Tensor Neural Network–Based Machine Learning Method for Elliptic Multiscale Problems

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Abstract: This report introduces a machine learning method that combines Tensor Neural Networks (TNN) with homogenization theory for solving elliptic multiscale equations. The core advantage of TNN lies in its unique tensor structure, which allows the computation of high-dimensional neural network function integrals to be reduced to one-dimensional integrals. This enables the design of highly accurate high-dimensional integration methods, whose computational complexity scales only polynomially with the number of dimensions. Leveraging this feature, we design a high-precision solver for multiscale problems. Specifically, the original problem is first transformed via homogenization into a series of cell problems and a homogenized equation. These are then solved separately using TNN-based methods. Unlike conventional machine learning methods that rely on Monte Carlo sampling, our approach employs deterministic numerical integration, achieving high computational accuracy. In particular, for cases where the multiscale coefficients depend on both fast and slow variables, the corresponding cell problems are defined on high-dimensional domains; the TNN-based approach enables efficient and accurate computation for such cases compared to traditional methods, thereby extending the applicability of homogenization techniques. We also generalize this approach to elliptic multiscale eigenvalue problems.