A quantum-inspired tensor network for physics-informed neural networks and satellite images

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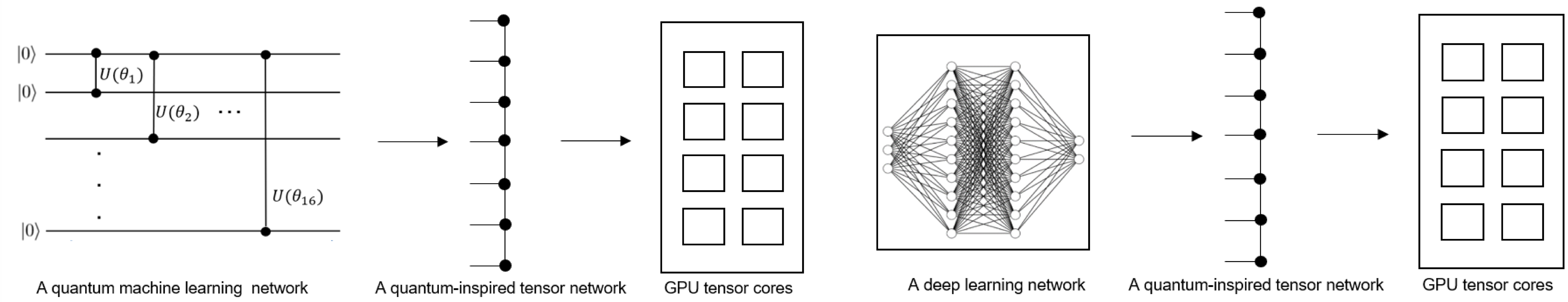
Abstract

Deep learning (DL) is one of many successful methodologies to extract informative patterns and insights from ever-increasing noisy large-scale datasets (in our case, satellite images). However, DL models consist of a few thousand to millions of training parameters, and these training parameters require a tremendous amount of electrical power for extracting informative patterns from noisy large-scale datasets (e.g., computationally expensive). Hence, we employ a quantum-inspired tensor network for compressing trainable parameters of physics-informed neural networks (PINNs) in Earth science. PINNs are DL models penalized by enforcing the law of physics; in particular, the law of physics is embedded in DL models. In addition, we apply tensor decomposition to Hyperspectral images (HSIs) to improve their spectral resolution. A quantum-inspired tensor network is also the native formulation to efficiently represent and train quantum machine learning models on big datasets on GPU tensor cores. Furthermore, the key contribution of this paper is twofold: (I) we reduced the number of trainable parameters of PINNs by using a quantum-inspired tensor network, and (II) we improved the spectral resolution of remotely sensed images by employing tensor decomposition. As a benchmark PDE, we solved Burger's equation. As practical satellite data, we employed HSIs of Indian Pine, USA and of Pavia University, Italy [1].



Contribution-I:

