HyperCAN: Hypernetwork-driven deep parameterized constitutive models for metamaterials

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Abstract

We introduce HyperCAN, a machine learning framework that utilizes hypernetworks to construct adaptable constitutive artificial neural networks for a wide range of beam-based metamaterials exhibiting diverse mechanical behavior under finite deformations. HyperCAN integrates an input convex neural network that models the nonlinear stress–strain map of a truss lattice, while ensuring adherence to fundamental mechanics principles, along with a hypernetwork that dynamically adjusts the parameters of the convex network as a function of the lattice topology and geometry. This unified framework demonstrates robust generalization in predicting the mechanical behavior of previously unseen metamaterial designs and loading scenarios well beyond the training domain. We show how HyperCAN can be integrated into multiscale simulations to accurately capture the highly nonlinear responses of large-scale truss metamaterials, closely matching fully resolved simulations while significantly reducing computational costs. This offers new efficient opportunities for the multiscale design and optimization of truss metamaterials.

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