Build Stuff

ROCK AND CODE

Johnny Hooyberghs

Quantum Computing Deep Dive

ìnvolved

MVP Microsoft® Most Valuable Professional

Johnny Hooyberghs

@djohnnieke

github.com/Djohnnie

www.involved-it.be

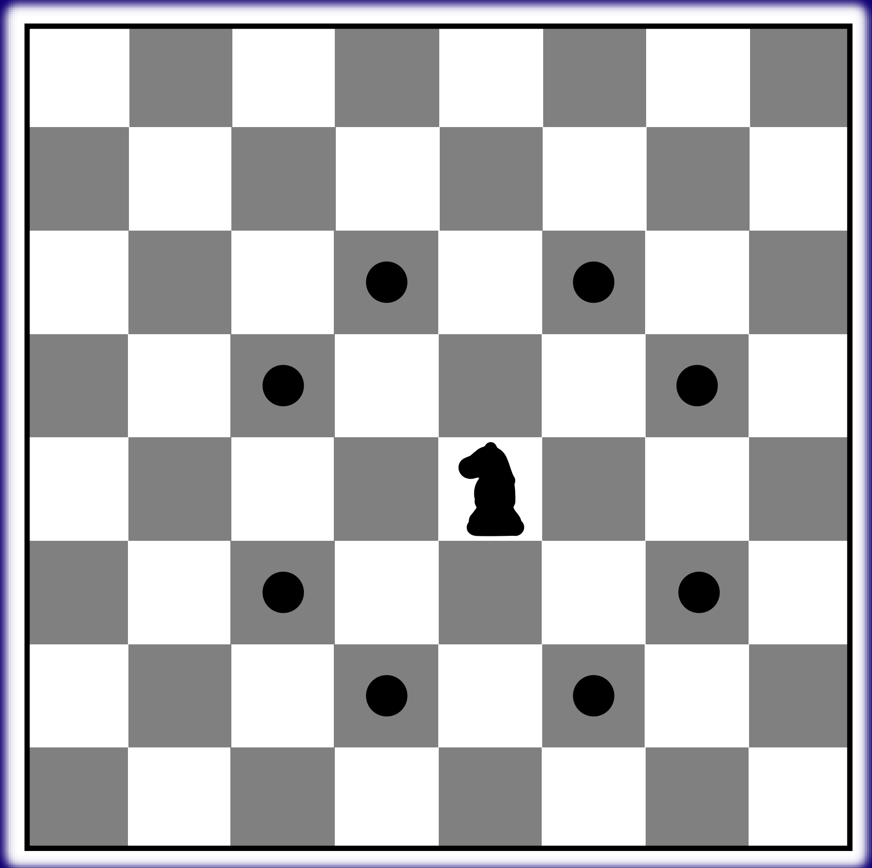
johnny.hooyberghs@involved-it.be

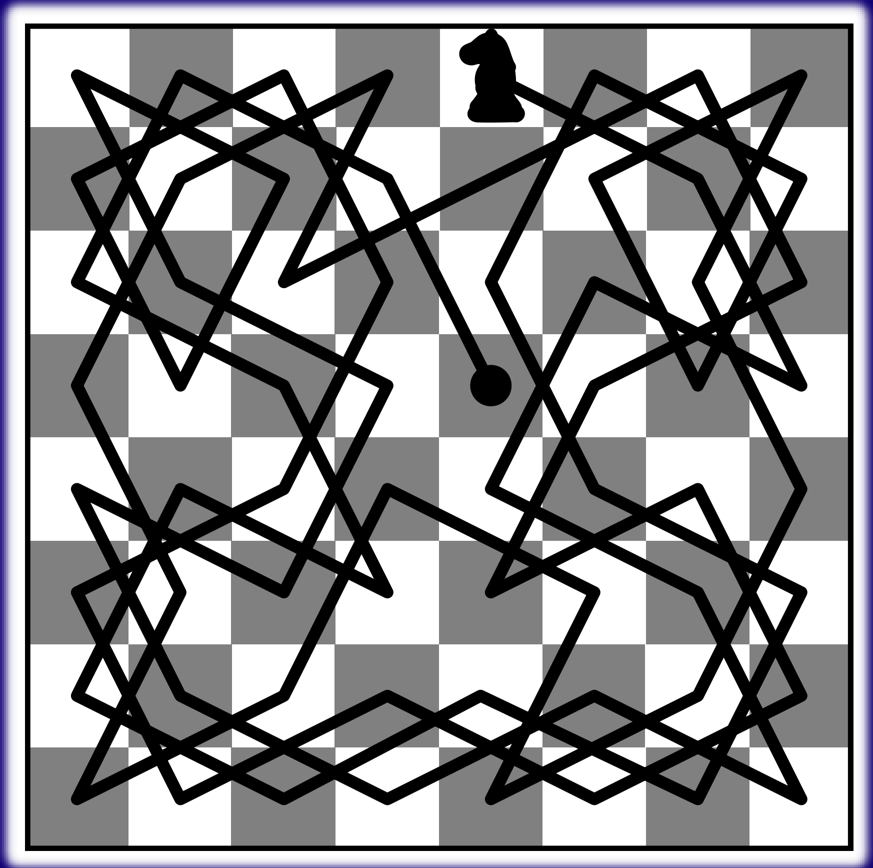
www.cvoantwerpen.be

Why Quantum Computing?

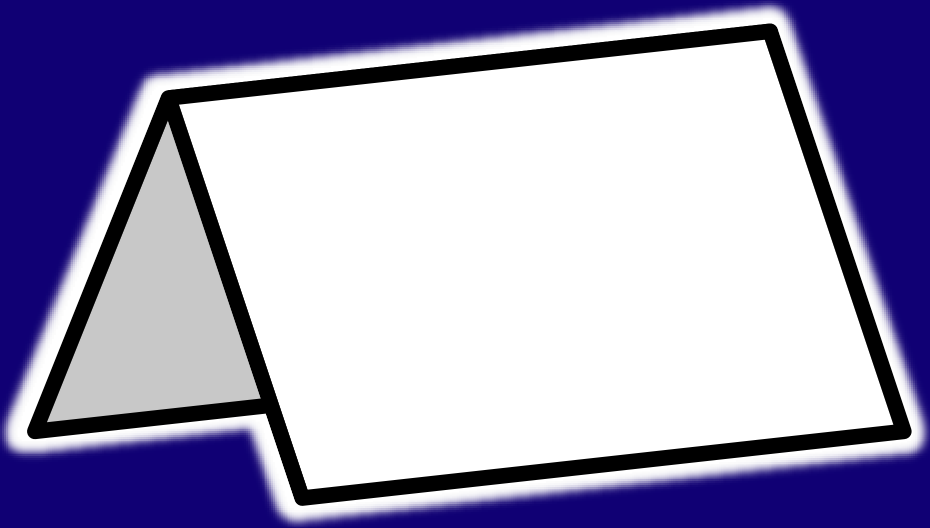
- There are still a lot of problems that cannot be solved by computers
- CPU’s have their physical limits
- Current classical computing architectures already have issues with unwanted quantum side effects because of their scale
- Why try to simulate a complex quantum world using classical computers?

Why Quantum Computing?





