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Exploring the latent space of Physically Recurrent Neural Networks in the low-data regime

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Surrogate models that combine conventional machine learning with physical constraints have gained traction in recent years. While these models are linked to better explainability and generalization properties than purely data-driven models, they often lack versatility for multiscale applications, particularly FE^2, where computational costs are extreme. In FE^2, the macroscopic constitutive behavior is associated to the homogenized response of a Representative Volume Element (RVE) at a lower scale. This eliminates the need for explicit constitutive laws at the macroscale, but solving a nested finite element problem at each integration point remains a major computational bottleneck.

To address this issue, we introduced the Physically Recurrent Neural Network (PRNN) [1], a hybrid surrogate model that embeds constitutive models within an encoder-decoder architecture to predict the homogenized response of heterogeneous materials with time and path dependence. This approach yields excellent generalization properties with minimal training data across various applications involving several constitutive model combinations in small and finite strain regimes [1-3]. Here, we shift our focus to understanding and illustrating how modifications in the decoder can shape the relation between our latent space and micromodel quantities without explicit training. These changes are also evaluated in terms of accuracy, with particular emphasis on the performance in the low-data regime.

References

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