Quantum Computing: Don't Panic

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QUANTUM COMPUTING

- What is quantum computing? Why is it important?
- How do we build a quantum computer?
- What kinds of physical systems are already in development?
- What is Q#/the QDK and why would you use it?
- Can we use Q# to teleport a quantum state?

Quantum mechanics is weird

...and we don't know why!

Imagine the quantum future…

Nitrogen Fixation

cheap fertilizer everywhere

Carbon Capture

mitigate global warming

Materials Science

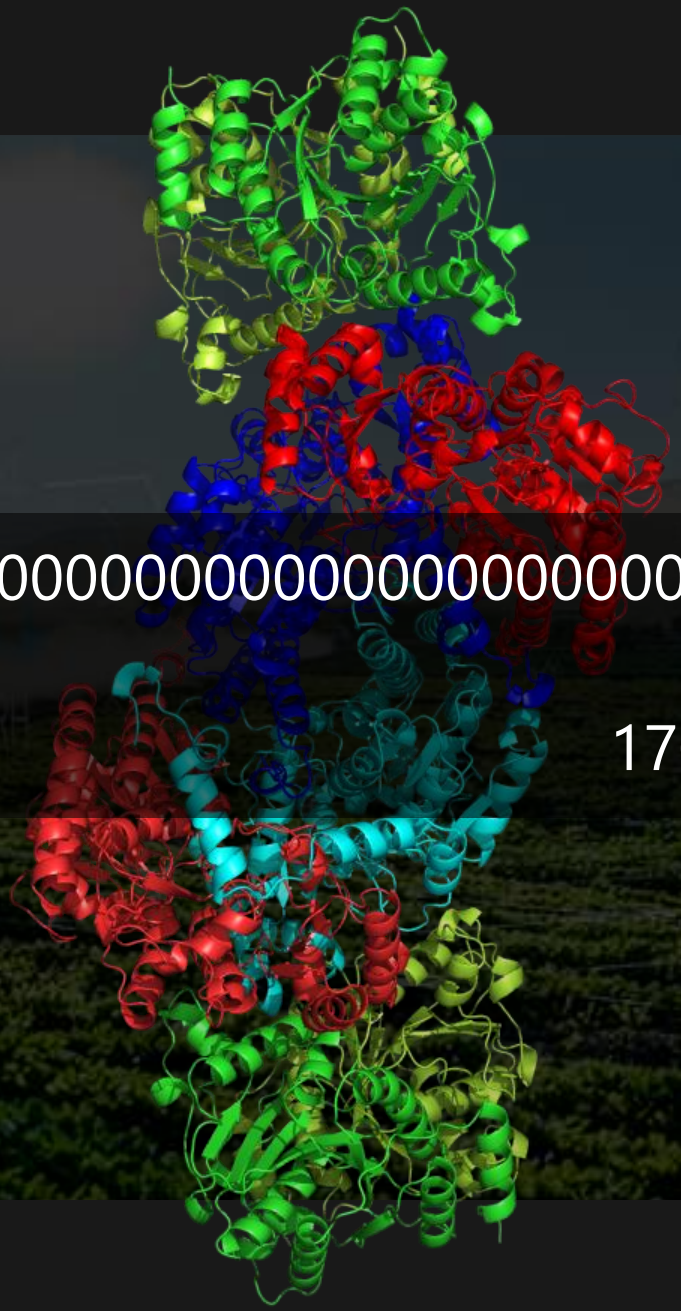
lossless power lines

better batteries

smart materials