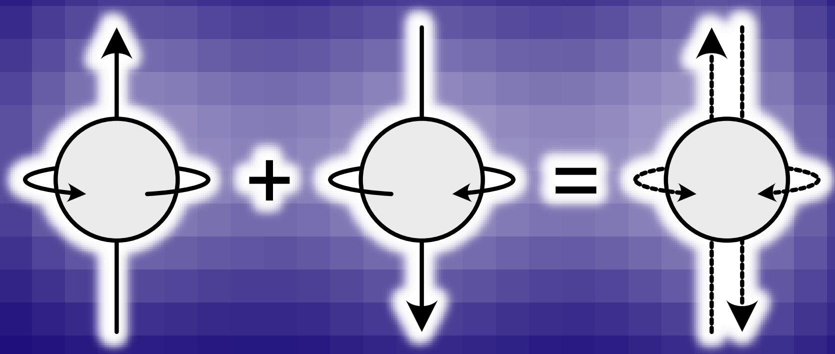
Why Quantum Computing?

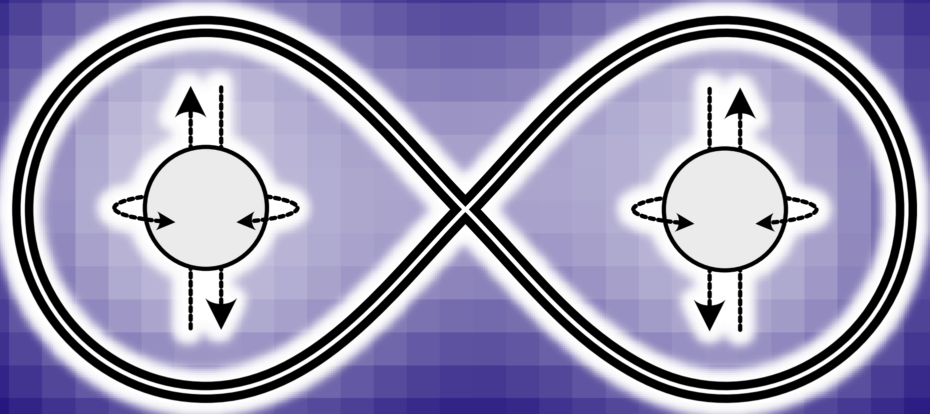


Superposition and Entanglement

Build Stuff

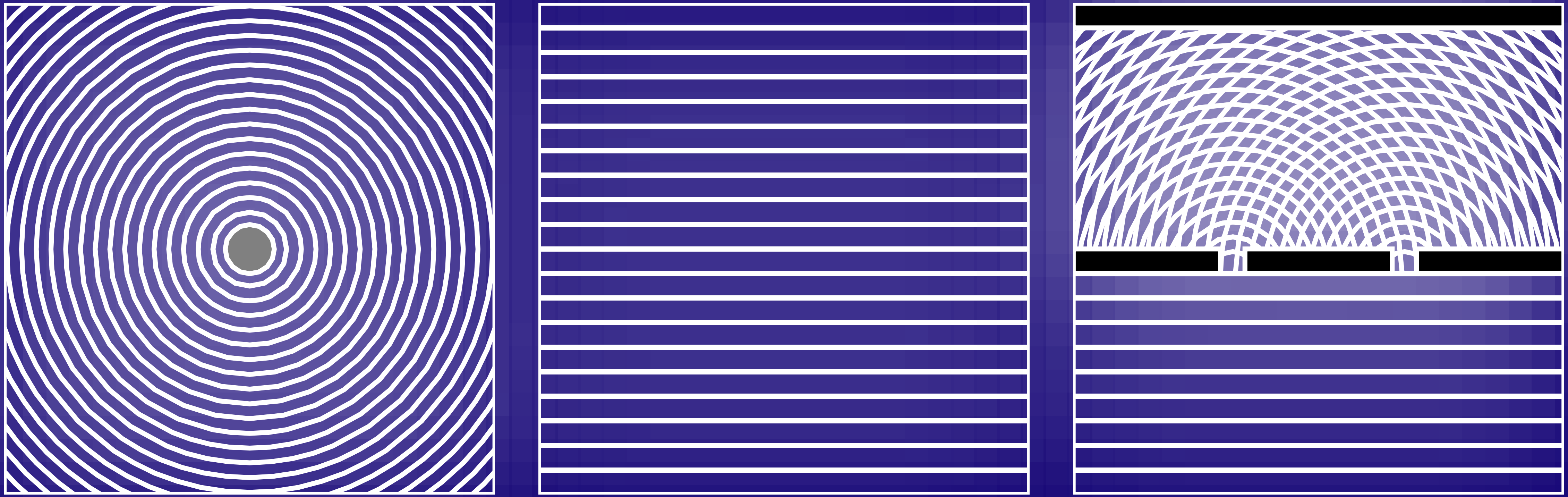
- Quantum mechanics describes superposition and entanglement of quantum particles
- Quantum Computing can use these phenomenon to its advantage



