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Quantum Computing: Implementations and Experimental Challenges

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As an emerging technology, quantum computing has rapidly grown from a small yet prosperous academic research field to one that generates frequent media excitement, extensive industry and government investment, and eager searches for expanding applications. Quantum computation requires quantum hardware platforms, which host the phenomena enabling computations that would be impossible on even the largest classical computers. But with fundamentally new computational hardware platforms come a new set of challenges facing the scientists and engineers who build them.

Quantum hardware is not a distant theoretical dream, but a daily reality. Quantum effects are ubiquitous and persistent, and the challenge of harnessing their computational power lies in the thorny but not intractable problem of scalability. Though quantum states abound in nature and in laboratories, the majority are fragile and easily subject to decoherence, an effect particular to quantum hardware that leads to errors in any quantum computation. Algorithmic error correction techniques exist, but even the most flexible of these will require breakthroughs in the materials and control systems comprising quantum hardware platforms. This presentation will focus on the efforts of the community to mitigate decoherence mechanisms at the hardware level.

The fundamental building blocks of a quantum computer are quantum bits (qubits) which demonstrate phenomena like superposition and entanglement. Different hardware platforms encode these qubits in different physical states of matter. For example, ionic qubits are encoded in the electronic energy levels of ionized atoms, while topological qubits are encoded as excitations of electrons in superconducting materials with special properties that protect these states against unwanted disturbance.

Efforts to scale these different quantum hardware platforms while minimizing decoherence can draw on a variety of techniques. My postdoctoral research at UC Berkeley focused on adapting powerful multi-qubit entangling techniques common in ionic qubits for use in superconducting circuits. These techniques allow for an increased number of operations in the span of the finite lifetimes of quantum states. In Microsoft Quantum, we alternatively emphasize the development of qubits that, through their topological properties, are inherently protected from the decohering mechanisms that limit these lifetimes.

Achieving scalable quantum hardware solutions requires attention not just to the qubits themselves, but also to their physical environments. A variety of research and development disciplines must join forces to address the thermal, mechanical, and radiative requirements for this new technology. As an example, quantum hardware platforms require special considerations for interfaces between the lowest qubit layer and each subsequent layer of a full computer stack. In the case of qubit technologies reliant on superconducting metals, cryogenic engineering solutions can improve some of these interfaces. Other challenges can be addressed with improvements to the quantum materials themselves. Still others require a fundamental rethinking of how the qubits are measured and made to interact.

BIO

Sydney Schreppler is a physicist and quantum engineer with Microsoft's quantum hardware group. Her research experience spans many of today's most promising quantum hardware platforms, from topologically protected qubits to trapped atoms to superconducting circuits. Prior to joining Microsoft, as a L'Oréal USA For Women in Science postdoctoral fellow at UC Berkeley, she developed quantum measurement techniques and multiqubit entangling gates for superconducting circuits. She received her B.S. in physics from Yale in 2010, and her M.A. in physics from UC Berkeley in 2012. She completed her PhD in 2016, also at UC Berkeley, with a focus on quantum measurement of ultracold atoms.