Machine learning

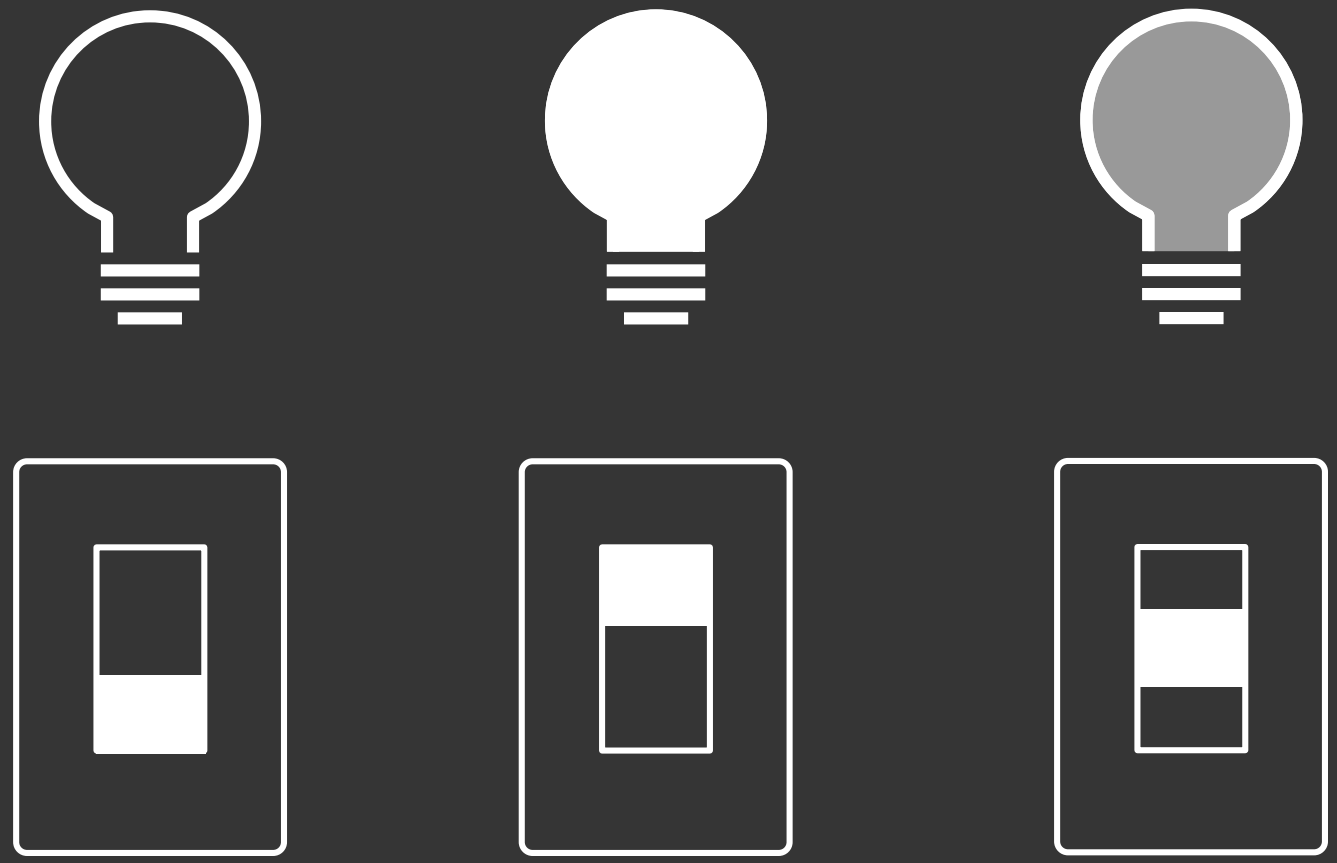

NITROGEN
19ppm
Recommendation:
25ppm
MOISTURE
39%RH

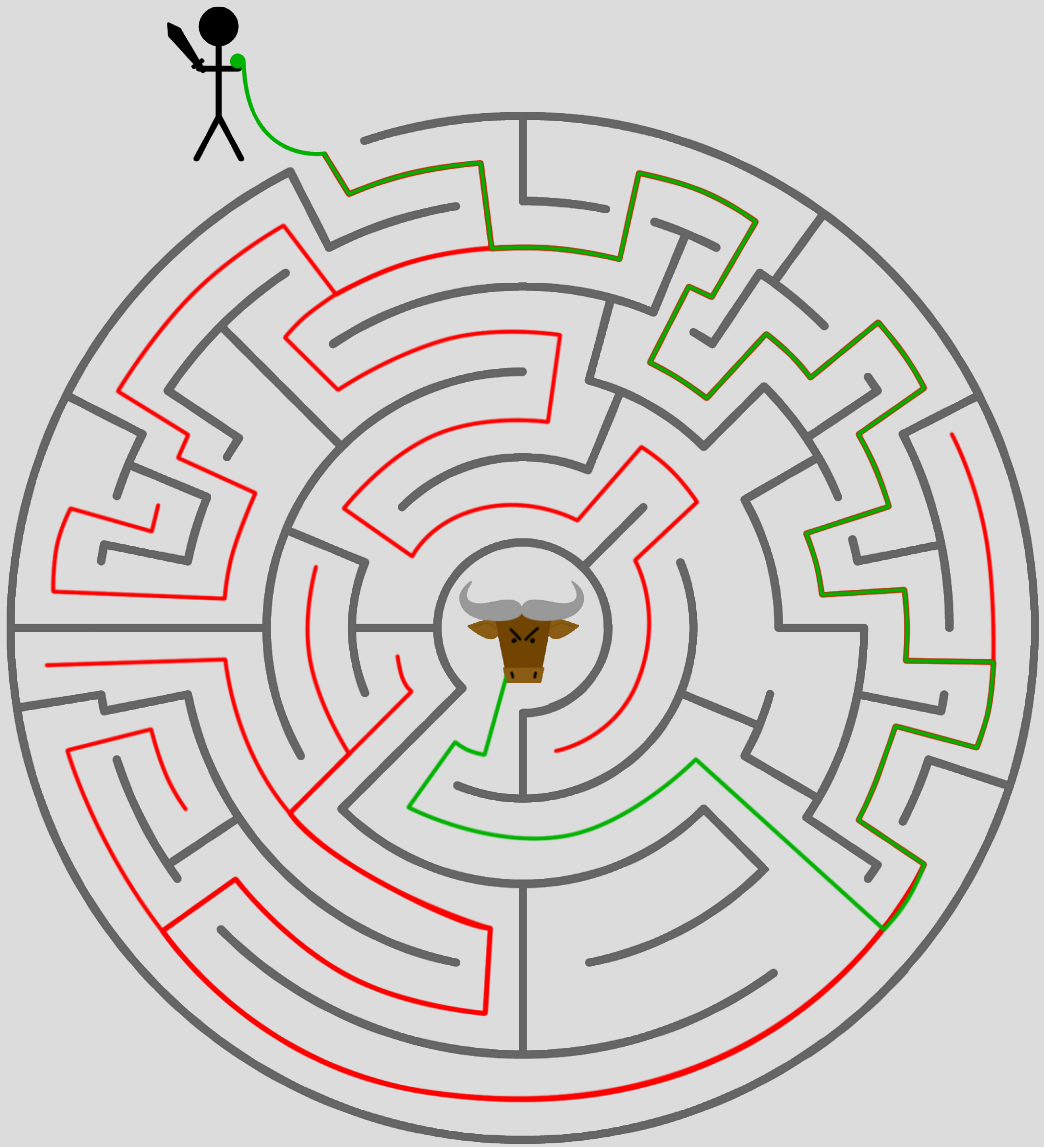


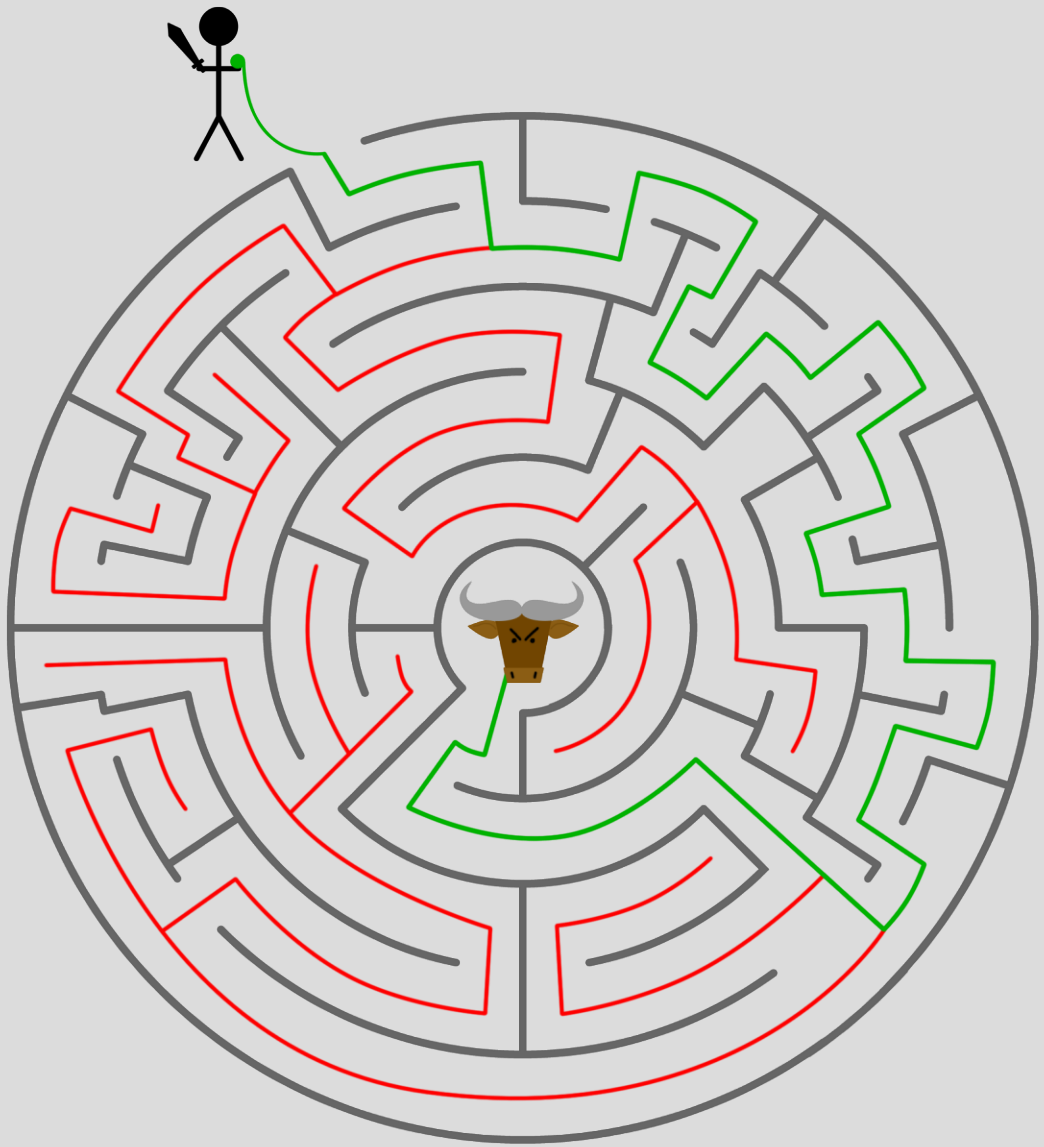
150000000000000000000000000000000000000000000000000 = 1.5×10^{51} bits

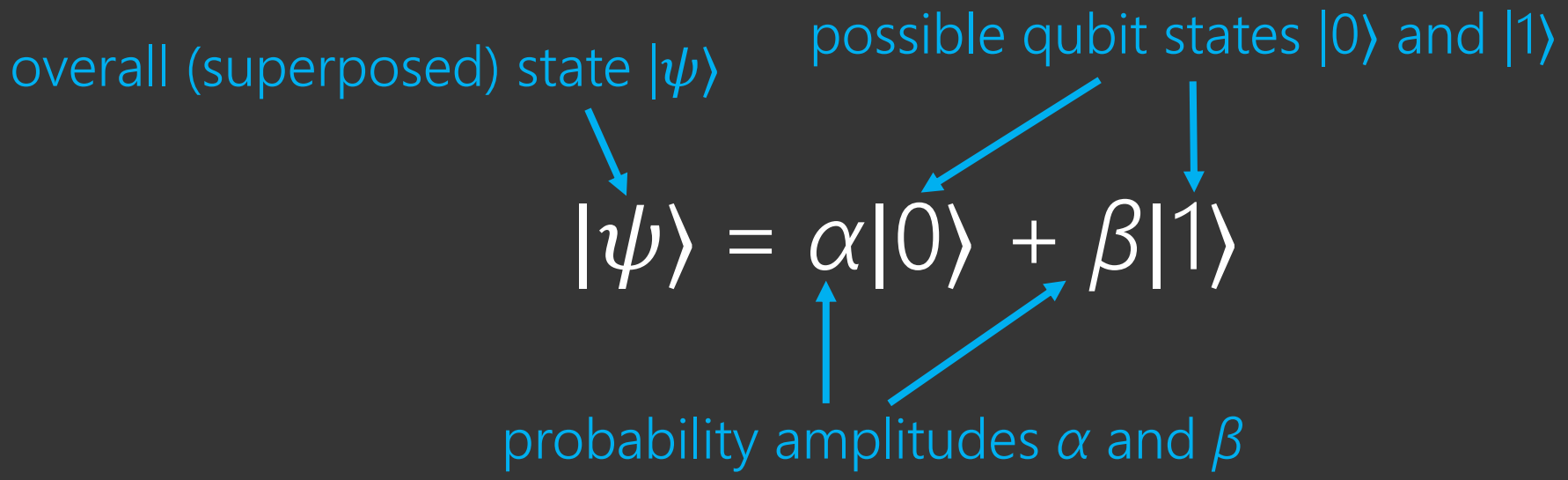
OR

170 qubits









Probability of seeing $|0\rangle$ when measured: $|\alpha|^2$

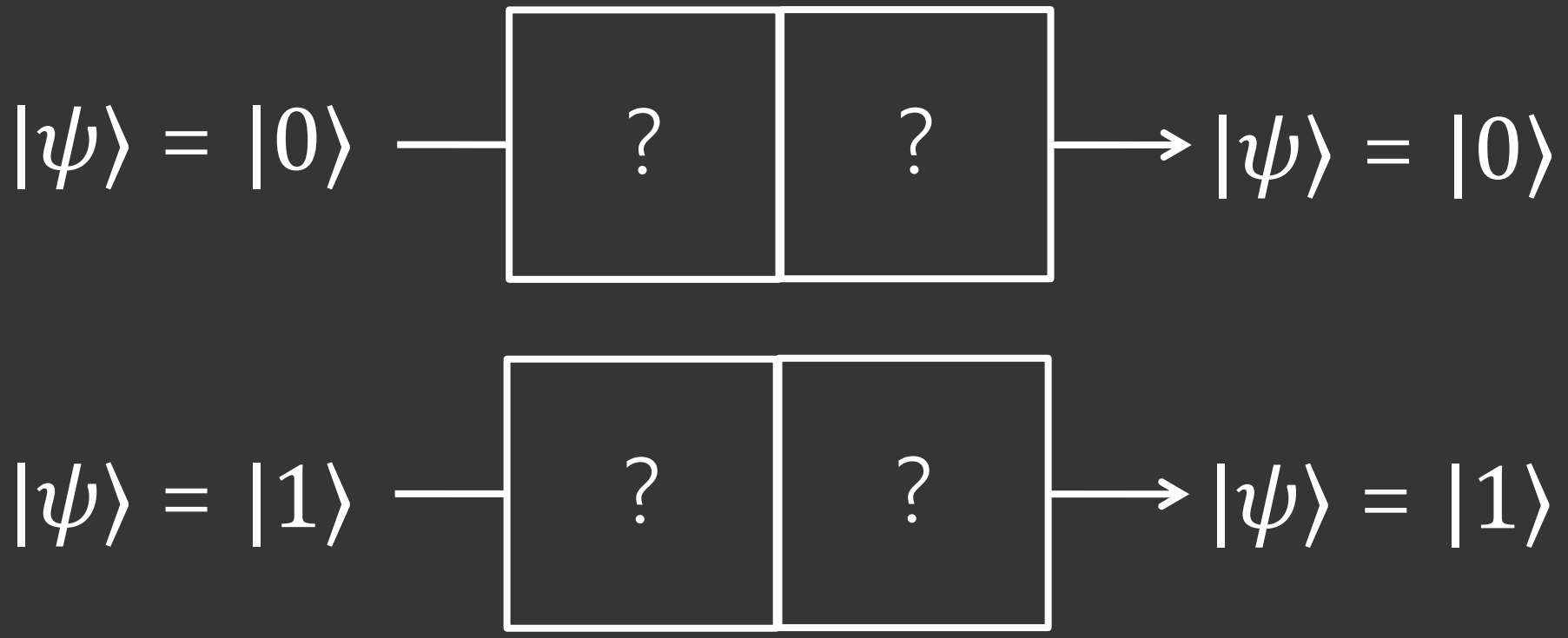
Probability of seeing $|1\rangle$ when measured: $|\beta|^2$

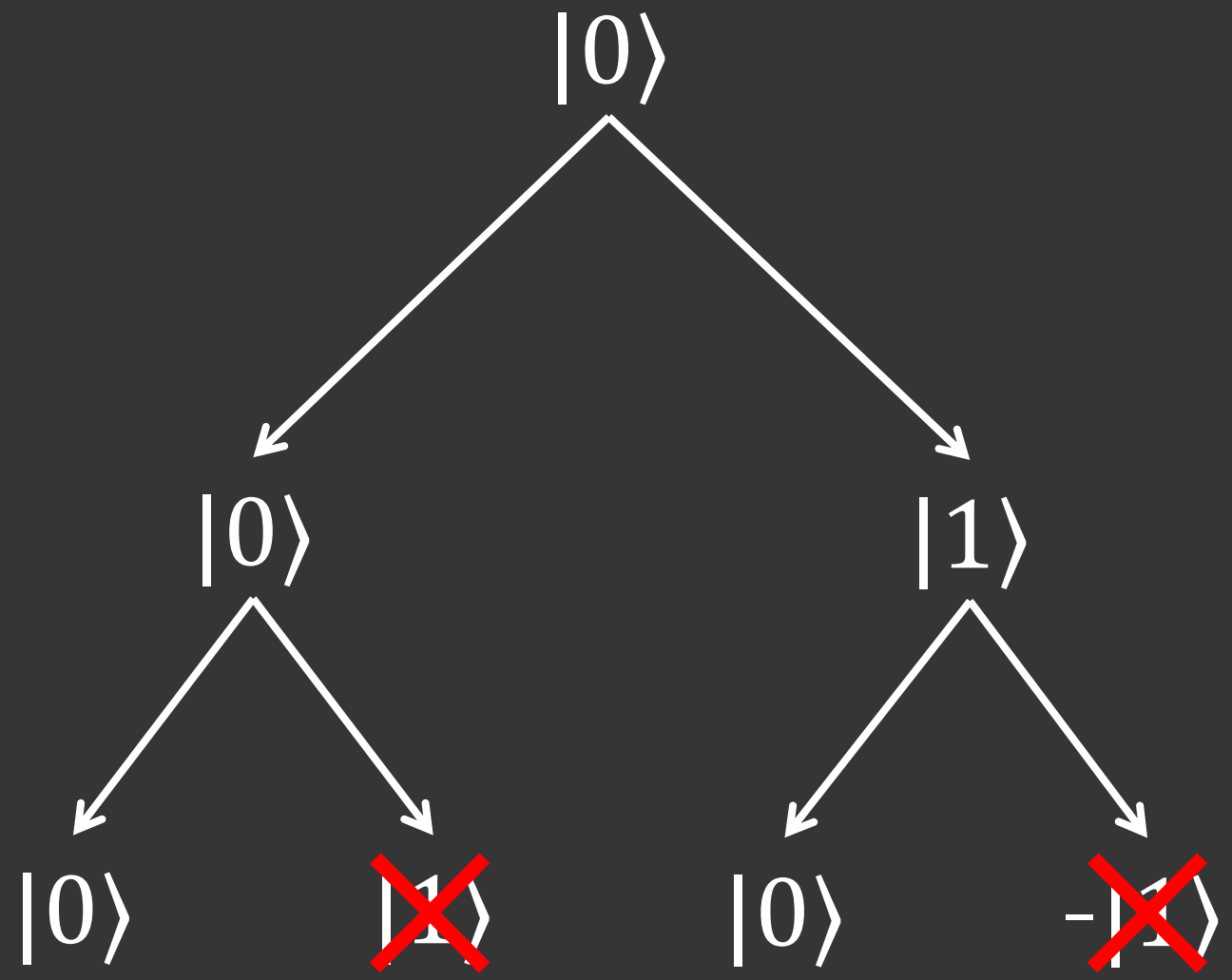
Total probability of seeing either $|0\rangle$ or $|1\rangle$: $|\alpha|^2 + |\beta|^2 = 1$

