PP21

Edyta Winciorek

Clinical Trials in the Quantum Era

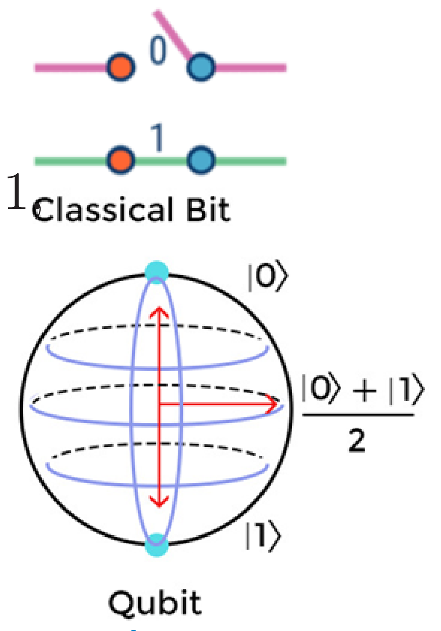
Michael Cooper

Qubits

Classical computers use **independent bits** to store information while quantum computers (QC) use **qubits**: $|0\rangle = \begin{bmatrix}1\\0\end{bmatrix}, \quad |1\rangle = \begin{bmatrix}0\\1\end{bmatrix}$.

A qubit can exist in a **superposition**:

$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle, |\alpha|^2 + |\beta|^2 = 1$



where $\alpha, \beta \in \mathbb{C}$ are **probability** of measuring $|0\rangle$ and $|1\rangle$, respectively.

Qubit state is often represented on the **Bloch sphere**: $|\psi\rangle = \cos\left(\frac{\theta}{2}\right)|0\rangle + e^{i\varphi}\sin\left(\frac{\theta}{2}\right)|1\rangle$.

Quantum Register

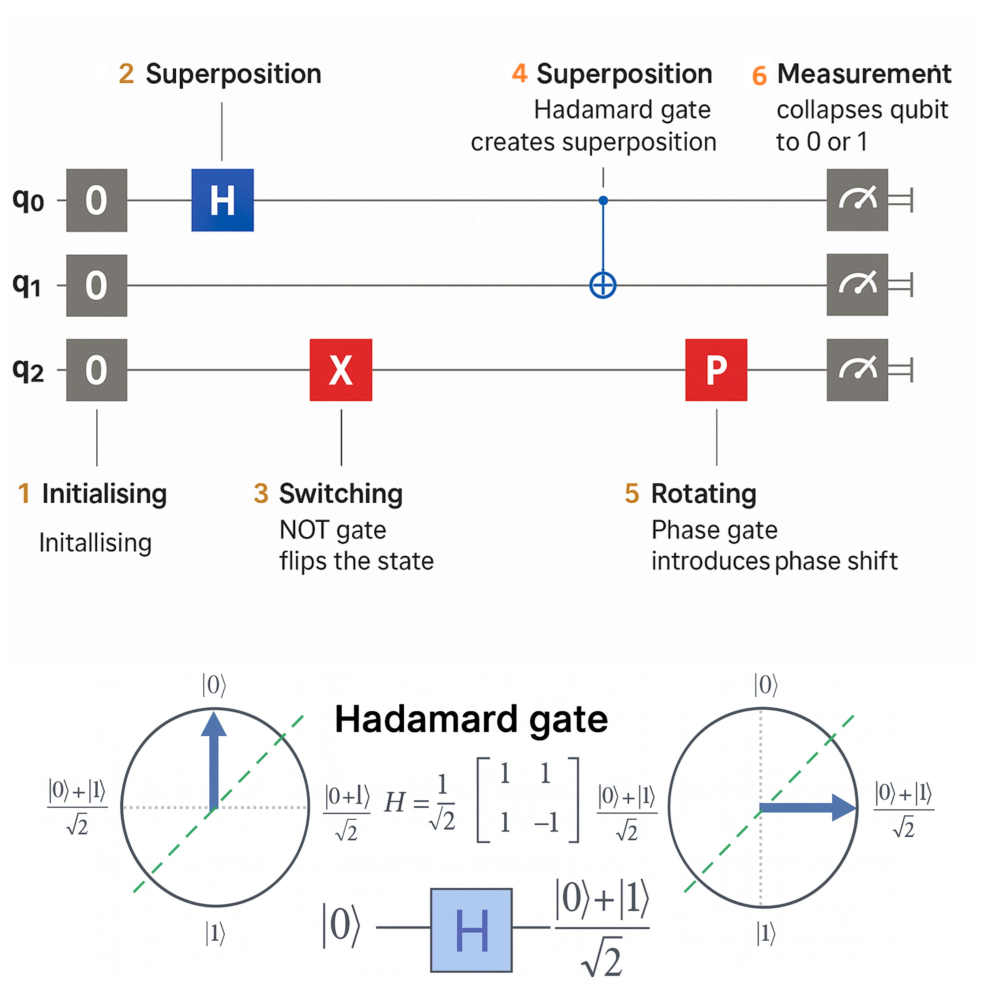
A set of n qubits forms a **quantum register** capable of representing 2^n states at once $|m\rangle = |q_0 q_1 \ldots q_{n-1}\rangle$ that can be in a **superposition** of many basis states simultaneously!

