

Quantum Computing

Gerald Gilbert, PhD

732-578-6366 • ggilbert@mitre.org

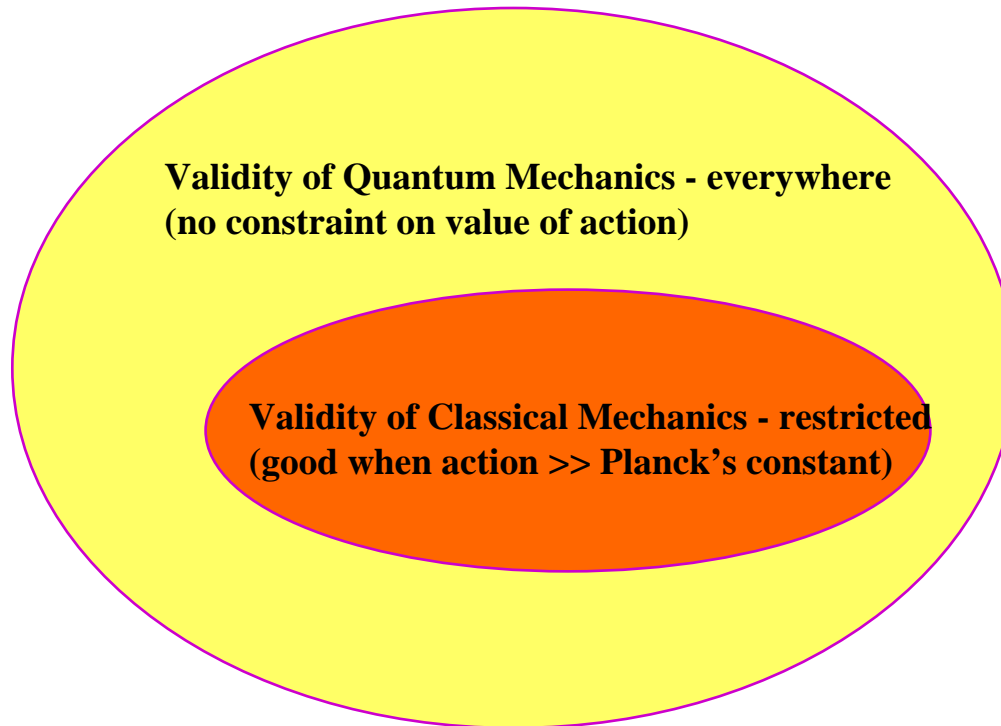
MITRE Sponsored Research



Problem

- **Quantum computers can solve problems that are effectively impossible to solve with classical computers.**
- **What is the best design for a practical quantum computer?**
 - **fault tolerance, scalability, efficiency**
- **Can we discover new quantum computing algorithms?**

Background



Quantum Information Science exploits unique features of quantum mechanics to obtain results difficult or impossible to achieve with classical mechanical systems.

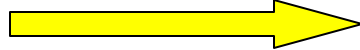
Objective

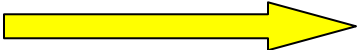
- **Develop the world's first efficient, scalable quantum computer design; prototype selected components of the design**
- **Contribute to solving problems of national importance in the areas of code-breaking, steganography analysis, real-time analysis of spread-spectrum communications, high-intensity computing, etc.**
- **Maintain MITRE's position as a world leader in the field of quantum information science**

Activities

- **Perform theoretical and systems-engineering quantum computing analyses**
- **Develop quantum information processing components using the linear quantum optics or cluster approach**
- **Design/demonstrate quantum memory device; prototype non-linear sign shift gate or cluster fusion operator**
- **Demonstrate quantum computing component(s)**

Highlight

CNOT: $U_{CN} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$  $\begin{array}{l} |00\rangle \rightarrow |00\rangle \\ |01\rangle \rightarrow |01\rangle \\ |10\rangle \rightarrow |11\rangle \\ |11\rangle \rightarrow |10\rangle \end{array}$

Hadamard: $H = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$  $\begin{array}{l} |0\rangle \rightarrow \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle) \\ |1\rangle \rightarrow \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle) \end{array}$

$$U_{CN} H |00\rangle = U_{CN} \frac{1}{\sqrt{2}} (|0\rangle + |1\rangle) |0\rangle$$
$$= \frac{1}{\sqrt{2}} (|00\rangle + |11\rangle)$$