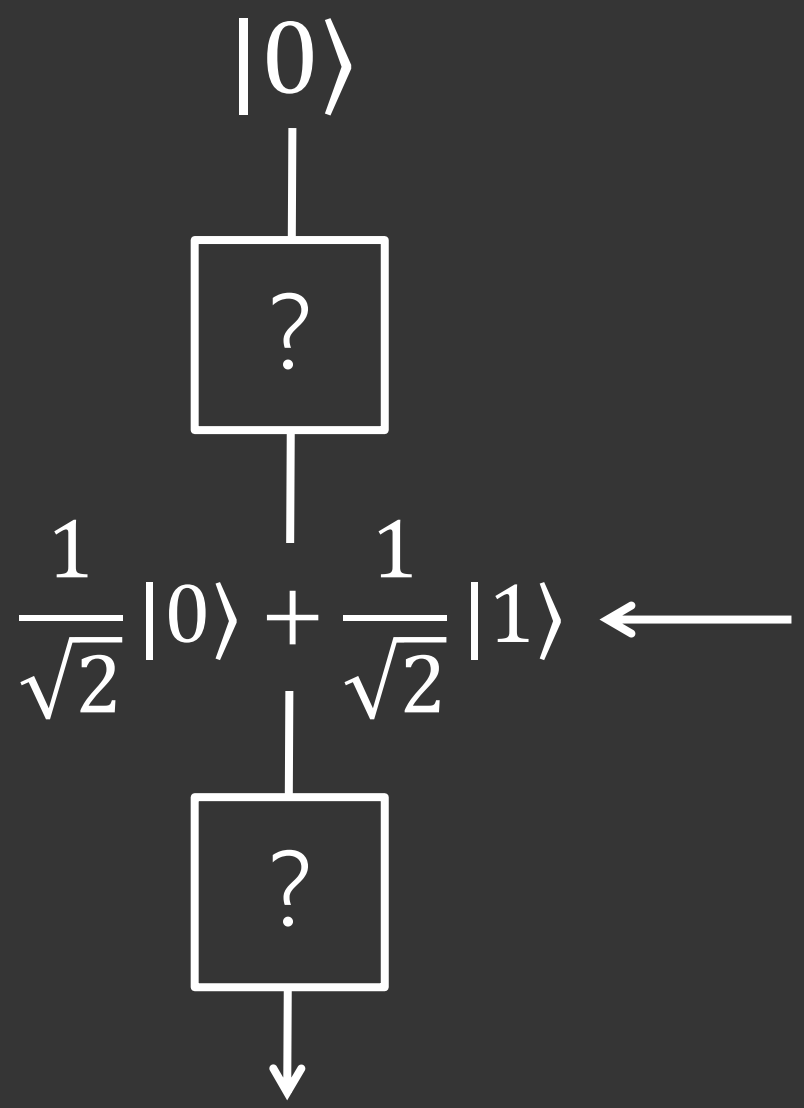
$|\psi\rangle = |0\rangle$ → [?] → $|\psi\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$

$|\psi\rangle = |1\rangle$ → [?] → $|\psi\rangle = \frac{1}{\sqrt{2}}|0\rangle - \frac{1}{\sqrt{2}}|1\rangle$

$$|\alpha|^2 = |\beta|^2 = \left|\frac{\pm 1}{\sqrt{2}}\right|^2 = \frac{1}{2}$$


$|\psi\rangle = |0\rangle$
?
?
$|\psi\rangle = |0\rangle$
$|\psi\rangle = |1\rangle$
?
?
$|\psi\rangle = |1\rangle$

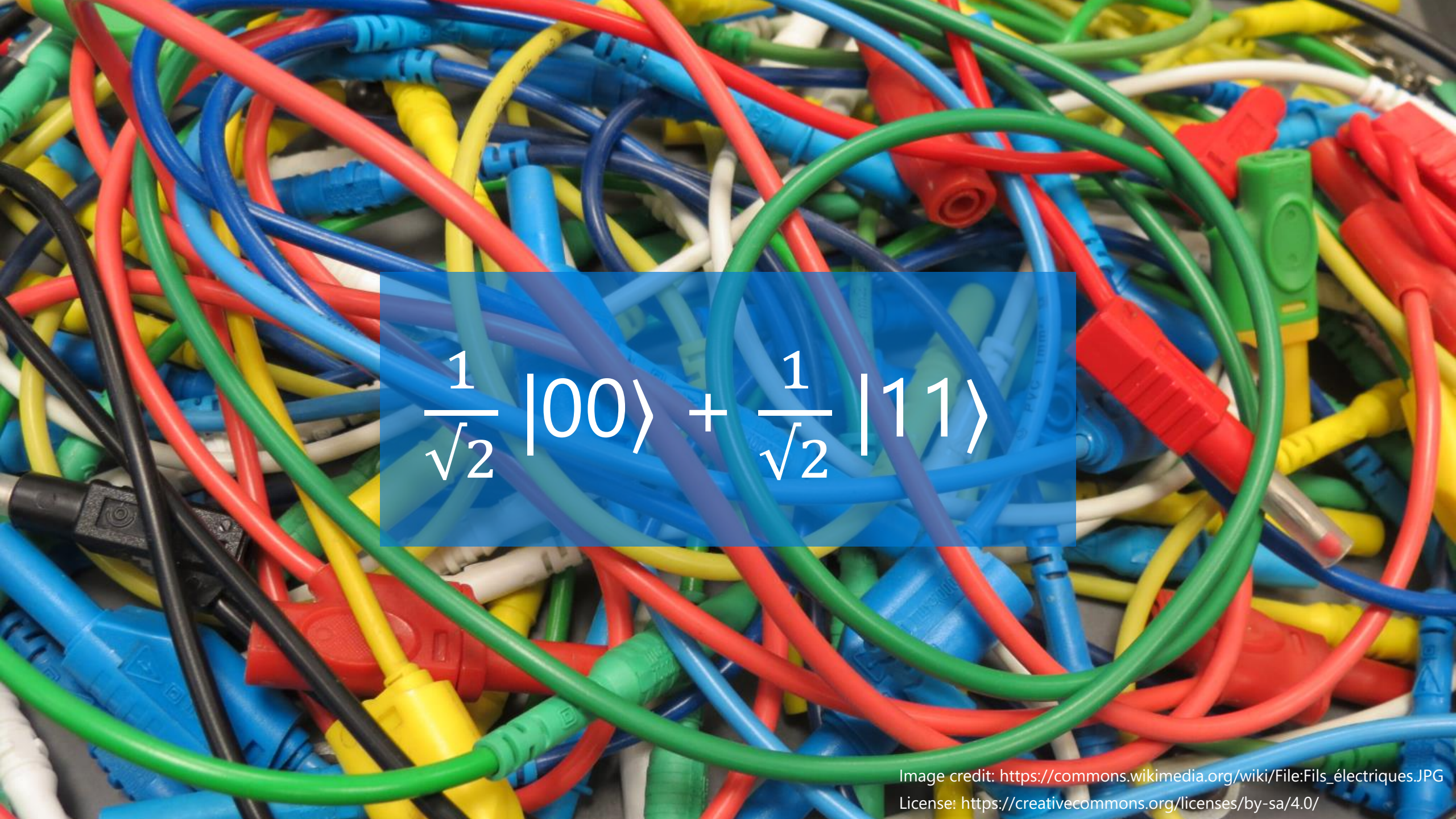

|0⟩
|0⟩
|1⟩
|0⟩
|1⟩
|0⟩
-|1⟩

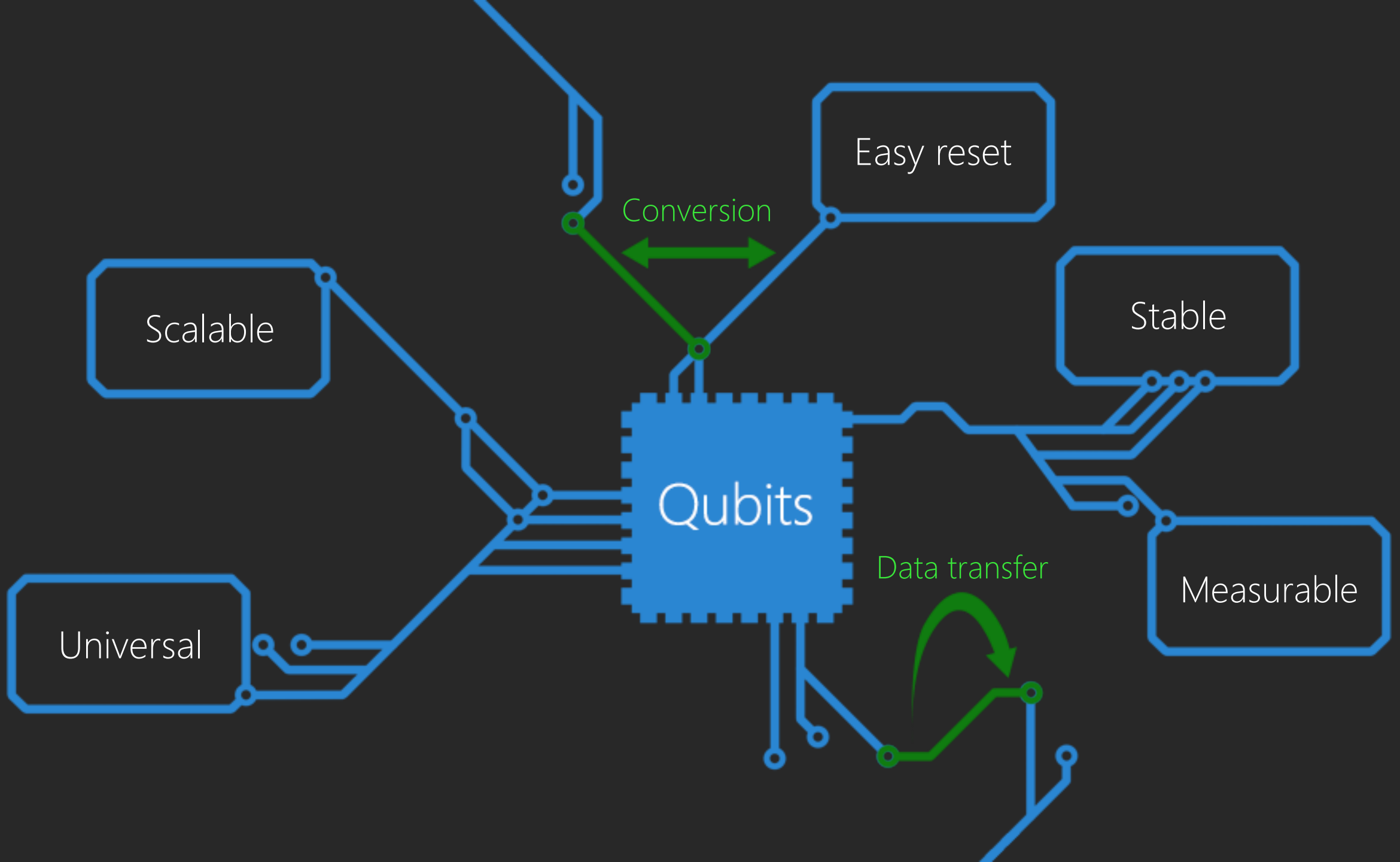


Not a measurement!