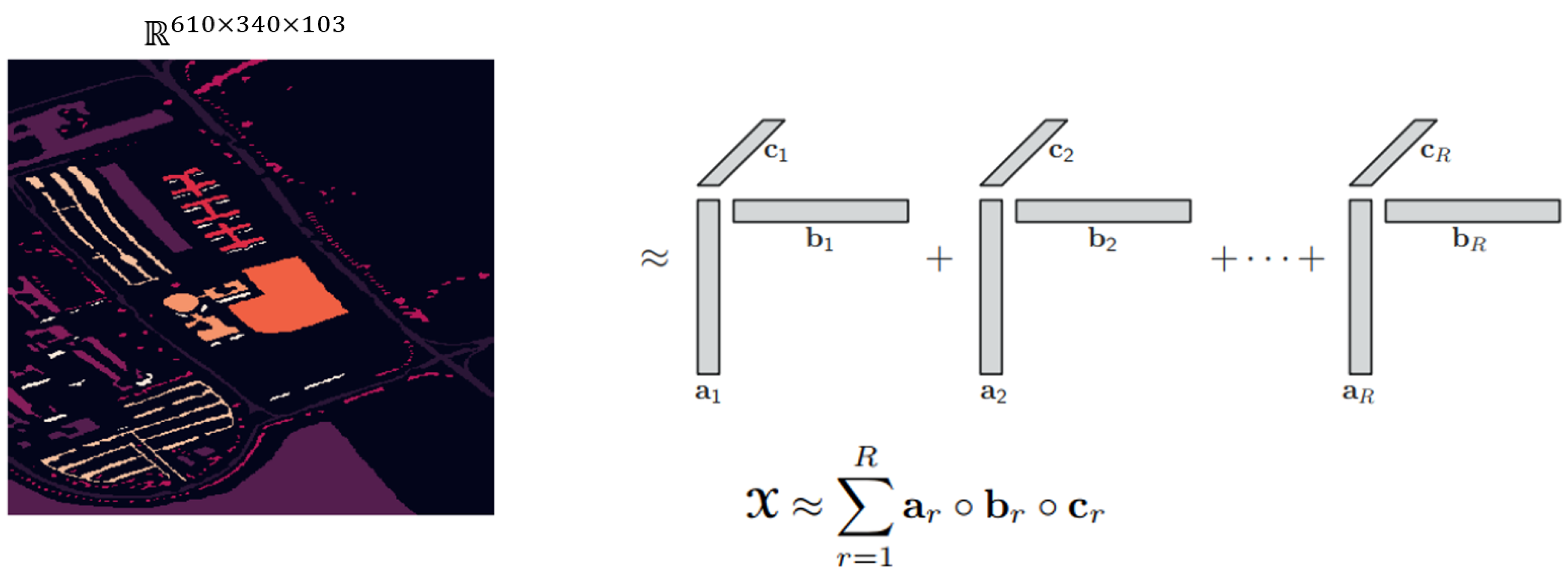


Fig1. compressing a third-order tensor via a quantum tensor network

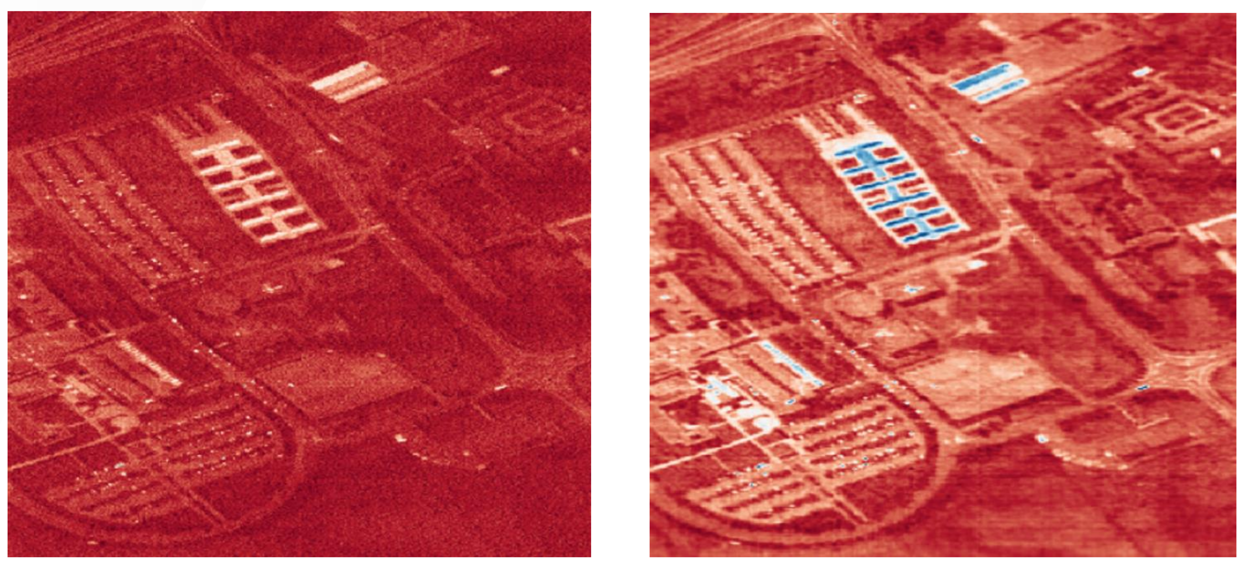


Fig 2. [Left] before a quantum tensor network, and [Right] after compressed via a quantum tensor network

Contribution-II:

$$u_t + uu_x - (0.01/\pi)u_{xx} = 0, \quad t \in [0,1],$$
$$u(0,x) = -\sin(\pi x),$$
$$u(t,-1) = u(t,1) = 0.$$

