EQUIVARIANT BOOTSTRAPPING FOR UNCERTAINTY QUANTIFICATION IN IMAGING INVERSE PROBLEMS

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Scientific imaging problems are often severely ill-posed, and hence have significant intrinsic uncertainty. Accurately quantifying the uncertainty in the solutions to such problems is therefore critical for the rigorous interpretation of experimental results as well as for reliably using the reconstructed images as scientific evidence. Unfortunately, existing imaging methods are unable to quantify the uncertainty in the reconstructed images in a manner that is robust to experiment replications. This paper presents a new uncertainty quantification methodology based on an equivariant formulation of the parametric bootstrap algorithm that leverages symmetries and invariance properties commonly encountered in imaging problems. Additionally, the proposed methodology is general and can be easily applied with any image reconstruction technique, including unsupervised training strategies that can be trained from observed data alone, thus enabling uncertainty quantification in situations where there is no ground truth data available. We demonstrate the proposed approach with a series of numerical experiments and through comparisons with alternative uncertainty quantification strategies from the state-of-the-art, such as Bayesian strategies involving score-based diffusion models and Langevin samplers. In all our experiments, the proposed method delivers remarkably accurate high-dimensional confidence regions and outperforms the competing approaches in terms of estimation accuracy, uncertainty quantification accuracy, and computing time.