$$\frac{1}{\sqrt{2}}\left(\frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle\right) + \frac{1}{\sqrt{2}}\left(\frac{1}{\sqrt{2}}|0\rangle - \frac{1}{\sqrt{2}}|1\rangle\right) = \frac{1}{2}|0\rangle + \frac{1}{2}|1\rangle + \frac{1}{2}|0\rangle - \frac{1}{2}|1\rangle = |0\rangle$$

Entanglement




Easy reset
Conversion
Scalable
Stable
Qubits
Universal
Data transfer
Measurable

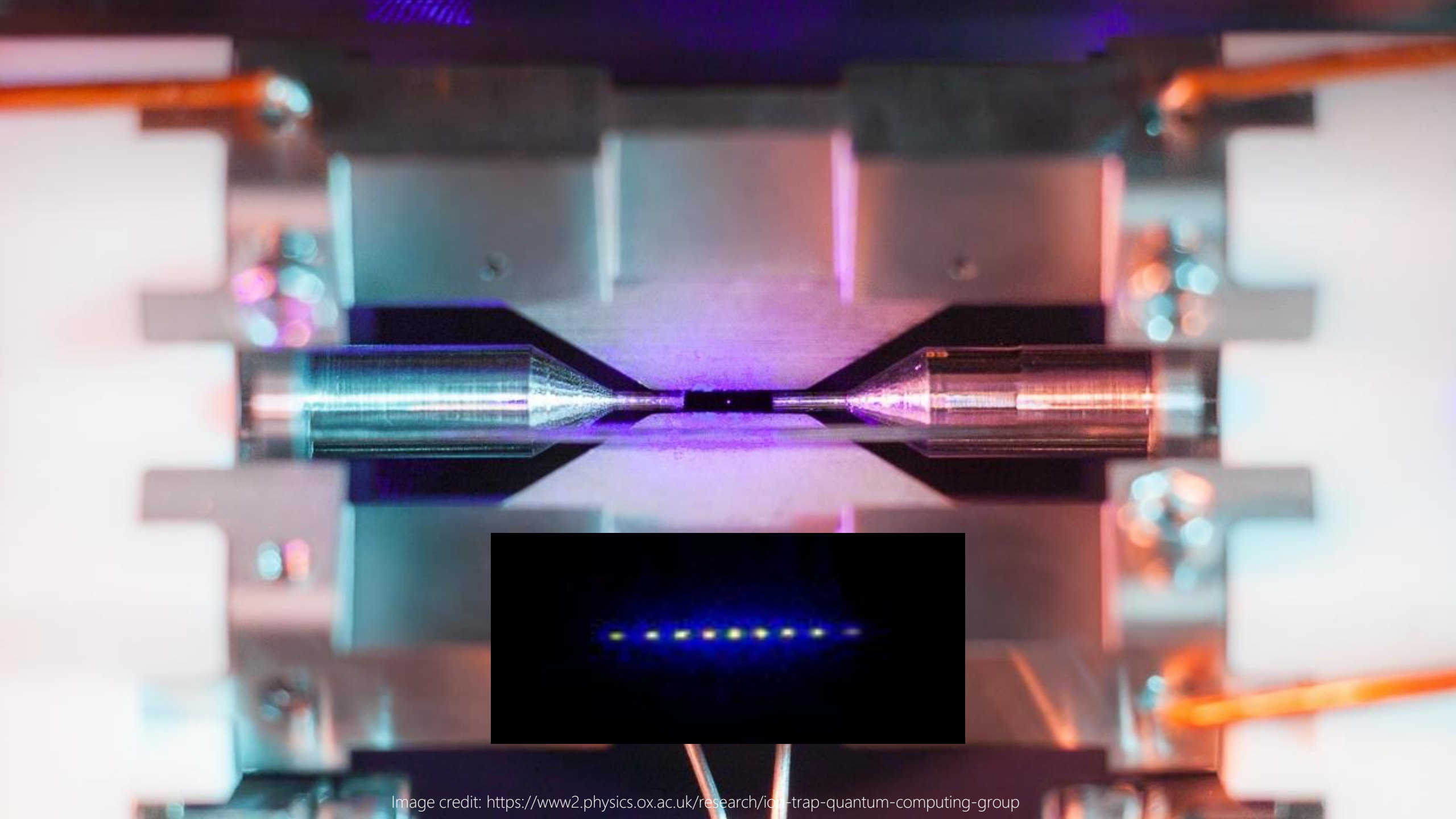


Image credit: https://www2.physics.ox.ac.uk/research/ion-trap-quantum-computing-group

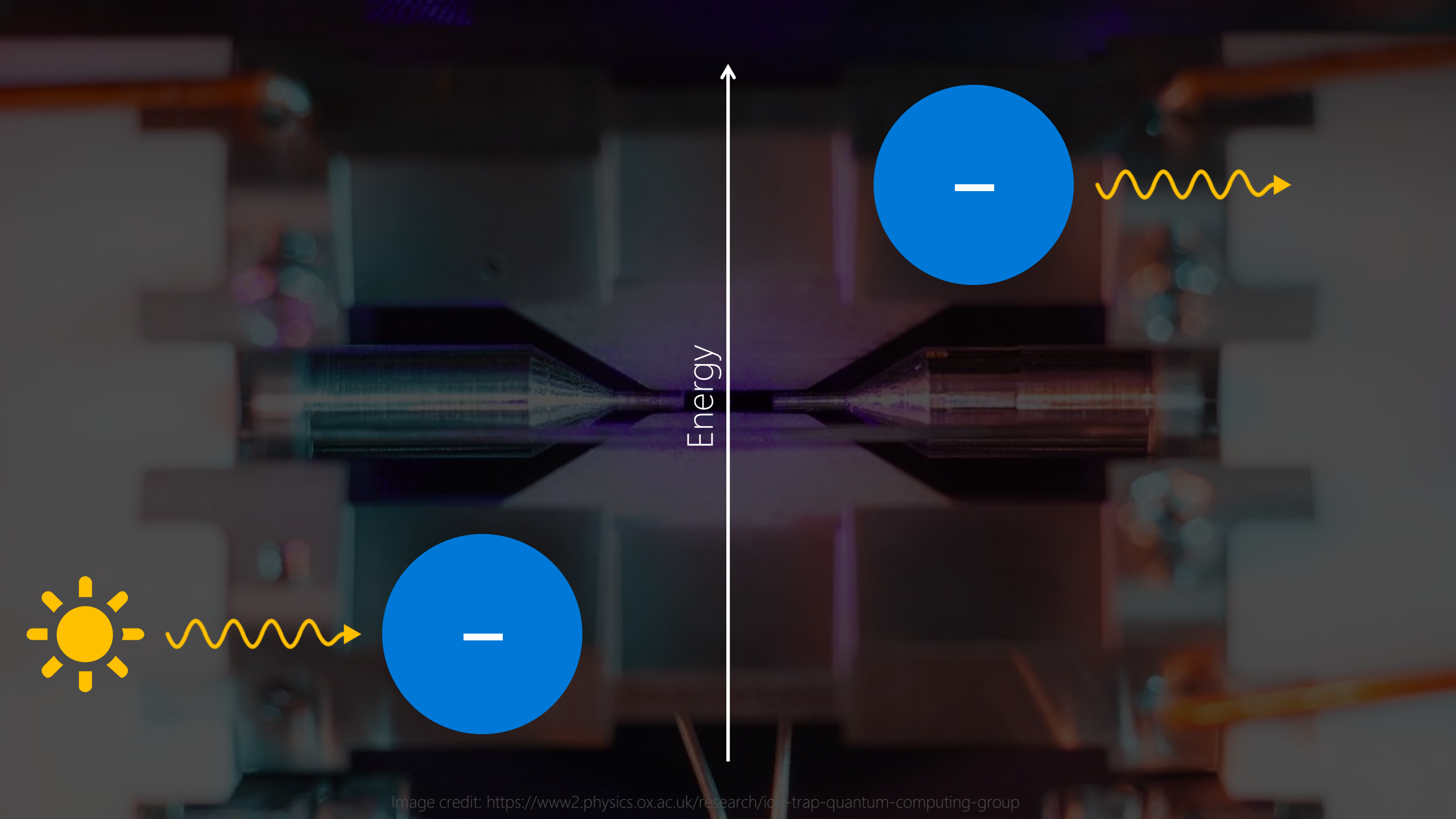


Image credit: https://www2.physics.ox.ac.uk/research/ion-trap-quantum-computing-group

