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Joint Parameter and Parameterization Inference with Uncertainty Quantification through Differentiable Programming

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Accurate representations of unknown and sub-grid physical processes through parameterizations (or closure) in numerical simulations with quantified uncertainty are critical for resolving the coarse-grained partial differential equations that govern many problems ranging from weather and climate prediction to turbulence simulations. Recent advances have seen machine learning (ML) increasingly applied to model these subgrid processes, resulting in the development of hybrid physics-ML models through the integration with numerical solvers. In this work, we introduce a novel framework for the joint estimation of physical parameters and machine learning parameterizations with uncertainty quantification. Our framework incorporates online training and efficient Bayesian inference within a high-dimensional parameter space, facilitated by differentiable programming. This proof of concept underscores the substantial potential of differentiable programming in synergistically combining machine learning with differential equations, thereby enhancing the capabilities of hybrid physics-ML modeling.

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