American University of Armenia | **Vani Mardirossian**
Introduction to Quantum Computing | **Project Task #04**
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Which modality do you think would be the first to support a functional quantum computer? Why do you think your chosen modality will be the first one in supporting a functional quantum computer? Compare at least three modalities. Think about the second modality that might be also a good candidate and answer the same as above.

Out of the discussed qubit modalities, it is my opinion that the superconducting platform will be the most successful one in achieving quantum computation, however, for the near future, the computers built with it will not be very scalable (mostly due to manufacturing challenges). I believe the trapped ion modality is showing enough potential to be considered a runner-up. Catching up to superconducting qubits might be challenging, since the roadblocks are more theoretical/scientific, whereas with superconducting, they are more manufacturing/engineering related.

I will discuss the specific reasons for choosing each modality in more detail in the upcoming paragraph.

Let's discuss three of the leading physical platforms for representing qubits that might potentially enable building a functional quantum computer. I choose to discuss

1. Neutral atom qubits,
2. Trapped ion qubits,
3. Superconducting qubits.

Neutral atom qubits The core idea behind this modality is holding atoms in place within an array by an intersection of laser beams, which minimise thermal motion. Because the atoms are neutral, there are no strong electromagnetic forces between them in an array, which enables close confinement (which is a challenge when using charged ions). The ability to coherently control single qubits within 2D or even 3D arrays has been demonstrated experimentally. The disadvantage of this modality, however, lies in high power requirements for laser generators (a considerable obstacle for scalability), as well as the development of arrays with precise integrated optics.

Trapped ion qubits Trapped ions are another promising basis for modeling qubits which have fulfilled DiVincenzo's criteria for successful computation. Before moving on, DiVincenzo's criterial for successful computation are the following, as stated in his paper [The Physical Implementation of Quantum Computation]:

1. A scalable physical system with well characterized qubits.
2. The ability to initialize the state of the qubits to a simple fiducial state, such as $|000...\rangle$.
3. Long relevant decoherence times, much longer than the gate operation time.
4. A "universal" set of quantum gates.

5. A qubit-specific measurement capability.
6. The ability to interconvert stationary and flying qubits.
7. The ability faithfully to transmit flying qubits between specified locations.

The first five, he believed to be necessary for realizing quantum computation, and the last two necessary for realizing quantum communication.

The primary advantage of progressing towards quantum computation with this model is that a majority of the necessary technology has already been developed (e.g. as a basis for an atomic clock). While trapped ions have demonstrated progress in maintaining high coherence times, performing high fidelity operations with few qubits, this method still has a few disadvantages, which might prevent scalable computation, such as low gate speeds, as well as reduced control and read-out of individual ions with increasing array size (which necessitates usage of macroscopic RF traps). This combination of having high coherence time, but also having disadvantages such as scalability issues and low gate speeds is the reason why I chose trapped ion qubits as the second modality that would be a viable choice in creating the first fully functioning quantum computer.

Superconducting qubits Superconducting qubits have been at the forefront of the quantum computing arms race. The modality owes its fame to its key advantages - widely accepted manufacturing technologies and easier control and readout (due to the qubit state being "encoded" in a macroscopic measurement). Due to a superconducting qubit being a circuit, it is possible to customise atomic properties (e.g. necessary energy levels), instead of relying on limited default properties of existing atoms. One of the biggest challenges with this modality is the cost of developing large-scale refrigeration systems, as superconducting properties are enabled in extremely low temperatures. As superconducting qubits are the leading modalities that are being implemented in current technological developments, asides from its high developmental costs, I believe it makes them the top candidate for implementing successful quantum computers.

When do you think the first functional quantum computer will be created? Why do you think it will take the time that you chose to create the first functional quantum computer? Argue at least two reasons. Think about the time frame of the second modality that might also be a good candidate. Argue at least two reasons.

Both modalities already have a preliminary implementation. General purpose trapped ion quantum computers are being developed by IonQ, and in 2018 they were successful in creating an 11 qubit trapped ion quantum computer. Other tech giants such as Google, IBM, and Intel, to name a few, are producing quantum computers using superconducting qubits. So in essence, some form of a functional quantum computer using both modalities has been created. But both of them require tweaking and improving in order to be the promising products that they have been hyped up to be.

In my opinion, superconducting quantum computers will require an additional 2-3 years at least. Whether this is a short or long period of time is relative, and does not have a clear cut answer. Some of the factors which I believe will speed up the process is first, superconducting qubits build upon existing technological capabilities, specifically, they leverage silicone technology, which is highly scalable, allowing superconducting quantum computers to reach a large number of qubits compared with other modalities. Secondly, they provide an ease of engineering, seeing as they are similar to classical transistor base circuits, using the same type of CAD software for simulation, as well as having similar implications as computer chips. The factor which I think is most important in somewhat slowing down this process is the challenge of achieving the desired temperature for large scale production of superconducting quantum computers, since they require to be refrigerated at low temperatures, and it could take a while to achieve the desired results. A combination of the factors that I believe will speed up the process, taken with some of the challenges which will slow down the process lead me to believe that it will take around 2-3 years to achieve a fully functional superconducting quantum computer.

As for trapped ion quantum computers, I believe that it will take longer, maybe 6-7 years. In much the same way as superconducting qubits, they leverage substantial existing technology, dating back as long as 30 years, used in the development of atomic clocks. They also have scientific advantages, such as the high degree of connectivity between the ions. The reason why I think that this process will take longer than superconducting quantum computer production is the challenge of scalability, as I mentioned in the first part, they have disadvantages such as low gate speeds, reduced control and read-out of individual ions when array sizes are increased, meaning that it will be harder to obtain a large number of qubits, which will be essential for creating a fully functional quantum computer, one that demonstrates quantum supremacy. Although trapped ions have other qualities which make up somehow for their disadvantages, I think that until they are able to use a larger number of qubits, superconducting qubits will be superior in time and functionality to trapped ion qubits.