Tensor Networks for quantum circuits and non-Markovian quantum optical systems

Giuseppe Magnifico[1,2]

1. *Dipartimento di Fisica, Università di Bari, I-70126 Bari, Italy*
2. *INFN, Sezione di Bari, I-70125 Bari, Italy*

Abstract: I will present recent developments in tensor network techniques, covering optimised contraction protocols for quantum circuit emulation, hybrid architectures, and non-Markovian simulations of waveguide QED systems, revealing time-delay-induced correlations, structured photon emission, and entanglement generation among multiple emitters.

Tensor network methods have emerged as powerful tools for tackling complex problems in quantum science and technology. In this talk, I will discuss recent developments in tensor network techniques. First, I will present the integration of optimised dynamical contraction protocols into tensor network algorithms for emulating quantum circuits, highlighting substantial improvements in computational efficiency and accuracy [1], as well as the potential of hybrid tensor network architectures [2]. Second, I will describe techniques for simulating quantum optical systems in the non-Markovian regime, focusing on waveguide quantum electrodynamics systems with multiple emitters. I will present results that show a rich interplay between time-delay-induced correlations, structured photon emission, and entanglement generation [3, 4].

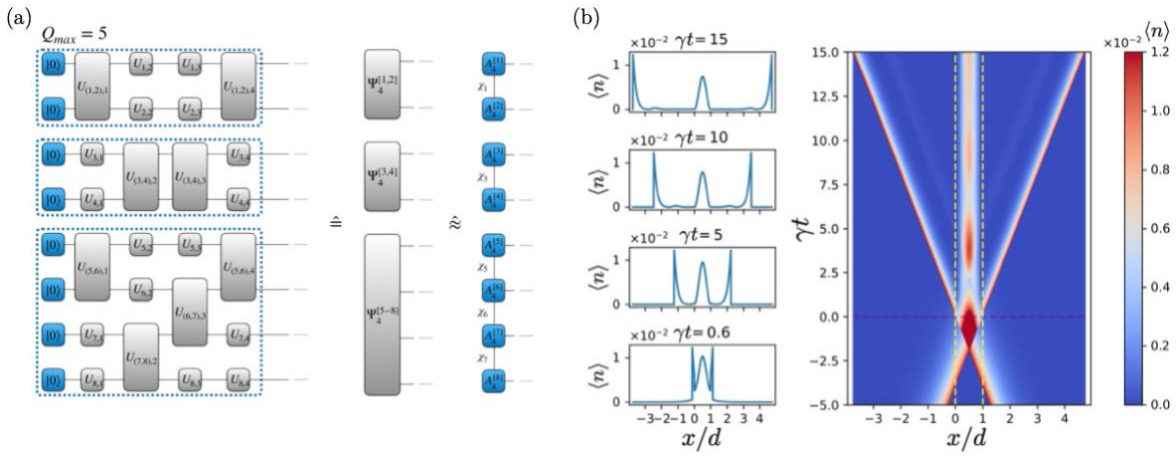

Fig. 1 (a) Reproduced from [1]: scheme of dynamical contraction protocol for quantum circuit emulations via tensor networks; (b) Reproduced from [3]: real-time dynamics of waveguide QED systems with two-level emitters.

References

[1] A. De Girolamo, P. Facchi, P. Rabl, S. Pascazio, C. Lupo, and G. Magnifico, "Dynamical cluster-based strategy for improving tensor network algorithms in quantum circuit simulations" Phys. Rev. Research **7**, 043170 (2025).

[2] J. Schuhmacher, M. Ballarin, A. Baiardi, G. Magnifico, F. Tacchino, S. Montangero, I. Tavernelli, "Hybrid Tree Tensor Networks for quantum simulation" PRX Quantum **6**, 010320 (2025).

[3] G. Magnifico, M. Maffei, D. Pomarico, D. Das, P. Facchi, S. Pascazio, and F. V. Pepe, "Non-Markovian dynamics of generation of bound states in the continuum via single-photon scattering" Phys. Rev. Research **7**, 033249 (2025).

[4] R. L. Capurso, G. Calajò, S. Montangero, S. Pascazio, F. V. Pepe, M. Maffei, G. Magnifico, and P. Facchi, "Superradiant decay in non-Markovian Waveguide Quantum Electrodynamics" *arXiv:2511.22332.*