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Temporal Variational Autoencoders and Simulation-based inference for interpolation of light curves of Gravitationally Lensed Quasars

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The Hubble Tension presents a crisis for the canonical LCDM model of modern cosmology: it may originate in systematics in data processing pipelines or it may come from new physics related to dark matter and dark energy. The aforementioned crisis can be addressed by studies of time-delayed light curves of gravitationally lensed quasars, which have the capacity to constrain the Hubble constant (H_0). A critical task in this analysis is the interpolation of time series with varying duration and irregular time sampling. In this problem, the baseline approach is Gaussian processes (GPs), which have issues in converging on the maximum likelihood. In this work, we compare the interpolation performance of multiple models: GPs inferred with maximum likelihood optimization, GPs inferred with neural density estimation (NDE), and heteroscedastic temporal neural networks. For the NDE approach, a normalizing flow infers the posteriors of GP's parameters from time series'encodings independent of duration or time sampling. Of the neural networks, we use spline-based convolutional variational autoencoders (VAEs) and multi-time attention VAEs.
We validate our methods on simulations of Gaussian processes, on the observed lensed quasar light curves as well as on real-world datasets that are baselines for irregularly sampled time series interpolation. Our analysis shows that the Gaussian processes inferred with neural density estimators outperform the other approaches in interpolation quality.

Significance

We introduce a modification to the stochastic model of the quasar light curve that lifts the necessity for numeric convolutions and facilitates maximum likelihood inference.

Moreover, we enhance the inference of quasar parameters using a combination of the latest advancements in temporal generative networks, NLP, and simulation-based inference.

As a result, the work makes a comparative analysis of state of the art stochastic and deep learning approaches in time series interpolation problems.

References

https://indico.fnal.gov/event/53945/contributions/243362/

Experiment context, if any

Lensed quasars observations by LSST, DES, COSMOGRAIL

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