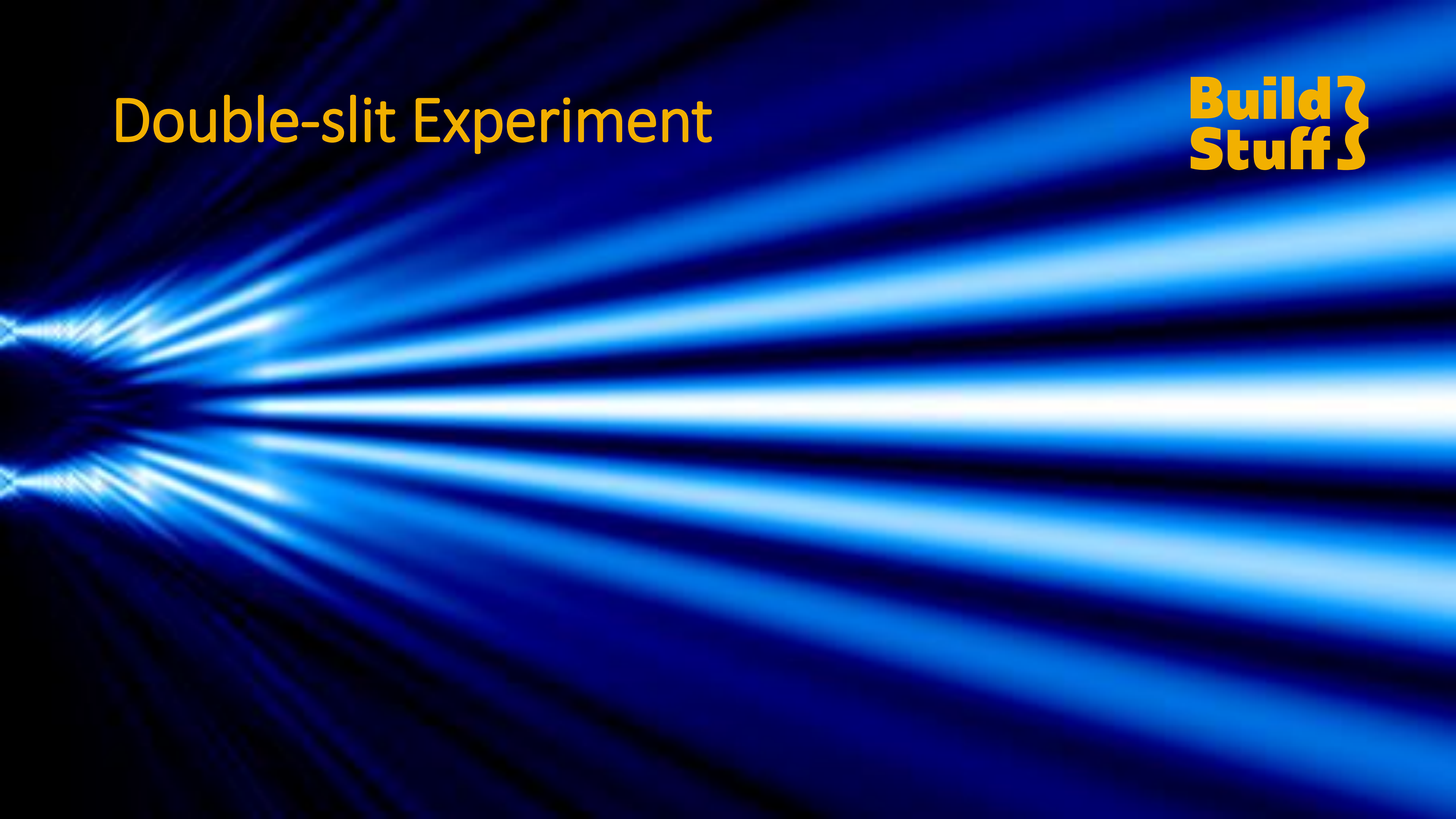


Double-slit Experiment

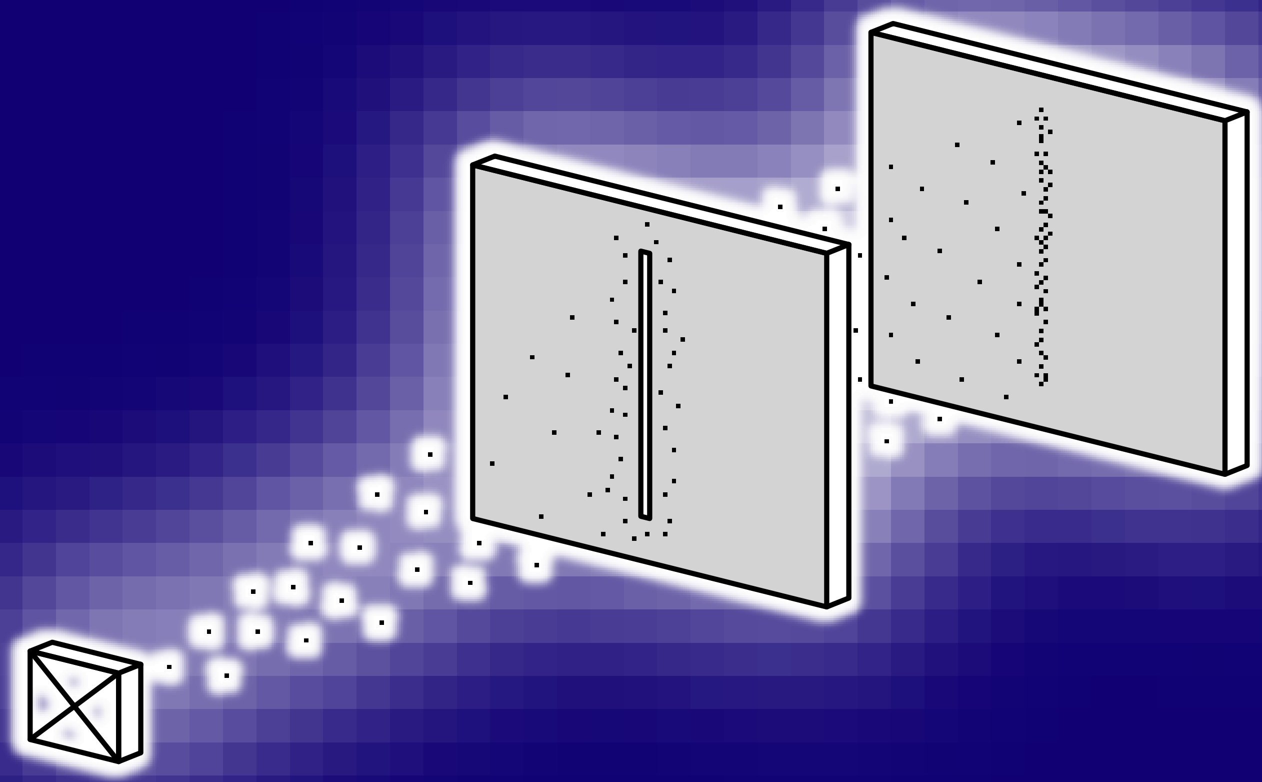
Build Stuff



Double-slit Experiment

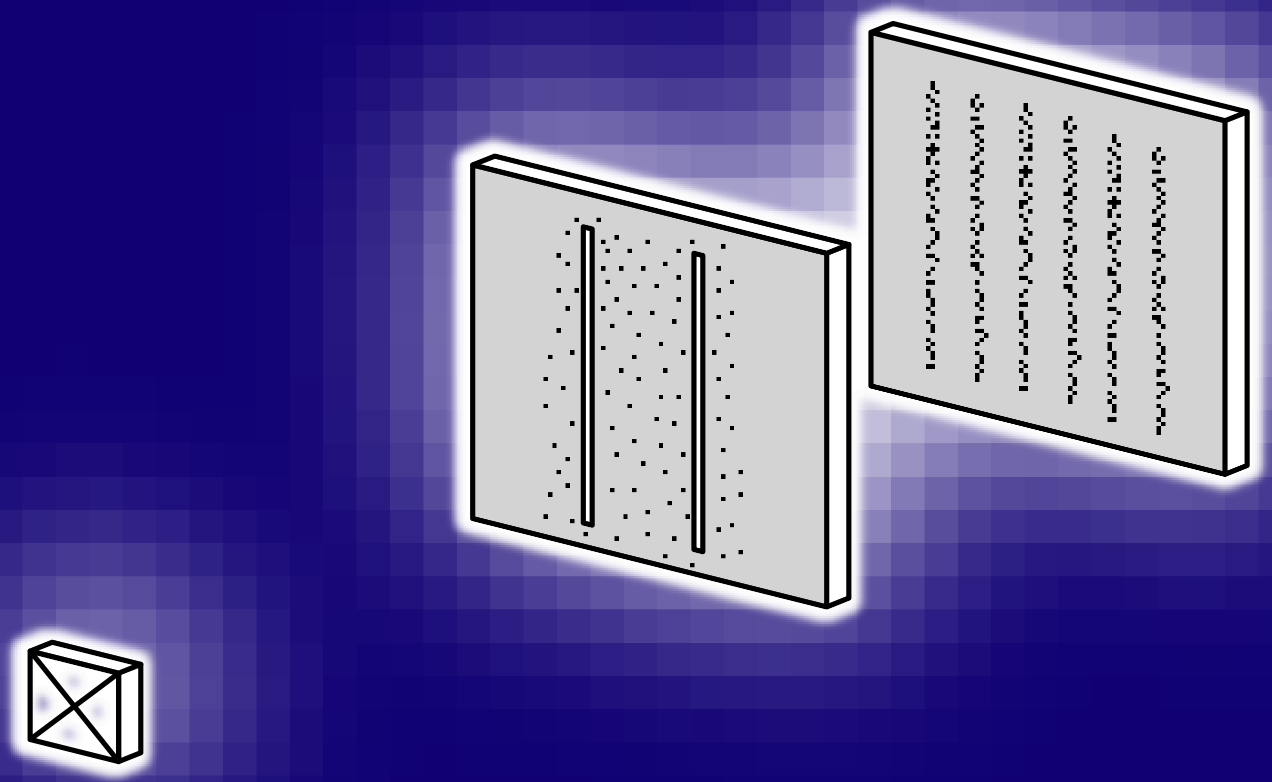


Double-slit Experiment

