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MOQI: Mathematical Optimization in Quantum Information

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Proposal duration: 60 months.

Summary:

Quantum computation aims to perform calculations with quantum systems, for example atoms or photons. But understanding what happens inside quantum computers presents huge mathematical challenges. Many of these are in the area of mathematical optimization, maximizing or minimizing some quantity of interest. These methods have now become workhorses for studying quantum behaviour. However, researchers face two larger challenges:

a) There are problems for which using numerical methods simply requires too much computer memory and computation time. An example is the study of quantum many-body system, where with each additional quantum mechanical spin described, the size of the optimization problem doubles. As a consequence, current work focuses on efficient approximations, which often - despite being efficient in a theoretical sense - still scale too badly to be used in practise. Yet for the understanding of quantum magnetism one wants to study systems of hundreds if not thousand spins, far beyond current computing capabilities. Another example, important for quantum cryptography, are certain regular geometrical alignments of lines. One wants to know whether a certain alignment with fixed angles between them is possible or not. Despite being well-known problems with ready formulations in terms of mathematical optimization, their size keeps them out of reach of being numerically solved.

b) Some long-standing open problems in quantum information theory are clearly about maximizing or minimizing a certain quantity. However, no closed-form formulation of these problems in terms of mathematical optimization is known. Examples are the quantum analog of a famous Shannon capacity of graphs (important for the reliable transmission of data), and the characterization of quantum correlations in network structures. Both problems are intensely studied in the field of quantum graphs and networks. Yet, researchers face certain mathematical obstructions to apply optimization methods in order to solve them.

The aim of this project is to address these two challenges, so that both very large problems can be solved computationally, and so that advanced methods from mathematical optimization can be used to attack a wider class of problems. Overall, the project provides recipes for the larger community, making mathematical optimization methods more powerful and more widespread applicable.