Easy reset

Measurable

Universal

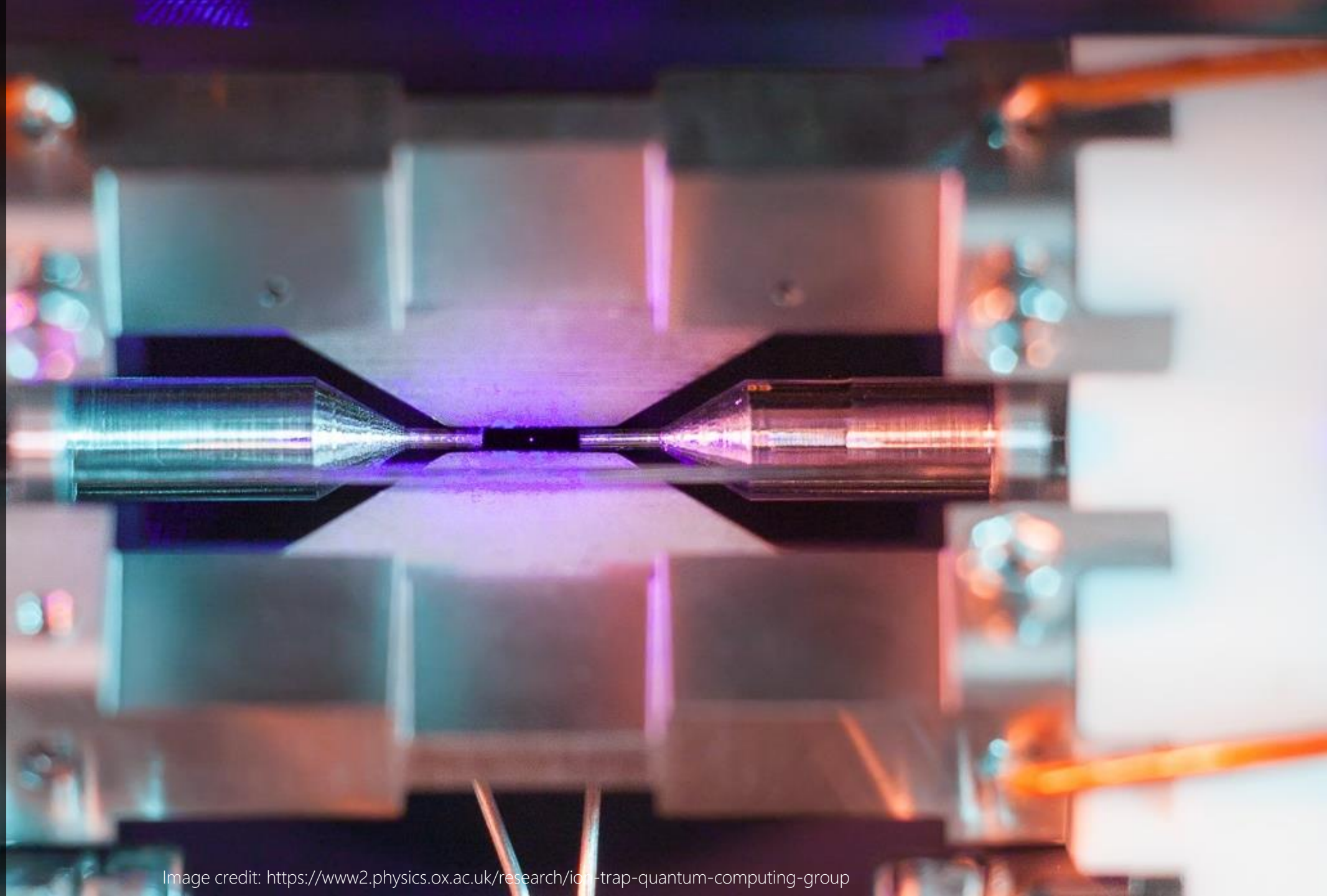
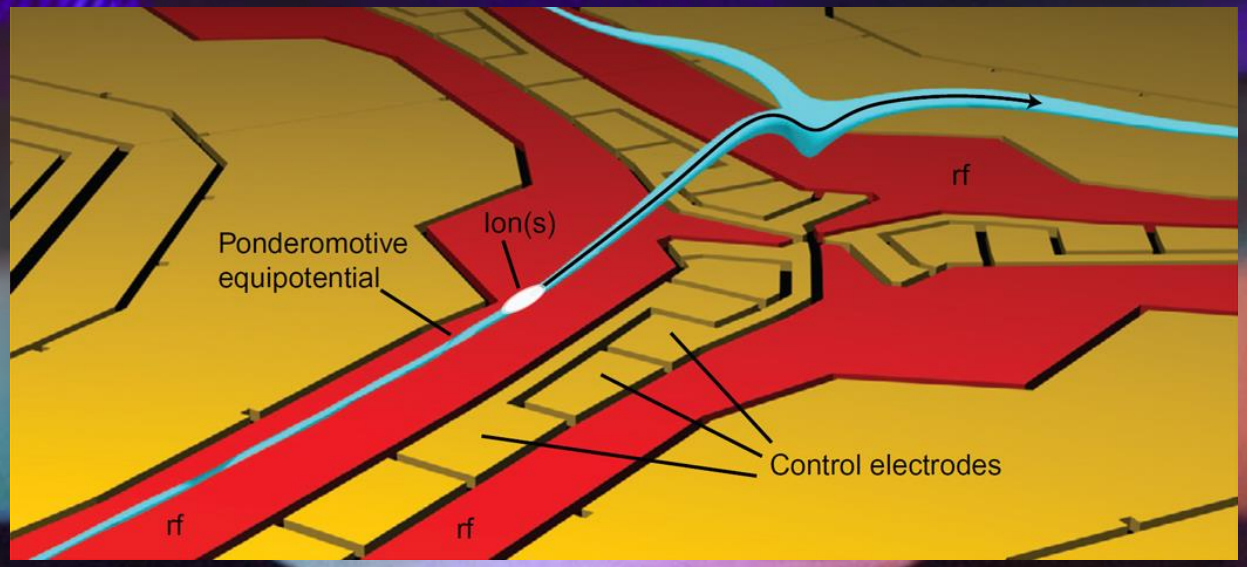


Image credit: https://www2.physics.ox.ac.uk/research/ion-trap-quantum-computing-group