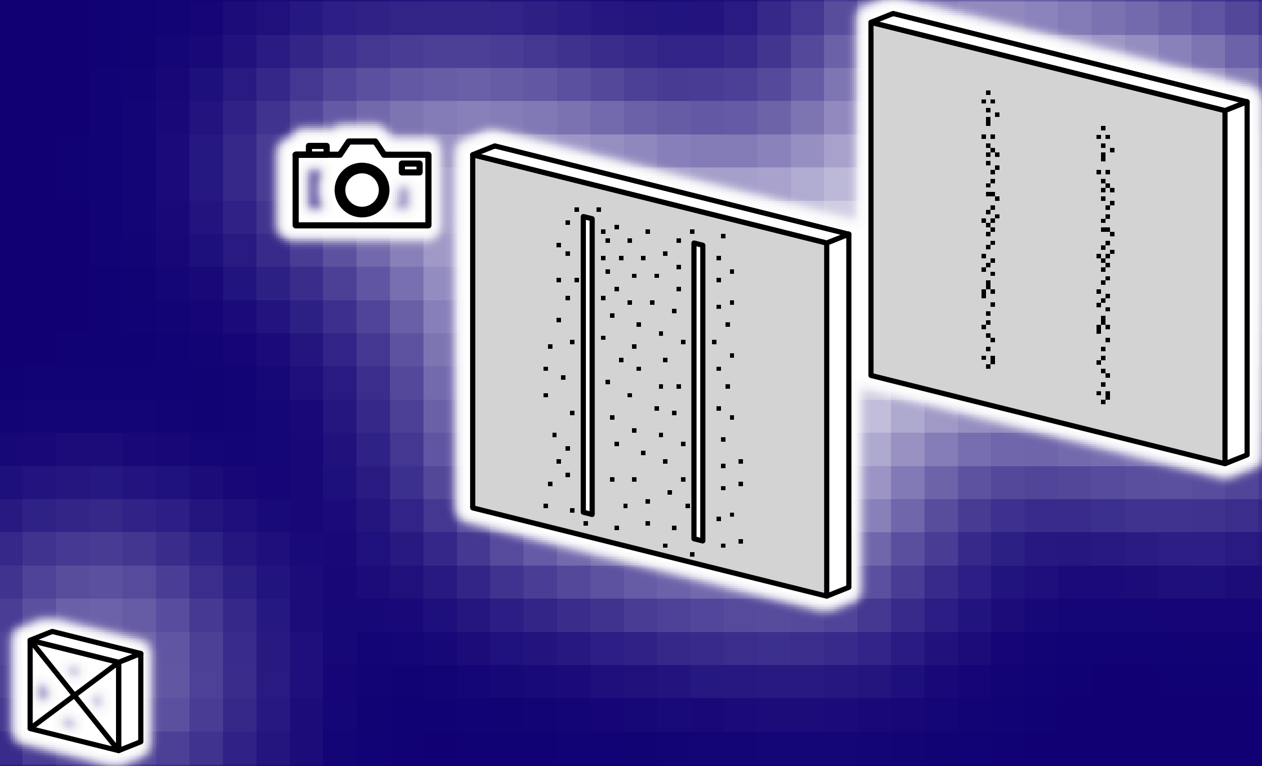


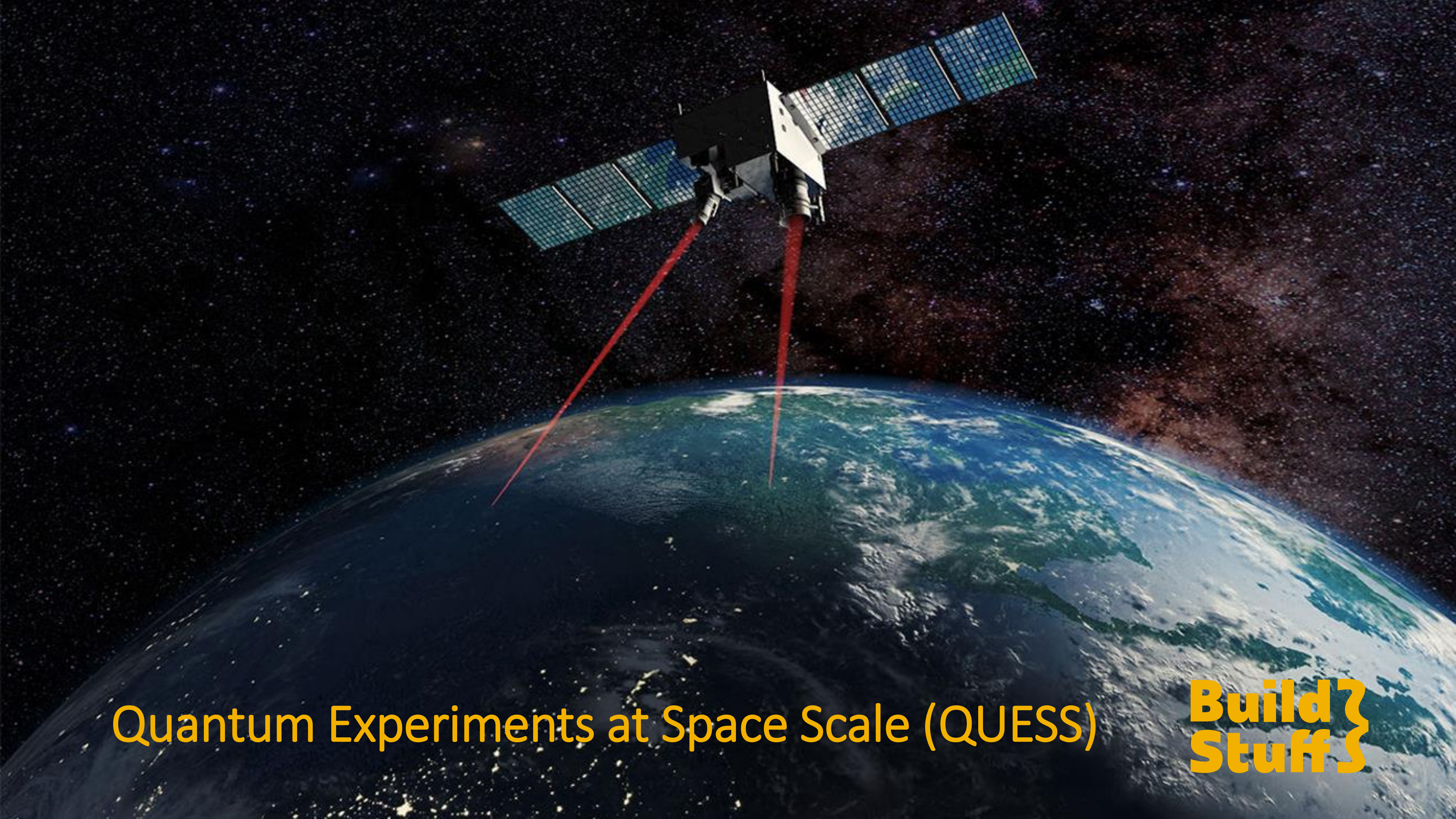
Build Stuff

Double-slit Experiment



Double-slit Experiment





Quantum Experiments at Space Scale (QUESS)

Why Quantum Computing?

