Quantum Computing

deep dive

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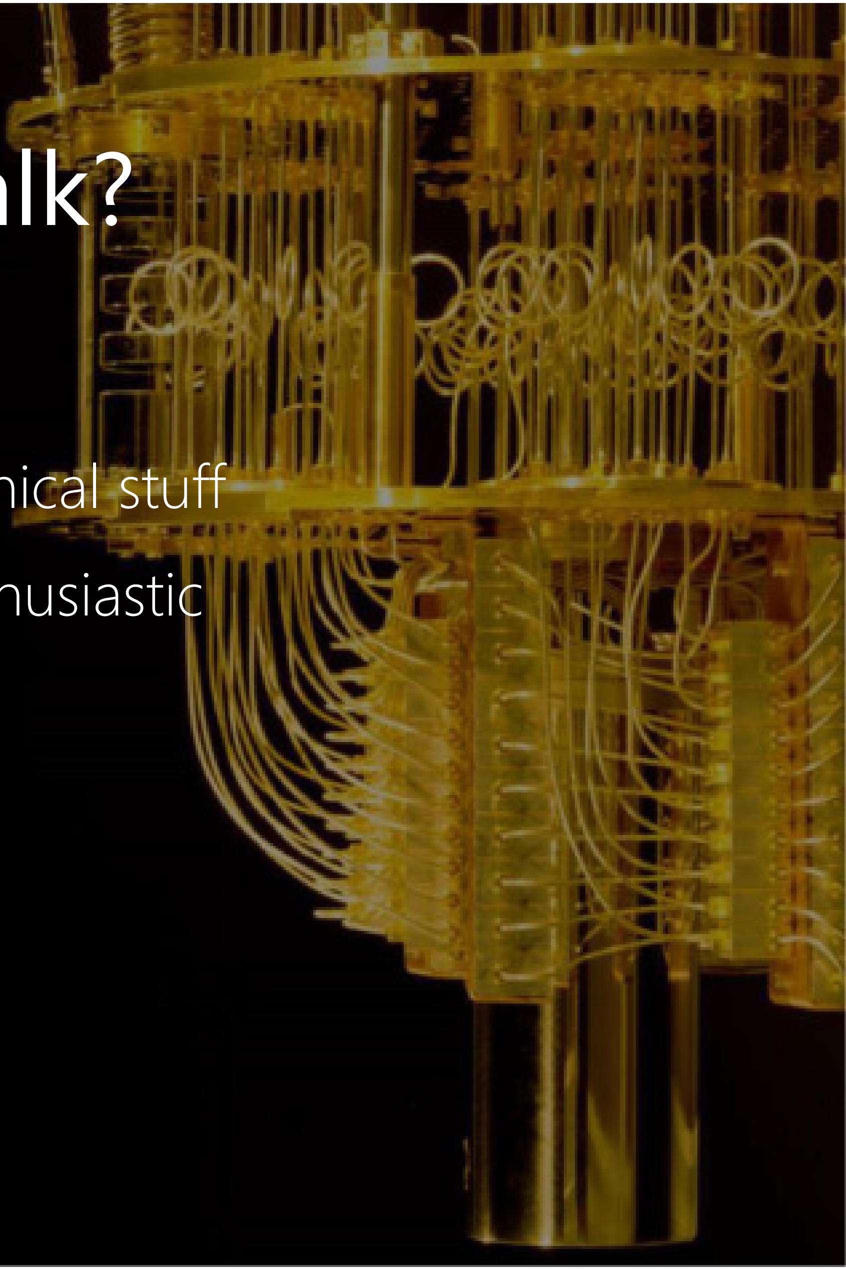
Why am I presenting this talk?

- As a human, I like to experiment and discover
- As a software engineer, I like to learn new technical stuff
- As a teacher, I like to teach and get people enthusiastic

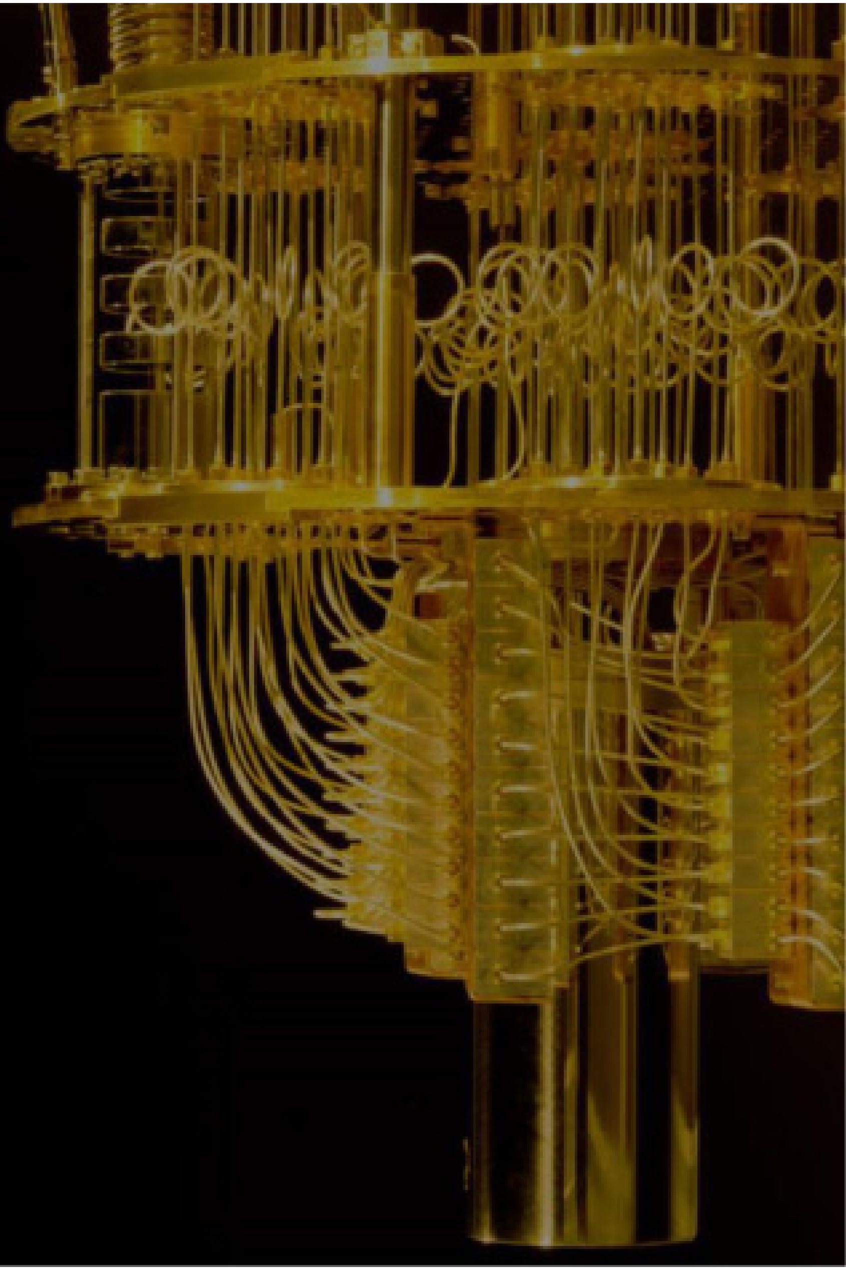


What will you do after this talk?

- ☑ Be able to explain why quantum computing matters?
- ☑ Study more about quantum computing?
- ☑ Understand the basics about quantum computing?
- ☑ Run quantum algorithms using IBM Q Experience and Microsoft Q#?
- ☒ Decipher quantum algorithms?
- ☒ Use quantum computing tomorrow?
- ☒ Use quantum computing in the next decade?

Agenda

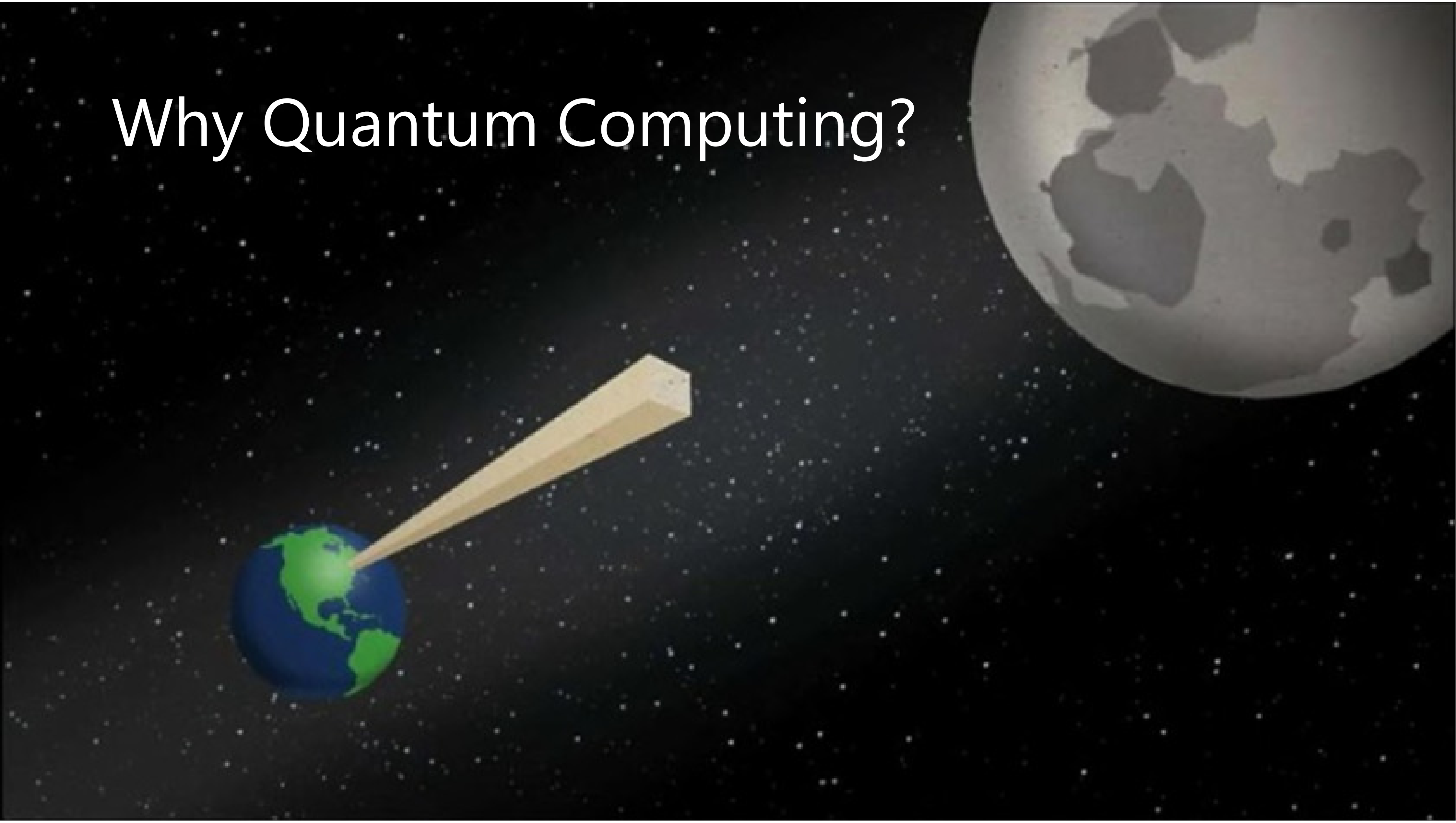
- Why Quantum Computing?
- Classic vs. Quantum
- Quantum superposition & entanglement
- Bit vs. Qubit
- IBM Q Experience
- Microsoft Q#
- Quantum Algorithms



Why Quantum Computing?

- Moores law has its physical limits
- Current classical computing architectures already have issues with quantum effects because of their scale
- Why try to simulate a quantum world using classical computers

Why Quantum Computing?



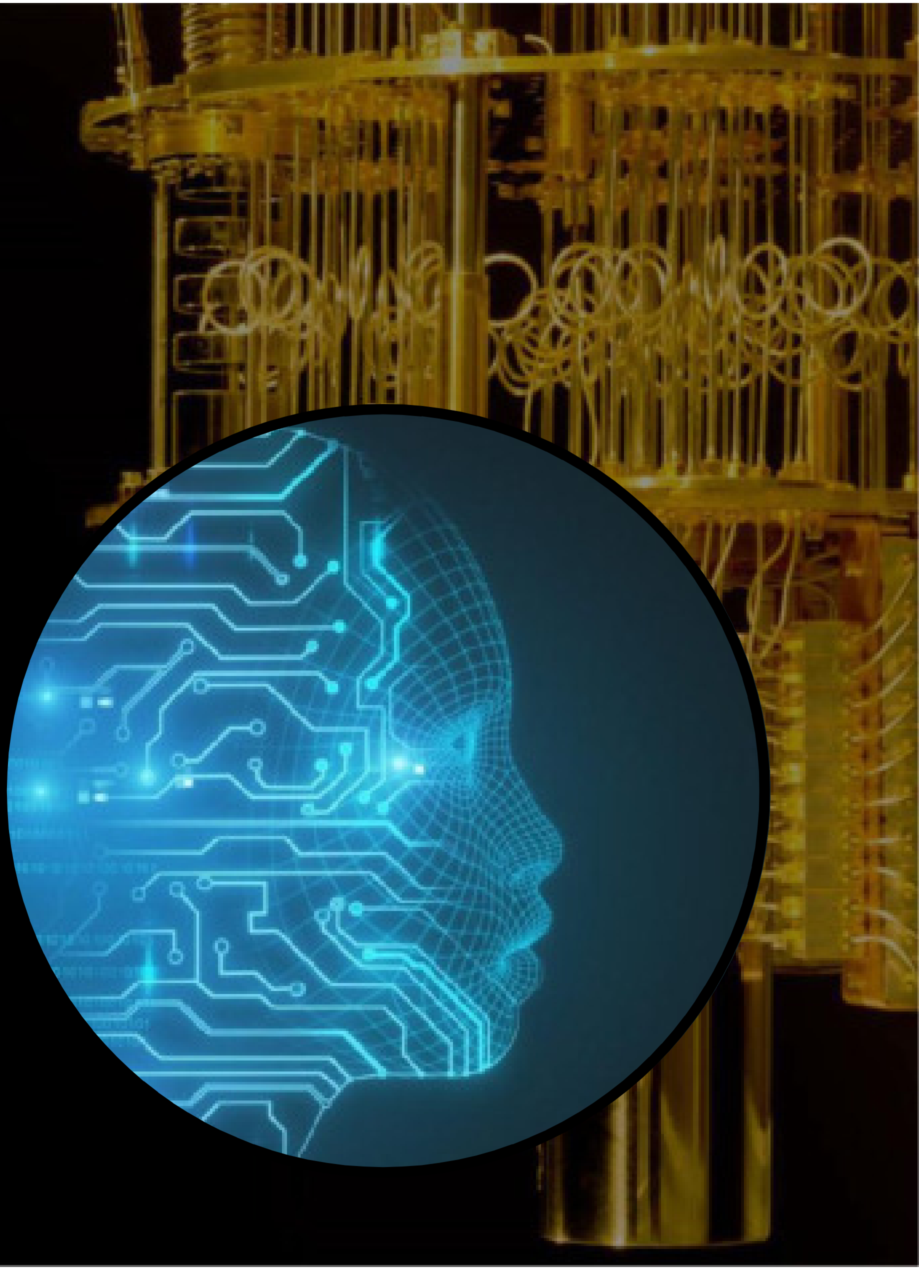
Why Quantum Computing?

Classical vs. Quantum

- Security
  - Public / private key encryption
  - Makes current encryption obsolete
  - QKD (Quantum Key Distribution)

Classical vs. Quantum

- Artificial Intelligence
  - Analyze large quantities of data
  - Fast feedback
  - Emulate human mind



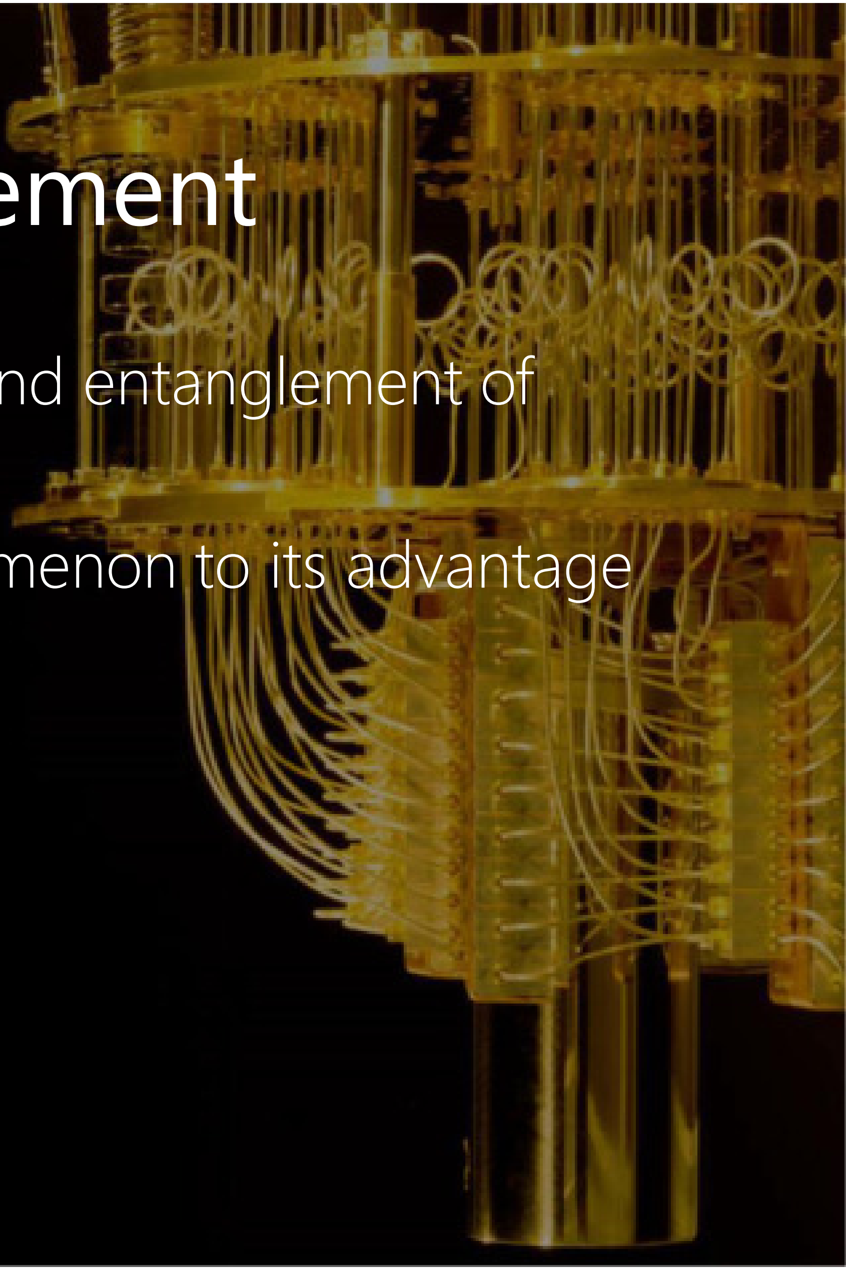
Classical vs. Quantum

- Drug development
  - It takes a quantum system to emulate quantum mechanics
  - Interactions between molecules
  - Gene sequencing

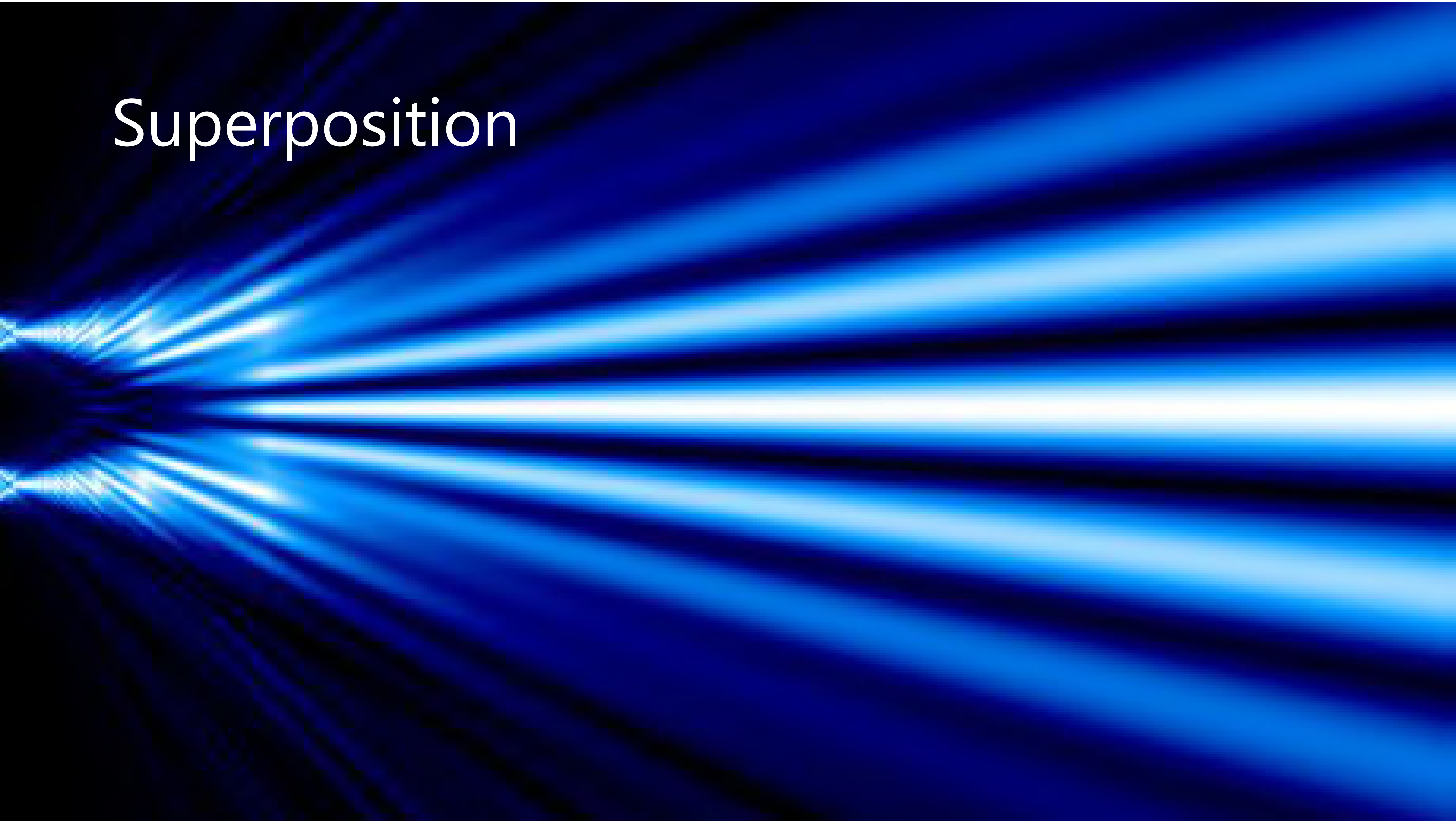

CAN IT RUN CRYSIS?

