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Grand challenge of quantum information theory

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The field of quantum information has undergone an impressive transformation during the last years. While, in its early days only a small core of optimists had hope that practical hardware would eventually be built, the expectation that quantum computers will soon be useful devices is growing in many computational sciences and industries. With growing expectations into the practical use of quantum information technologies also the interest of public and private bodies in investments to-wards quantum information has grown to levels that once seemed unthinkable.

In addition to the resultant growth of the field, also the character of the community's activities has changed a lot. Theory and experiment were largely disjoint in the early days of quantum information: while theorists considered quantum algorithms with enormous gate counts or manipulation of entangled states in the asymptotic limit with perfect accuracy, many experimental activities were focussed on the identification of suitable systems to devise individual qubits, and the implementation of a single entangling gate was a great milestone.

Experimental progress enabling the implementation of actual gate sequences on registers of several qubits has changed the playing field quite a bit. Every theorist can play experimentalist on the growing number of publicly accessible quantum devices, and previously disjoint branches now form a cohesive community. Since this community is highly interdisciplinary with members from natural sciences, computer science, mathematics and engineering, there is not a generic type of publication, but there is a full spectrum ranging from abstract mathematical pieces of work up to engineering of hardware components.

While early work in quantum information was often focussed on one specific branch of the field, the community now develops a much more wholistic perspective. We develop algorithms that are tailored to-wards the capabilities of currently existing devices, and the development of special purpose devices such as quantum simulators is guided by open questions in material sciences.

The expectation on developments over the next years varies quite a bit in the community. While there is the expectation that quantum devices with hundreds or thousands of qubits will be available in the foreseeable future, so that there is no need to focus on qubit-efficient algorithms that yield moderate improvements over classical algorithms, there is also the perspective that very substantial hardware improvements are necessary before large qubit registers can be brought to use in an algorithm. Given this large uncertainty on what can be expected from future hardware, we certainly need a broad spectrum of algorithms ranging from applications of hardware with limited performance up to full-fledged algorithms that can exploit the power of the devices that we dream of.

On the experimental side, we are still far from having identified the platform that clearly outperforms all its competitors. While some technologies are sufficiently mature to run some algorithms, the potential for quantum information of many newer platforms is still being explored. The question of what level of hardware will be eventually be realised is likely to depend on the possibility to combine different components in order to benefit of the advantages and to avoid the disadvantages of the individual physical systems.

A central goal of this journal is to follow the developments in experiments and theory of quantum information, and to help identify what are the most promising paths forward. In order to achieve this, we aim to help bridging between the different branches of quantum information and to help developing an agenda to-wards achievable, but impactful goals for the community.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Conflict of interest

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