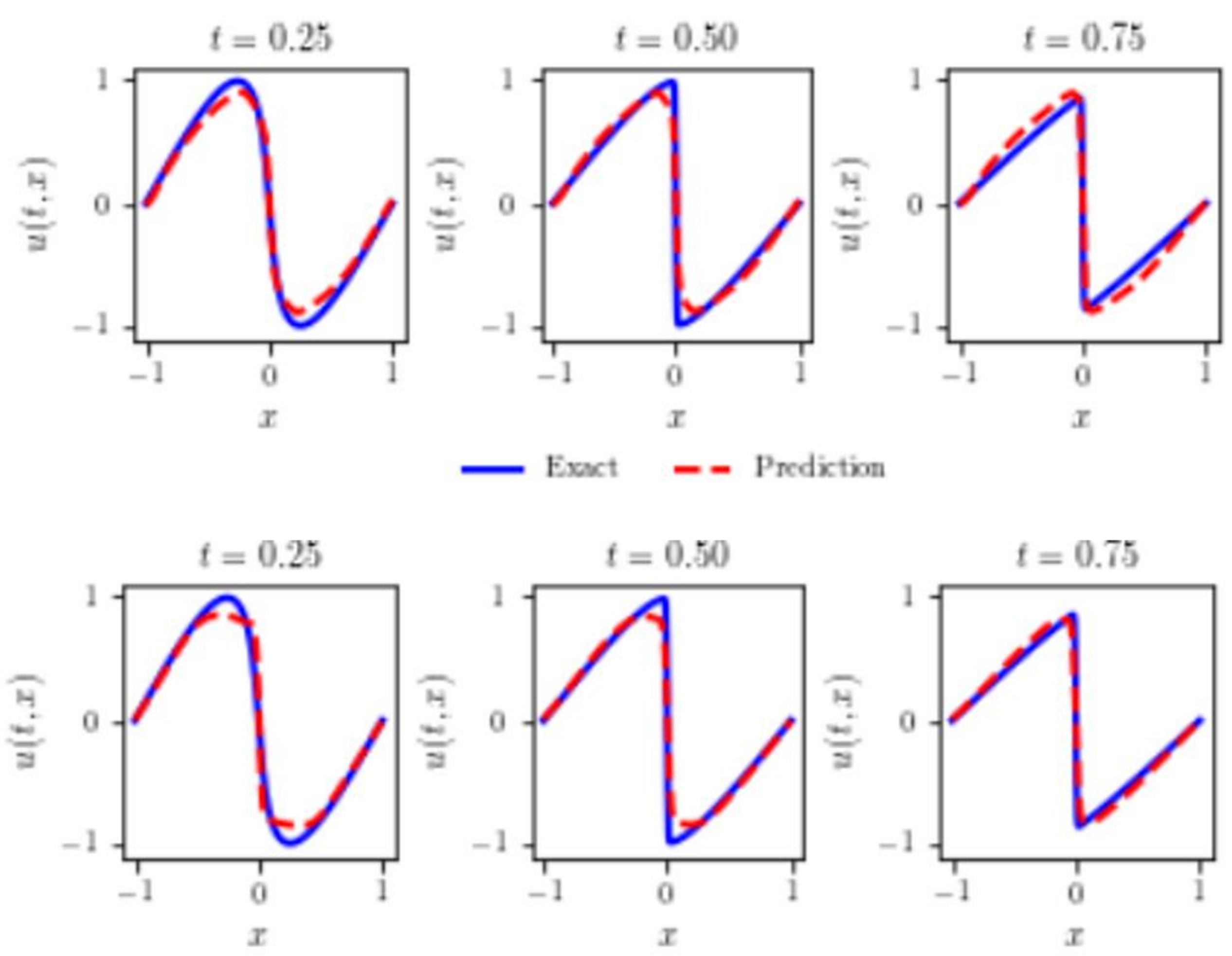


Fig 3. A solution to Burger's equation (blue is an exact solution, and red is a predicted solution): [Top] The original PINN, and [Bottom] The compressed PINN.

Conclusion

This paper focused on designing and applying a quantum-inspired tensor network to DL models and real-world data tensors. Our contribution is twofold: (I) We reduced the parameters of a DL model when compressing them by using TT-decomposition. As a DL model, we utilized a physics-informed neural network for finding a solution to 1D Burger's equation. The compressed model generates solutions to 1D Burger's equation with high accuracy, such as having produced by its original one. (II) We improved the spectral resolution of hyperspectral images (i.e., data tensors) by decomposing them in sparse factor matrices through CP decomposition. The decomposed data tensors are represented by sparse tensors, while the decomposition time was extremely small (around 1 second). Additionally, we can store these decomposed images (i.e., sparse tensors) efficiently and securely in distributed storage devices thanks to their sparse factor matrices. As practical HSIs, we used HSIs of Indian Pine, USA, and Pavia University, Italy.

[1] S. Otgonbaatar and D. Kranzlmüller, "Quantum-Inspired Tensor Network for Earth Science," *IGARSS 2023 - 2023 IEEE International Geoscience and Remote Sensing Symposium*, Pasadena, CA, USA, 2023, pp. 788-791, doi: 10.1109/IGARSS52108.2023.10282577.

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