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Microstructure-informed reduced modes for simulations with fully resolved modular microstructures

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We present a reduced order modelling scheme suited for macro scale problems incorporating fully resolved microstructural details of stochastic heterogeneous materials. Our scheme builds on a compressed representation of a microstructural geometry by means of Wang tiles [1], which are a natural extension of the traditional representation based on Periodic Unit Cell (PUC). Instead of being attributed to a single cell, the microstructural information is stored within a set of modules (Wang tiles) with predefined mutually compatibility. With a simple stochastic algorithm, the modules can be assembled into arbitrary large microstructural realizations devoid of spurious periodicity, which is otherwise inherent to PUC. Inspired by computational homogenization, we extract a-priori fluctuation fields from the compressed representation as characteristic responses of the set of tiles to generalized loading represented by the first- and second-order macroscopic gradients. By construction, these tile-wise defined fields are continuous across matching edges and, consequently, they can be assembled in the same way the microstructural geometry of a macroscopic problem is assembled from the tiles. The assembled fluctuation fields are then converted into microstructure-informed reduced modes specific for a given macroscopic problem using the ansatz of the Generalized Finite Element method. We illustrate the performance of the scheme with a two-dimensional, scalar elliptic problem. We demonstrate that our scheme handles significant changes in the macroscopic geometry or loading without the need for recalculating the offline phase, unlike standard snapshot-based reduced-order approaches [2].

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