- Security
  - Public/private key encryption?
  - Could make current RSA encryption obsolete
  - QKD (Quantum Key Distribution)

3.167 x 6.301 = 19.955.267

Why Quantum Computing?

- Drug development
  - It takes a quantum system to simulate a quantum system
  - Interactions between molecules
  - Gene sequencing
  - Protein folding

Why Quantum Computing?

- Machine Learning
  - Analyze large quantities of data
  - Fast feedback
  - Emulate human mind

?


CAN IT RUN CRYSIS?

Bits vs. Qubits

Build Stuff

0

1

Bits vs. Qubits

100110

Bits vs. Qubits

Build Stuff

$$|0\rangle \qquad\qquad |1\rangle$$

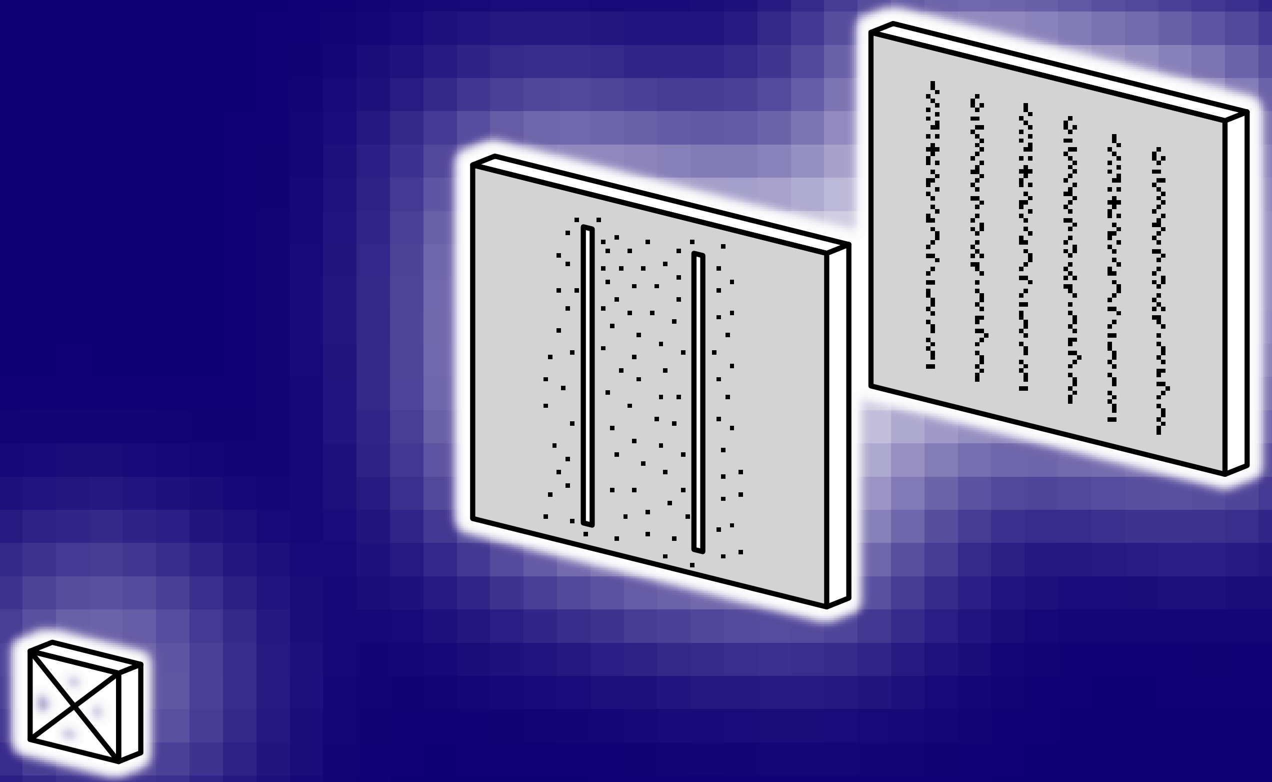
Bits vs. Qubits

Build Stuff

$$|100110\rangle$$

Quantum state

Build Stuff



Quantum state

$$\alpha|0\rangle + \beta|1\rangle$$

Quantum state

$$\boldsymbol{\alpha}|0\rangle + \boldsymbol{\beta}|1\rangle$$

$$|\alpha|^2 + |\beta|^2 = 1$$

Quantum state

$$\boldsymbol{\alpha}|0\rangle + \boldsymbol{\beta}|1\rangle$$

$$|\boldsymbol{\alpha}|^2 + |\boldsymbol{\beta}|^2 = 1$$

