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Learning Constitutive Relations using Symmetric Positive Definite Neural Networks

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We present a new neural-network architecture, called the Cholesky-factored symmetric positive definite neural network (SPD-NN), for modeling constitutive relations in computational mechanics. Instead of directly predicting the stress of the material, the SPD-NN trains a neural network to predict the Cholesky factor of the tangent stiffness matrix, based on which the stress is calculated in the incremental form. As a result of this special structure, SPD-NN weakly imposes convexity on the strain energy function, satisfies time consistency for path-dependent materials, and therefore improves numerical stability, especially when the SPD-NN is used in finite element simulations. Depending on the types of available data, we propose two training methods, namely direct training for strain and stress pairs and indirect training for loads and displacement pairs. We demonstrate the effectiveness of SPD-NN on hyperelastic, elasto-plastic, and multiscale fiber-reinforced plate problems from solid mechanics. The generality and robustness of SPD-NN make it a promising tool for a wide range of constitutive modeling applications.

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