Optimal quantum circuits for the quantum simulation of quantum matter

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Optimal-depth quantum circuits are crucial for pushing the boundaries of current noisy intermediate-scale quantum technology, where noise effects in the output become stronger with the depth of the quantum circuit. When constructing (the cycles of) the quantum circuits for the quantum simulation of quantum matter by Trotterization, typically, a two-qubit quantum gate must be added for each edge of a lattice graph, with qubits on its vertices. Since each qubit can participate in at most one quantum gate at a time, associating colors with layers of quantum gates, a depth-optimal cycle is described by a minimal edge coloring of the lattice graph. We develop and implement a classical algorithm that efficiently finds minimal edge colorings of lattice graphs and thereby depth-optimal circuits for the quantum simulation of quantum matter [1,2]. Once a solution is found that solution can be repeated indefinitely by translational symmetry. We demonstrate the algorithm by minimal edge coloring a plethora of relevant lattice graphs, including the meshes of all k-uniform tilings of the plane for k less than 7, while utilizing modest computational resources.

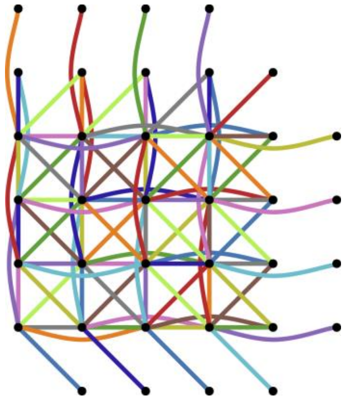

Figure 1: Optimal circuit for the quantum simulation of the Heisenberg model on the square lattice, with nearest, next-nearest and next-next-nearest neighbor interactions. Every color represents a layer in the quantum circuit. The solution can be repeated indefinitely in the vertical and horizontal directions without two edges of the same color meeting at a vertex, or, when interpreted as a circuit, without gate collisions.

References

[1] https://github.com/kattemolle/ecolpy
[2] Joris Kattemölle, Edge coloring lattice graphs. To appear on the arxiv this week.