$$\boldsymbol{\alpha} = a + bi$$

$$\boldsymbol{\beta} = c + di$$

Quantum state

Build Stuff

$$\frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

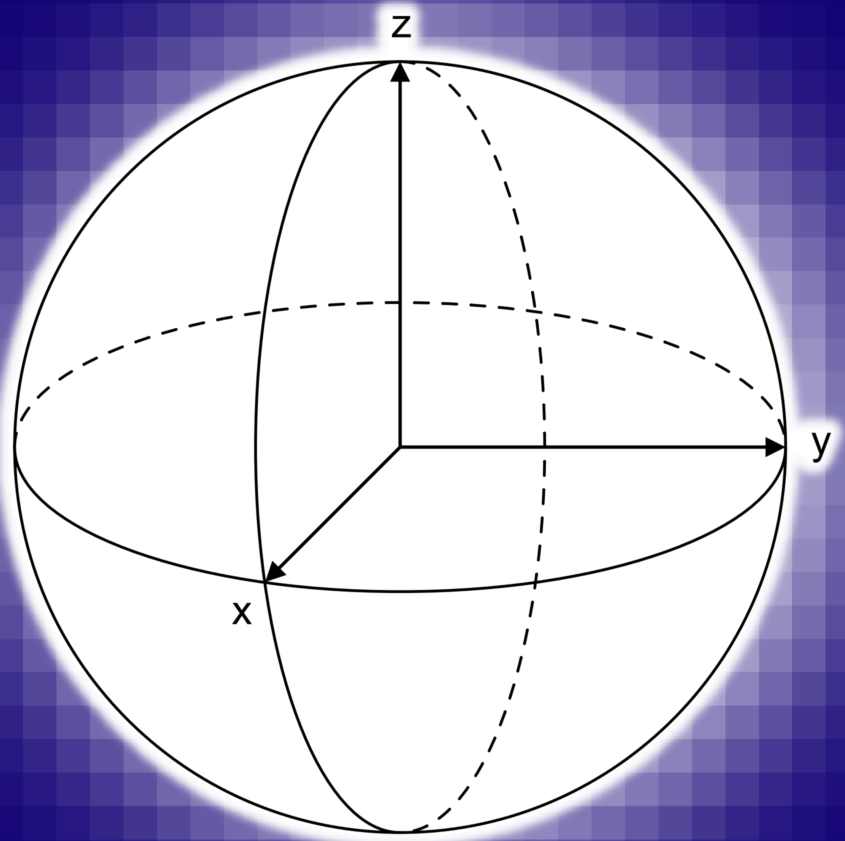
Quantum state

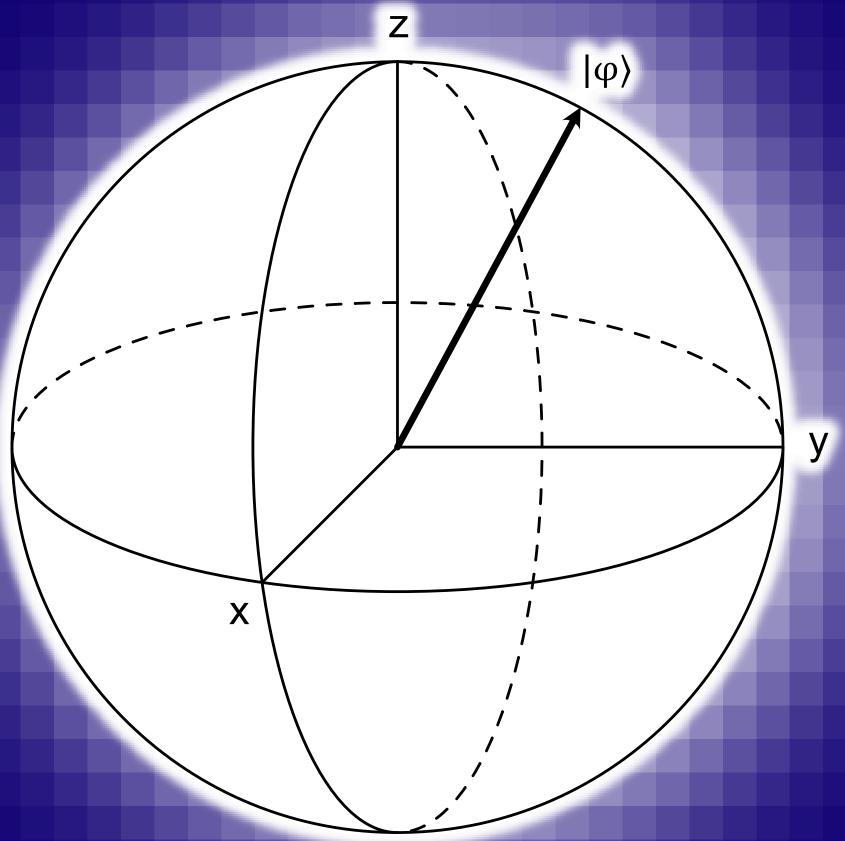
- Classical bit 0, Quantum bit $|0\rangle$
- Classical bit 1, Quantum bit $|1\rangle$
- Quantum bit in superposition

$$\boldsymbol{\alpha}|0\rangle + \boldsymbol{\beta}|1\rangle \text{ where } |\boldsymbol{\alpha}|^2 + |\boldsymbol{\beta}|^2 = 1$$

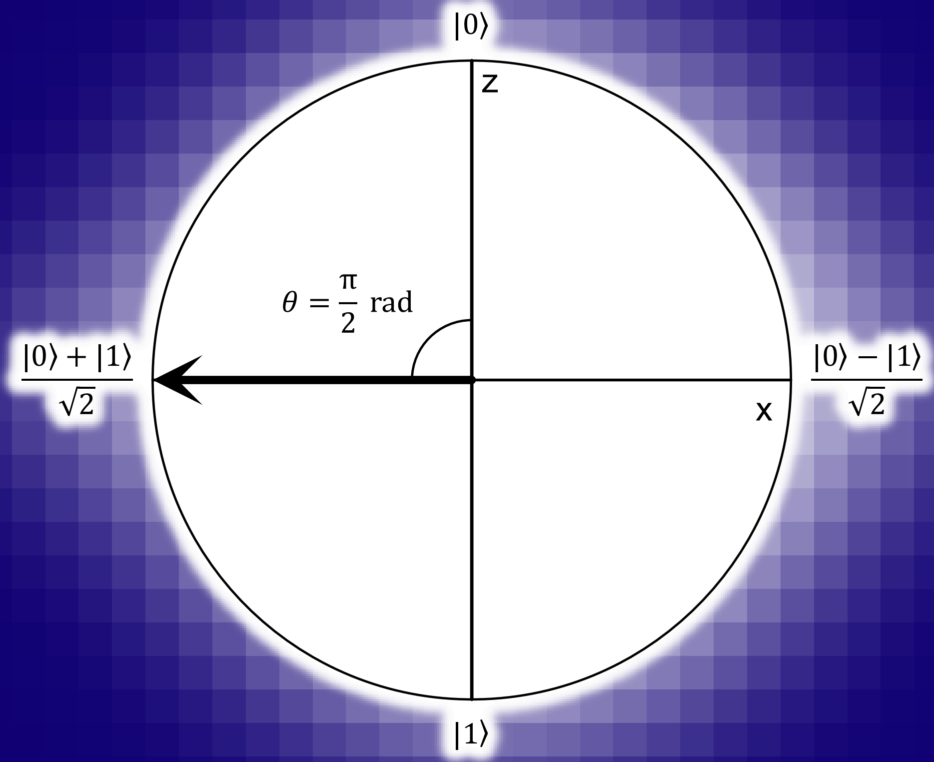
- $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are complex numbers $(\mathrm{a}i + \mathrm{b})$
- Value known after measurement
- Collapses to $|0\rangle$ with probability $|\boldsymbol{\alpha}|^2$ or $|1\rangle$ with probability $|\boldsymbol{\beta}|^2$

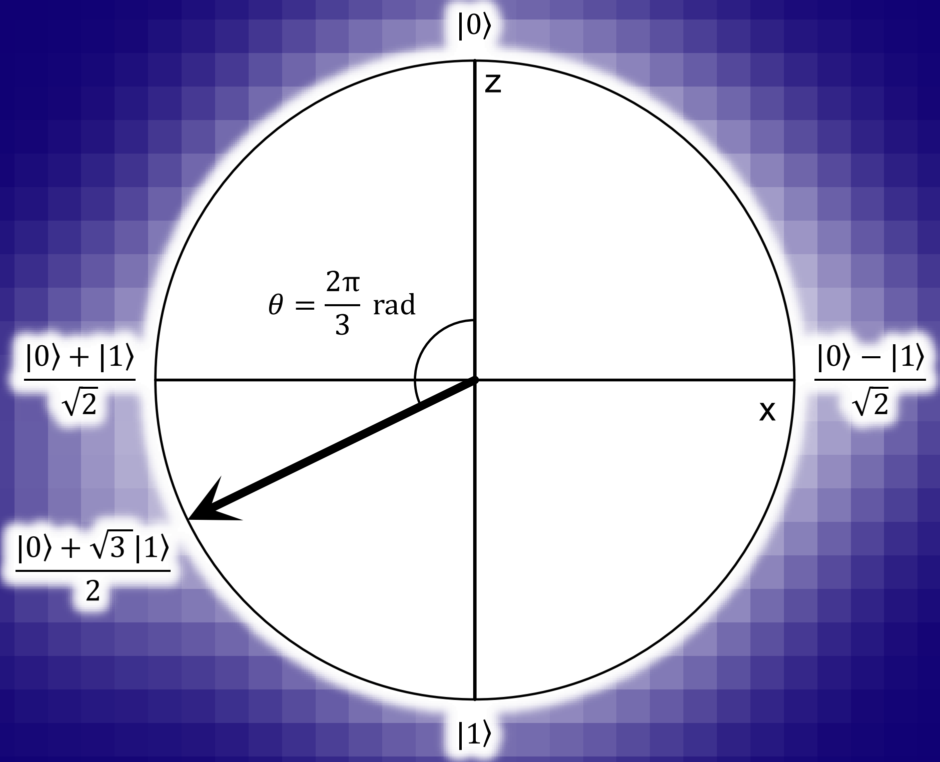
Quantum state





Quantum state





Quantum state

- 2 Qubit system (4 values):

$$\boldsymbol{\alpha}|00\rangle + \boldsymbol{\beta}|01\rangle + \boldsymbol{\gamma}|10\rangle + \boldsymbol{\delta}|11\rangle$$

