Conditional Rectified Flow for stochastic homogenization of materials with random non-periodic structures

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Analyzing properties of composite materials with random microstructures is of crucial importance in many engineering and industrial applications. Stochastic homogenization provides a framework to make the prohibitively high computational complexity tractable and for linking microscopic randomness to macroscopic behavior. Existing approaches typically focus on estimating the effective properties of individual microstructured materials, while characterization of their underlying distribution under varying conditions remains computationally challenging. We propose a conditional generative framework based on rectified flow to model the distribution of homogenized properties in random composites. Conditioning variables are incorporated into the training process, enabling efficient generation of effective properties for random domains with inclusions under prescribed conditions. The method is applied to stochastic diffusion and linear elasticity problems. Numerical results demonstrate that it accurately reproduces the target distributions of effective properties, providing an efficient data-driven surrogate for stochastic homogenization in heterogeneous media.

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