Superposition and Entanglement

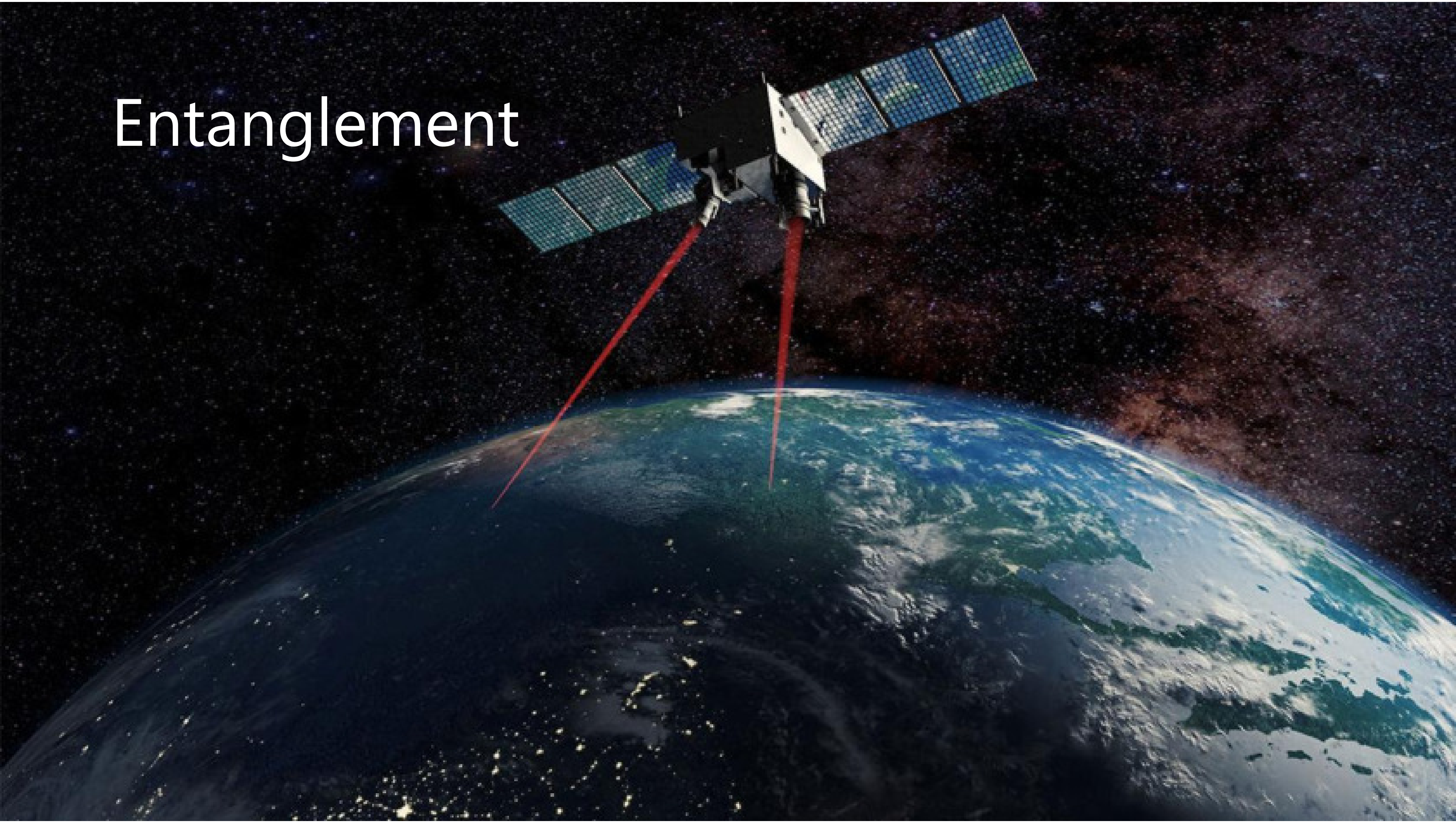
- Quantum Physics describes superposition and entanglement of quantum particles
- Quantum Computing can use these phenomenon to its advantage



Superposition



Superposition


Entanglement

Bits vs. Qubits

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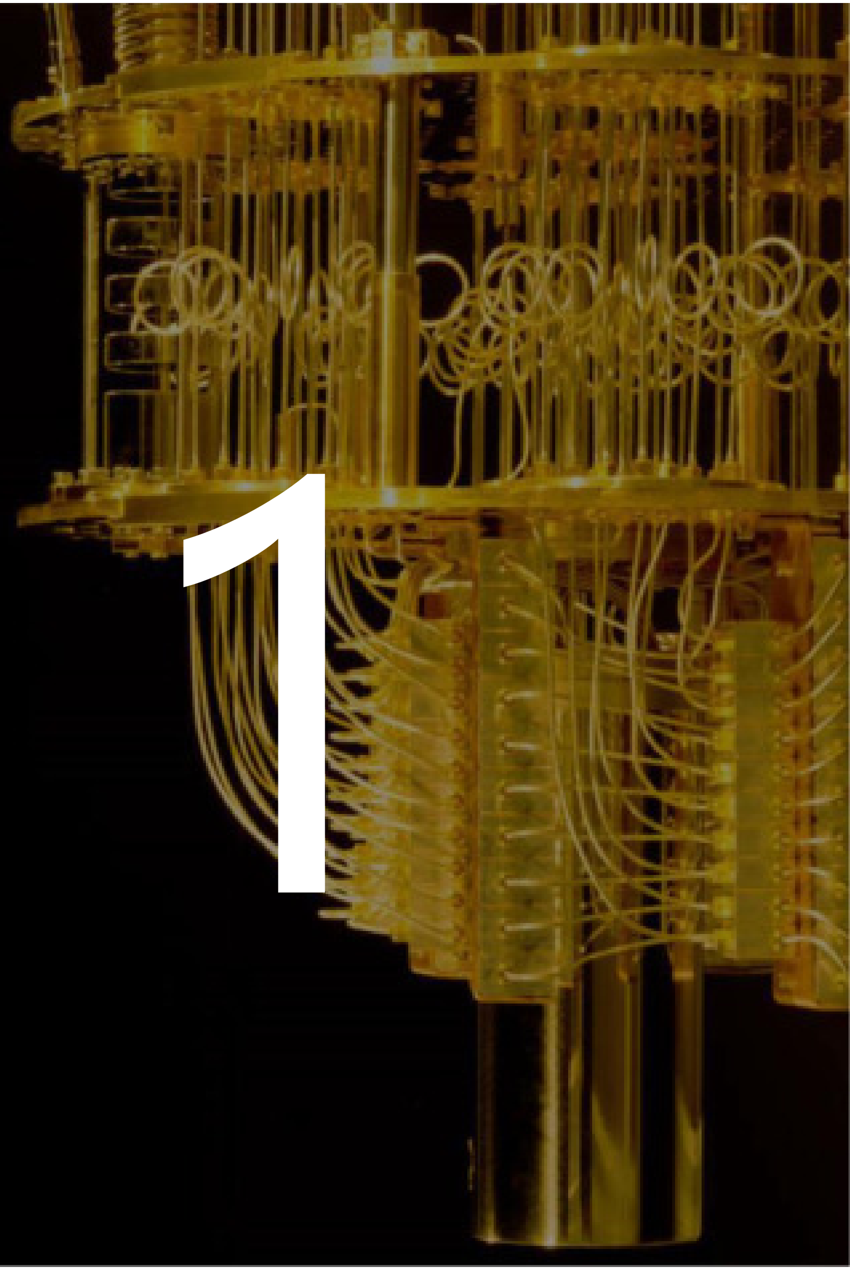

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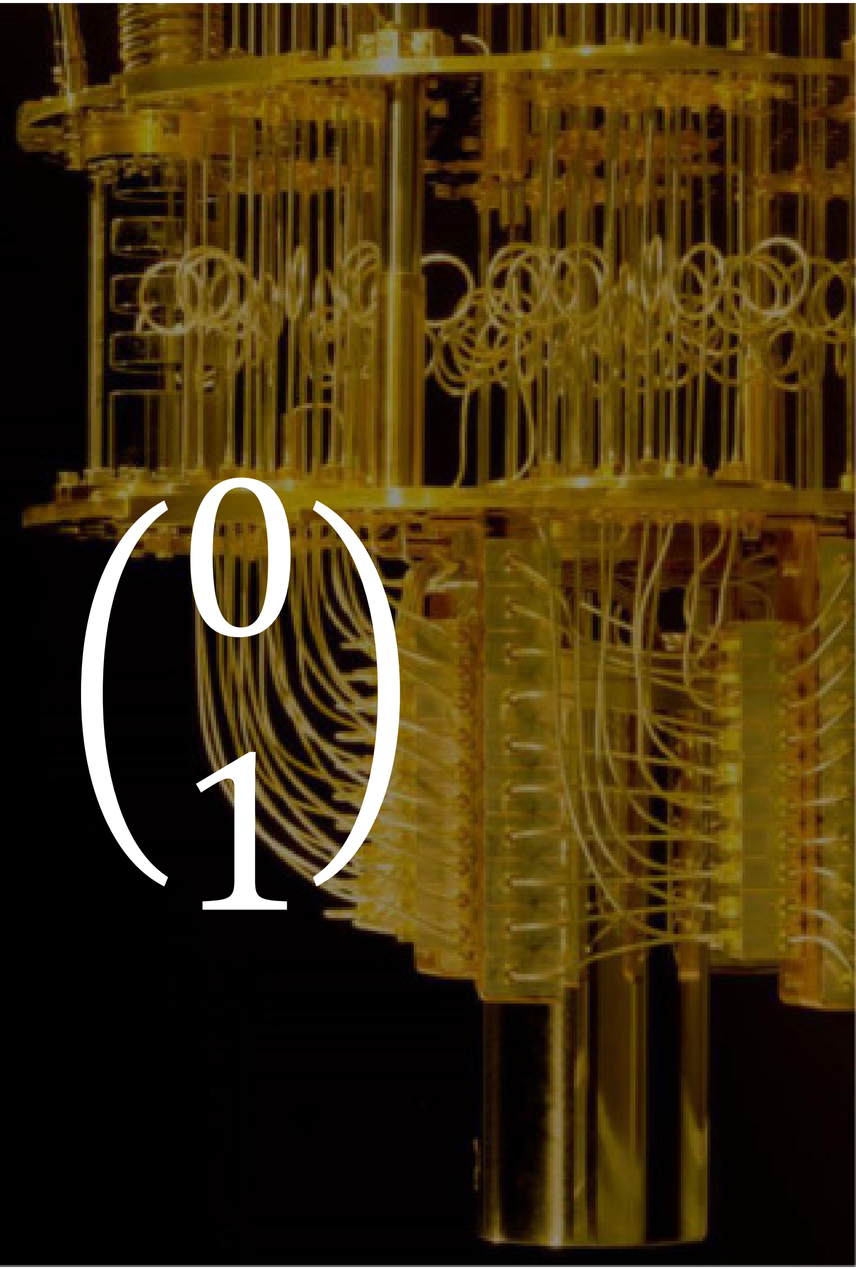
Bits vs. Qubits

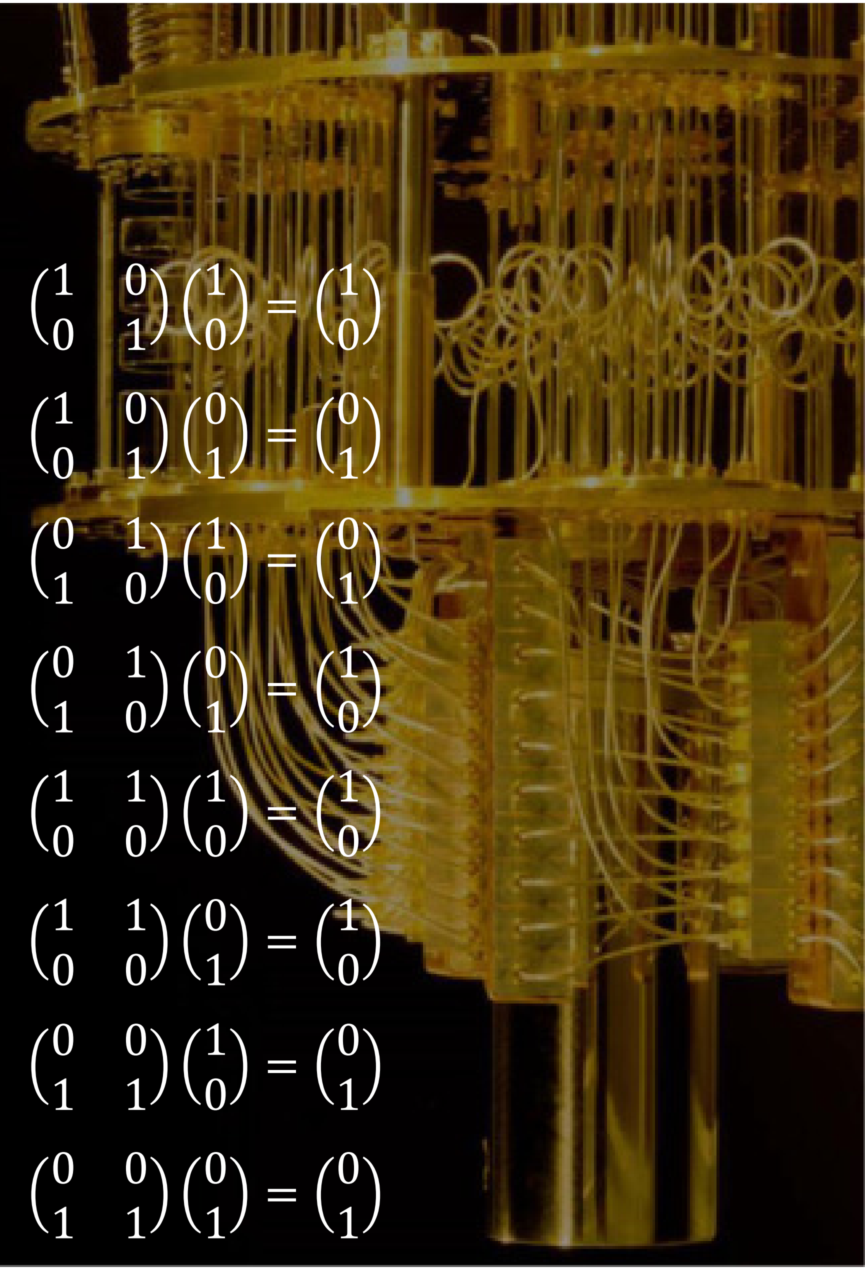
$$\begin{pmatrix}1\\0\end{pmatrix}$$

$$\begin{pmatrix}0\\1\end{pmatrix}$$

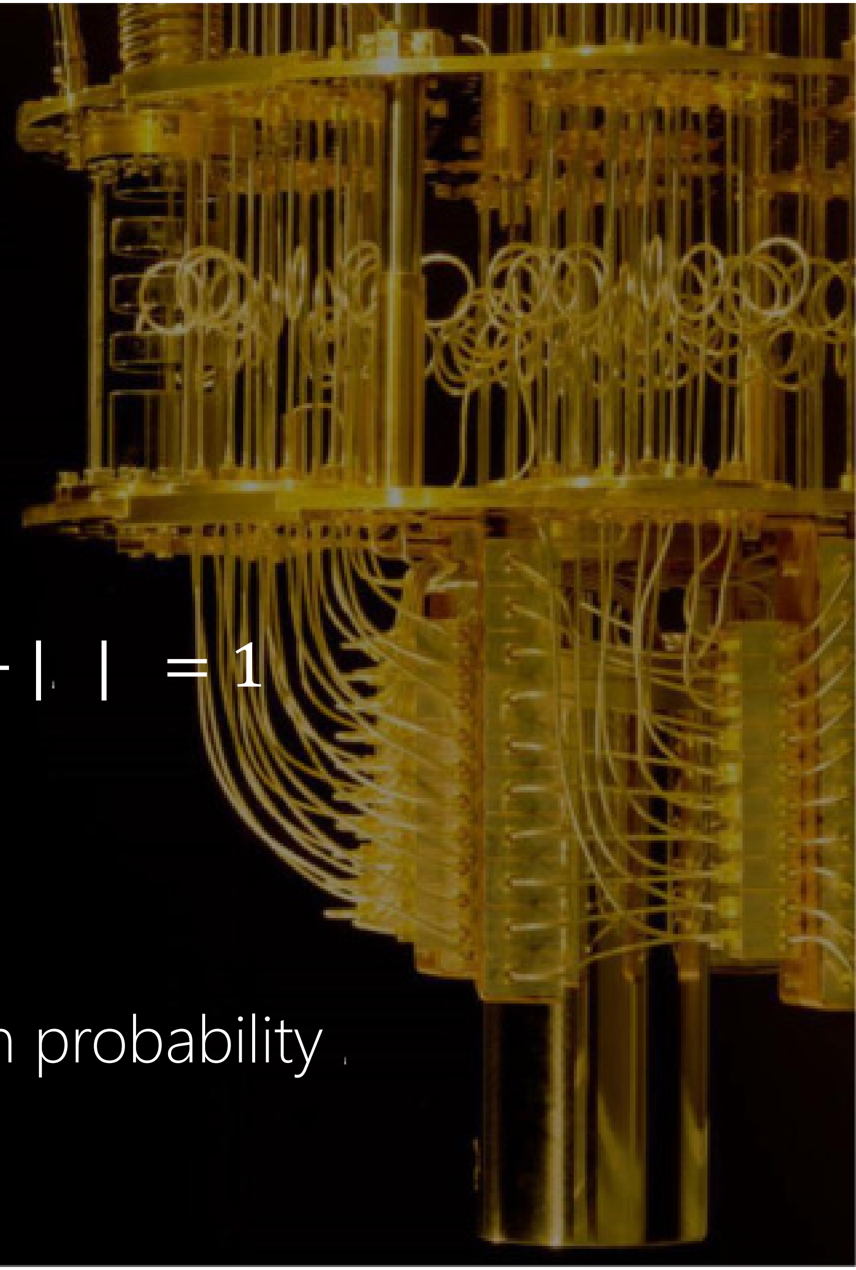


Bits vs. Qubits

Identity	$(\,.\,) = .$	$0 \rightarrow 0$	$\begin{pmatrix}1 & 0\\0 & 1\end{pmatrix}\begin{pmatrix}1\\0\end{pmatrix} = \begin{pmatrix}1\\0\end{pmatrix}$
		$1 \rightarrow 1$	$\begin{pmatrix}1 & 0\\0 & 1\end{pmatrix}\begin{pmatrix}0\\1\end{pmatrix} = \begin{pmatrix}0\\1\end{pmatrix}$
Negation	$(\,.\,) = \neg .$	$0 \rightarrow 1$	$\begin{pmatrix}0 & 1\\1 & 0\end{pmatrix}\begin{pmatrix}1\\0\end{pmatrix} = \begin{pmatrix}0\\1\end{pmatrix}$
		$1 \rightarrow 0$	$\begin{pmatrix}0 & 1\\1 & 0\end{pmatrix}\begin{pmatrix}0\\1\end{pmatrix} = \begin{pmatrix}1\\0\end{pmatrix}$
Constant-0	$(\,.\,) = 0$	$0 \rightarrow 0$	$\begin{pmatrix}1 & 1\\0 & 0\end{pmatrix}\begin{pmatrix}1\\0\end{pmatrix} = \begin{pmatrix}1\\0\end{pmatrix}$
		$1 \rightarrow 0$	$\begin{pmatrix}1 & 1\\0 & 0\end{pmatrix}\begin{pmatrix}0\\1\end{pmatrix} = \begin{pmatrix}1\\0\end{pmatrix}$
Constant-1	$(\,.\,) = 1$	$0 \rightarrow 1$	$\begin{pmatrix}0 & 0\\1 & 1\end{pmatrix}\begin{pmatrix}1\\0\end{pmatrix} = \begin{pmatrix}0\\1\end{pmatrix}$
		$1 \rightarrow 1$	$\begin{pmatrix}0 & 0\\1 & 1\end{pmatrix}\begin{pmatrix}0\\1\end{pmatrix} = \begin{pmatrix}0\\1\end{pmatrix}$



Bits vs. Qubits



- Classical bit $\mathbf{0}$, Quantum bit $|\mathbf{0}\rangle$
- Classical bit $\mathbf{1}$, Quantum bit $|\mathbf{1}\rangle$
- Quantum bit in superposition

$$|0\rangle + \quad |1\rangle \text{ where } | \quad | + | \quad | = 1$$

- and are complex number $(\mathbf{a} \ + \mathbf{b})$
- Value known after measurement
- Collapses to $\mathbf{0}\rangle$ with probability or $\mathbf{1}\rangle$ with probability

Bits vs. Qubits

- 2 Qubit system (4 values):