Quantum parallelism → QC can process **many possibilities at the same time**.

Example 1. *The number 3 → in binary: 011 → in quantum:* $|\Psi\rangle = \frac{1}{\sqrt{2}}\big(|0\rangle + |1\rangle\big) \otimes |1\rangle \otimes |1\rangle$.
We put the first qubit into a superposition (+) of $|0\rangle$ *and* $|1\rangle$*, while the others are fixed!*
The register represents both numbers 3 and 7 at the same time: $\frac{1}{\sqrt{2}}\big(|011\rangle + |111\rangle\big)$.

$|\Psi\rangle = \left(\frac{|0\rangle+|1\rangle}{\sqrt{2}}\right)^{\otimes 3} = ???$

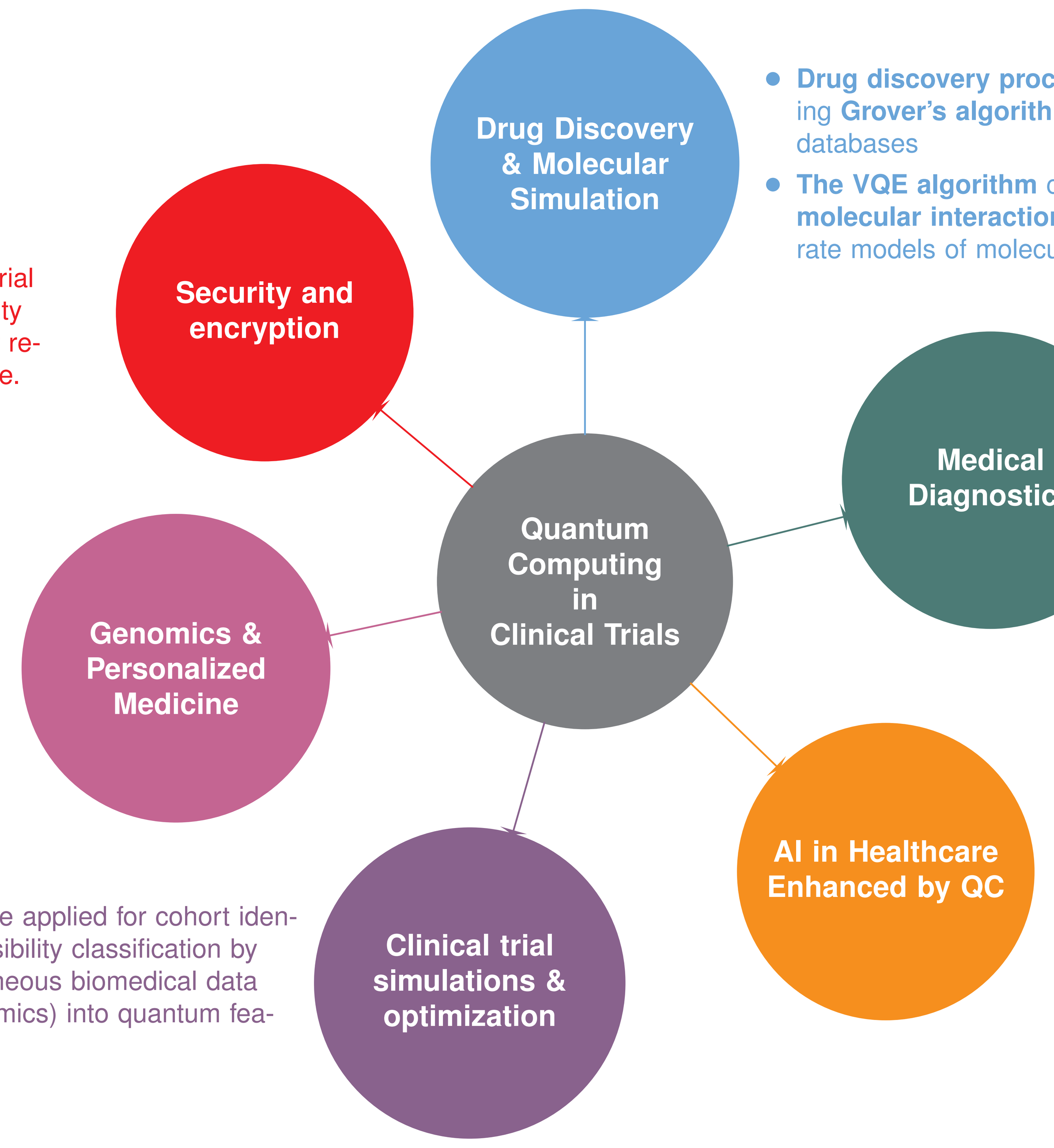
Quantum Gates



Current Challenges in QC

- **Qubit Decoherence and Noise:** Qubits lose state fast, causing errors.
- **Error Rates and Fault Tolerance:** Gates accumulate errors rapidly and *error correction* requires thousands of qubits.
- **Scalability:** Building large-scale systems with stable, controllable qubits is demanding and expensive.
- **Cryogenic and Hardware Constraints:** Most quantum computers operate near absolute zero, requiring costly cooling and isolation systems.

Practical Applications of QC in Clinical Trials



- **Drug discovery process** will be **accelerated** by harnessing **Grover's algorithm** which is designed to search unsorted databases
- **The VQE algorithm** can be used to **simulate the structure of molecular interactions at quantum level** to provide more accurate models of molecular behavior

- **Post-quantum cryptography (PQC):** allow to migrate clinical trial systems to PQC with crypto-agility so algorithms can be updated or replaced easily as standards evolve.

- **Pattern recognition** using QML such as **quantum neural networks** or **quantum support vector machines** will be able to process complex datasets more efficiently
- **Early disease detection** due to recognizing unique patterns in higher resolution images generated using QC and **quantum sensors**

- By using **quantum computation power, genetic interaction analysis** can be handled with greater precision and complexity, resulting in a deeper understanding of these interactions and what they mean for potential treatment options
- By leveraging this deeper molecular understanding, **personalized treatment plans** can be developed to provide more directed and patient-centric care

- **Predictive healthcare** analytics can be **elevated** by combined QC and AI to analyze large, multi-dimensional datasets with greater precision, with IBM, Google and Rigetti Computing at the forefront of the current research in the combination of QC and AI techniques

- **QML methods** can be applied for cohort identification and site feasibility classification by embedding heterogeneous biomedical data (EHR, imaging, genomics) into quantum feature spaces

Future Directions

Evolution of QC Statistical Modeling

Short-term

- **Faster Model Convergence**
  Increased processing power could allow running far more iterations in complex models.
- **Enhanced Imputation Workflows**
  Ability to test of multiple imputation approaches for handling missing data.
- **Reduced Program Run Times**
  QC could speed up existing long-running models such as JFM.