Conversion

Data transfer



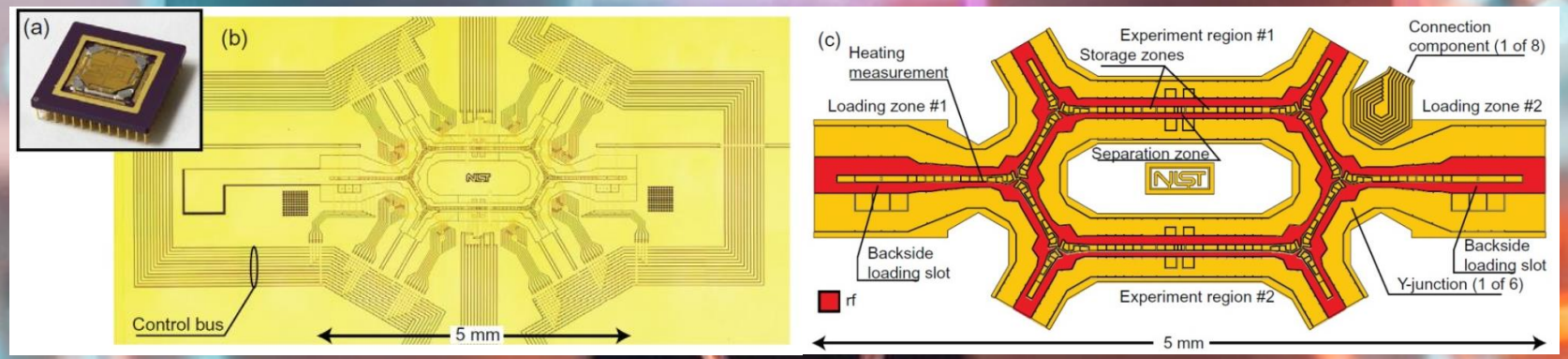


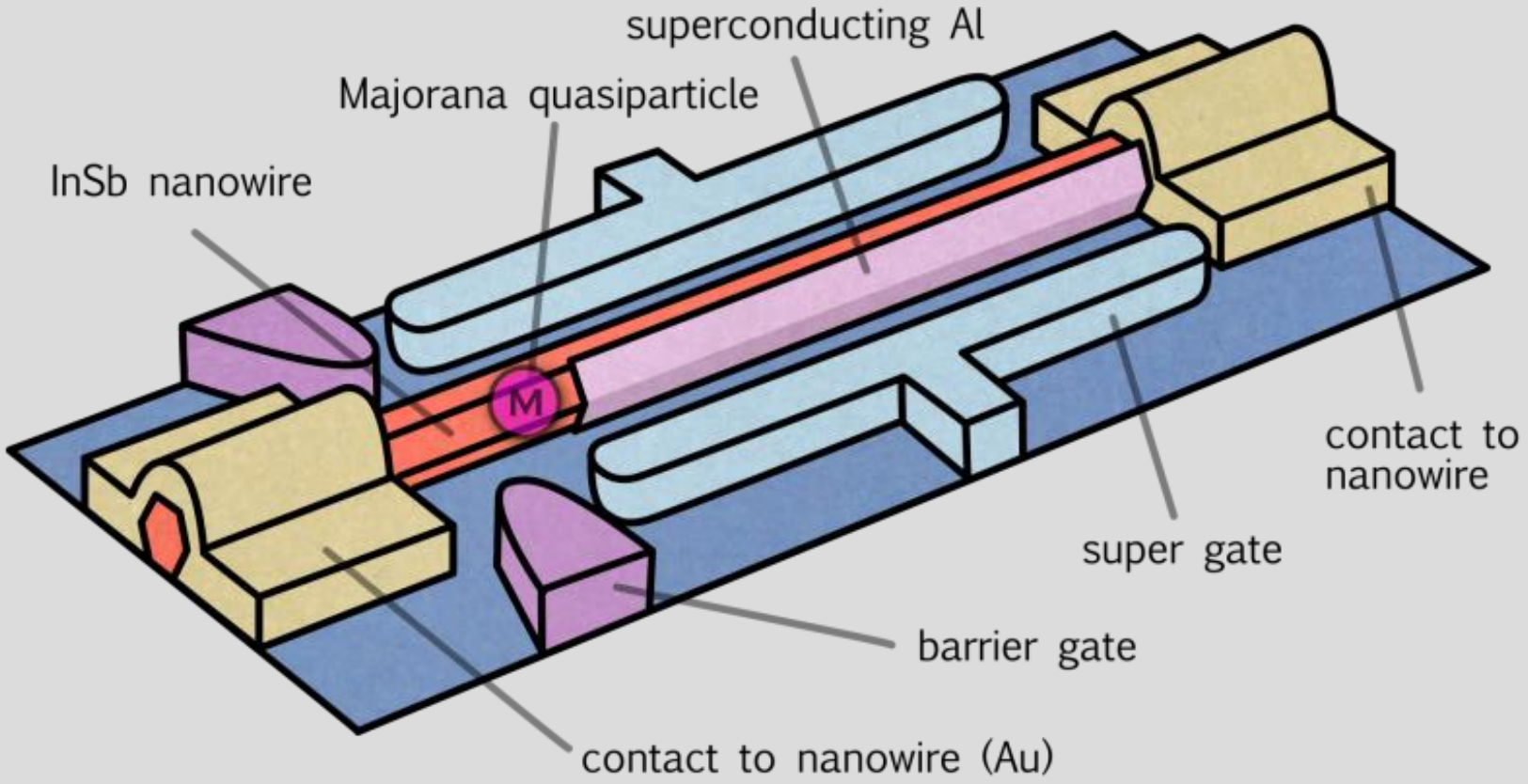
Image credit: NIST, 2010

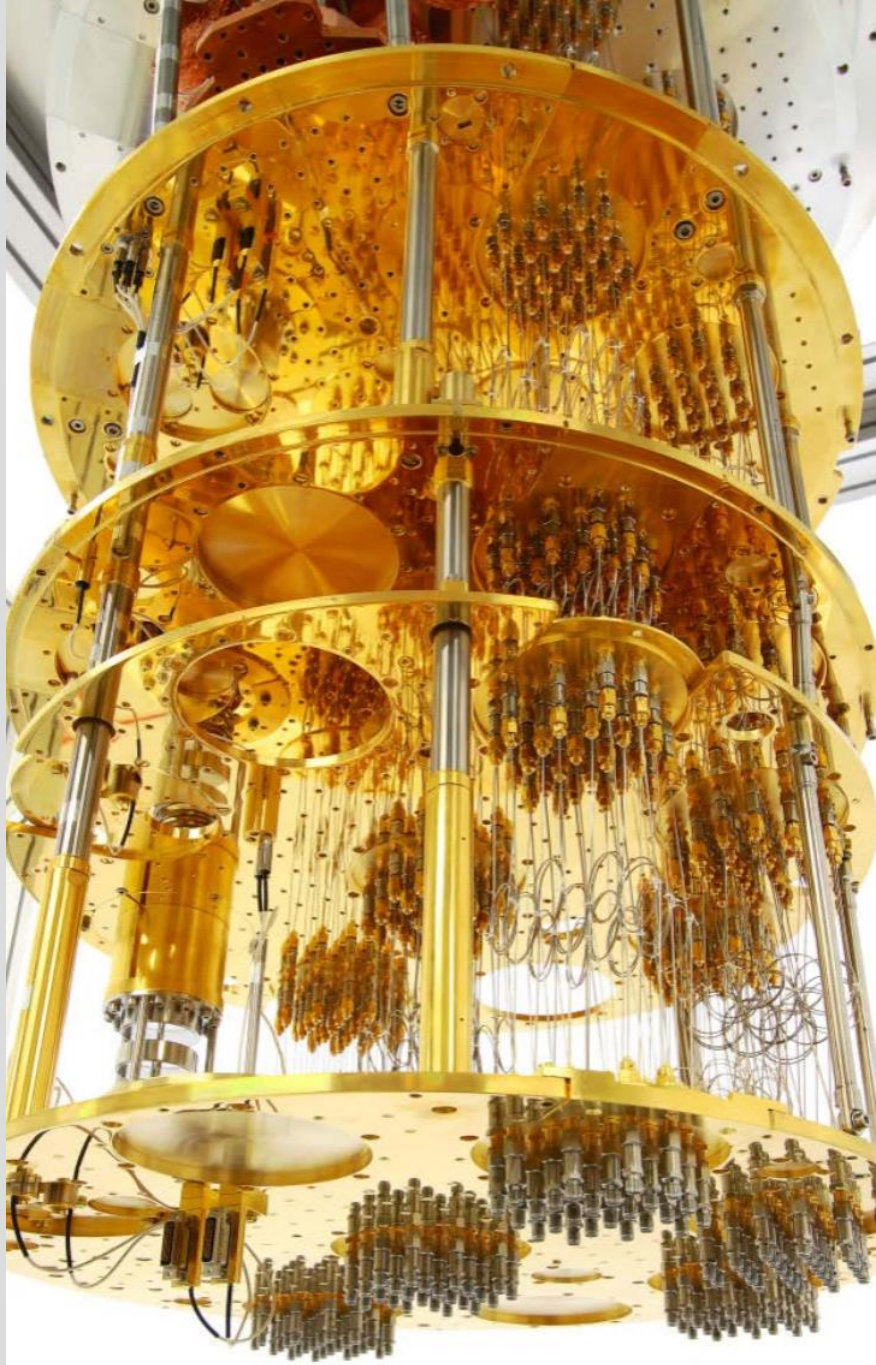
Image credit: https://www2.physics.ox.ac.uk/research/ion-trap-quantum-computing-group

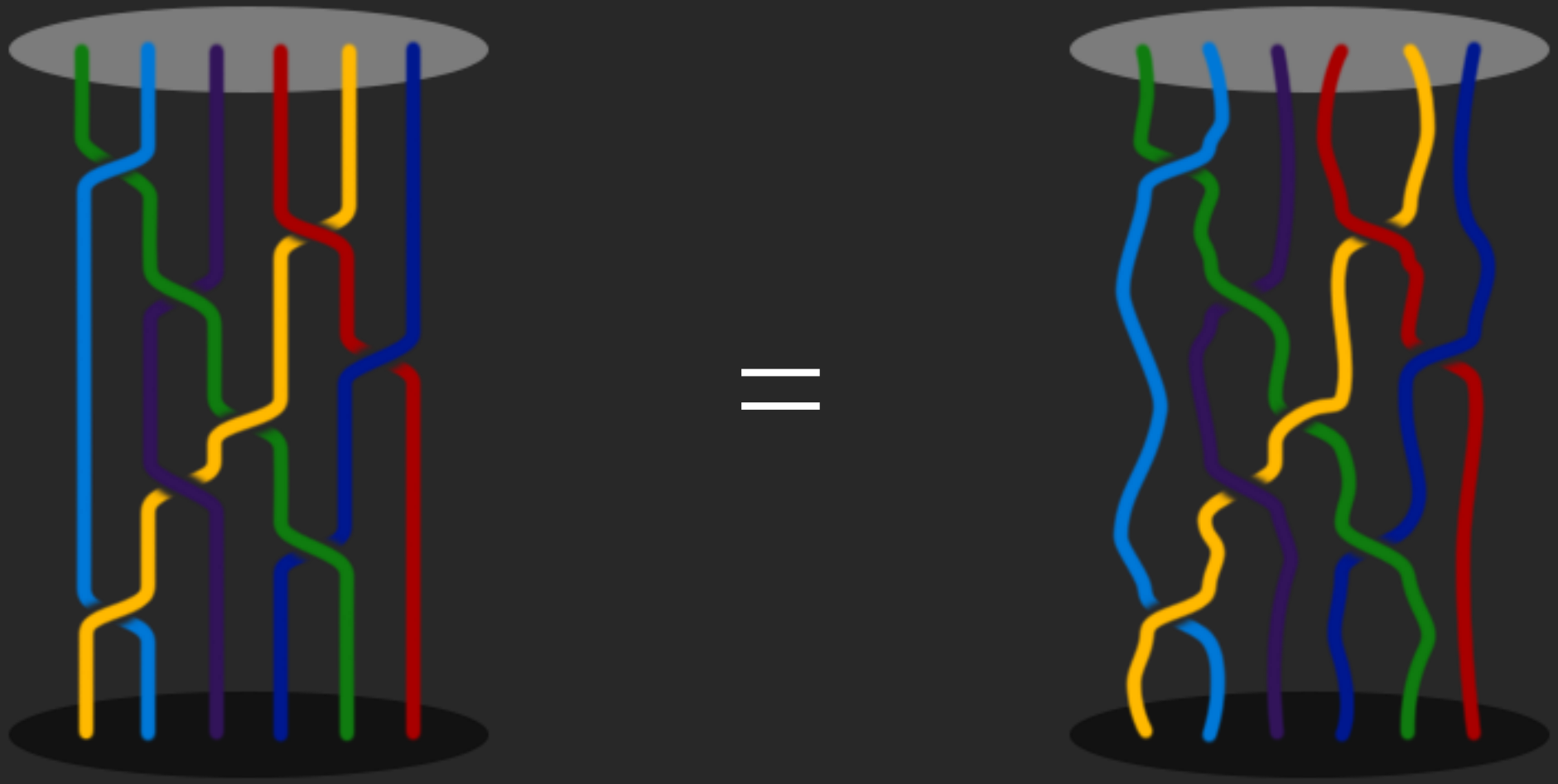
Stable

Scalable

Image credit: https://www2.physics.ox.ac.uk/research/ion-trap-quantum-computing-group

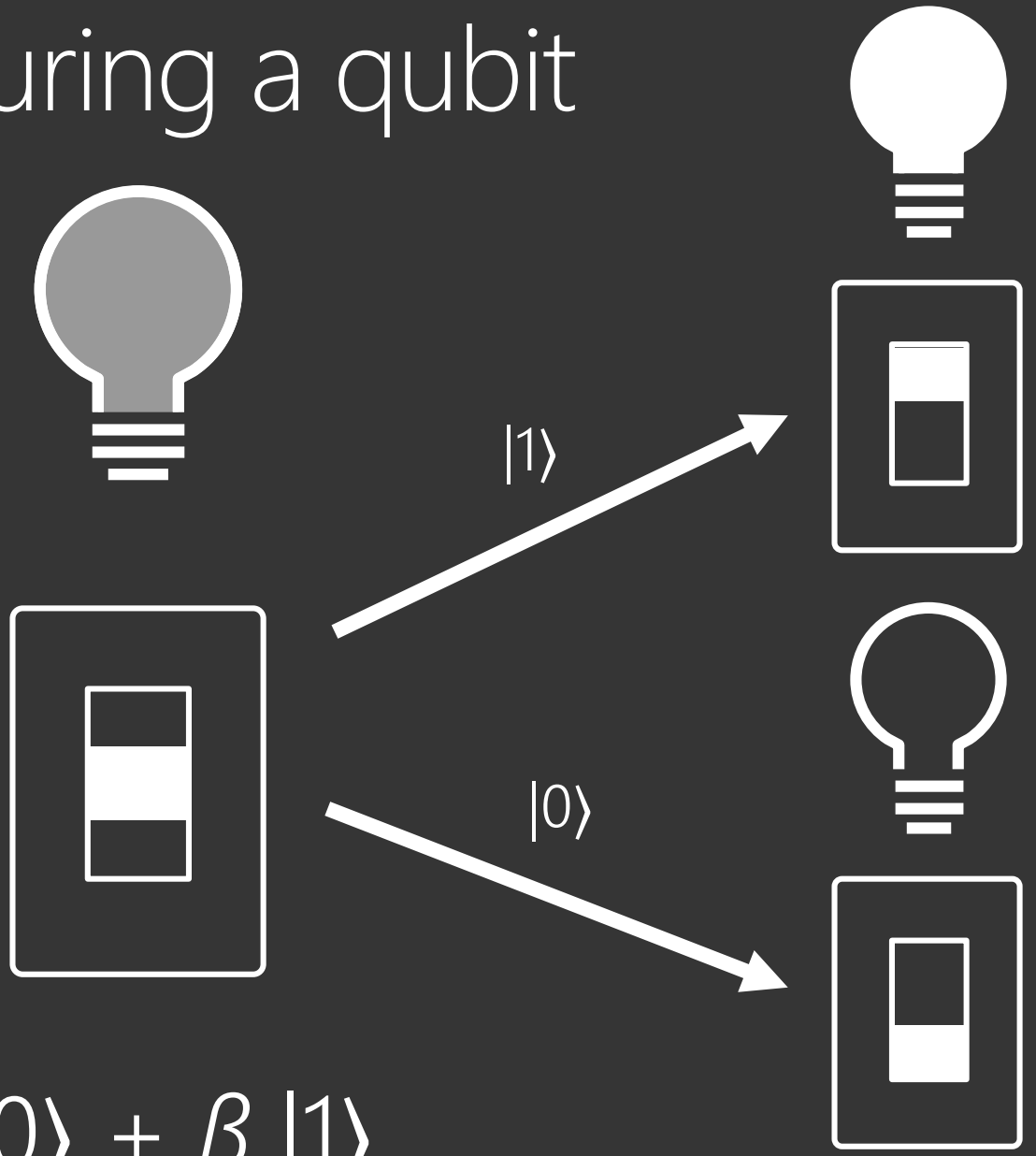

superconducting Al
Majorana quasiparticle
InSb nanowire
M
contact to nanowire
super gate
barrier gate
contact to nanowire (Au)





