Neural Network simulations of quantum long range models

David Zueco
Instituto de Nanociencia y Materiales de Aragón CSIC-Unizar, Zaragoza (Spain)
dzueco@gmail.com

Quantum Many-Body Problems range from those that are tractable with techniques such as Matrix Product States (MPS) for non-critical 1D systems [1], Dynamical Mean Field Theory (DMFT) for impurity models [2], Quantum Monte Carlo [3], and physically inspired ansätze (like the Bethe ansatz and perturbation theories), to those that are computationally challenging, such as 2D materials on different lattice topologies [4]. Beyond these, quantum simulations offer hope. In recent years, however, Neural Network ansätze are being investigated to overcome the limitations of these numerical methods. In this talk, I will compare different NN architectures such as Restricted Boltzmann Machines (RBMs) [6], feed-forward neural networks, and Transformers [5] for solving spin long-range models, both in weak and strong interaction regimes, for uniform models like the transverse Ising model or models with all-to-all couplings and quenched disorder in the couplings and longitudinal field, such as the Quantum Sherrington-Kirkpatrick Model.
We will discuss the physics of the different NN ansätze, show the phase diagram [See figure 1], the critical exponents, and the physics of the models, as well as the computational complexity of the neural networks in comparison to other numerical methods. The idea of the talk is to demonstrate that AI-inspired techniques can be useful for quantum many-body problems and can complement the efforts in quantum simulators.

References

[1] R. Orus, Annals of Physics 349 117-158 (2014).
[2] A. Georges *et al.*, Rev. Mod. Phys. 68, 13–125 (1996).
[3] F. Becca and S. Sorella, *Quantum Monte Carlo Approaches for Correlated Systems* (Cambridge University Press, 2017).
[4] Y. Alexeev et al., arXiv:2312.09733 (2023)
[5] L L Viteritti, et al., Phys. Rev. Lett. 130, 236401 (2023)
[6] G. Carleo and M. Troyer, Science 355, 602 (2017)
[7] G. Sun Phys. Rev. A 96, 043621 (2017)

Figures

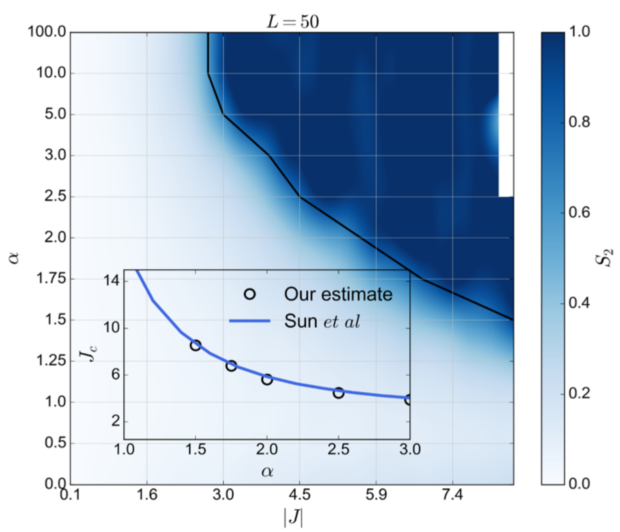

Figure 1: Phase diagram for the antiferromagnetic quantum Ising model with long-range interactions (i.e., the spin-spin interaction decreases as J/|i-j|), plotted as a function of J and . This serves as an example of preliminary calculations performed with 50 spins, utilizing the transformer as a variational ansatz. The phase boundary aligns with those obtained from the Density Matrix Renormalization Group (DMRG) calculations, which are more computationally intensive [7].