Lightning-Fast Gravitational Wave Parameter Inference through Neural Amortization

Gravitational waves from compact binaries are routinely analyzed using MCMC sampling algorithms which typically require days of computation. We show how neural simulation-based inference can speed up the inference time from days to minutes.

Objective: Given a detected gravitational wave \( x \), compute \( p(\theta | x) \) based on a model for \( p(x | \theta, \phi) \) and a prior \( p(\theta, \phi) \)

\[ p(\theta | x) = \frac{p(x | \theta, \phi) p(\theta, \phi)}{\int p(x | \theta, \phi) p(\theta, \phi) d\theta d\phi} = \frac{\int p(x | \theta, \phi) p(\theta, \phi) d\theta d\phi}{\int p(x | \theta, \phi) p(\theta, \phi) d\theta d\phi} p(\theta). \]

Current analyses
- Sample from \( p(\theta, \phi | x) \) using MCMC techniques.
- Estimate \( p(\theta | x) \) based on those samples.

We aim to approximate the likelihood-to-evidence ratio

\[ r(x | \theta) = \frac{p(x | \theta)}{p(x)}. \]

We train a convolutional neural network \( \phi \) to discriminate between

\[ (x, \theta) \sim p(x | \theta) \rightarrow y = 1 \] and \( (x, \theta) \sim p(x) p(\theta) \rightarrow y = 0. \]

We use it to compute an approximation of the likelihood-to-evidence ratio [Herns+ al., 2019]

\[ \hat{r}(x | \theta) = \frac{s(x, \theta)}{1 - s(x, \theta)}, \quad \hat{p}(\theta | x) = \hat{r}(x | \theta) p(\theta). \]

Posterior

Log likelihood-to-evidence ratio

Multilayer perceptron
3 layers of 200 units
Concatenation of \( \theta \)
Stack of 13 blocks with dilated
Convolutional layers
Conv. layer
H1/L1 strains (2 \( \times \) 8192)

Take-home message
- Neural amortization reduces inference time from days to minutes.
- Our method produces credible intervals that are less constrained than those produced with MCMC techniques but results are promising.
- Further assessments of the statistical validity of the estimated posteriors would be needed before making any reliable scientific claims.