Entanglement-Enhanced Electron Microscopy and Its Generalizations

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Quantum electron microscopy (QEM) is emerging at the boundary between the fields of electron microscopy and quantum information science, although it is still in its infancy. One of its main objectives is to address the problem of radiation damage. In QEM, we strive to use a minimal number of electrons to extract as much information as possible from a specimen before the specimen is destroyed, for example by approaching the Heisenberg limit. Examples of expected, simulated images of a biological molecule, without averaging over many molecules, are shown in Fig. 1 [1]. Mainly two schemes of QEM, namely multi-pass TEM [2] and entanglement-enhanced (qubit-assisted) TEM [3], have been put forward. We are currently working on the latter: A cryogenic electron optical testbed for a proof-of-principle experiment, along with relevant superconducting circuits, is under development [4].

Looking ahead, we envision *universal* QEM [5], which is a generalized version of single-qubit-assisted QEM. Universal QEM may be programmed to do anything quantum mechanically possible and can, in particular, *query* the specimen in the sense relevant to the "query model" of computational complexity theory. For example, one might imagine Grover-like search for a known molecule in a crowded cellular environment in cryoelectron tomography. In the absence of near-term "killer apps" of quantum computing, QEM could be a much-desired small-scale application of quantum computing with provable quantum advantage.

(a) (b) (c)

Fig. 1. Simulated images of the molecule VP35 [1]. (a) A band-pass filtered phase map. (b) An ideal conventional method. (c) Quantum-enhanced image. The horizontal length of each image is 10 nm.

References

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