- 3 Qubit system (8 values):

$$\boldsymbol{\alpha}|000\rangle + \boldsymbol{\beta}|001\rangle + \boldsymbol{\gamma}|010\rangle + \boldsymbol{\delta}|011\rangle + \boldsymbol{\varepsilon}|100\rangle + \boldsymbol{\epsilon}|110\rangle + \boldsymbol{\zeta}|101\rangle + \boldsymbol{\eta}|111\rangle$$

- 4 Qubit system (16 values):

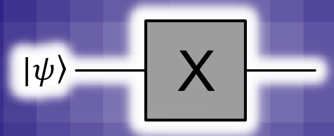
…

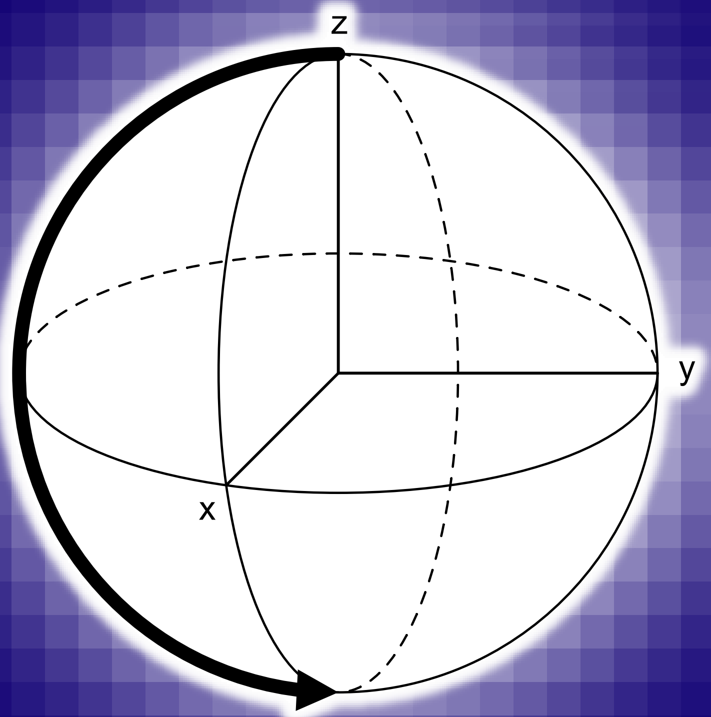
Quantum state

$$|0\rangle \qquad |1\rangle$$

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

X-gate

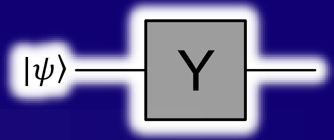


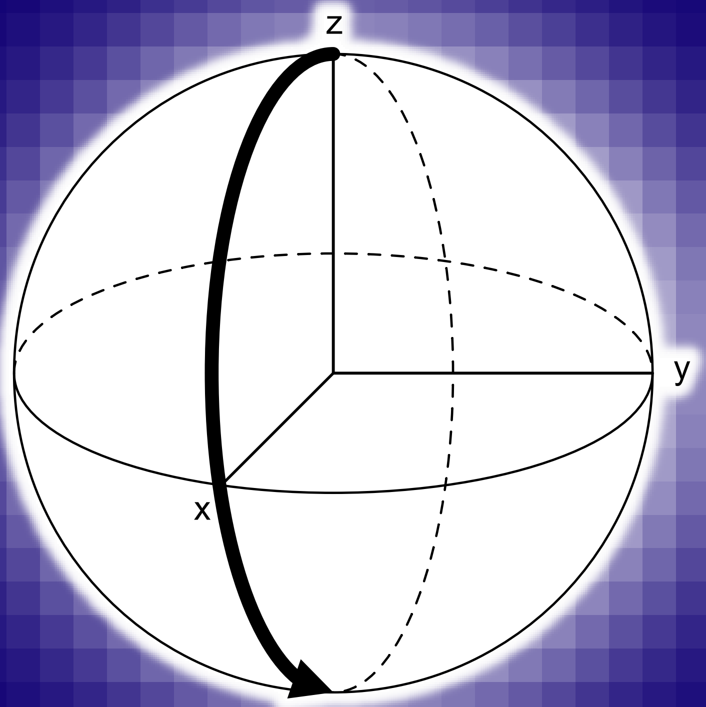


$$\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

Build Stuff

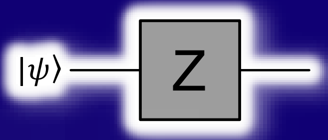
Y-gate

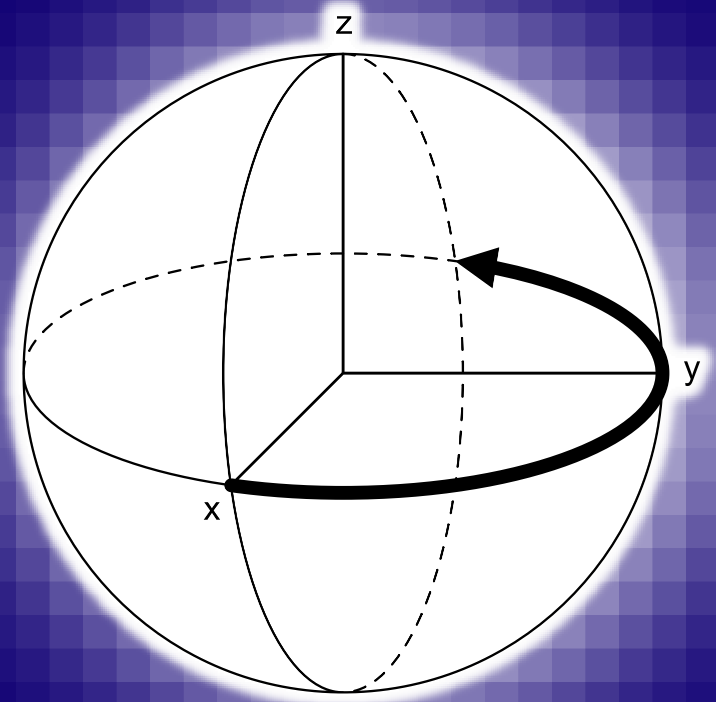




$$\begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$$

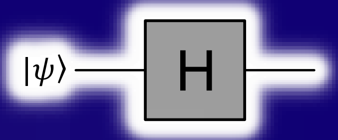
Z-gate

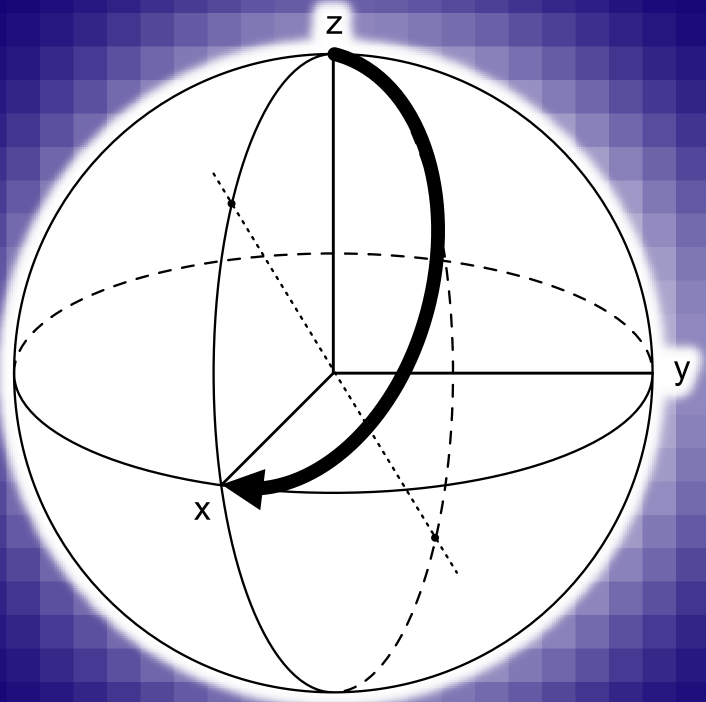




$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

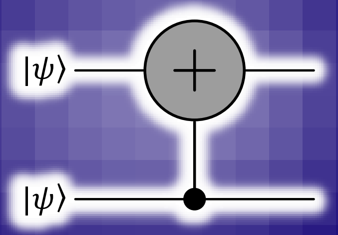
H-gate





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

CNOT-gate



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

Build Stuff

IBM Q Experience

- https://quantum-computing.ibm.com

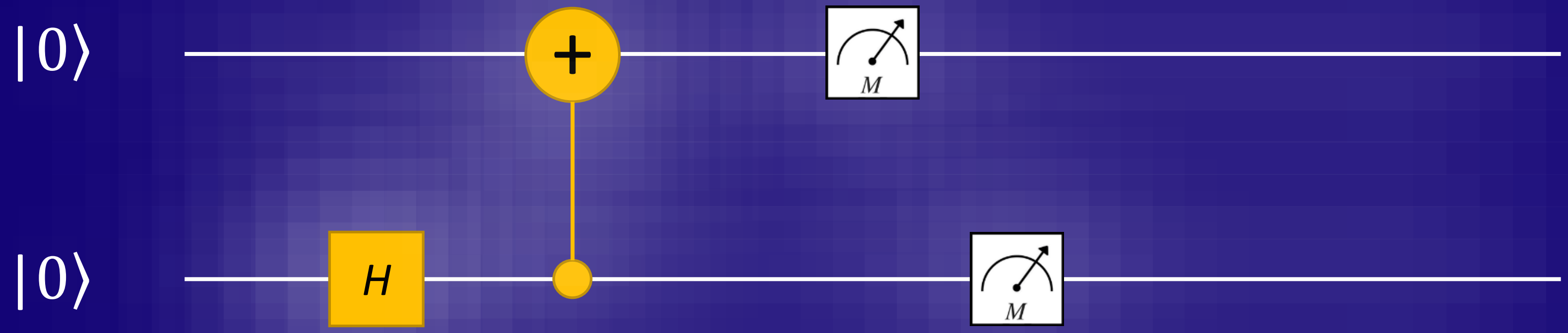
Microsoft Q#

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

Azure Quantum

- Quantum in the cloud
  - Optimization
  - Machine Learning
  - Quantum Simulation
- Access to quantum hardware
  - Microsoft (Topological)