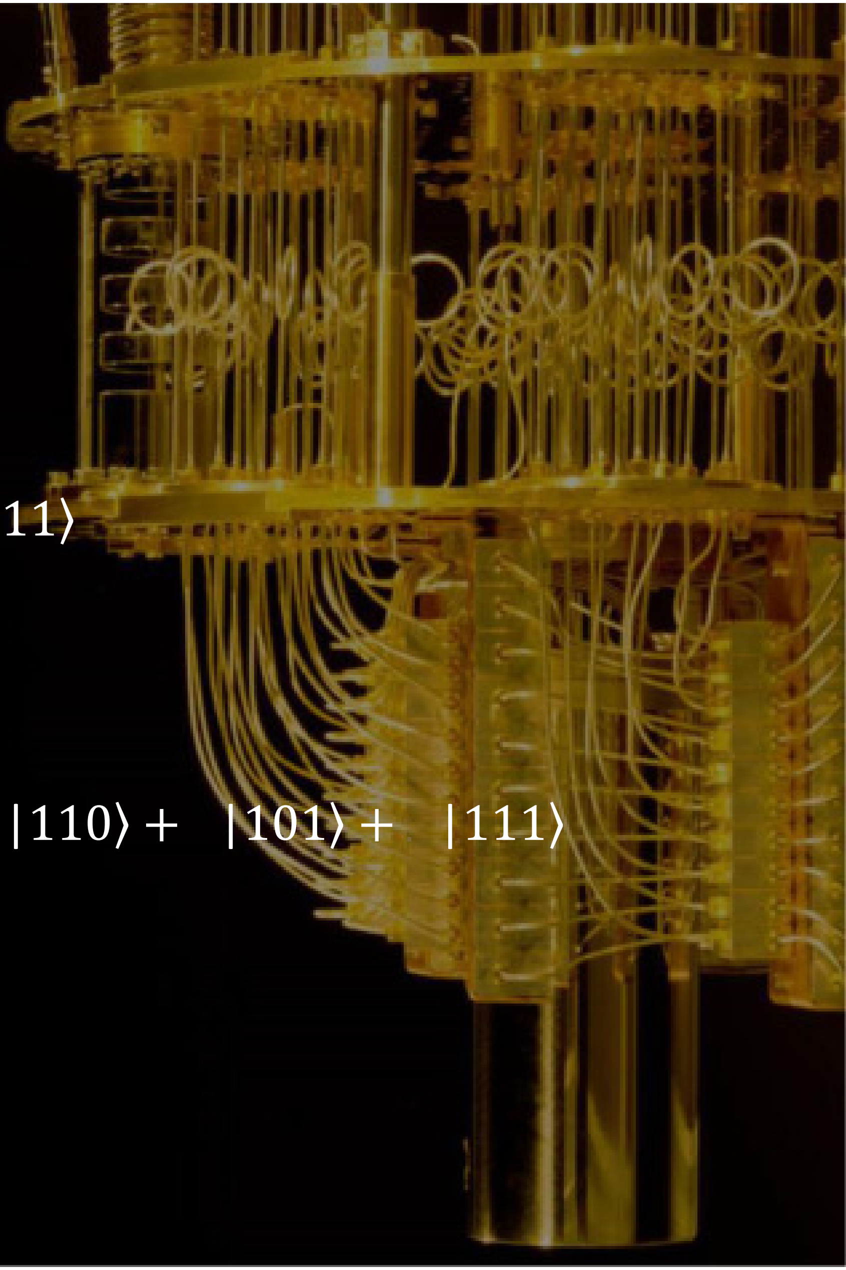
$$|00\rangle + \quad |01\rangle + \quad |10\rangle + \quad |11\rangle$$

- 3 Qubit system (8 values):

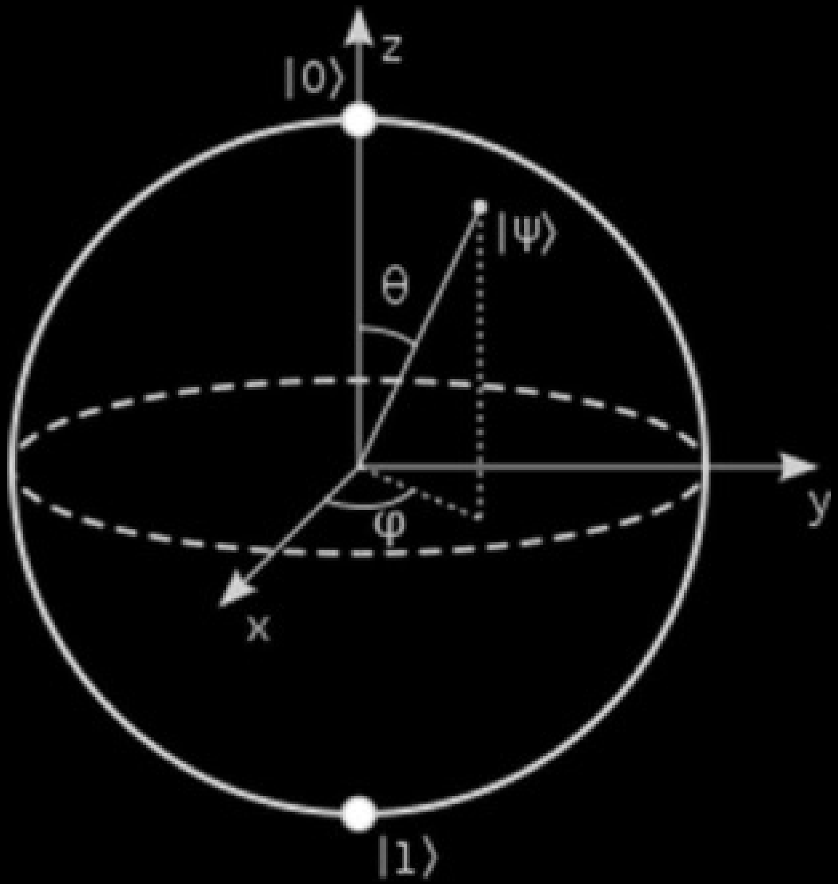
$$|000\rangle + \quad |001\rangle + \quad |010\rangle + \quad |011\rangle + \quad |100\rangle + \quad |110\rangle + \quad |101\rangle + \quad |111\rangle$$

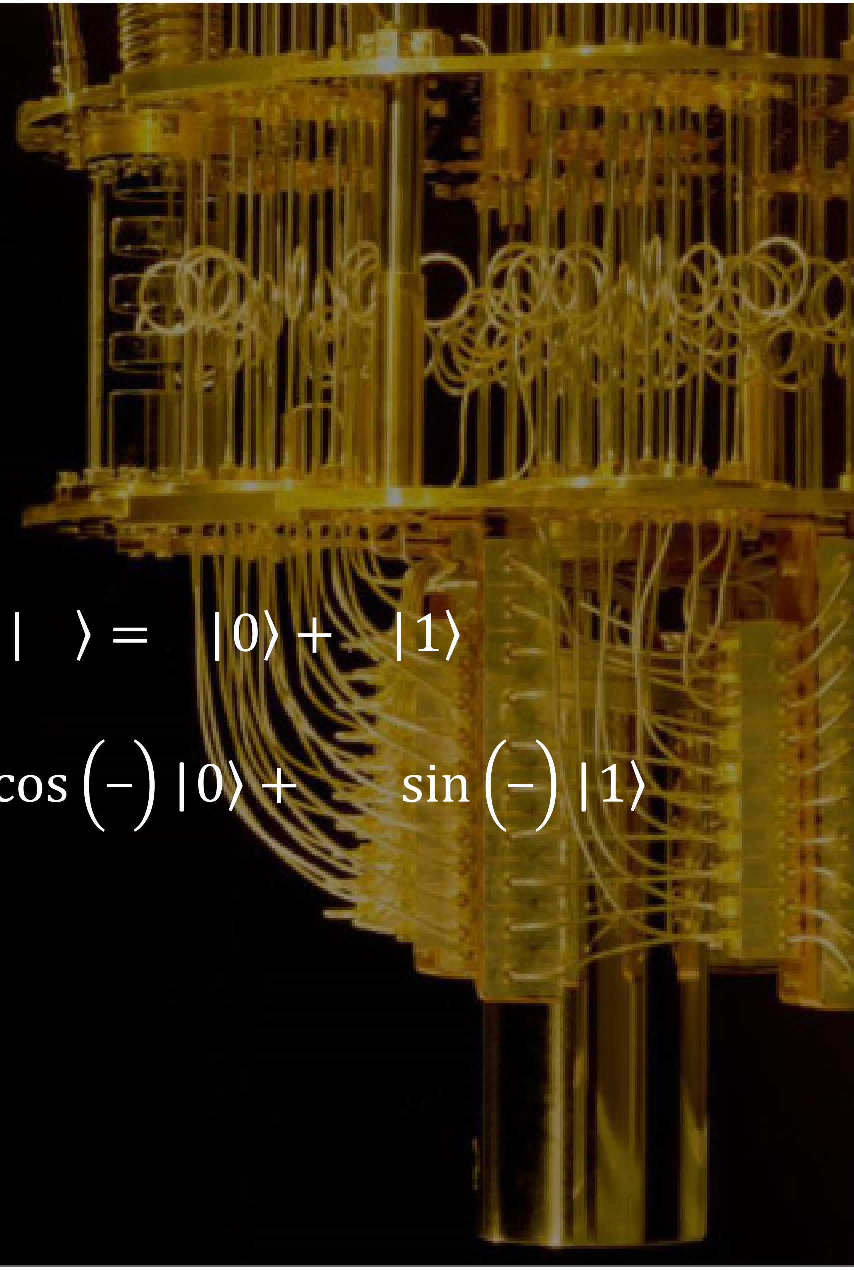
- 4 Qubit system (16 values):

...



Bits vs. Qubits

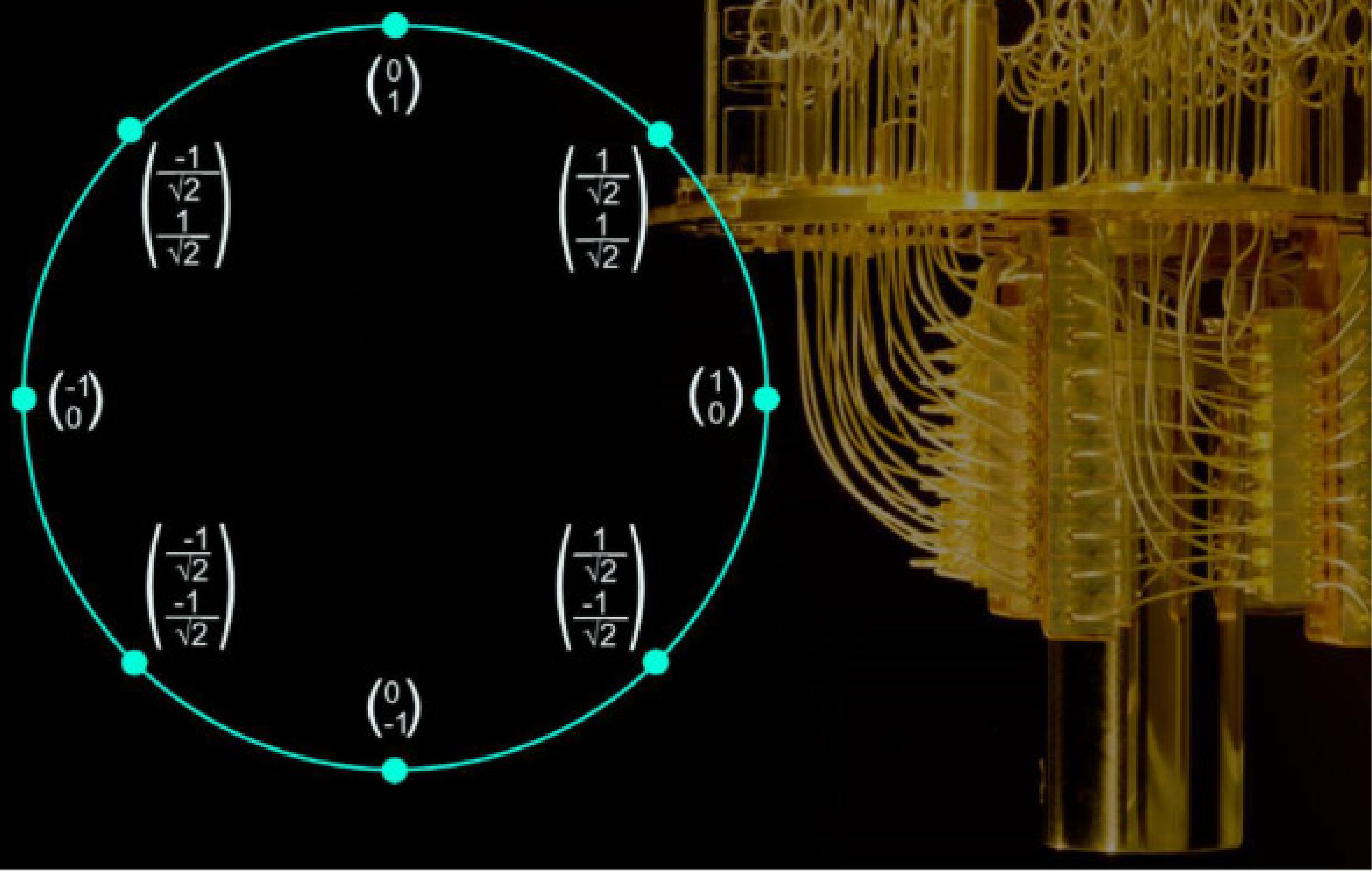




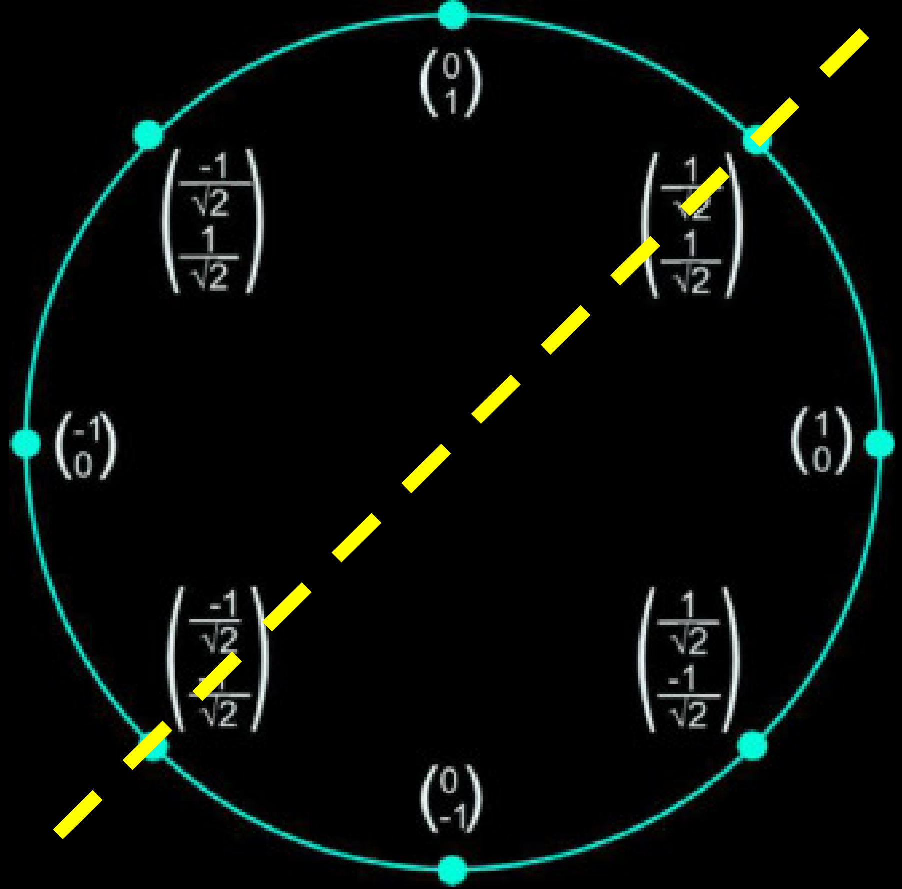
$$|\quad\rangle = \quad |0\rangle + \quad |1\rangle$$

$$|\quad\rangle = \cos\left(-\right) |0\rangle + \quad \sin\left(-\right) |1\rangle$$

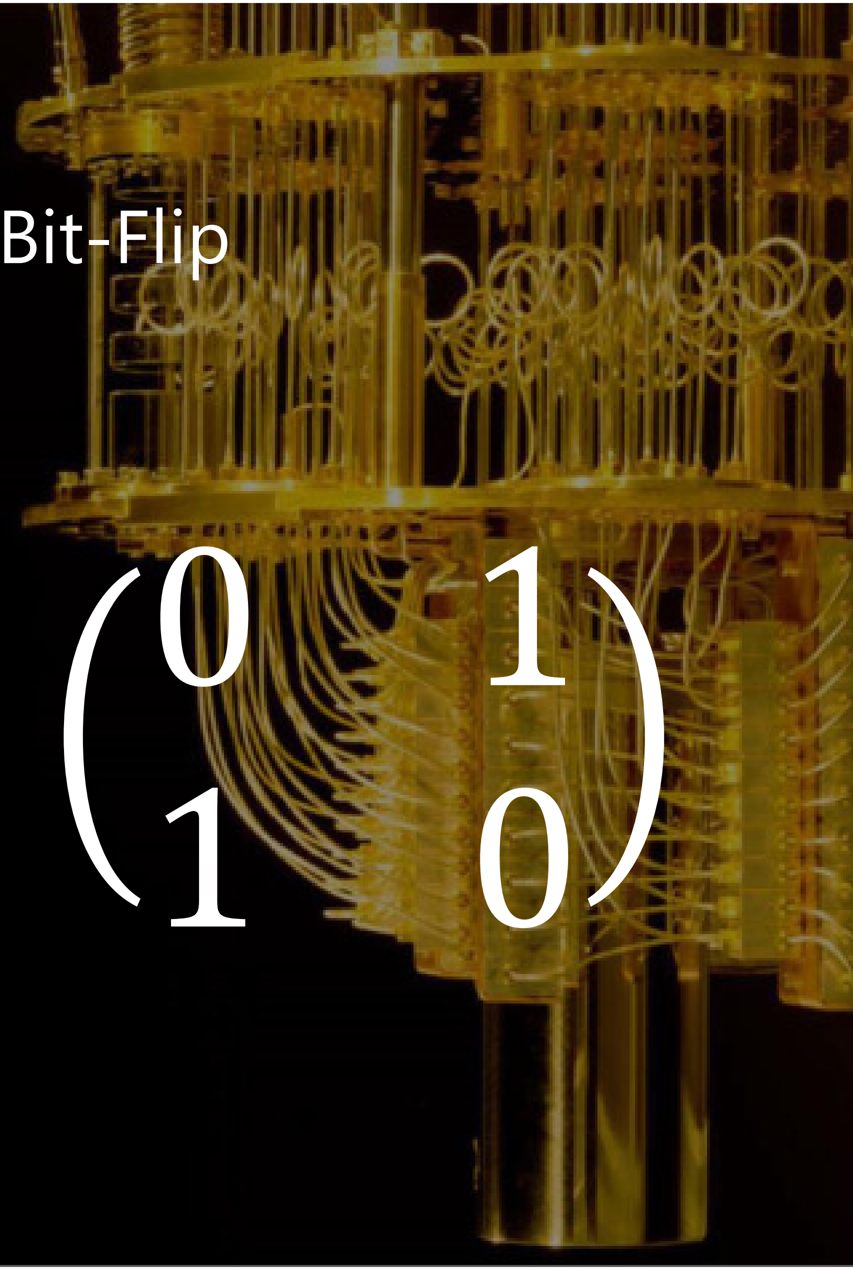
Bits vs. Qubits



Bits vs. Qubits

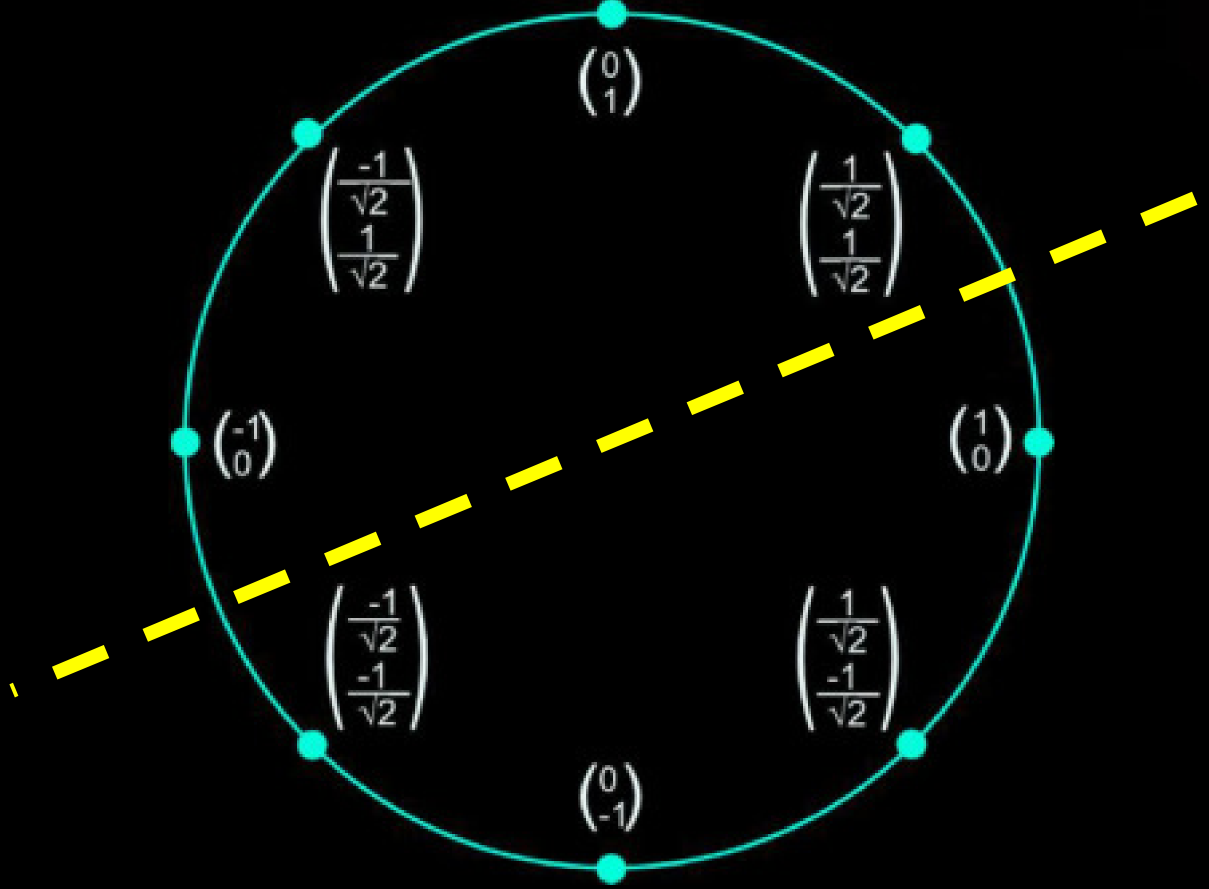


x Bit-Flip



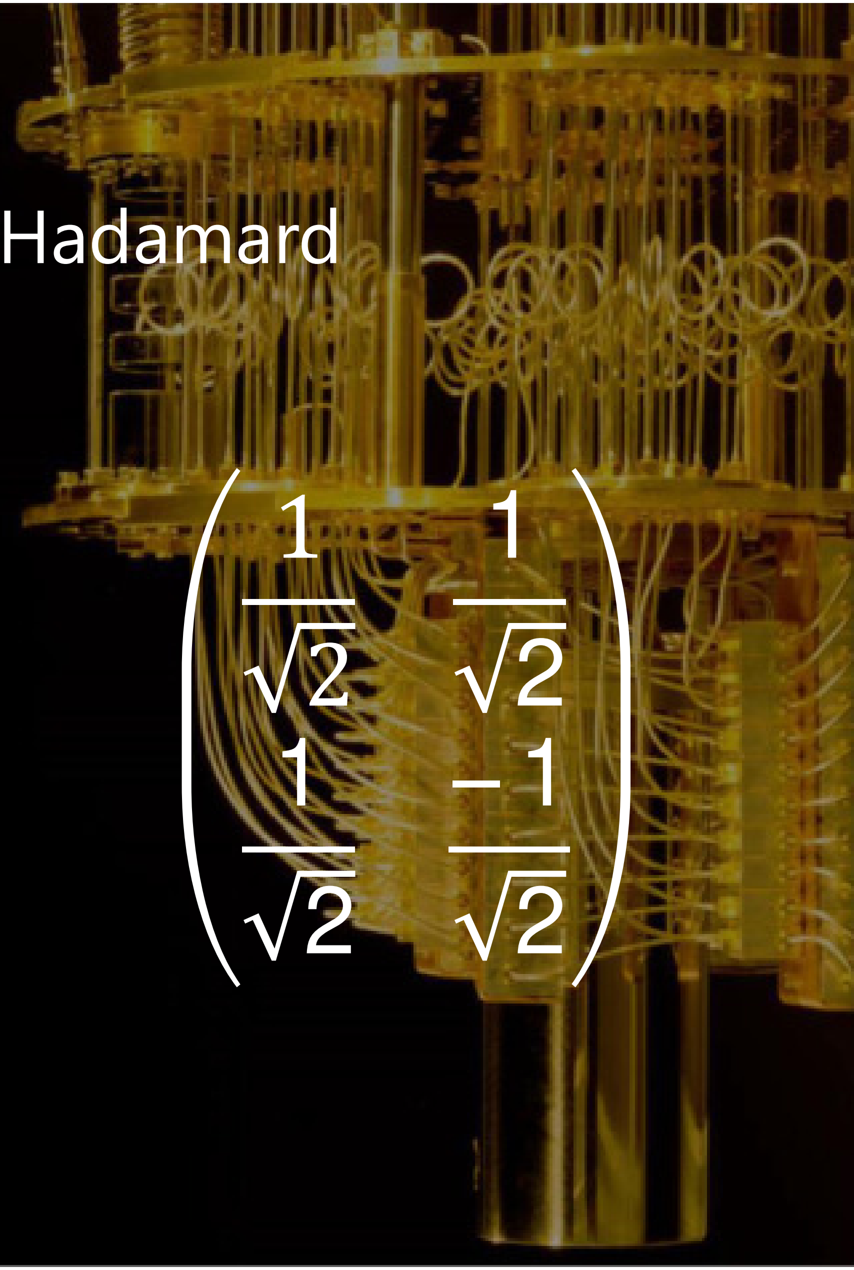
$$\begin{pmatrix}0 & 1\\ 1 & 0\end{pmatrix}$$

