CONSTITUTIVE ARTIFICIAL NEURAL NETWORKS

Establishing benchmarks for training and validation

Kevin Linka, Sarah R. St. Pierre, Ellen Kuhl

Stanford University, Stanford, California, United States

ABSTRACT

Constitutive modeling and parameter identification are the cornerstones of computational mechanics. For decades, the gold standard in constitutive modeling has been to first select a model and then fit its parameters to data. However, the scientific criteria for model selection remain poorly understood, and the success of this approach depends largely on user experience and personal preference. Our goal is to democratize constitutive modeling and establish a family of constitutive artificial neural networks that simultaneously and fully autonomously discover the model, parameters, and experiments that best characterize the constitutive behavior of soft matter [1]. Mathematically, model discovery translates into a complex non-convex optimization problem, which we solve by formulating it as a neural network and harnessing the success, robustness, and stability of adaptive gradient-based optimizers developed for deep learning. Yet, we do not use classical off-the-shelf neural networks, which are known to overfit sparse data, violate the fundamental laws of physics, and introduce parameters with no real physical meaning. Instead, we design our own family of constitutive artificial neural networks with activation functions that feature popular constitutive models and parameters that have a clear physical interpretation. To appropriately train and validate these networks, we establish a broad set of benchmarks for a variety of hyperelastic materials including rubber [1], skin [2], and the human brain [3] with data from uniaxial tension and compression, pure and simple shear, and biaxial extension [4]. In the spirit of this workshop, this presentation seeks to inspire discussion around benchmarking more broadly, with a special focus on redefining standards for training, validation, and generalization in view of physics-informed machine learning.

REFERENCES

[1] K. Linka, E. Kuhl. A new family of Constitutive Artificial Neural Networks towards automated model discovery. *Comp Meth Appl Mech Eng.* **403**:115731, 2023.

[2] K. Linka, A. Buganza Tepole, G.A. Holzapfel, E. Kuhl. Automated model discovery for skin: Discovering the best model, data, and experiment. *bioRxiv*, doi:10.1101/2022.12.19.520979.

[3] S. St Pierre SR, Linka K, Kuhl E. Principal-stretch-based constitutive neural networks autonomously discover a subclass of Ogden models for human brain tissue. *bioRxiv*.

[4] Linka K, St Pierre SR, Kuhl E. Automated model discovery for human brain using Constitutive Artificial Neural Networks. *bioRxiv*; doi:10.1101/2022.11.08.515656.