  - IonQ & Honeywell (Ion Traps)
  - QCI (Superconducting)
- Q# & QDK
  - Quantum Intermediate Representation (QIR)

Entanglement



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

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

Entanglement

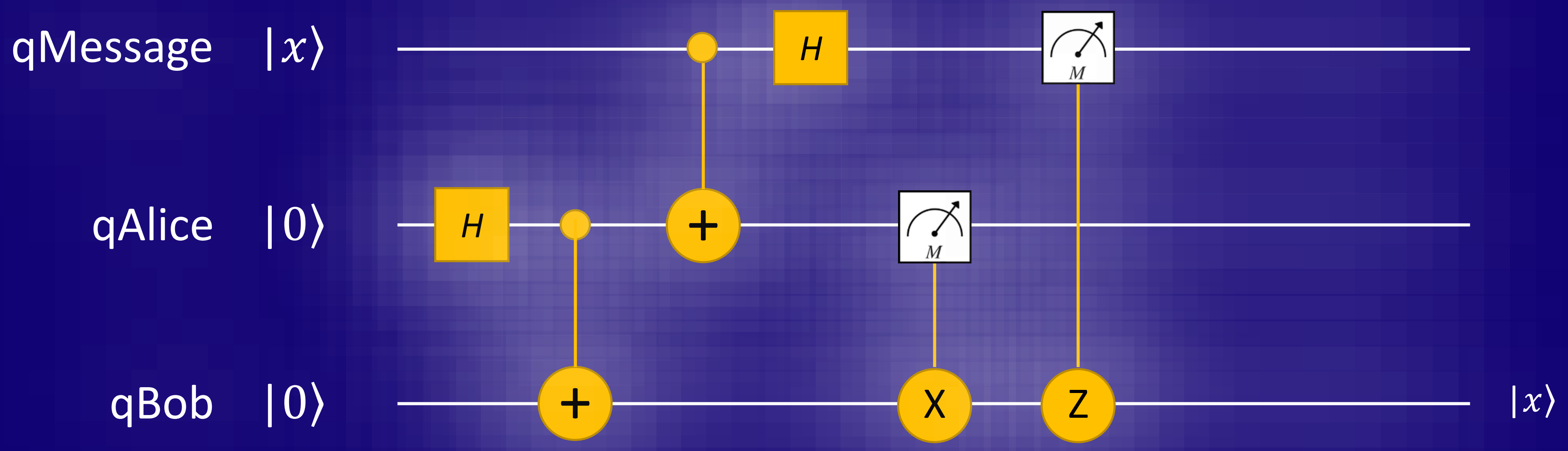
Build Stuff

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

$$\begin{pmatrix} \frac{1}{\sqrt{2}} \\ 0 \\ 0 \\ \frac{1}{\sqrt{2}} \end{pmatrix} = \begin{pmatrix} a \\ b \end{pmatrix} \otimes \begin{pmatrix} c \\ d \end{pmatrix} \rightarrow \begin{aligned} ac &= \frac{1}{\sqrt{2}} \\ ad &= 0 \\ bc &= 0 \\ bd &= \frac{1}{\sqrt{2}} \end{aligned}$$

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

Teleportation



Quantum Algorithms

- Deutch (1985)
  - Is there a problem that a Quantum Computer can solve faster than a Classical Computer?
  - Deterministic!

Quantum Algorithms

- Deutsch–Jozsa (1992)
  - Based on Deutch (for 1 bit), but applicable for n-bits
  - Deterministic!

Quantum Algorithms

Build Stuff

- Grover's algorithm (1996)
  - “Searching a database”
  - Probabilistic!

Quantum Algorithms

- Shor's algorithm (1994)
  - Prime factorization of integers
  - Combination of classical and quantum algorithm
  - Probabilistic!

Thank you, be professional, and have fun out there!

Johnny Hooyberghs
@djohnnieke
github.com/Djohnnie
www.involved-it.be
johnny.hooyberghs@involved-it.be
www.cvoantwerpen.be

https://github.com/Djohnnie/QuantumComputing-BuildStuff-2020