Bits vs. Qubits

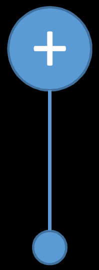


H Hadamard

$$\begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}}\end{pmatrix}$$

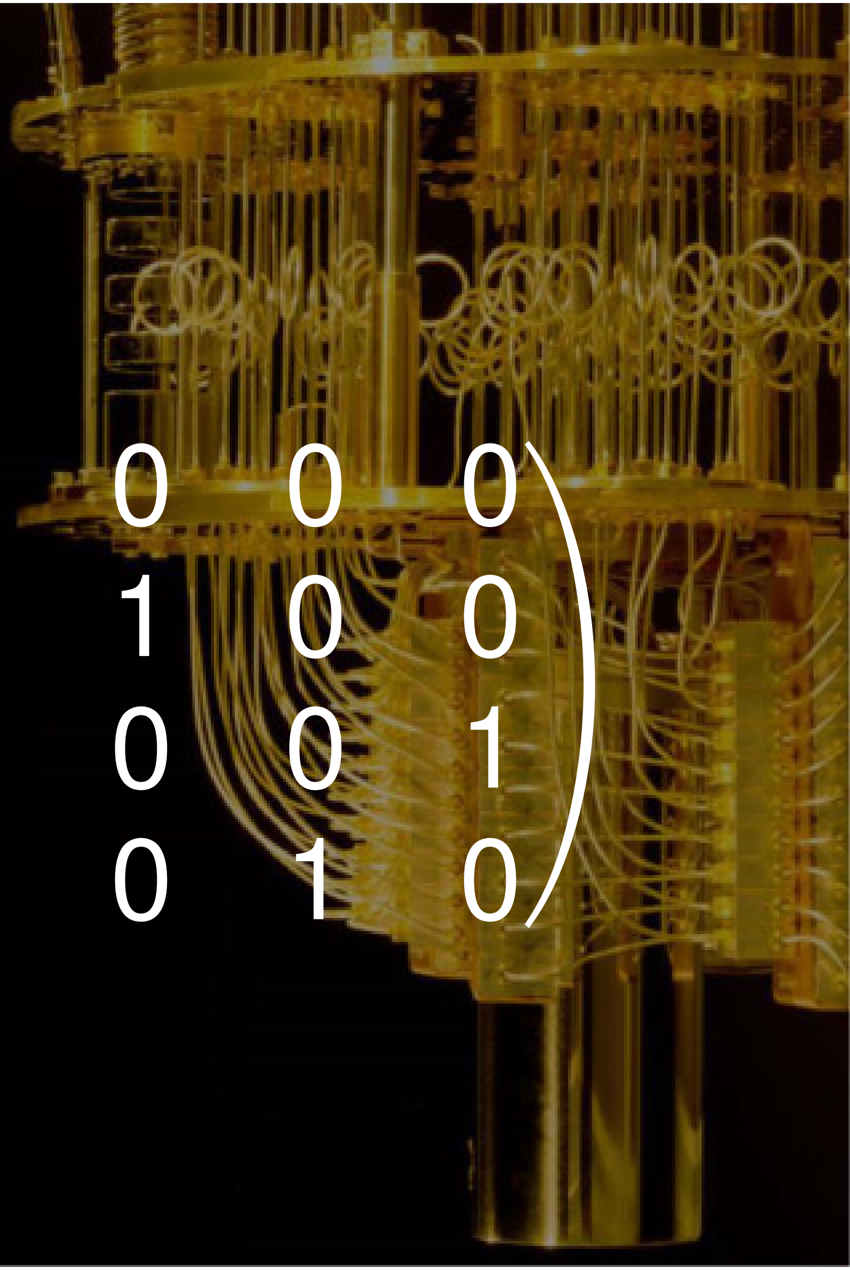


Bits vs. Qubits

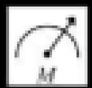


CNOT
(2-qubit gate)

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$



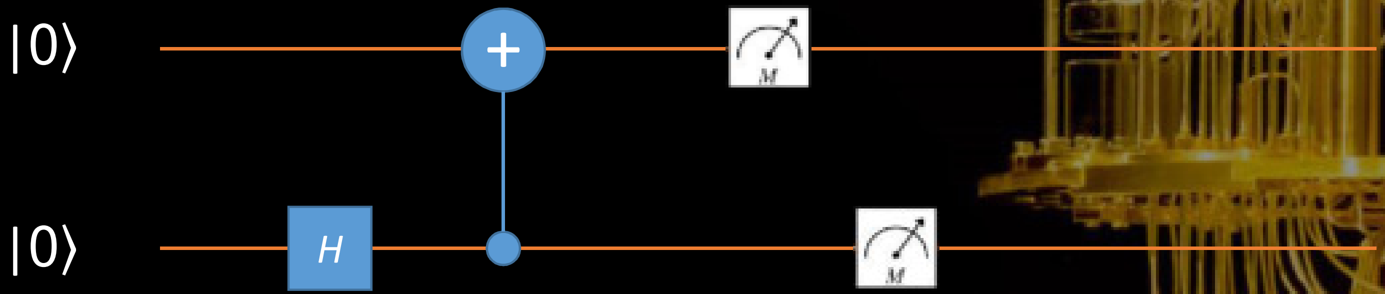
Bits vs. Qubits

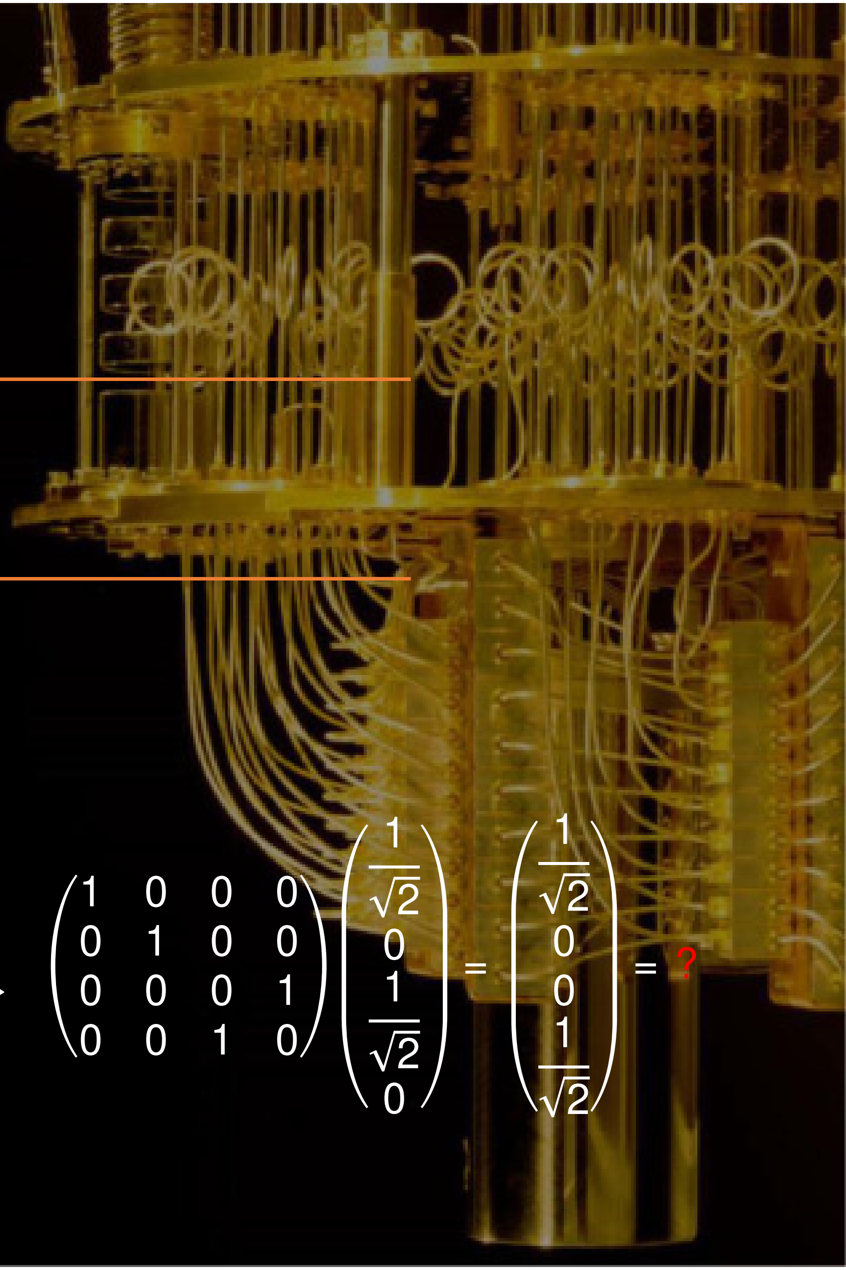


Measurement

- Collapses a qubit to either $|\ \rangle$ or $|\ \rangle$
- A qubit in superposition has a 50% chance to collapse to $|\ \rangle$ and a 50% chance to collapse to $|\ \rangle$
- A measurement destroys any complex quantum state

Entanglement





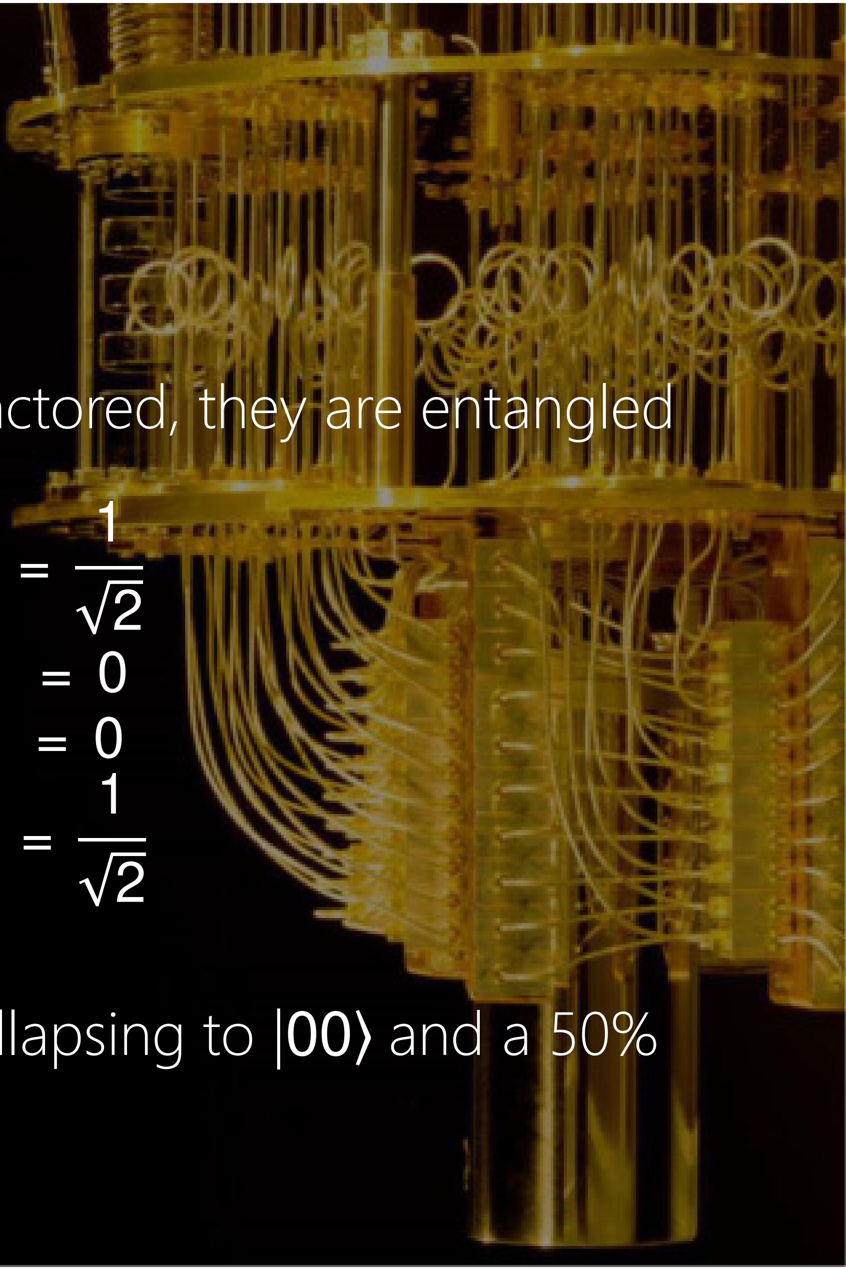
$$|0\rangle = \begin{pmatrix}1\\0\end{pmatrix}$$

$$|0\rangle = \begin{pmatrix}1\\0\end{pmatrix} \rightarrow \begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}}\end{pmatrix}\begin{pmatrix}1\\0\end{pmatrix} = \begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}}\end{pmatrix} = \begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}}\end{pmatrix} \otimes \begin{pmatrix}1\\0\end{pmatrix} = \begin{pmatrix}\frac{1}{\sqrt{2}}\\ 0\\ \frac{1}{\sqrt{2}}\\ 0\end{pmatrix} \rightarrow \begin{pmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 1\\ 0 & 0 & 1 & 0\end{pmatrix}\begin{pmatrix}\frac{1}{\sqrt{2}}\\ 0\\ \frac{1}{\sqrt{2}}\\ 0\end{pmatrix} = \begin{pmatrix}\frac{1}{\sqrt{2}}\\ 0\\ 0\\ \frac{1}{\sqrt{2}}\end{pmatrix} = ?$$

Entanglement

- If the product state of two qubits cannot be factored, they are entangled

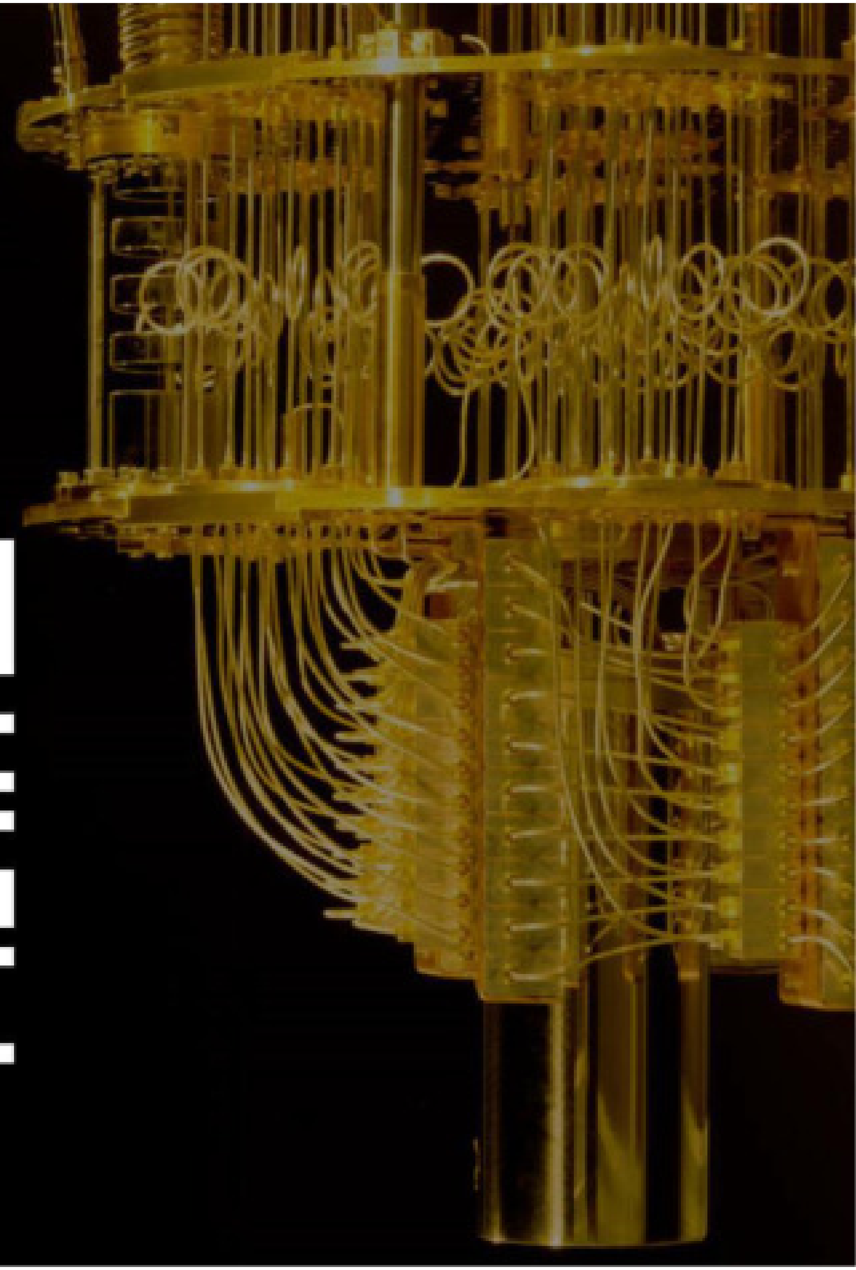
$$\begin{pmatrix} \frac{1}{\sqrt{2}} \\ 0 \\ 0 \\ \frac{1}{\sqrt{2}} \end{pmatrix} = \begin{pmatrix} \ \end{pmatrix} \otimes \begin{pmatrix} \ \end{pmatrix} \rightarrow \begin{matrix} = \frac{1}{\sqrt{2}} \\ = 0 \\ = 0 \\ = \frac{1}{\sqrt{2}} \end{matrix}$$



- This set of two qubits has a 50% chance of collapsing to $|00\rangle$ and a 50% chance of collapsing to $|11\rangle$

