Algebraic Bethe Circuits

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The Algebraic Bethe Ansatz (ABA) is a highly successful analytical method used to exactly solve several physical models in both statistical mechanics and condensed-matter physics. Here we bring the ABA into unitary form, for its direct implementation on a quantum computer. This is achieved by distilling the non-unitary R matrices that make up the ABA into unitaries using the QR decomposition. Our algorithm is deterministic and works for both real and complex roots of the Bethe equations.
We illustrate our method on the spin-1/2 XX and XXZ models. We show that using this approach one can efficiently prepare eigenstates of the XX model on a quantum computer with quantum resources that match previous state-of-the-art approaches. Moreover, we propose the analytical expressions for the circuit elements building an arbitrary eigenstate of the XX model. We give the exact solution implementing 2 and 3-magnons states of the XXZ chain.
We run small-scale error-mitigated implementations on the IBM quantum computers, including the preparation of the ground state for the XX and XXZ models on 4 sites. Finally, we derive a new form of the Yang-Baxter equation using unitary matrices, and also verify it on a quantum computer.