Quantum Development – Microsoft's QDK

Measuring a qubit



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

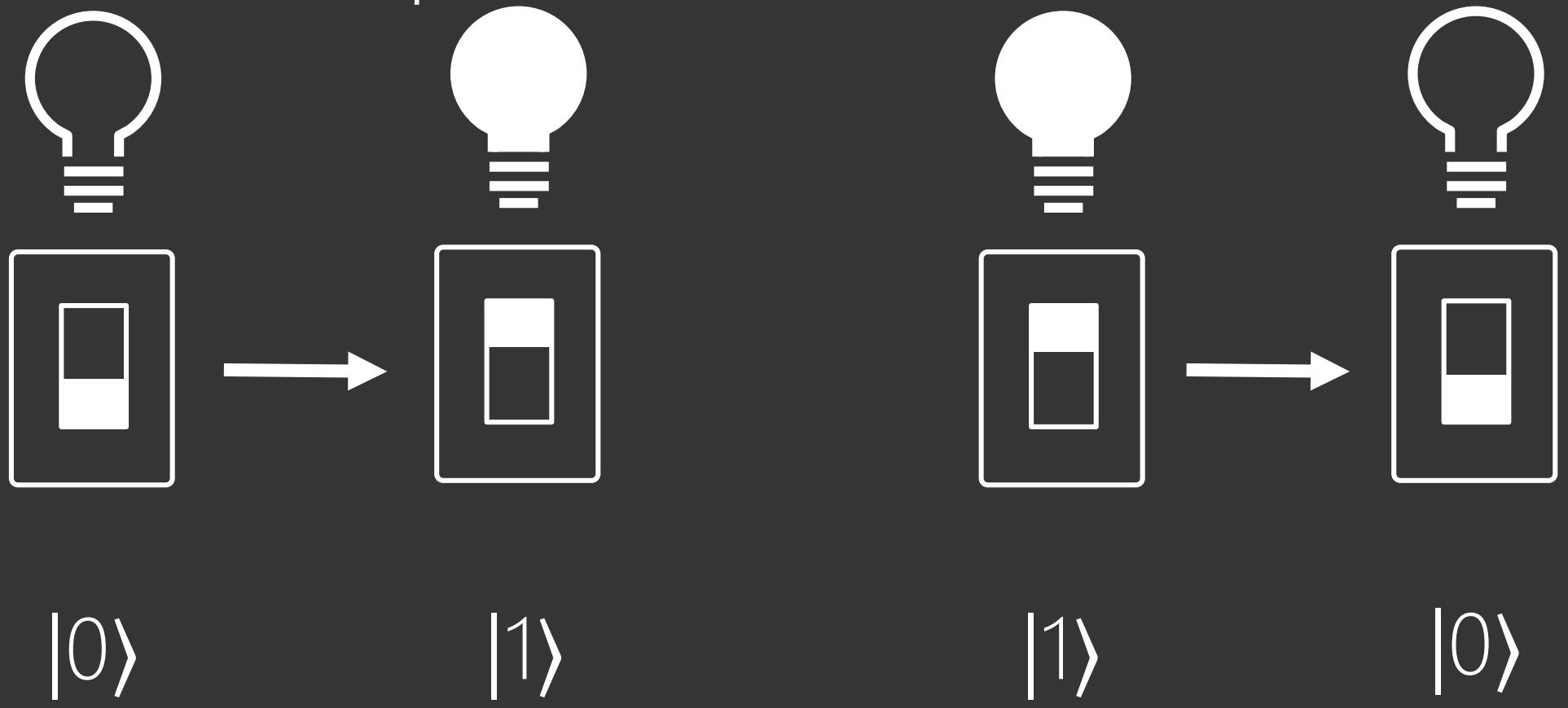
1 with probability $|\beta|^2$

0 with probability $|\alpha|^2$

Measuring a qubit

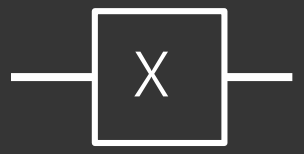
```
operation M (qubit : Qubit) : Result
```