IBM Q Experience

- https://quantumexperience.ng.bluemix.net

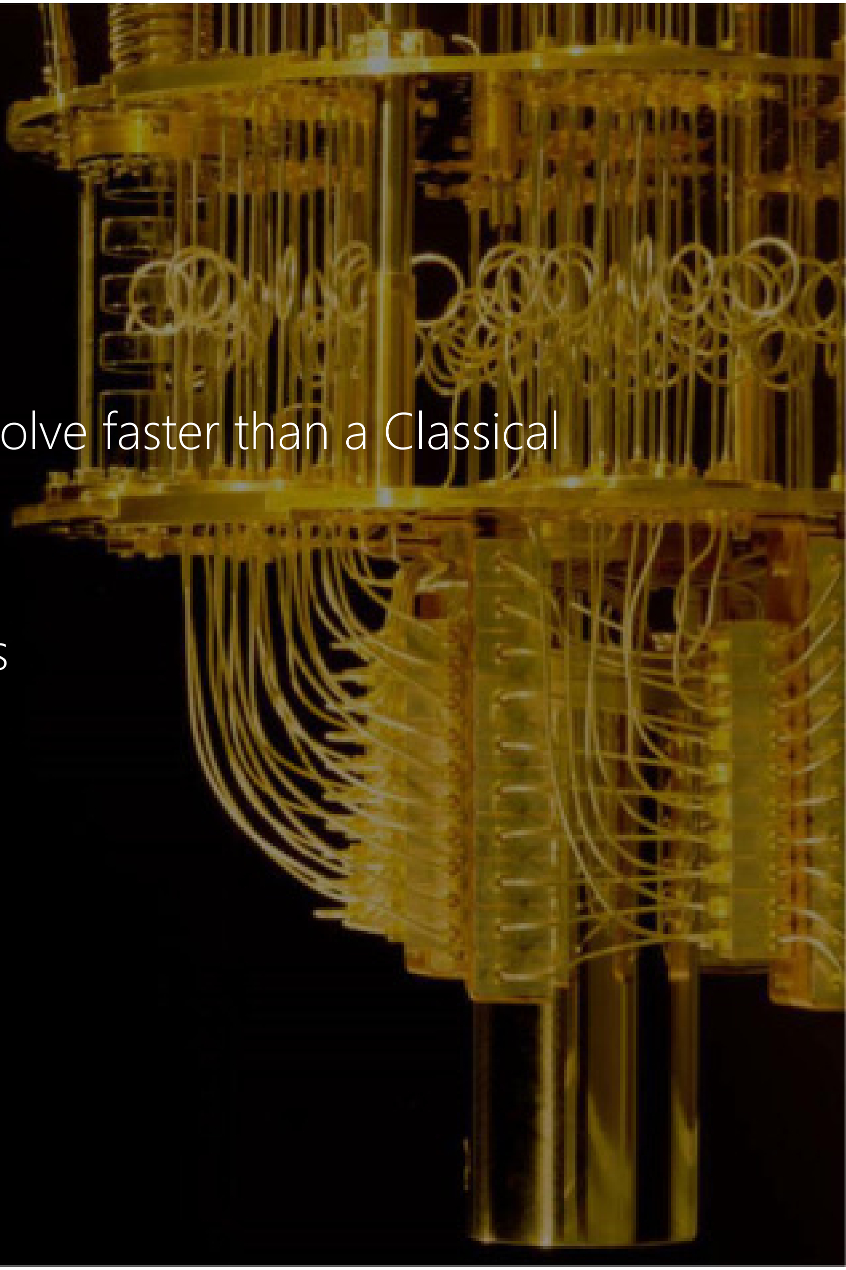


Microsoft Q#

- https://www.microsoft.com/en-us/quantum/development-kit

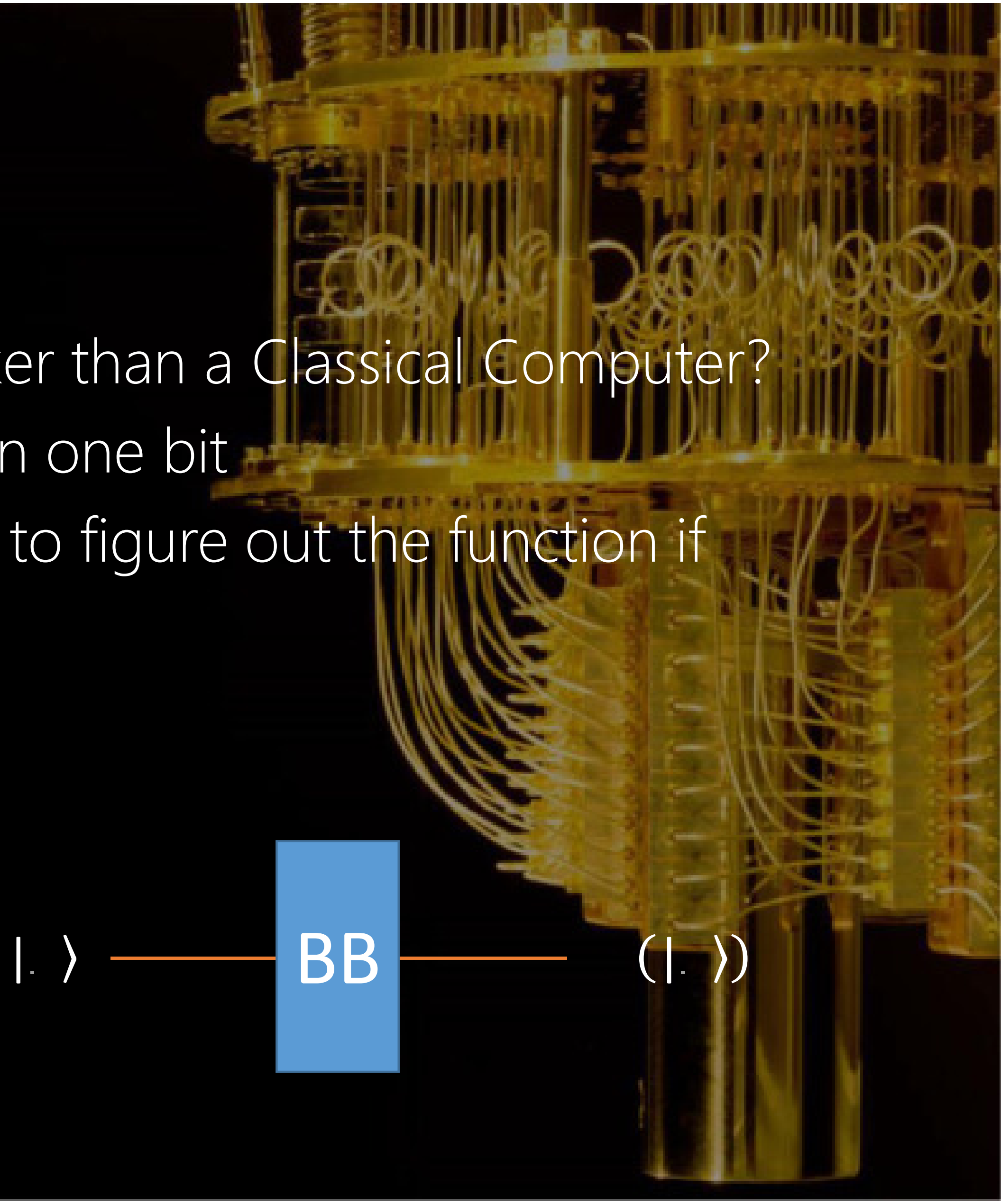
Quantum Algorithms

- Deutch (1985)
  - Is there a problem that a Quantum Computer can solve faster than a Classical Computer?
  - Deterministic!
- Deutsch–Jozsa (1992)
  - Based on Deutch (for 1 bit), but applicable for n-bits
  - Deterministic!
- Grover's algorithm (1996)
  - “Searching a database”
  - Probabilistic!
- Shor's algorithm (1994)
  - Prime factorization of large integers
  - Combination of classical and quantum algorithm
  - Probabilistic!



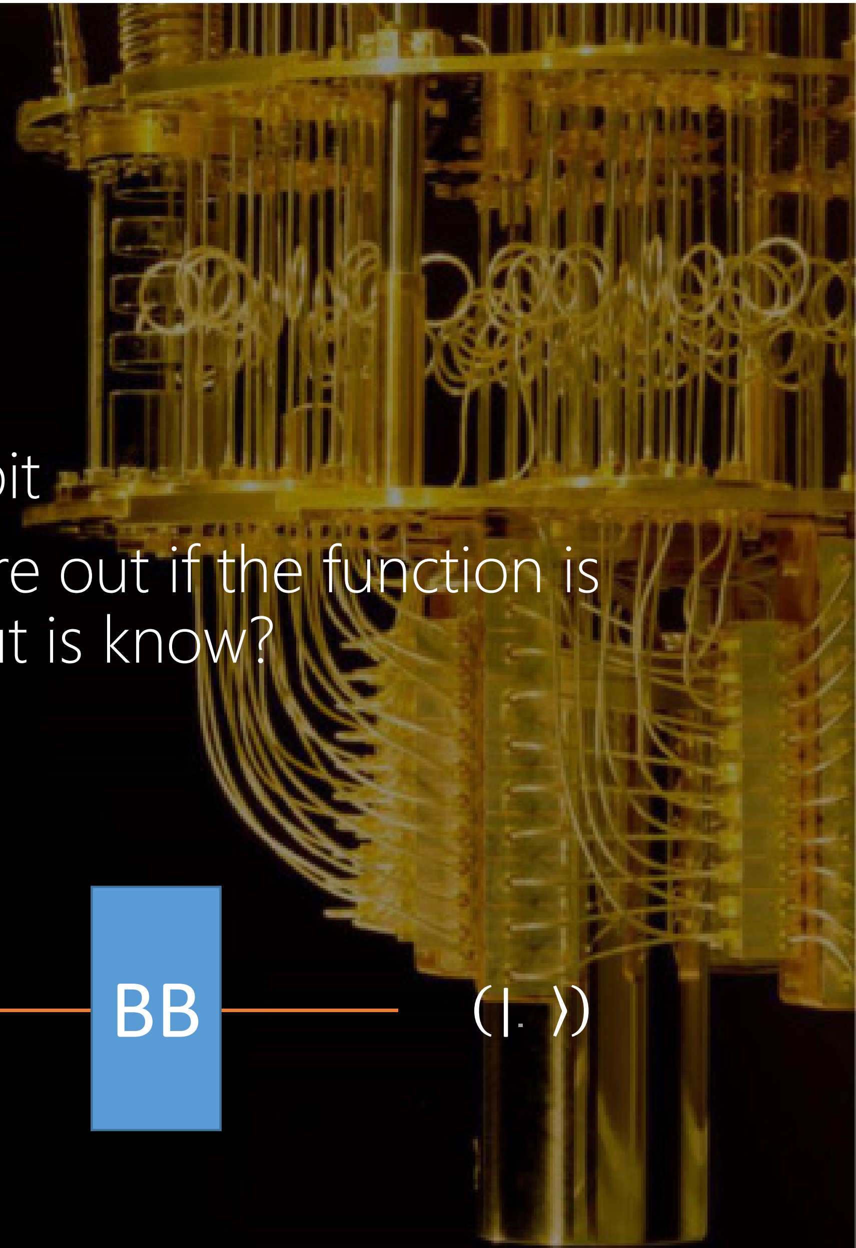
Deutsch's algorithm

- Can a Quantum Computer be quicker than a Classical Computer?
- A Black-Box containing a function on one bit
- How many operations do you need to figure out the function if input and output is know?
  - On a Classical Computer?
  - On a Quantum Computer?



Deutsch's algorithm

- It is important to ask the right question!
- A Black-Box containing a function on one bit
- How many operations do you need to figure out if the function is CONSTANT or VARIABLE if input and output is know?
  - On a Classical Computer?
  - On a Quantum Computer?



|. ⟩ BB ⟨|. ⟩⟩

Deutsch's algorithm

- It is important to ask the right question!
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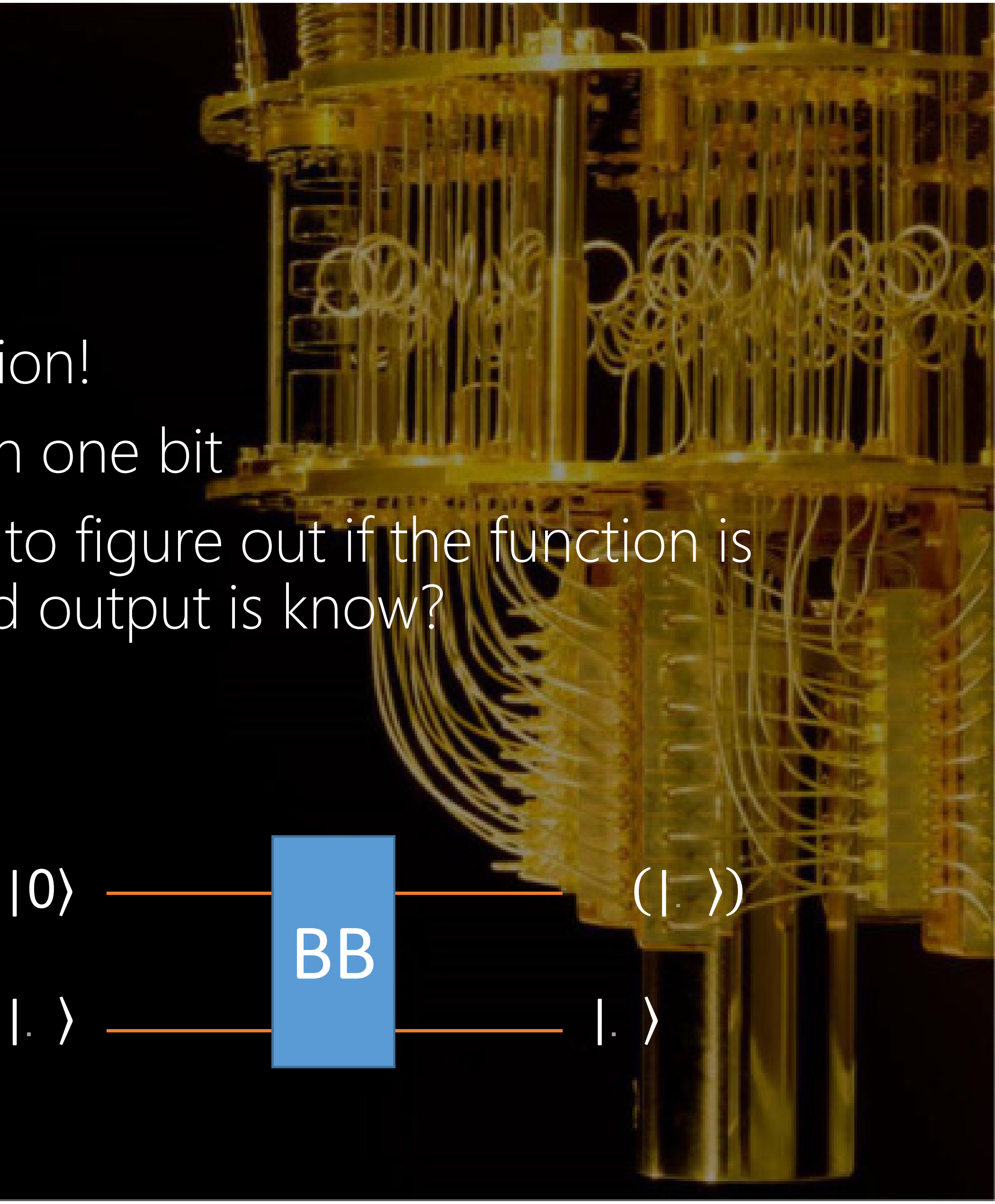
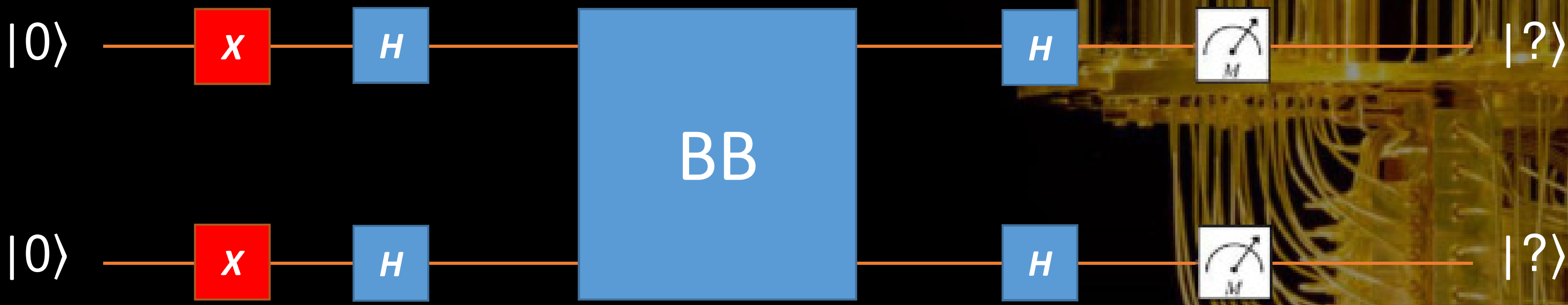


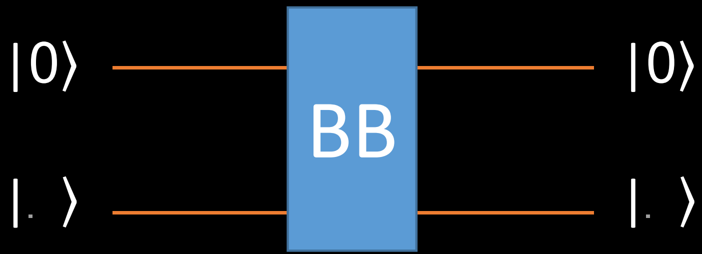
Deutsch's algorithm

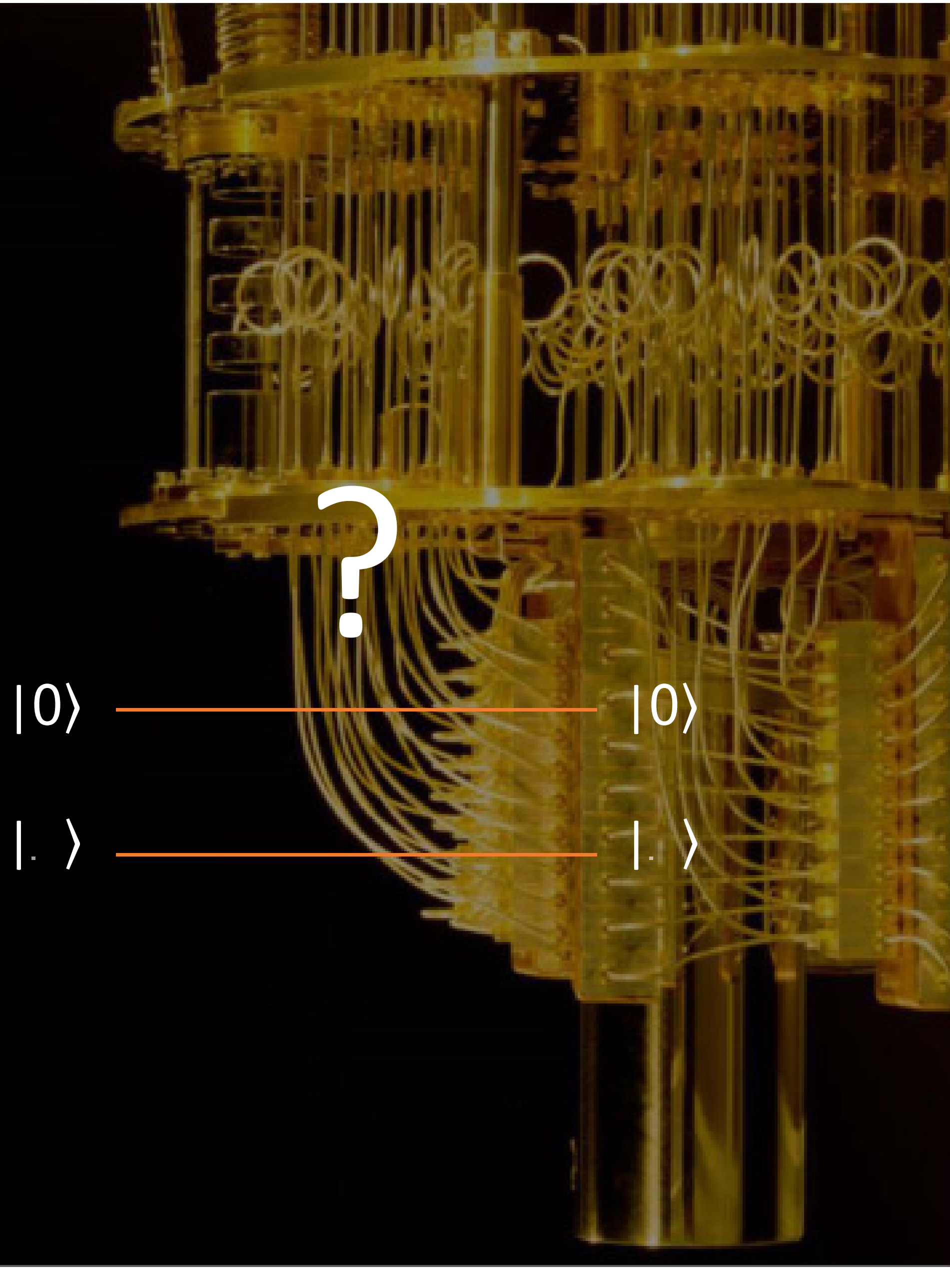


- If BB is a constant function → Quantum state will always measure to $|11\rangle$
- If BB is a variable function → Quantum state will always measure to $|01\rangle$