**Hadamard followed by CNOT
yields an entangled state.**

Demonstration

Quantum Computing “square root of not” gate

$$M = \frac{1+i}{2} \begin{pmatrix} 1 & -i \\ -i & 1 \end{pmatrix} = \frac{1}{\sqrt{2}} e^{i\pi/4} \begin{pmatrix} 1 & -i \\ -i & 1 \end{pmatrix}$$

$$M \cdot |1\rangle \Rightarrow \frac{1+i}{2} \begin{pmatrix} 1 & -i \\ -i & 1 \end{pmatrix} \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \frac{1+i}{2} \begin{pmatrix} -i \\ 1 \end{pmatrix}$$

$$M \cdot |1\rangle = \frac{1+i}{2} |1\rangle - \frac{i-1}{2} |0\rangle$$

Interim state is quantum mechanical
superposition not possible in classical
mechanics

$$M^2 \cdot |1\rangle = \left(\frac{1+i}{2}\right)^2 \begin{pmatrix} 1 & -i \\ -i & 1 \end{pmatrix} \begin{pmatrix} -i \\ 1 \end{pmatrix} = \frac{i}{2} \begin{pmatrix} -2i \\ 0 \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} = |0\rangle$$

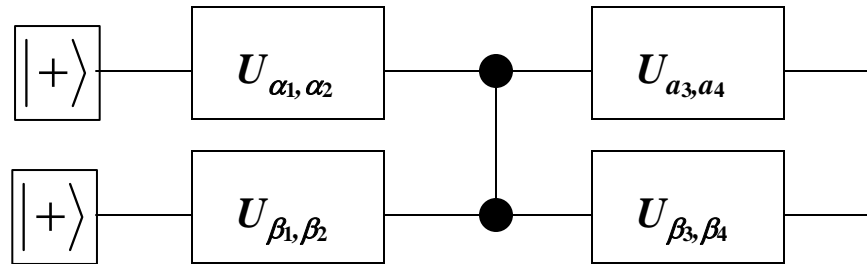
The interim state allows *quantum parallel processing* and *entanglement*.

Impacts

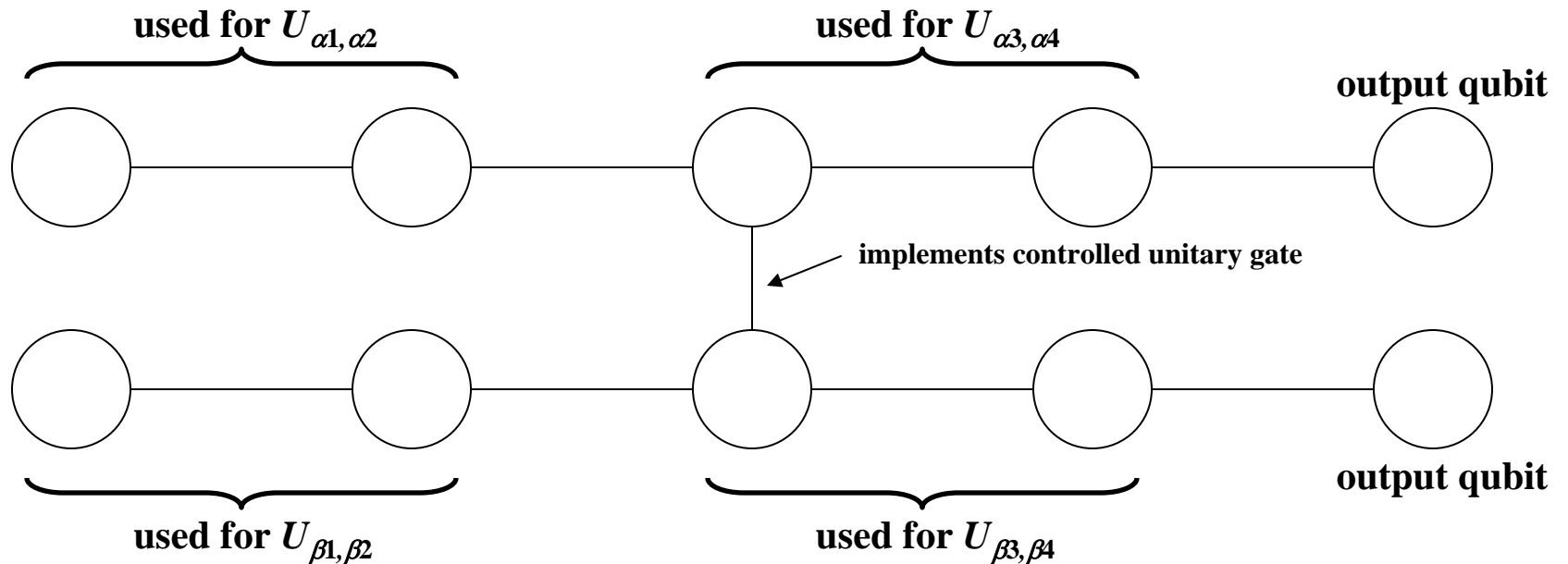
- This work places MITRE at the very frontier of research worldwide.
- MITRE is now recognized as a leading player in this high-visibility research area.
- We will continue to develop a unique resource to assist government to manage development and deployment of this new technology.
- We will make basic advances in technology that will be crucial in addressing problems of national importance.

Future Plans

gate paradigm



cluster paradigm



MITRE

© 2005, The MITRE Corporation