Quantum Tensor Networks for Strongly Correlated Systems

These days we still are freshly impressed by the recent demonstration of quantum supremacy. Spectacular as it may be, at the same time the feat reminds us how far we still are from the desired universal fault-tolerant quantum computation with its promise to revolutionize quantum mechanical calculations. There is, however, a class of important hard problems that do not require quantum computers because – satisfying the area law for quantum entanglement – they can be treated by tensor networks on the robust classical digital computers. These include strongly interacting two-dimensional condensed matter systems like the celebrated Hubbard model of the high T_c superconductivity. Some of them support topologically ordered ground states with emergent anyonic quasipartiles – that are neither bosons nor fermions – that in turn could be employed to implement the topologically protected fault-tolerant quantum computation. Identification of such systems is non-trivial due to non-local nature of the topological order. It is the same non-locality that protects the quantum information from being scrambled.

While the community at large was mainly occupied with increasingly more accurate calculation of ground states, we – encouraged by their achievements – proposed a tensor network algorithm to calculate thermal states of strongly correlated systems, an indispensable tool if realistic comparisons with experiments are to be made. It is free of the notorious fermionic sign problem and therefore is capable to treat problems intractable by the well established methods like the celebrated quantum Monte Carlo algorithm. Our approach was successfully tested in realistic benchmark applications and proved to be ripe for applications in realistic problems like the materials designed to support topological order necessary for quantum information processing, strongly frustrated magnets, or the hypothetical models of the high-T_c superconductivity - a phenomenon with great potential for industrial applications but still poorly understood theoretically. It is ripe for further progress, this time hand in hand with experimenters.

Thanks to their resilience to local perturbations, the non-Abelian topological states (where an exchange of two quasiparticles not only changes the phase of the wave function but also alters the quasiparticles' identities) have been proposed as a promising platform for fault-tolerant quantum computing. They attracted lots of attention in the field of quantum information. They also triggered intensive experimental search for topologically ordered materials of which rhutenates now seem to be the most promising candidates. The quantum tensor networks can be used to calculate ground states of such materials but – due to the non-local nature of the topological order – it is not straightforward to determine whether a given ground state represented by a tensor network is topological or not. We plan to design new algorithms to distill the information about topological order from the tensor network representation. The algorithms we will used to select materials for a perfect quantum computer.