Deutsch's algorithm

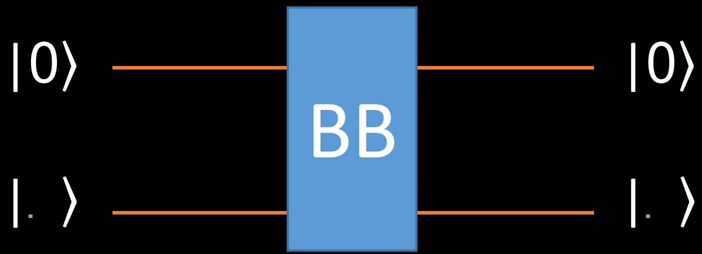
- Constant-0

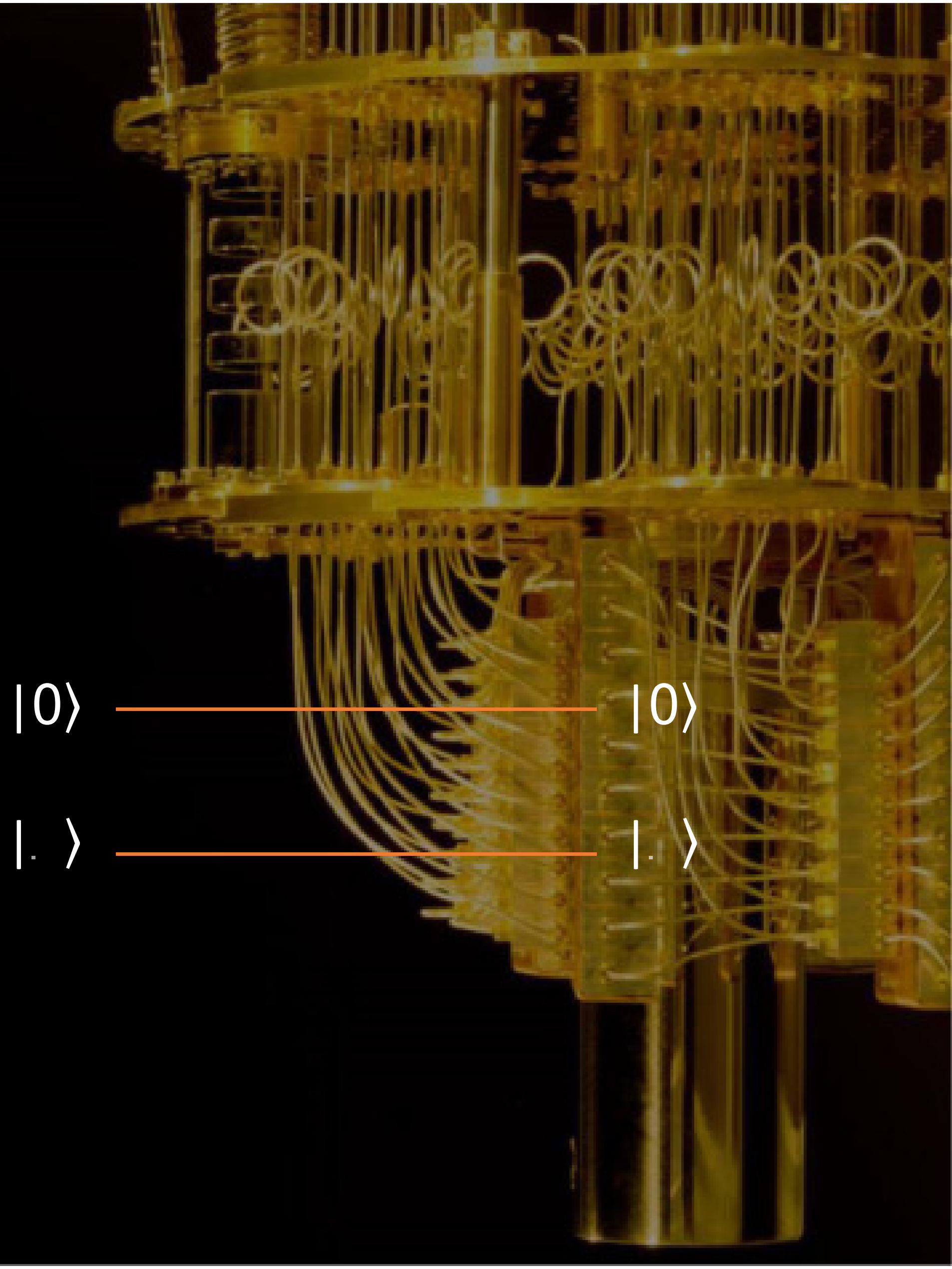




Deutsch's algorithm

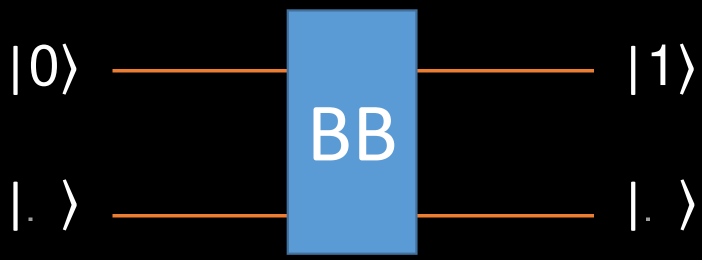
- Constant-0

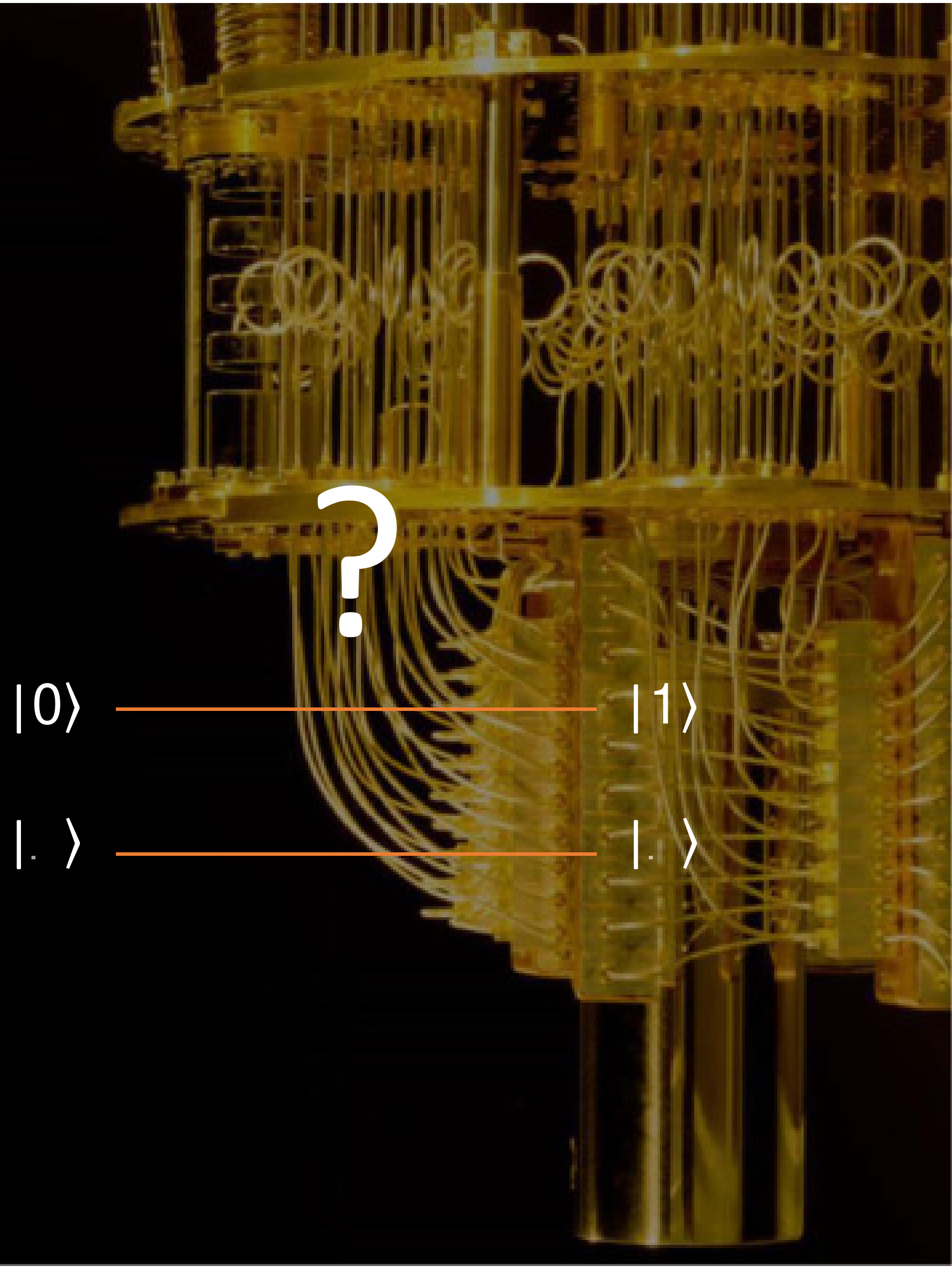




Deutsch's algorithm

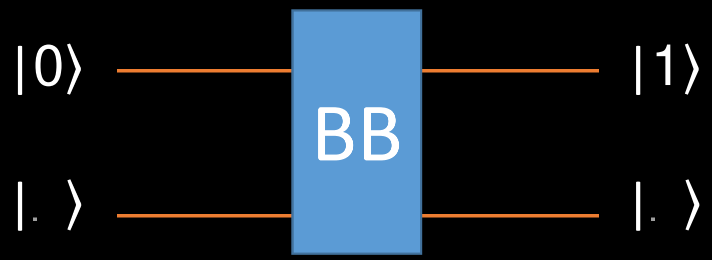
- Constant-1

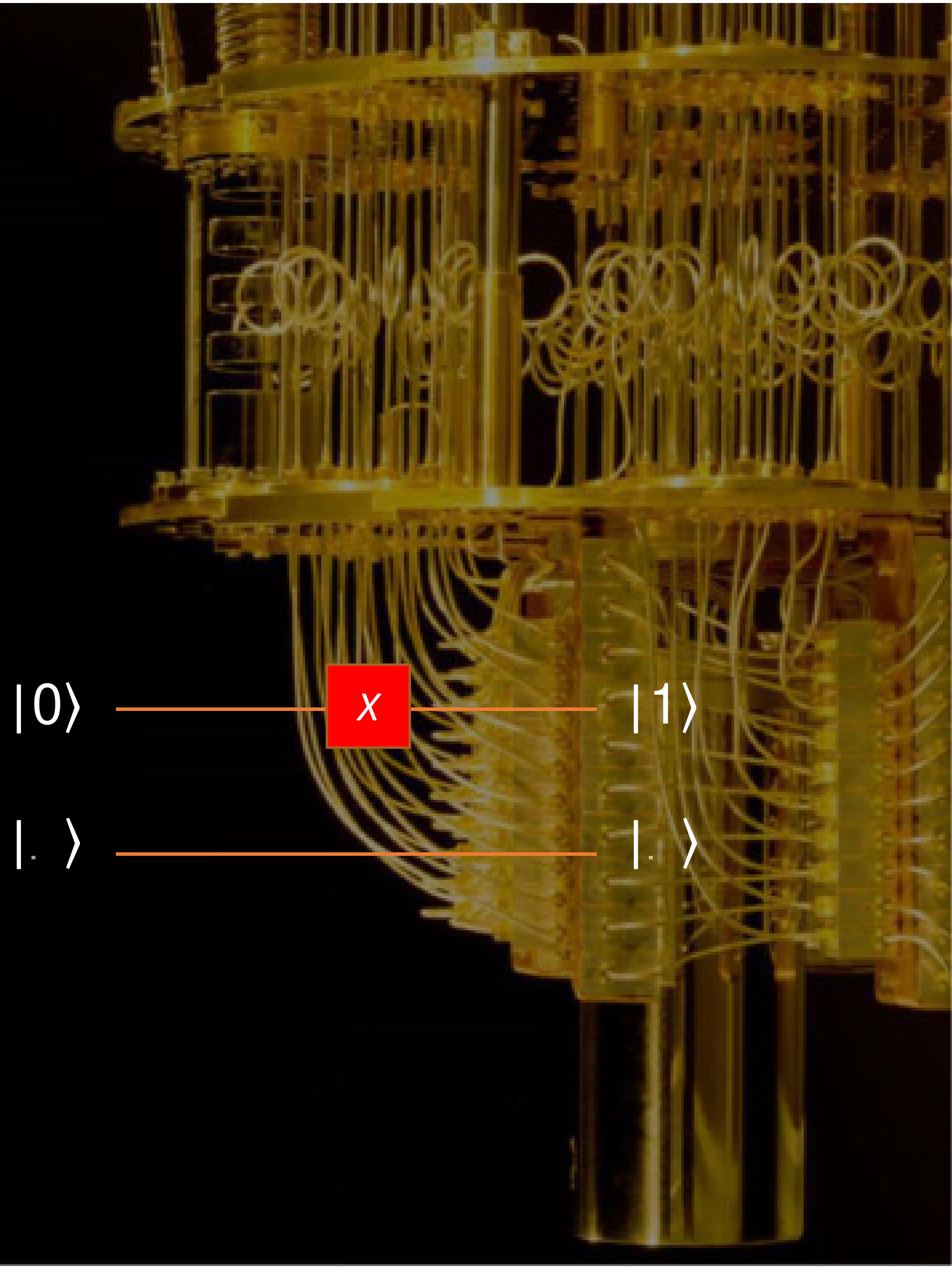




Deutsch's algorithm

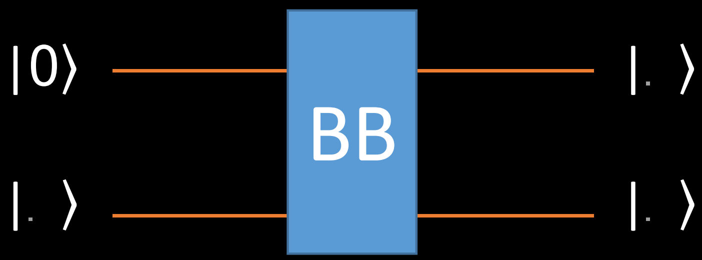
- Constant-1

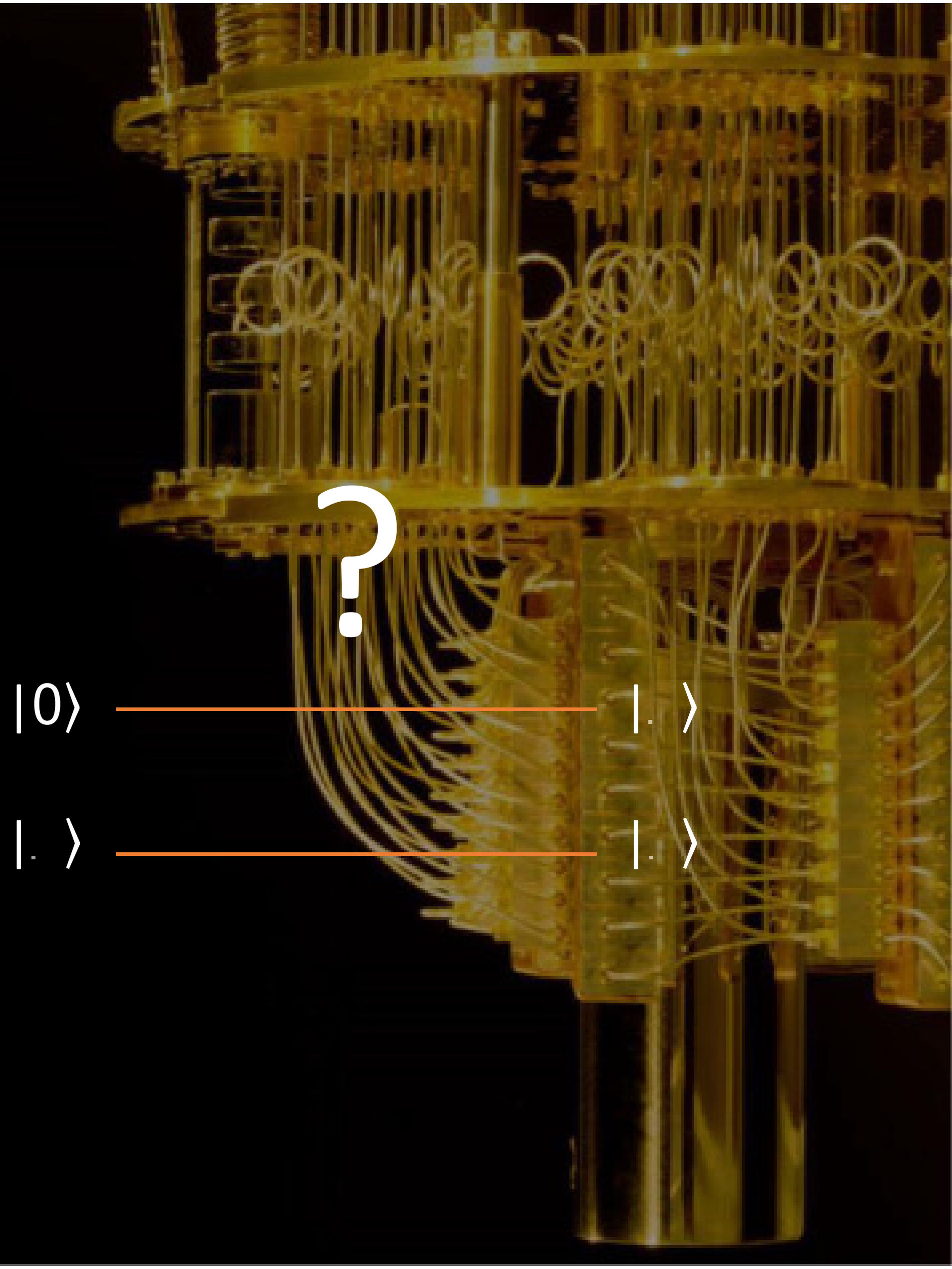




Deutsch's algorithm

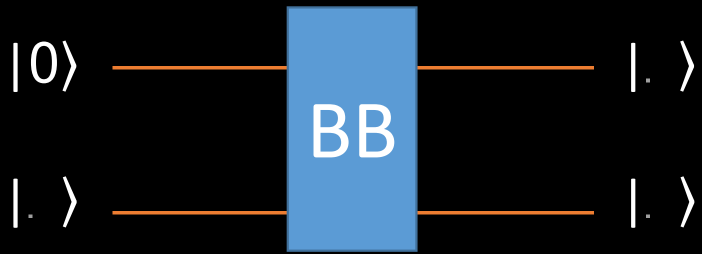
- Identity

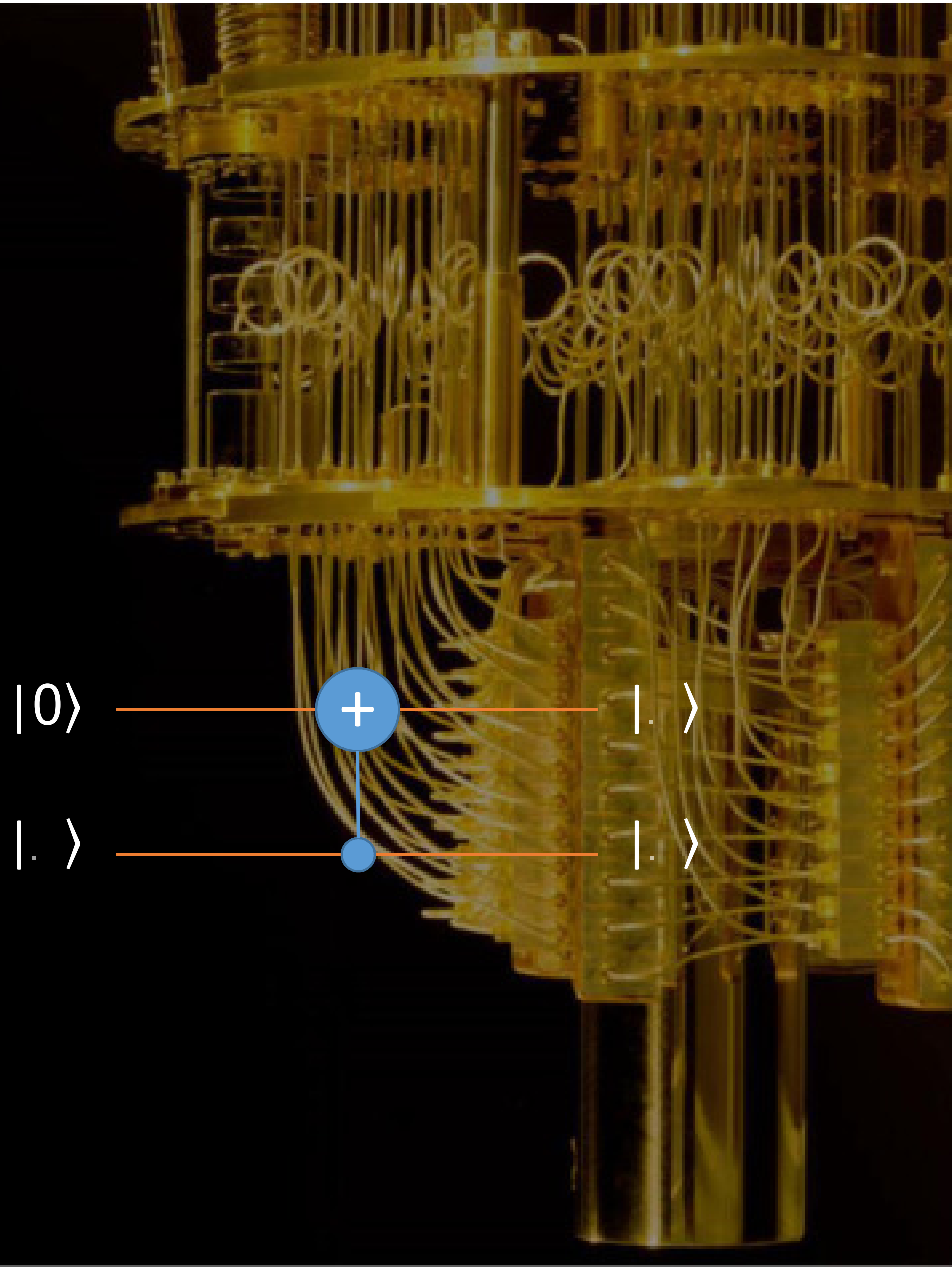




Deutsch's algorithm

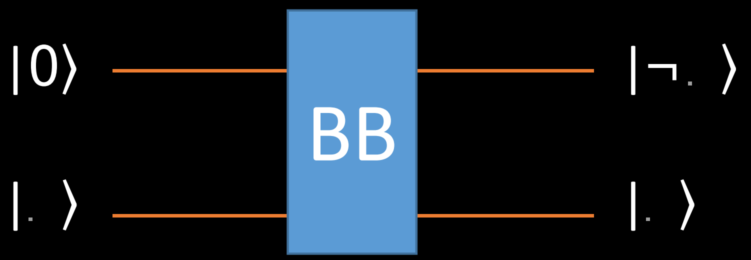
- Identity

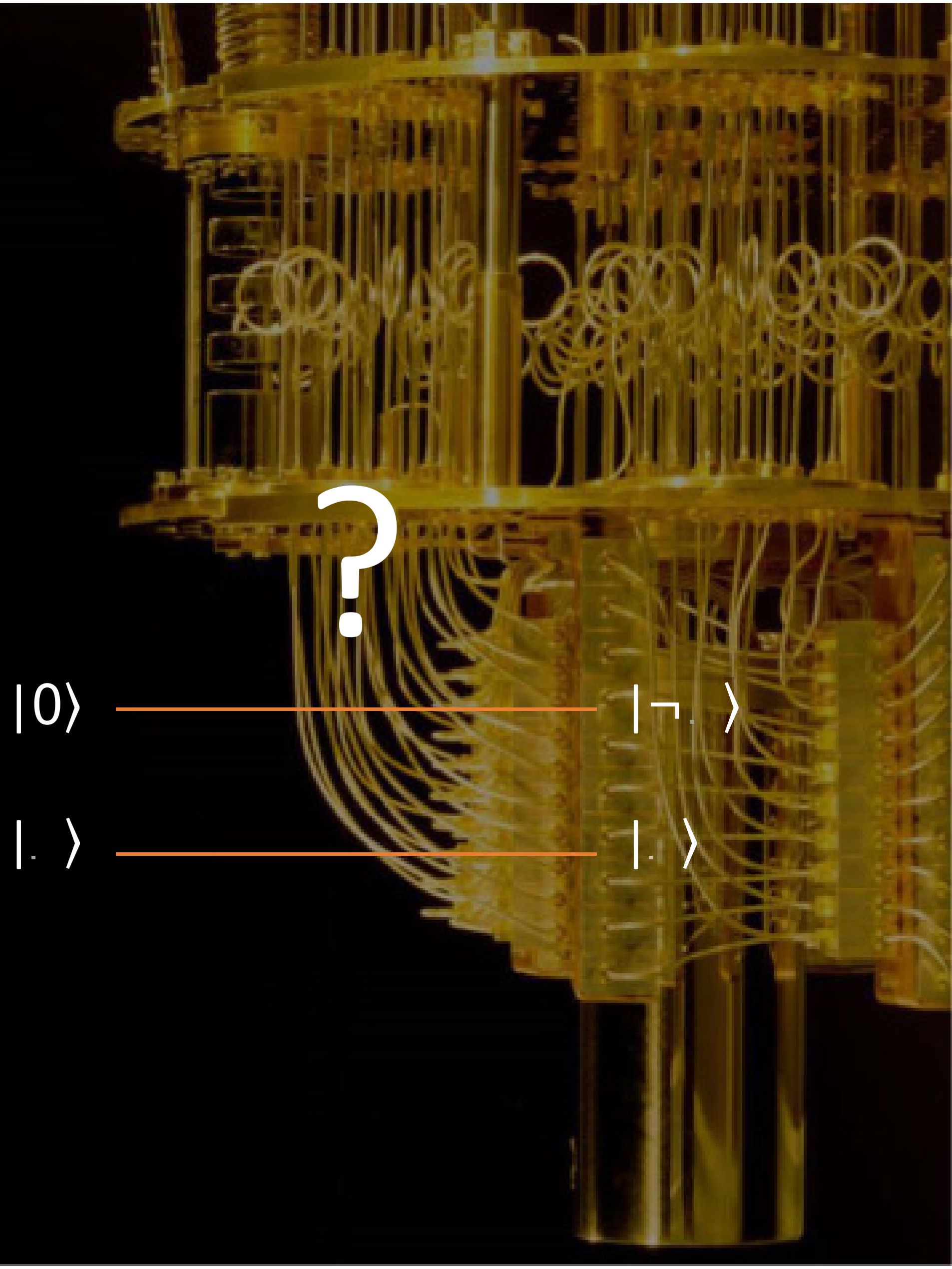




Deutsch's algorithm

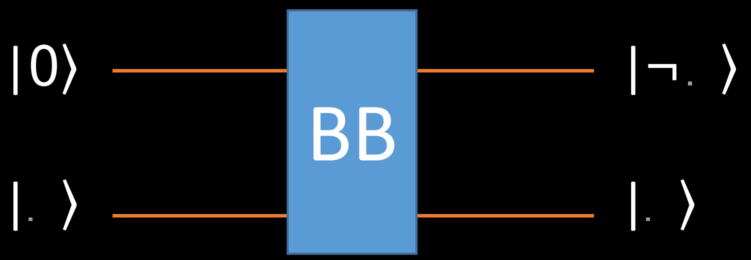
- Negation

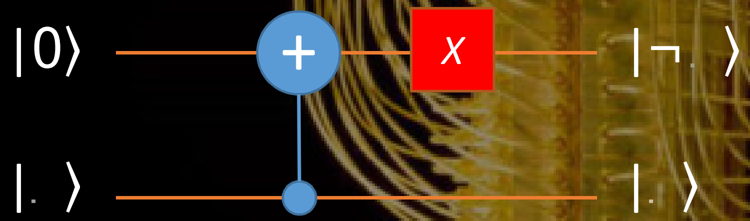




Deutsch's algorithm

- Negation



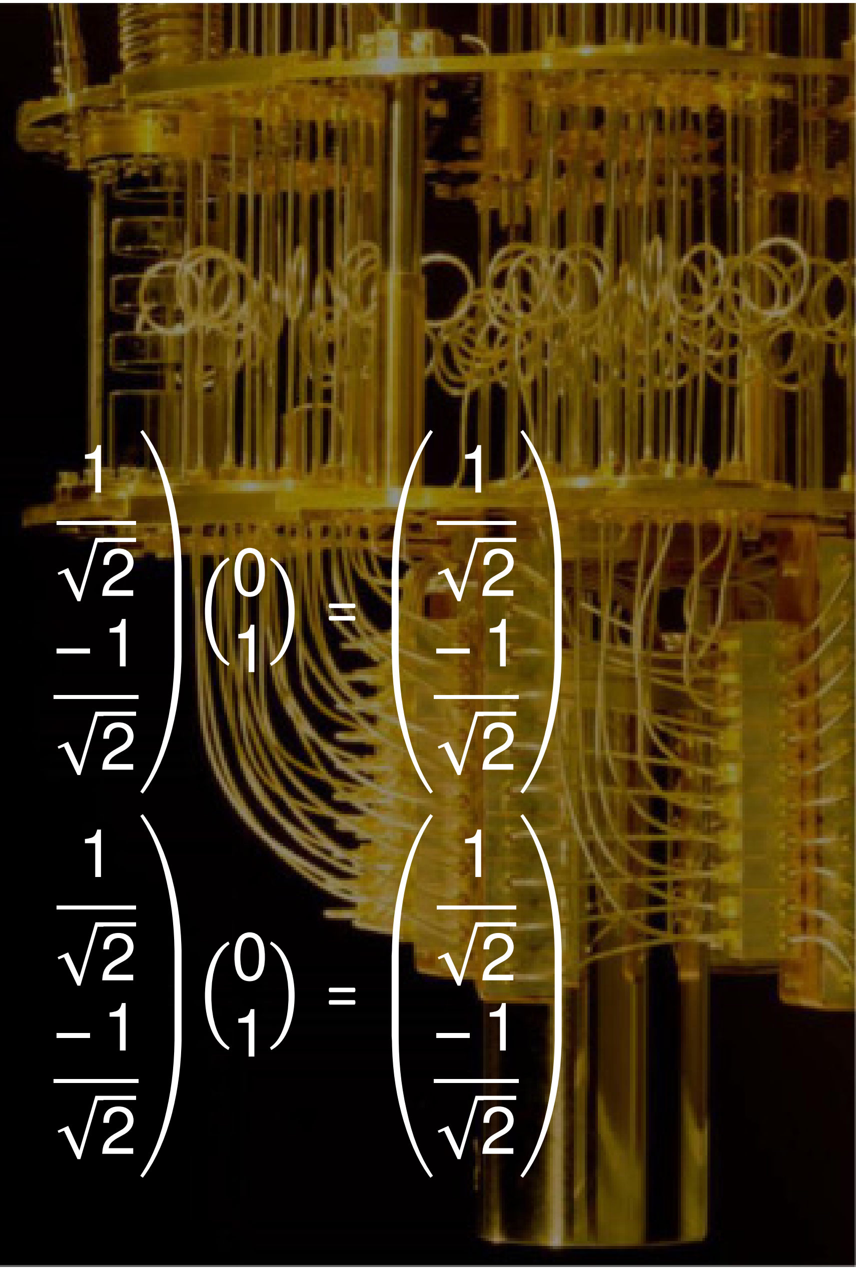


Deutsch's algorithm

- Constant-0 (circuit overview)

Deutsch's algorithm

- Constant-0 (calculated proof – part 1)



$$|0\rangle = \begin{pmatrix}1\\0\end{pmatrix} \rightarrow \begin{pmatrix}0 & 1\\1 & 0\end{pmatrix}\begin{pmatrix}1\\0\end{pmatrix} = \begin{pmatrix}0\\1\end{pmatrix} \rightarrow \begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}}\end{pmatrix}\begin{pmatrix}0\\1\end{pmatrix} = \begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix}$$

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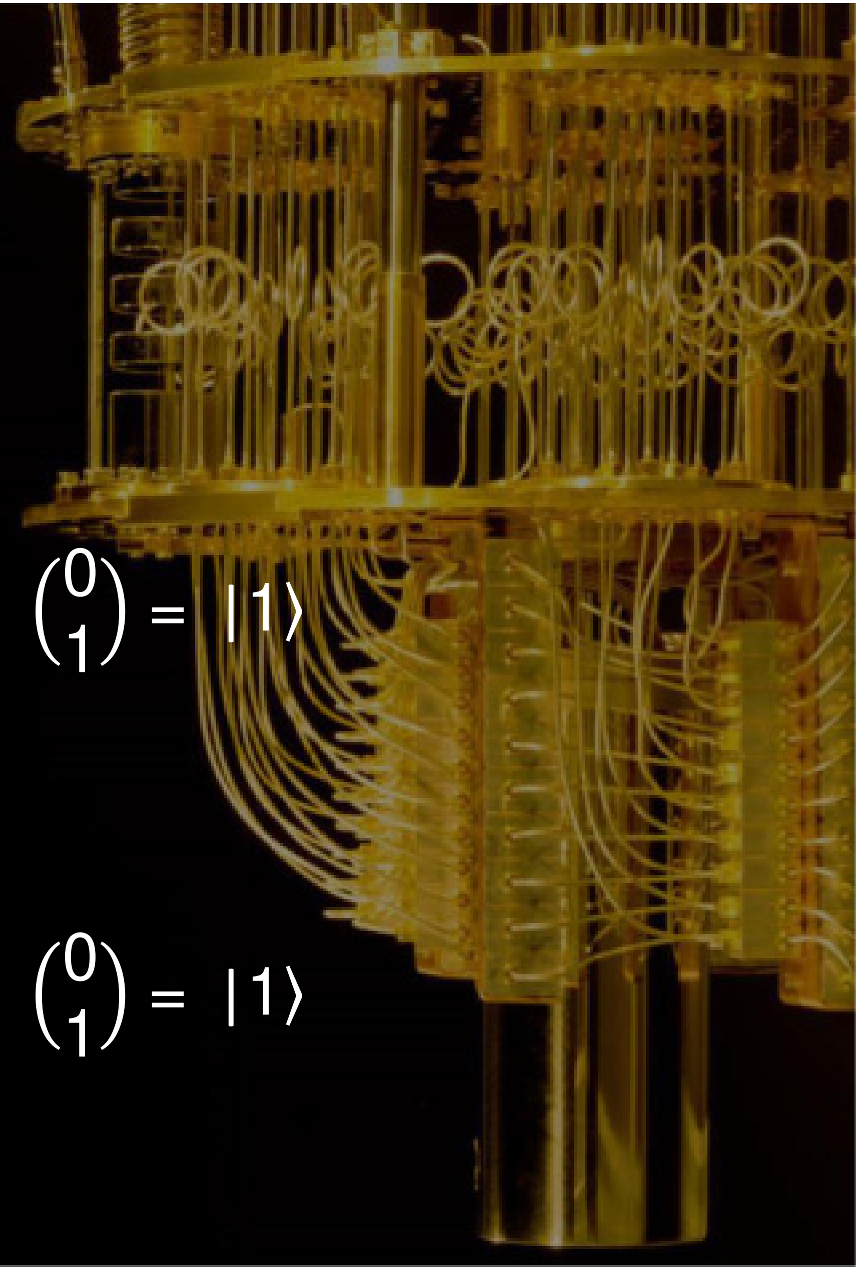
Deutsch's algorithm

- Constant-0 (calculated proof – part 2)

