Neural wave-based imaging with amortized uncertainty quantification

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An overview is given on solving high-dimensional Bayesian Inference with expensive nonlinear (wave-based) forward operators with applications in medical and seismic imaging. After improving MAP estimates with conditional Normalizing Flows (CNFs), a full characterization of the posterior will be given with Bayesian Variational Inference using Simulation-Based Inference. Two complementary techniques to close the amortization gap will be reviewed and evaluated on realistic medical and seismic imaging problems. One is amortized and based on recursive refinements [1] (by improving fiducial points, \(x_0\)) of the score-based summary statistics [3, 4], 
\[
\bar{y} = \nabla_x \log p(y|x)\big|_{x_0},
\]
so that 
\[
p(x|\bar{y}) \approx p(x|y) \quad \text{in} \quad \hat{\theta} = \arg \min_{\theta} \frac{1}{M} \sum_{m=1}^M \left( \|f_{\theta}(x^{(m)}; \bar{y}^{(m)})\|_2^2 - \log |\det J_{f_{\theta}}| \right)
\]
where \(f_{\theta}(\cdot; \cdot)\) is a CNF with weights \(\theta\) and Jacobian, \(J_{f_{\theta}}\), while the other corrects the amortized CNF (obtained by forward KL) by minimizing the reverse KL
\[
\text{minimize}_{x_i, \phi} \frac{1}{N} \sum_{i=1}^N \frac{1}{2\sigma^2} \|F(x_i) - y^{\text{obs}}\|^2_2 + \frac{1}{2\gamma^2} \|x_i - f_{\theta}^{-1}(h_\phi(z_i); y^{\text{obs}})\|^2_2 + \frac{1}{2} \|h_\phi(z_i)\|^2_2 - \log |\det J_{h_\phi}|.
\]
with \(z_i \sim N(0, I)\), \(h_\phi(\cdot)\), the correction NF, and \(y^{\text{obs}}\) the observed data.

References


