, and realistic instrumental simulation. All latent parameters, including instrumental and survey-related ones, per-object and population-level properties, are then implicitly marginalised, while the cosmological parameters of interest are inferred directly.
As a proof-of-concept we apply neural ratio estimation (NRE) to a Bayesian hierarchical model for measured SALT parameters of supernovae in the context of the BAHAMAS model. We first verify the NRE results on a simulated dataset the size of the Pantheon compilation (~ 1000 objects) before scaling to $\mathcal{O}(10^6)$ objects as expected from LSST. We show, lastly, that with minimal additional effort, we can also obtain marginal posteriors for all of the individual SN parameters (e.g. absolute brightness and redshift) by exploiting the conditional structure of the model.

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