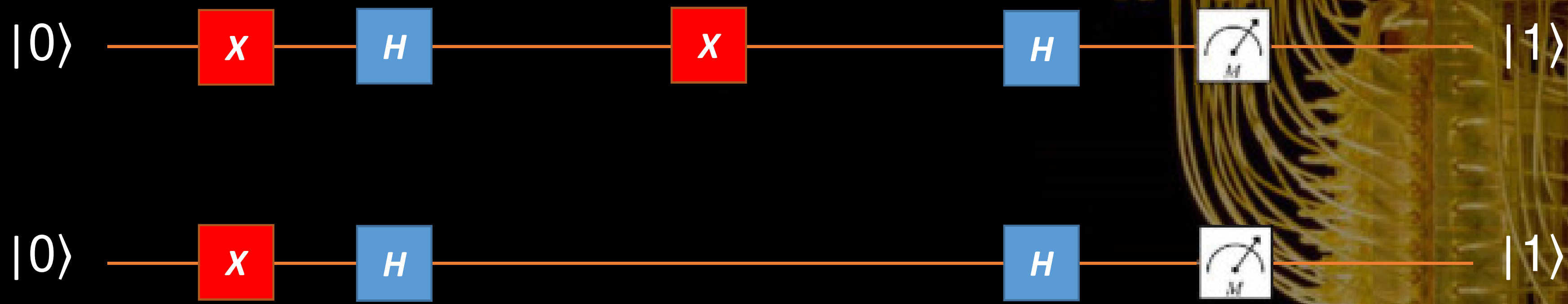
$$\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{-1}{\sqrt{2}} \end{pmatrix} \rightarrow \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{-1}{\sqrt{2}} \end{pmatrix} = \begin{pmatrix} 0 \\ 1 \end{pmatrix} = |1\rangle$$

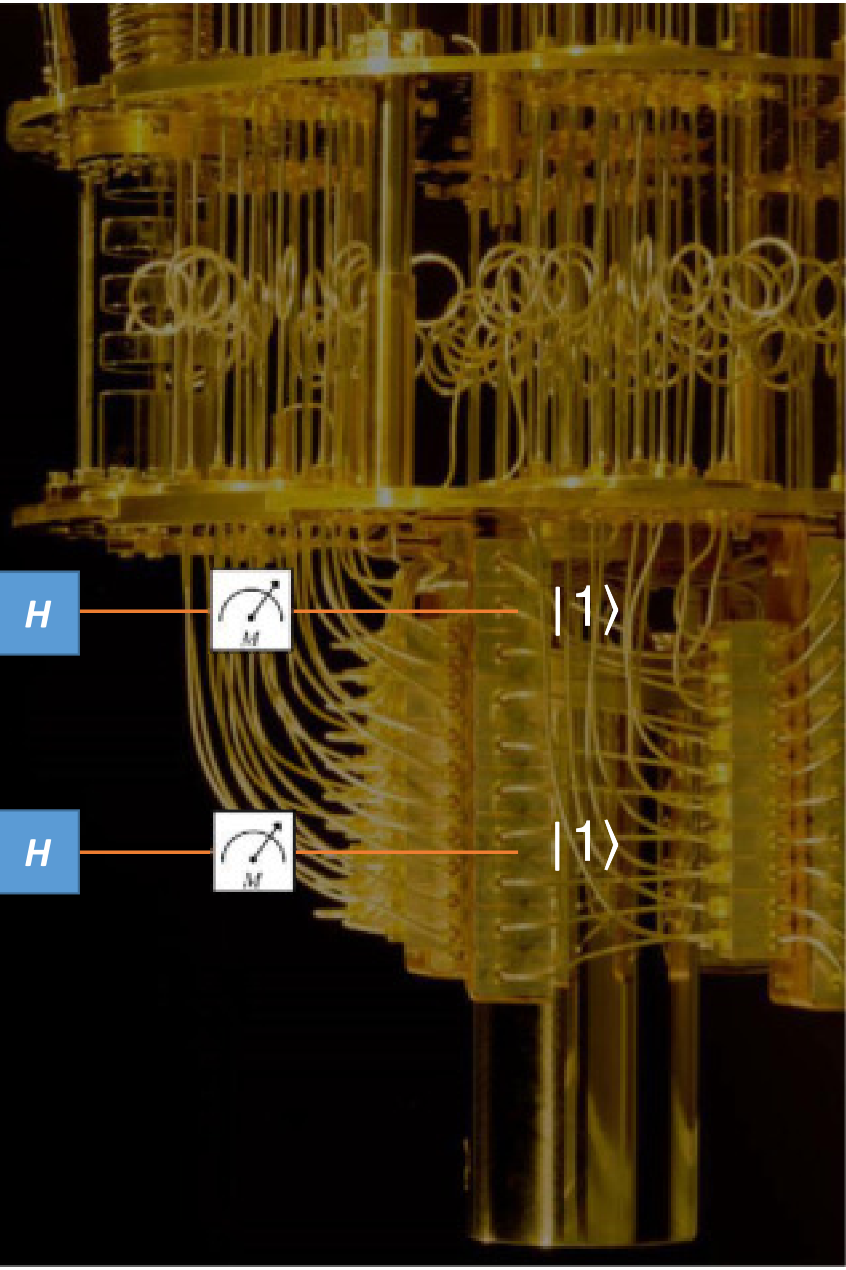
$$\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{-1}{\sqrt{2}} \end{pmatrix} \rightarrow \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{-1}{\sqrt{2}} \end{pmatrix} = \begin{pmatrix} 0 \\ 1 \end{pmatrix} = |1\rangle$$



Deutsch's algorithm

- Constant-1 (circuit overview)



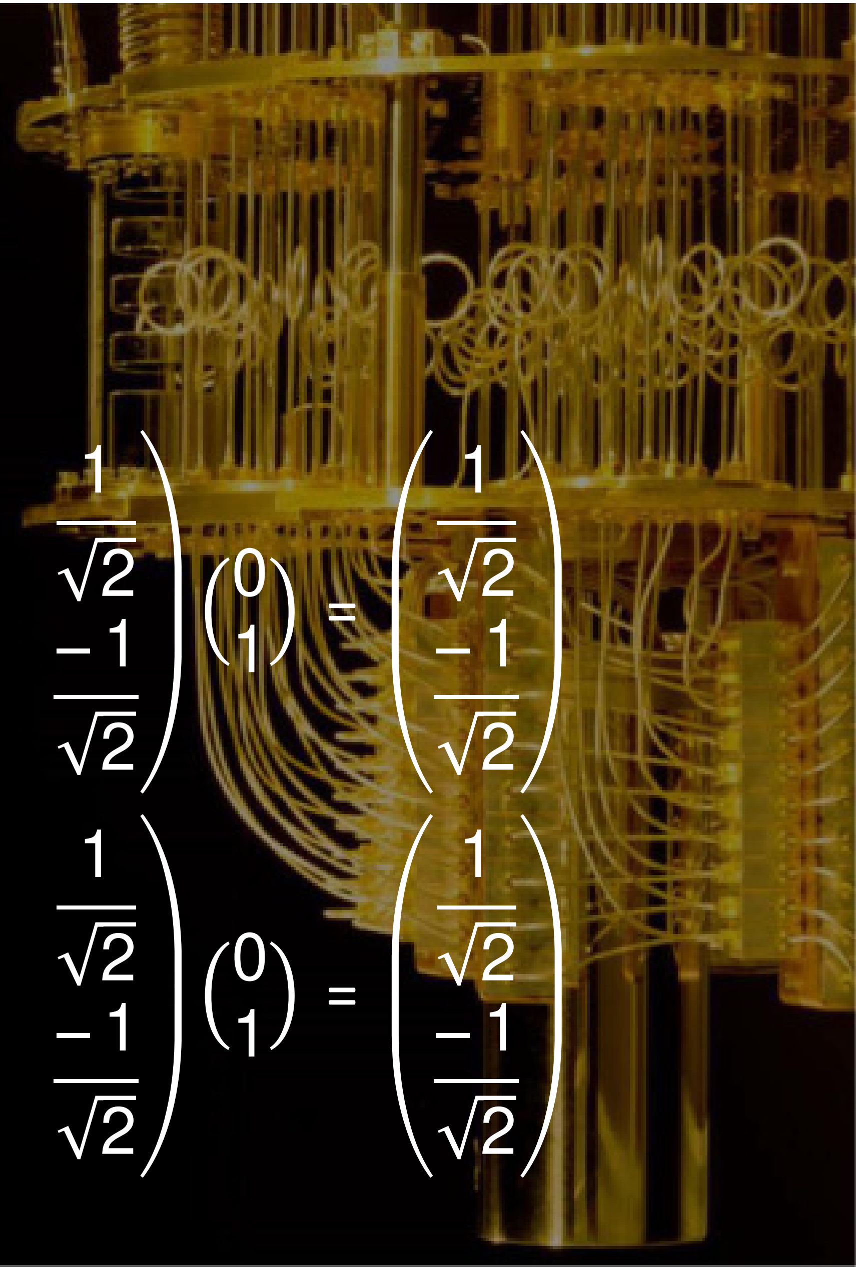


Deutsch's algorithm

- Constant-1 (calculated proof – part 1)

$$|0\rangle = \begin{pmatrix}1\\0\end{pmatrix} \rightarrow \begin{pmatrix}0 & 1\\1 & 0\end{pmatrix}\begin{pmatrix}1\\0\end{pmatrix} = \begin{pmatrix}0\\1\end{pmatrix} \rightarrow \begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}}\end{pmatrix}\begin{pmatrix}0\\1\end{pmatrix} = \begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix}$$

$$|0\rangle = \begin{pmatrix}1\\0\end{pmatrix} \rightarrow \begin{pmatrix}0 & 1\\1 & 0\end{pmatrix}\begin{pmatrix}1\\0\end{pmatrix} = \begin{pmatrix}0\\1\end{pmatrix} \rightarrow \begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}}\end{pmatrix}\begin{pmatrix}0\\1\end{pmatrix} = \begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix}$$

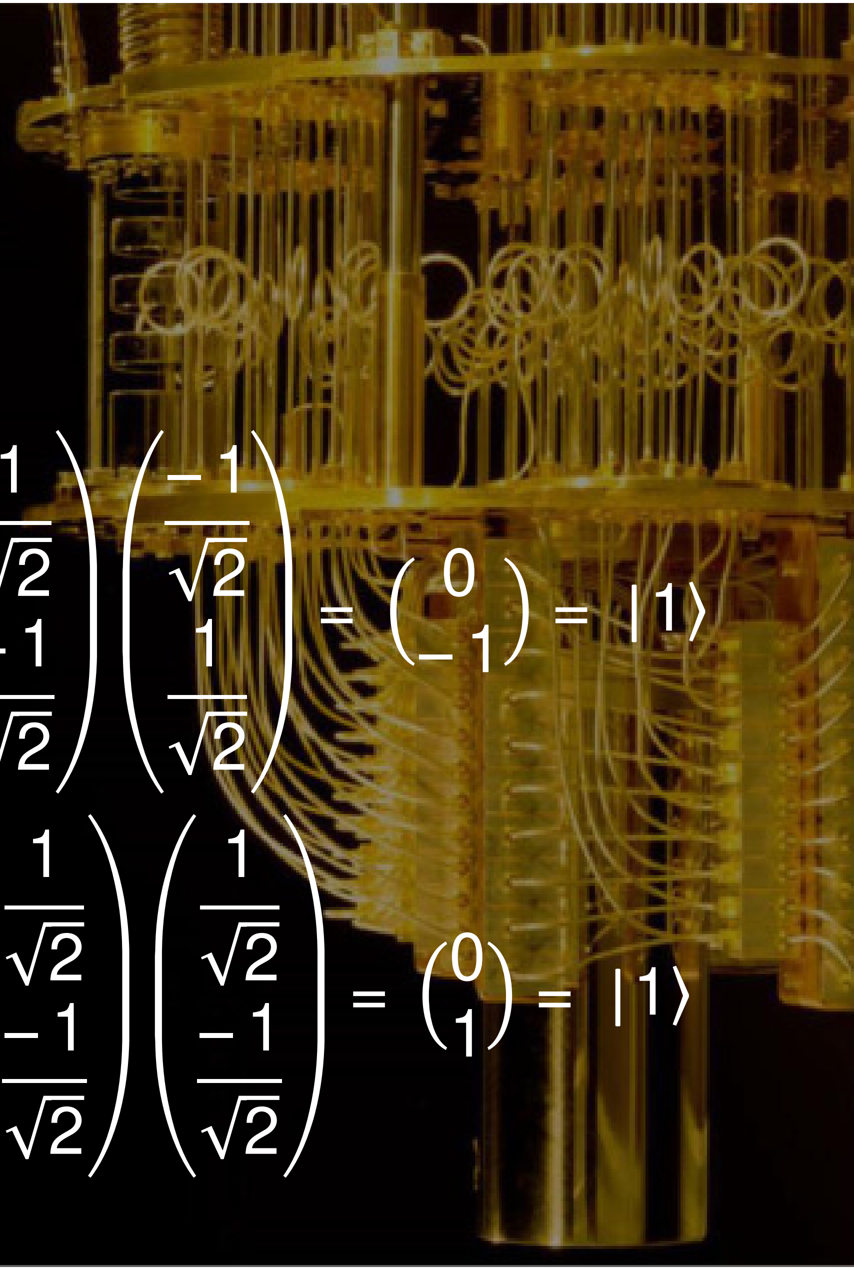


Deutsch's algorithm

- Constant-1 (calculated proof – part 2)

