Formalizing the existence of entanglement in a quantum spin chain in new physical settings via Matrix Product States

Andrea Cadarso
Universidad Complutense de Madrid

Entanglement plays a central role in many-body quantum systems as it can be used to understand the structure of the quantum states that appear in nature. In systems governed by short-range interactions, low energy states possess very little entanglement. In contrast, states evolved after quenches display large amounts of entanglement. These different behaviors, which are supported by abundant numerical evidence, have been recently established on solid grounds in one spatial dimension.

Apart from the cases mentioned above, there exist practically no other physical situation where the existence of large or small amounts of entanglement can be rigorously established. In this work, we identify two scenarios in one spatial dimension that can be connected to the presence of entanglement.

The first scenario corresponds to the presence of fractionalization, a striking phenomenon that arises whenever certain observables, which are expected to take on integer expectation values, appear to be fractional-valued instead. We establish a lower bound for the entanglement entropy of any (connected and sufficiently large) region of a quantum spin chain in terms of the fractionalized magnetization.

The second scenario corresponds to a situation where the area law does not apply, namely when we have a spin chain with long-range interactions.

Intuitively, one can expect that such interactions give rise to large amounts of entanglement since any specific region will be correlated to any other part of the chain. In fact, we will prove a Theorem that formalizes this statement.

All this will show how MPS are powerful enough to provide formal proofs of certain believed statements on strongly correlated spin systems that were lacking a mathematical treatment. Moreover, since MPS seem to be the right representation for the low energy sector of 1D systems, one may postulate the results being true in full generality.