Time-Evolution of Tensor Networks in Quantum Electrodynamcis

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Due to high intensities and small wavelengths in modern light sources such as free electron lasers, a non-pertubative and beyond-dipole description of the coupling of electrons and photons is necessary. To describe the dynamics in such coupled electron-photon systems, time-dependent density-functional theory was recently extended to include quantum-electrodynamical effects (QEDFT) [1].

Like all density-functional approaches, this description is formally exact. However, for current approximate QEDFT functionals, no error bars for the deviation from the exact solution of the Schrödinger equation are known. In order to develop such error bars, we construct systematically improvable approximations for the wavefunction of lattice quantum-electrodynamics. In our work, we expand the many-body wavefunction in terms of a tensor network [2] to express the wave function in a way that regards the geometry induced by the entanglement of the states. For quantum electrodynamics this leads naturally to two different strategies.

In the first approach, we employ the Lanczos algorithm in order to compute the dynamical evolution of the system in terms of generalized matrix-product states. If all the symmetries of the Hamiltonian and of the initial state are exploited, we find from our analysis that only a few possible states have to be retained to describe the whole dynamics of the system.

In our second approach, we consider a tensor network in discrete space and time variables. Globally optimizing this tensor network according to the the McLachlan variational principle [3], we detemine states which are equivalent to stationary solutions of the action principle of quantum electrodynamics.

In both cases, we analyze the entanglement of the involved states and compare our approach to QEDFT. The amount of entanglement is the only approximation that is inherent in the tensor networks that we consider. Since this quantity can be converged by increasing the bond dimension of the network, we can assess the deviation from the exact solution of the problem with an asymptotic analysis.

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