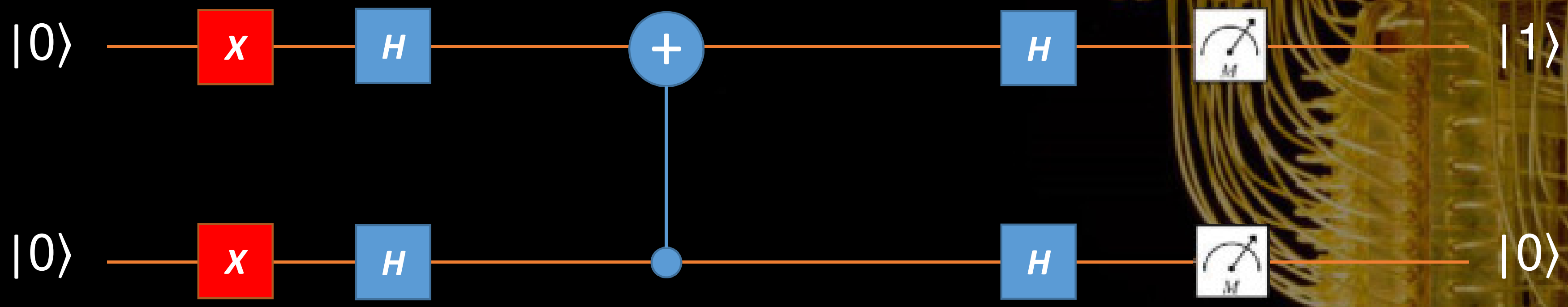
$$\begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix} \rightarrow \begin{pmatrix}0 & 1\\ 1 & 0\end{pmatrix}\begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix} = \begin{pmatrix}\frac{-1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}}\end{pmatrix} \rightarrow \begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}}\end{pmatrix}\begin{pmatrix}\frac{-1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}}\end{pmatrix} = \begin{pmatrix}0\\ -1\end{pmatrix} = |1\rangle$$

$$\begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix} \rightarrow \begin{pmatrix}1 & 0\\ 0 & 1\end{pmatrix}\begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix} = \begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix} \rightarrow \begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}}\end{pmatrix}\begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix} = \begin{pmatrix}0\\ 1\end{pmatrix} = |1\rangle$$



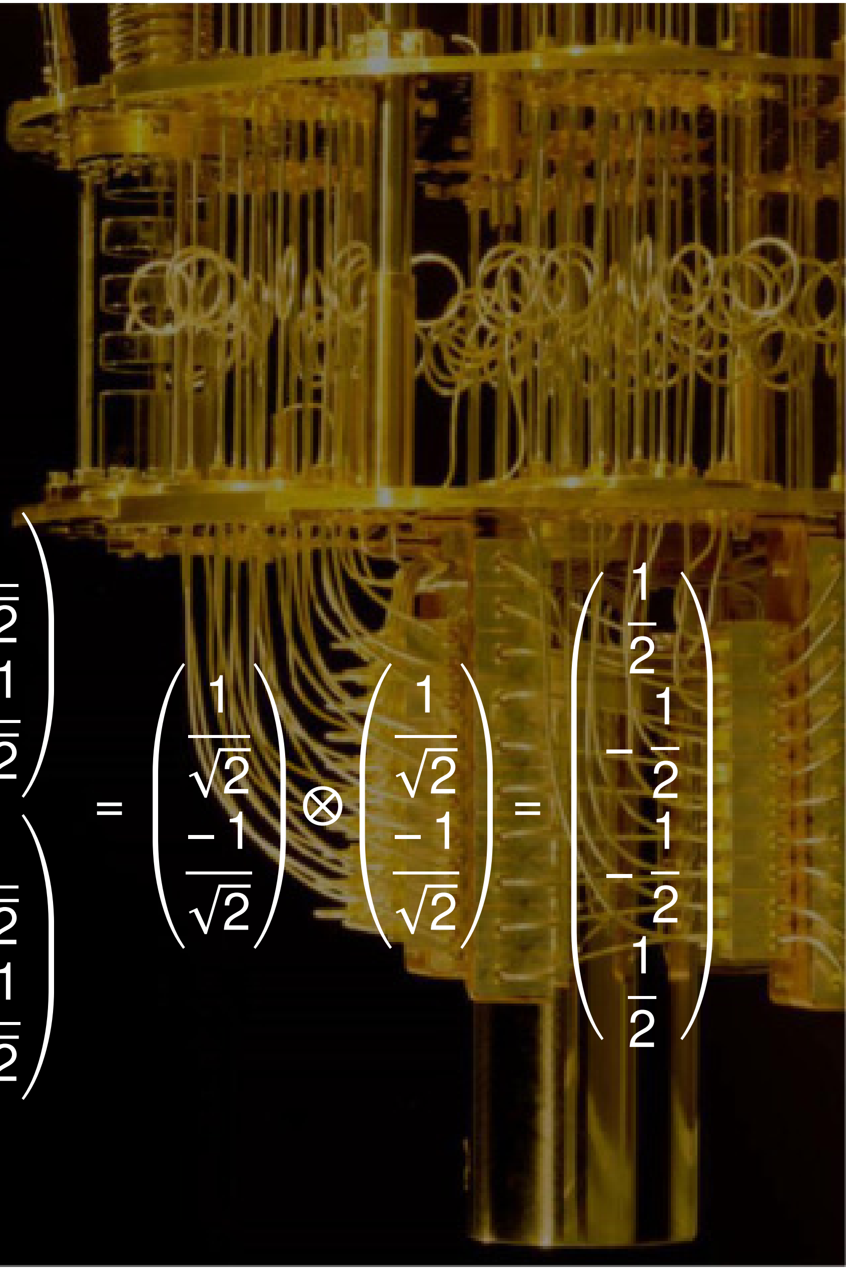
Deutsch's algorithm

- Identity (circuit overview)



Deutsch's algorithm

- Identity (calculated proof – part 1)



$$|0\rangle = \begin{pmatrix}1\\0\end{pmatrix} \rightarrow \begin{pmatrix}0 & 1\\1 & 0\end{pmatrix}\begin{pmatrix}1\\0\end{pmatrix} = \begin{pmatrix}0\\1\end{pmatrix} \rightarrow \begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}}\end{pmatrix}\begin{pmatrix}0\\1\end{pmatrix} = \begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix}$$

$$|0\rangle = \begin{pmatrix}1\\0\end{pmatrix} \rightarrow \begin{pmatrix}0 & 1\\1 & 0\end{pmatrix}\begin{pmatrix}1\\0\end{pmatrix} = \begin{pmatrix}0\\1\end{pmatrix} \rightarrow \begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}}\end{pmatrix}\begin{pmatrix}0\\1\end{pmatrix} = \begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix}$$

$$= \begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix} \otimes \begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix} = \begin{pmatrix}\frac{1}{2}\\ -\frac{1}{2}\\ -\frac{1}{2}\\ \frac{1}{2}\end{pmatrix}$$

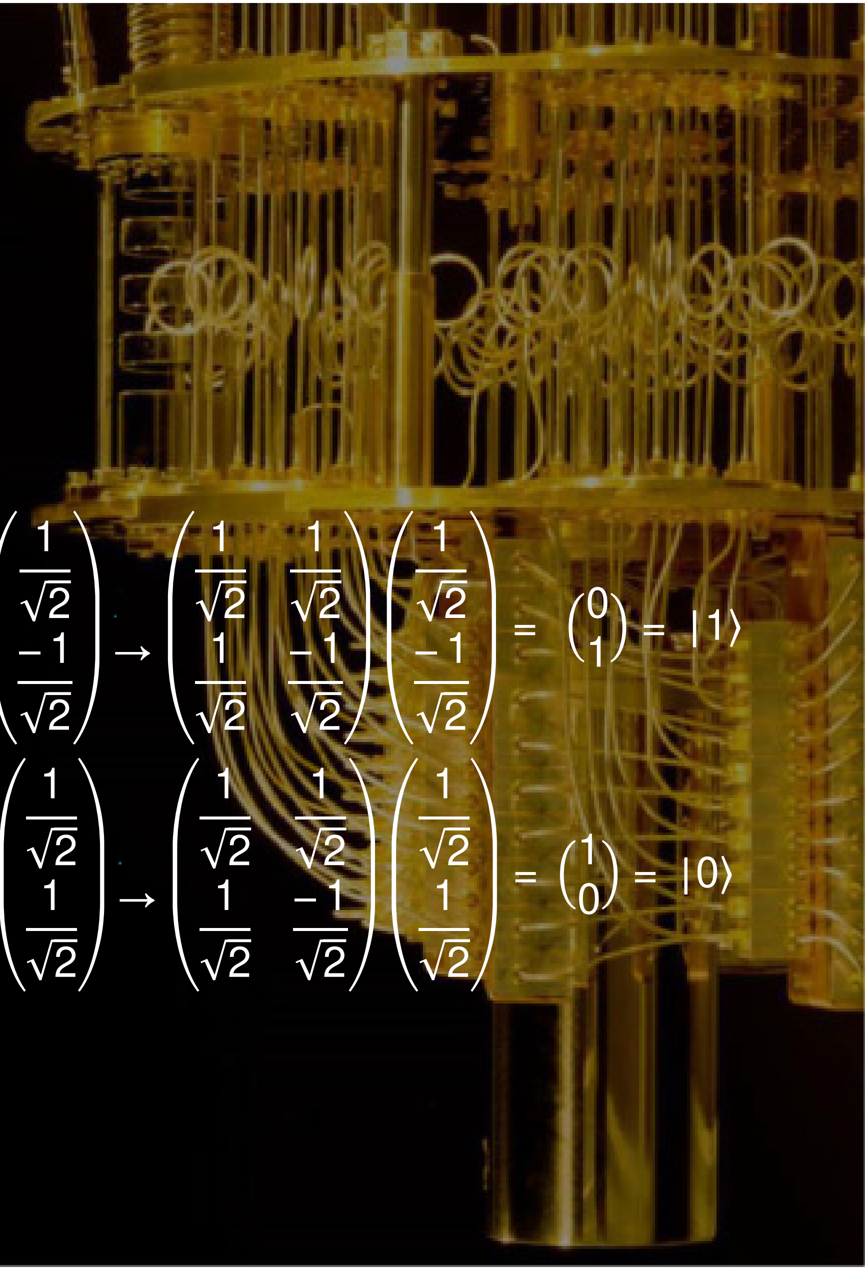
Deutsch's algorithm

- Identity (calculated proof – part 2)

$$\begin{pmatrix} \frac{1}{2} \\ -\frac{1}{2} \\ -\frac{1}{2} \\ \frac{1}{2} \end{pmatrix} \rightarrow \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} \frac{1}{2} \\ -\frac{1}{2} \\ -\frac{1}{2} \\ \frac{1}{2} \end{pmatrix} = \begin{pmatrix} \frac{1}{2} \\ -\frac{1}{2} \\ \frac{1}{2} \\ -\frac{1}{2} \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} \end{pmatrix} \otimes \begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{-1}{\sqrt{2}} \end{pmatrix} =$$

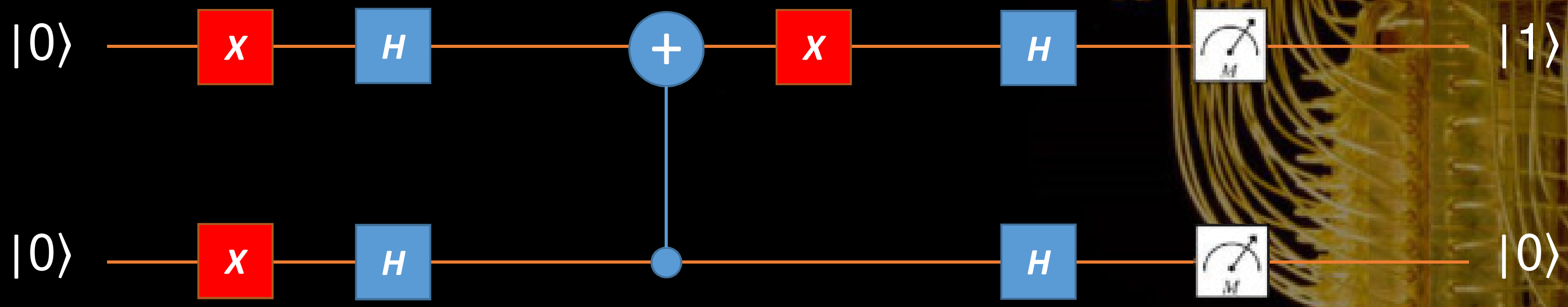
$$\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{-1}{\sqrt{2}} \end{pmatrix} \rightarrow \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{-1}{\sqrt{2}} \end{pmatrix} = \begin{pmatrix} 0 \\ 1 \end{pmatrix} = |1\rangle$$

$$\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} \end{pmatrix} \rightarrow \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} = |0\rangle$$



Deutsch's algorithm

- Negation (circuit overview)



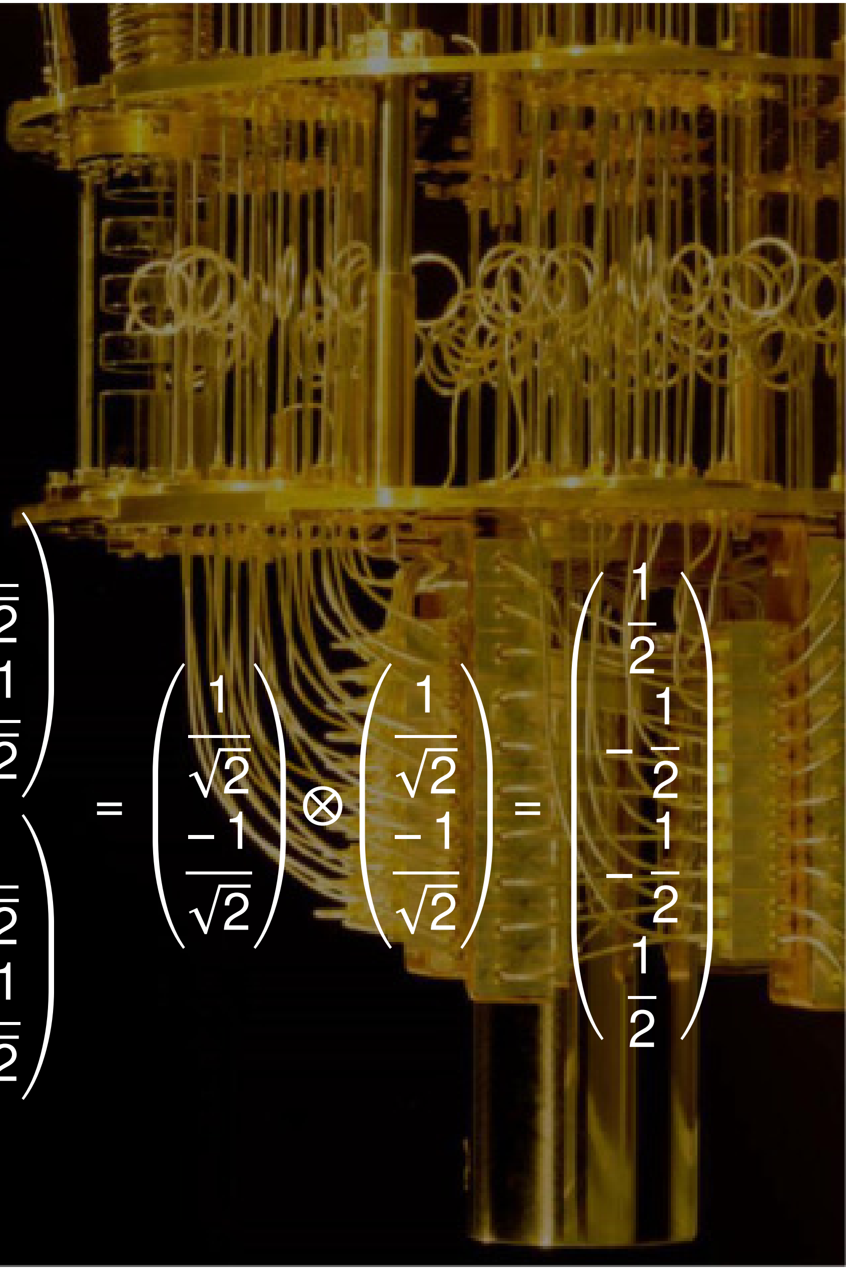
Deutsch's algorithm

- Negation (calculated proof – part 1)

$$|0\rangle = \begin{pmatrix}1\\0\end{pmatrix} \to \begin{pmatrix}0 & 1\\1 & 0\end{pmatrix}\begin{pmatrix}1\\0\end{pmatrix} = \begin{pmatrix}0\\1\end{pmatrix} \to \begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}}\end{pmatrix}\begin{pmatrix}0\\1\end{pmatrix} = \begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix}$$

$$|0\rangle = \begin{pmatrix}1\\0\end{pmatrix} \to \begin{pmatrix}0 & 1\\1 & 0\end{pmatrix}\begin{pmatrix}1\\0\end{pmatrix} = \begin{pmatrix}0\\1\end{pmatrix} \to \begin{pmatrix}\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}}\end{pmatrix}\begin{pmatrix}0\\1\end{pmatrix} = \begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix}$$

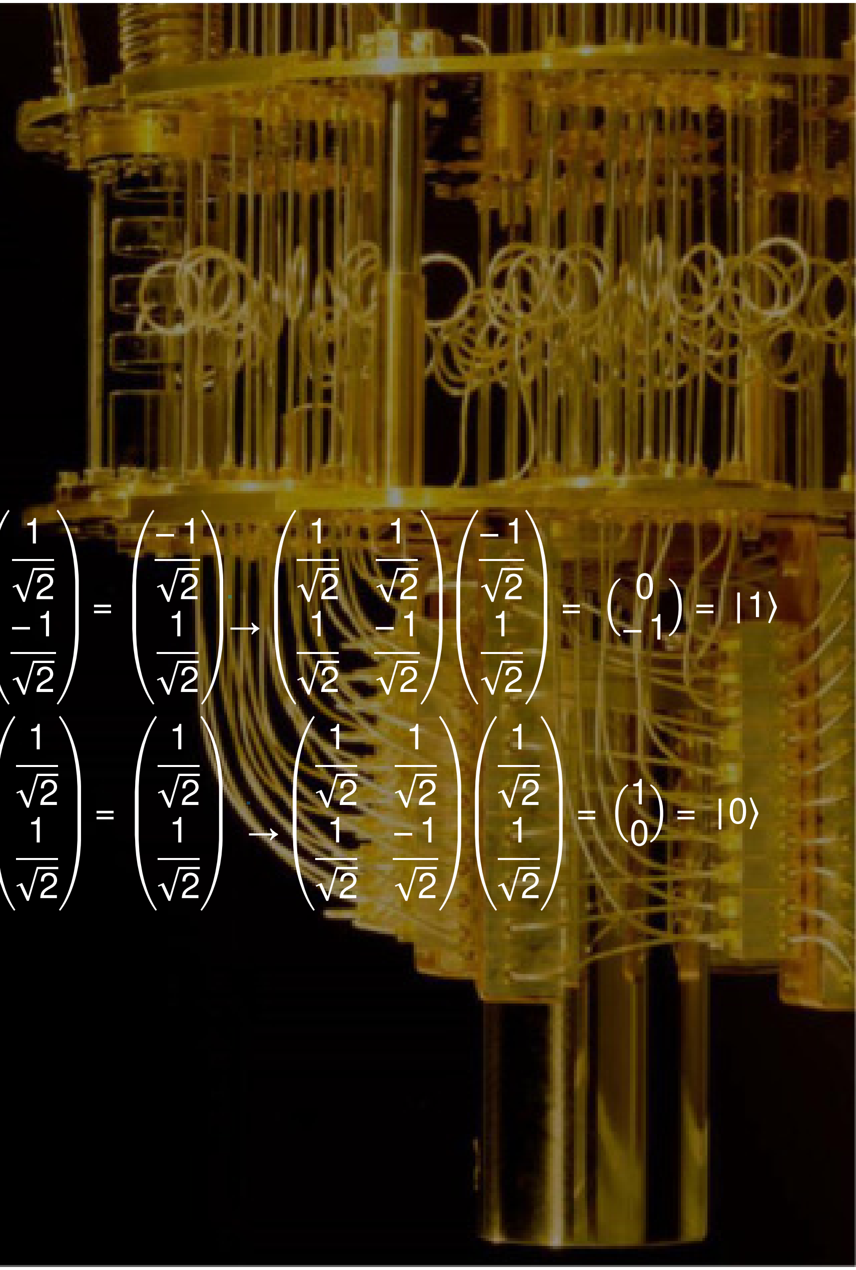
$$= \begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix} \otimes \begin{pmatrix}\frac{1}{\sqrt{2}}\\ \frac{-1}{\sqrt{2}}\end{pmatrix} = \begin{pmatrix}\frac{1}{2}\\ -\frac{1}{2}\\ -\frac{1}{2}\\ \frac{1}{2}\end{pmatrix}$$



Deutsch's algorithm

- Negation (calculated proof – part 2)

$$
\begin{pmatrix} \frac{1}{2} \\ -\frac{1}{2} \\ -\frac{1}{2} \\ \frac{1}{2} \end{pmatrix}
\rightarrow
\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}
\begin{pmatrix} \frac{1}{2} \\ -\frac{1}{2} \\ -\frac{1}{2} \\ \frac{1}{2} \end{pmatrix}
=
\begin{pmatrix} \frac{1}{2} \\ -\frac{1}{2} \\ \frac{1}{2} \\ -\frac{1}{2} \end{pmatrix}
=
\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} \end{pmatrix}
\otimes
\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{-1}{\sqrt{2}} \end{pmatrix}
=
\begin{matrix}
\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{-1}{\sqrt{2}} \end{pmatrix}
\rightarrow
\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}
\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{-1}{\sqrt{2}} \end{pmatrix}
=
\begin{pmatrix} \frac{-1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} \end{pmatrix}
\rightarrow
\begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} \end{pmatrix}
\begin{pmatrix} \frac{-1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} \end{pmatrix}
=
\begin{pmatrix} 0 \\ -1 \end{pmatrix}
= |1\rangle
\\
\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} \end{pmatrix}
\rightarrow
\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}
\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} \end{pmatrix}
=
\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} \end{pmatrix}
\rightarrow
\begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} \end{pmatrix}
\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} \end{pmatrix}
=
\begin{pmatrix} 1 \\ 0 \end{pmatrix}
= |0\rangle
\end{matrix}
$$



"About your cat, Mr. Schrödinger – I have good news and bad news."

$$\begin{pmatrix} \frac{}{\sqrt{}} & \frac{}{\sqrt{}} \\ \frac{}{\sqrt{}} & -\frac{}{\sqrt{}} \end{pmatrix}\begin{pmatrix} \textbf{Johnny Hooyberghs} \\ \textbf{Robin Vercammen} \end{pmatrix}$$

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https://github.com/Djohnnie/QuantumComputingQSharpIntroduction2018

www.involved-it.be