Contribution ID: **111** Type: **not specified**

Tensor network methods for solving nonlinear PDEs

Thursday, 28 August 2025 09:30 (1 hour)

Tensor network decompositions are a famous way to compress tensors of coefficients of multivariate wavefunctions in quantum physics and chemistry. Their efficiency hinges on the approximate separability of the variables. This separability can be underpinned by different assumptions. In addition to the area laws of the wavefunctions governed by the Schroedinger equation, a similar separation of length scales manifests in the solution to the Navier-Stokes Equations (NSE) in certain regimes. Higher efficiency of the tensor network (Matrix Product States/Tensor Train) is achieved by splitting the original variables (such as the two spatial directions in the 2D NSE) into further virtual variables similarly to digits in the binary system. The sought tensor is reshaped into a higher-dimensional tensor indexed by those virtual variables, and is approximated by a tensor network. Specifically, if the Matrix Product States is used with binary virtual variables, the corresponding decomposition is called the Quantized Tensor Train, but this can be generalized trivially. If the original variables are discretized via a structured mesh, the virtual variables correspond to different length scales within that mesh, and hence the physical space. In the case of the NSE exhibiting a scale-locality of the turbulent energy cascade (e.g. a jet or the Taylor-Green vortex flow in a rectangular or unbounded domain), this leads to the separability of the virtual variables. Numerical experiments demonstrate that the number of tensor network parameters required to represent such velocity field is reduced by more than an order of magnitude compared to direct numerical simulation.

Based on the joint work https://www.nature.com/articles/s43588-021-00181-1

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Session Classification: Invited talk

Track Classification: Invited talk