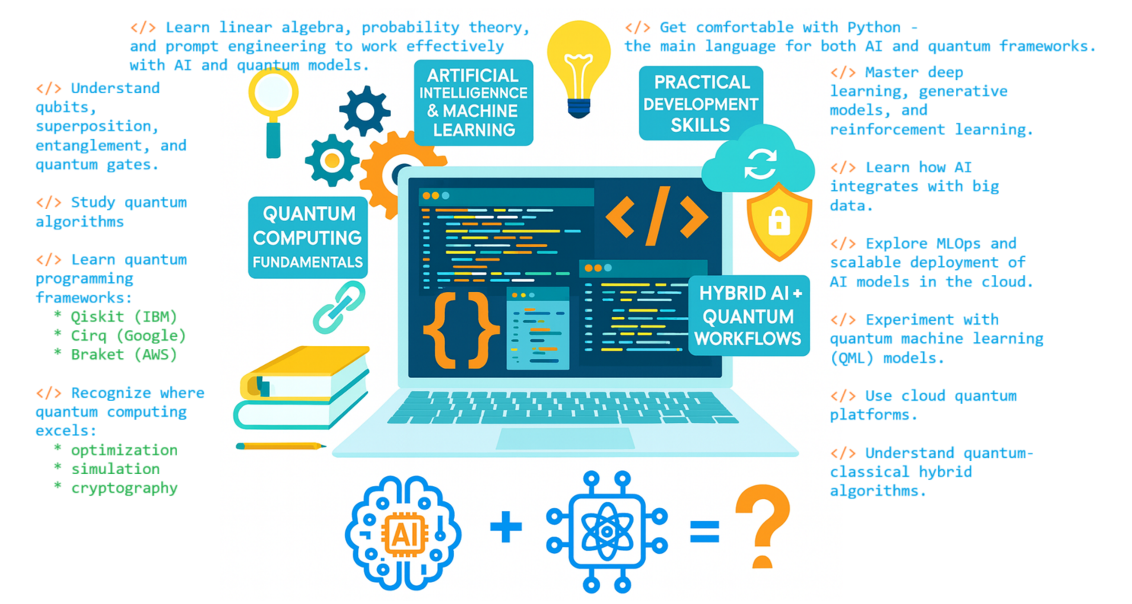
Mid-term

- **Quantum-Accelerated Bayesian Modeling**
  Improved handling of non-convergence and complex hierarchical models.
- **Dynamic Missing Data Solutions**
  QC-driven imputation methods designed for challenging and specialized clinical trial designs.
- **Programming Workflows**
  Clinical Trial timelines reduction by faster execution of complete analysis workflows.

Long-term

- **Real-Time Adaptive Modeling**
  On-the-fly model updates and re-convergence during live trials.
- **Personalized Statistical Simulations**
  Rapid simulation and analysis for highly individualized treatments.
- **Instant Data Processing**
  Dramatically shorter time from data lock to regulatory-ready outputs.

Prepare as a Developer



Conclusion

Quantum computing shows **tremendous potential**, with applications already emerging in **medicine, genomics, and personalized treatment**. Its rapid progress could greatly improve healthcare and clinical trials, offering **better therapies and patient outcomes**.

However, **major challenges remain**: quantum computers require **extreme cooling**, have **high error rates**, and **development costs are very high**, limiting access to only the **largest tech companies**. Regulatory bodies may also face **difficulties reproducing trial results** if they lack the same technology.

For quantum computing to truly transform healthcare, **hardware must become less restrictive, barriers to entry must fall**, and **costs must drop** to make these benefits widely accessible. Despite these hurdles, current progress is a **promising step toward more effective and equitable healthcare**.

References

[1] P. Hayden and H. Inamori. *Basic concepts in quantum computation*. University of Oxford, https://arxiv.org/abs/quant-ph/0011013v1 Submitted on 2 Nov 2000, November 26, 2024.

[2] J. Chow. Quantum computing in medicine. *Med. Sci.*, 12(67):2–16, October 2024.

Contact Information

https://elderbrook.de/

michael.cooper@ext.elderbrooksolutions.com

edyta.winciorek@ext.elderbrooksolutions.com