Quantum Operations – NOT

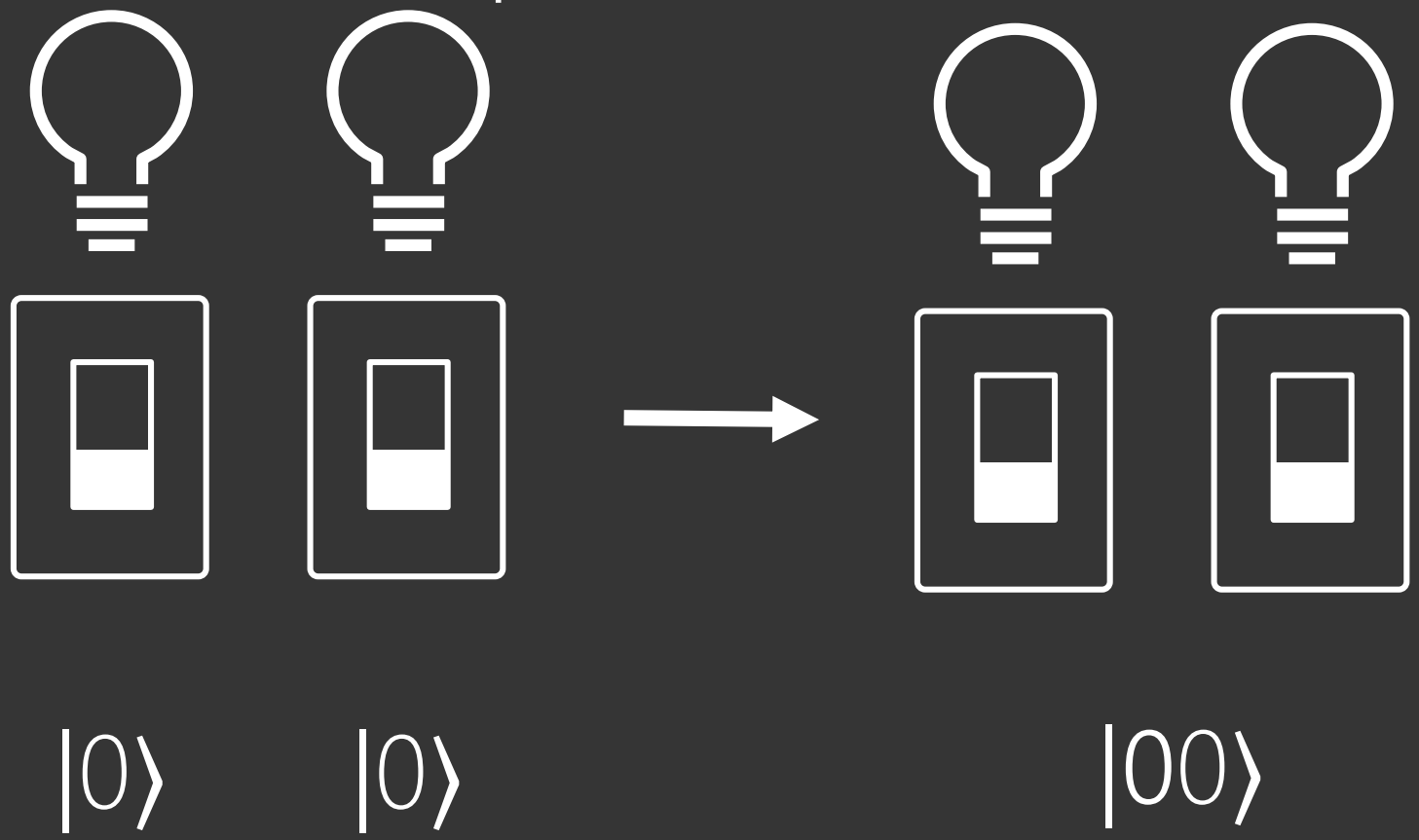


Quantum Operations – NOT

```
operation X (qubit : Qubit) : ()
```

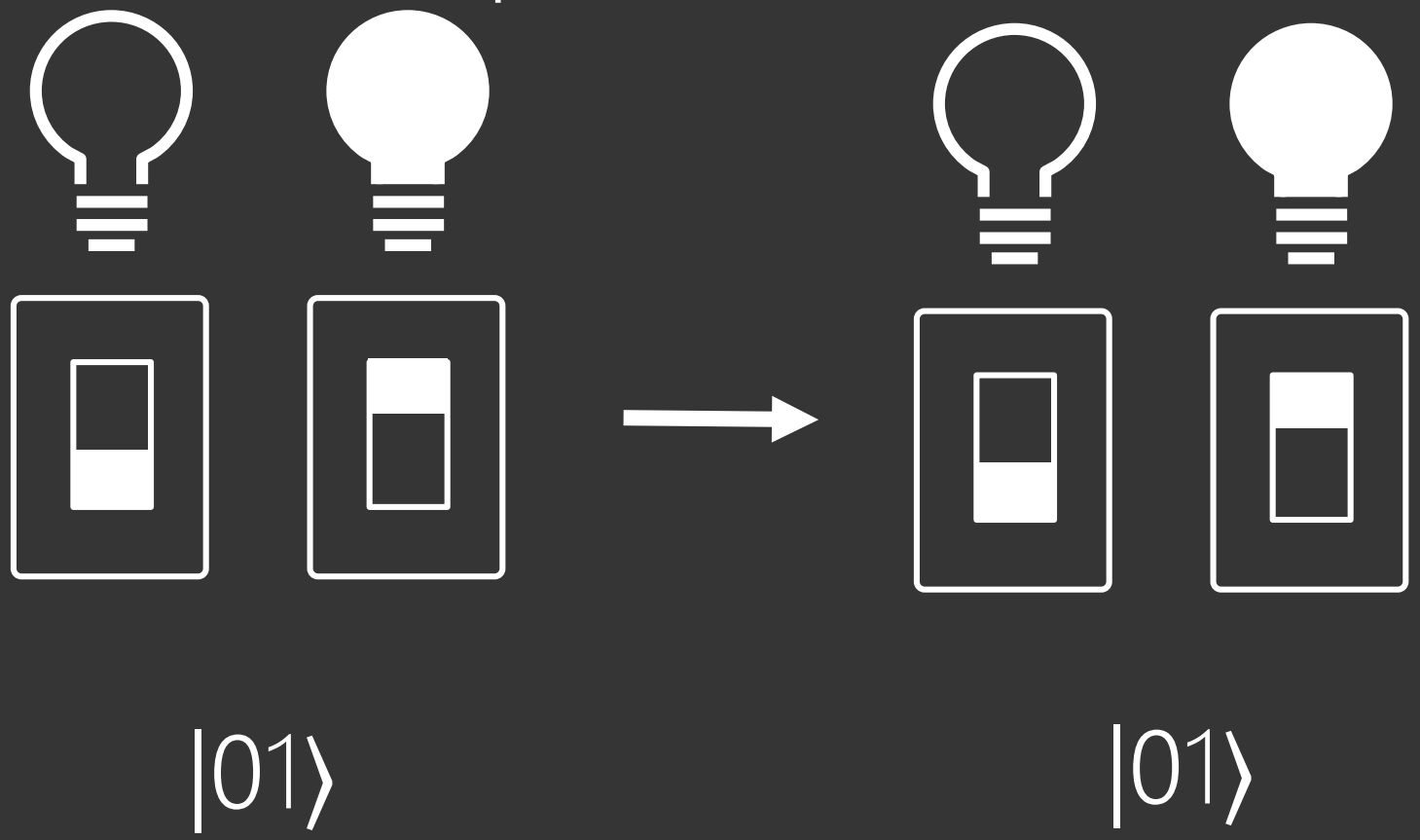


Quantum Operations - CNOT



Input	Output
$\|00\rangle$	$\|00\rangle$

Quantum Operations - CNOT

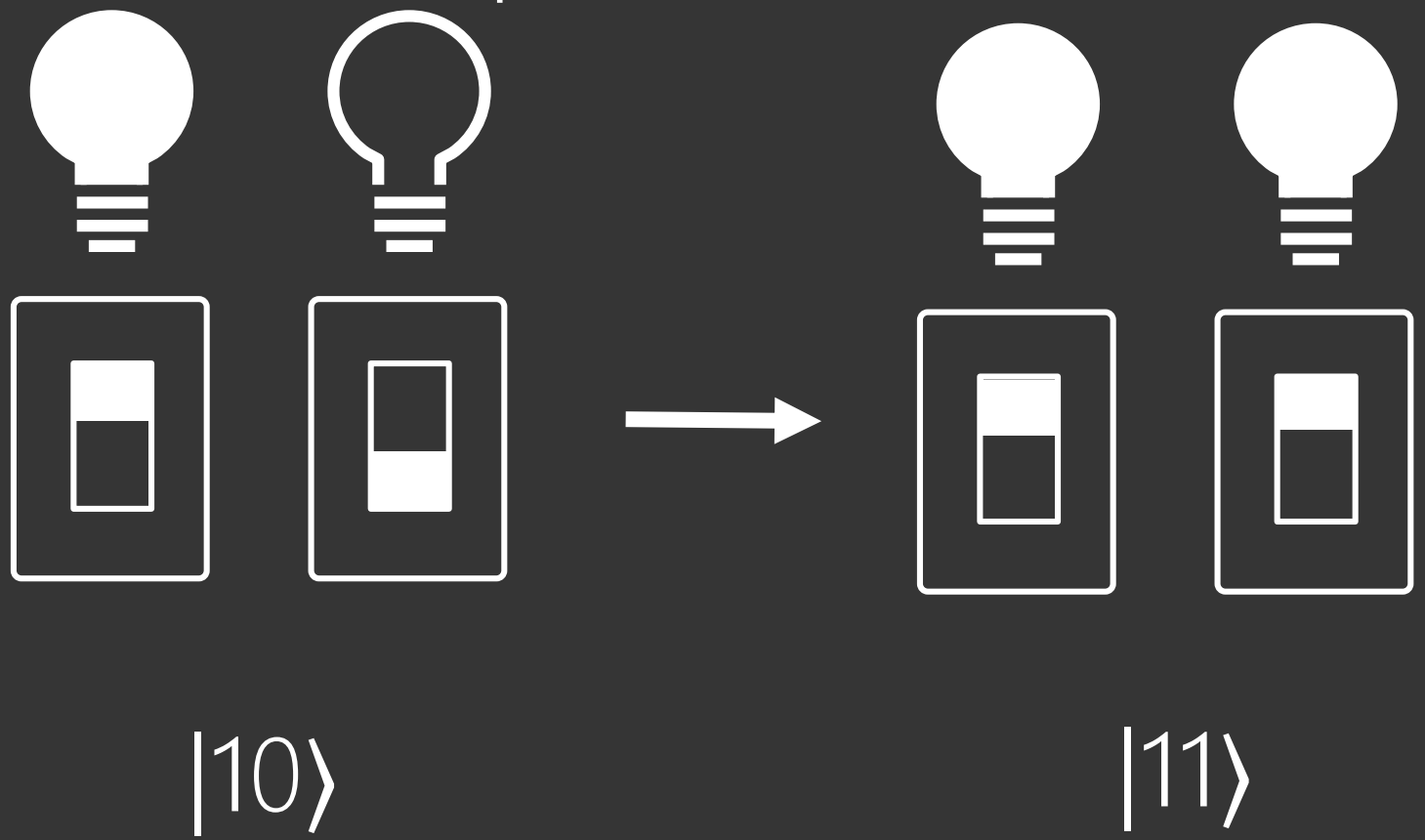


$|01\rangle$ $|01\rangle$

control target

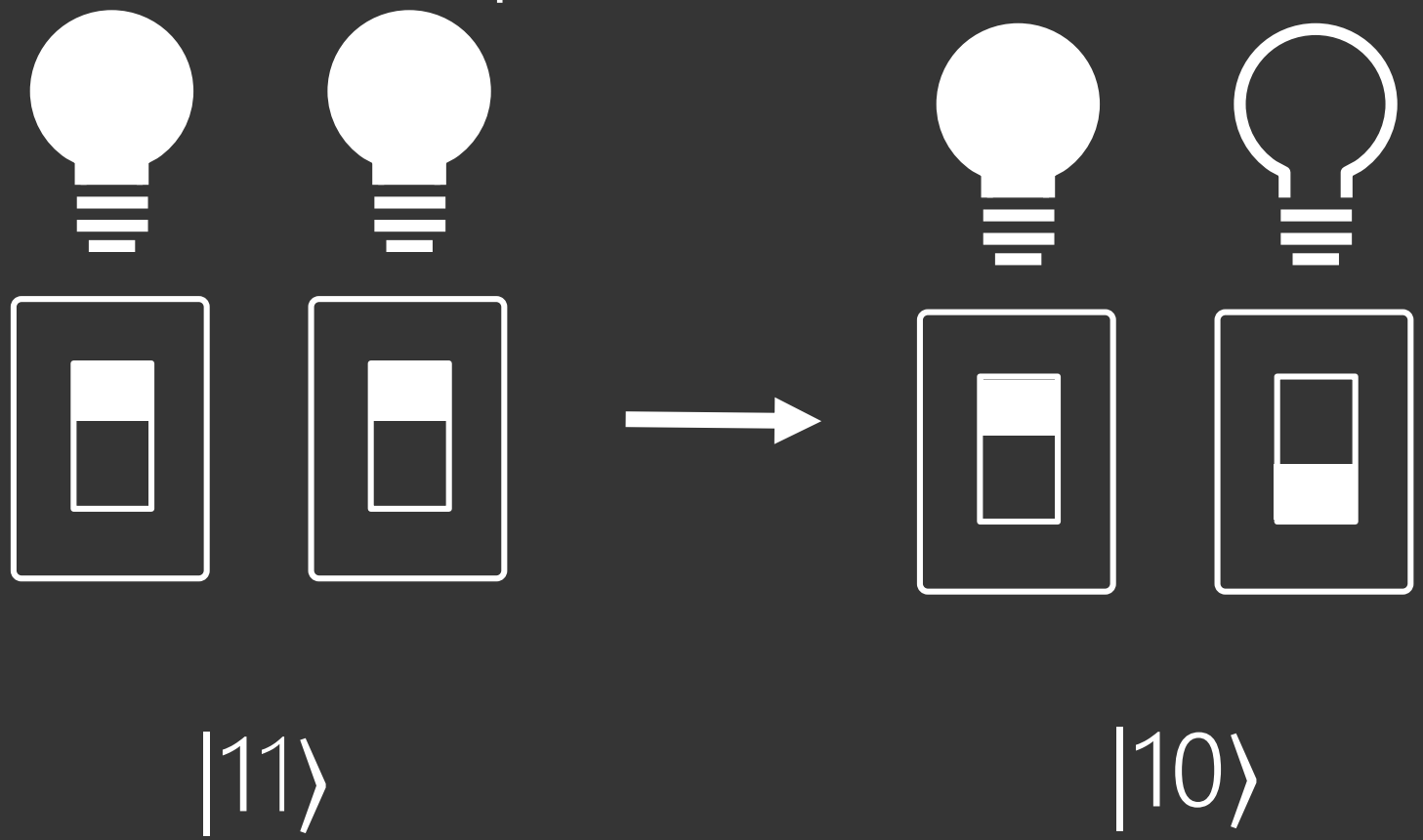
Input	Output
$\|00\rangle$	$\|00\rangle$
$\|01\rangle$	$\|01\rangle$

Quantum Operations - CNOT



Input	Output
$\|00\rangle$	$\|00\rangle$
$\|01\rangle$	$\|01\rangle$
$\|10\rangle$	$\|11\rangle$

Quantum Operations - CNOT



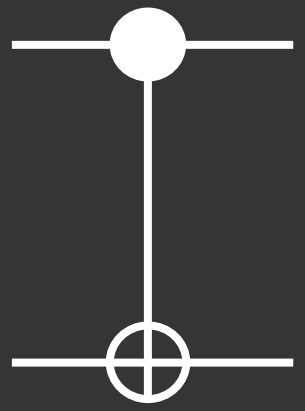
|11⟩ |10⟩

control target

Input	Output
|00⟩	|00⟩
|01⟩	|01⟩
|10⟩	|11⟩
|11⟩	|10⟩

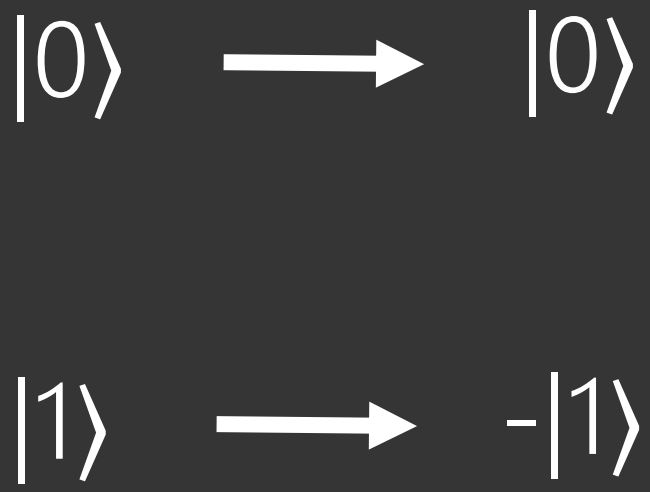
Quantum Operations – CNOT

```
operation CNOT (control : Qubit, target : Qubit) : ()
```



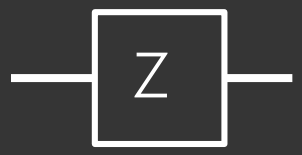
Quantum Operations - Z

Input	Output
$\|0\rangle$	$\|0\rangle$
$\|1\rangle$	$-\|1\rangle$

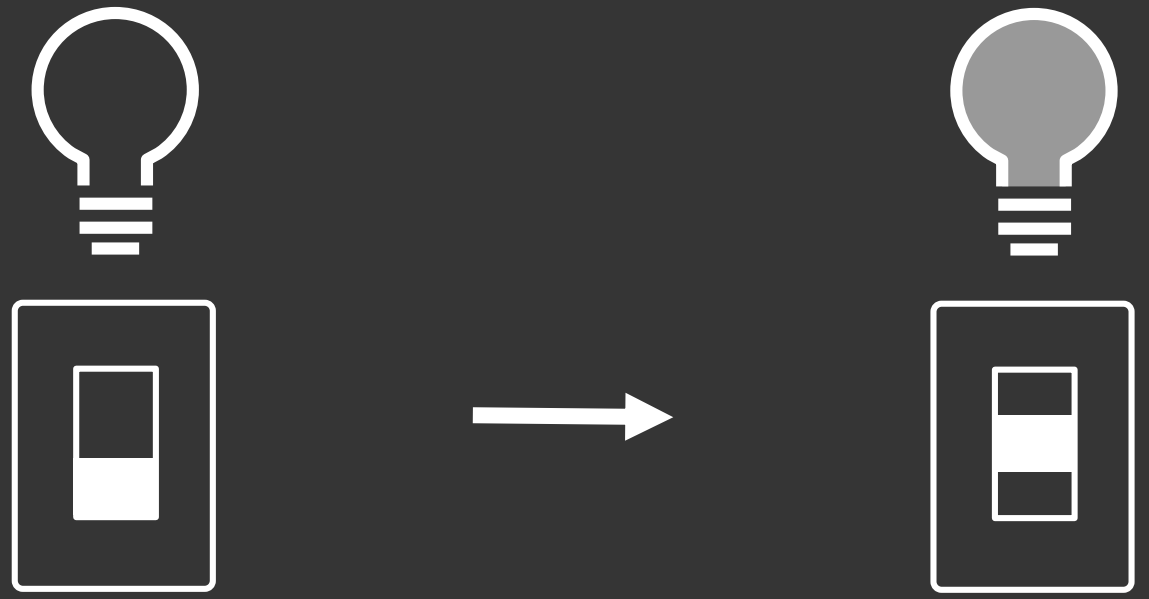


Quantum Operations – Z

```
operation Z (qubit : Qubit) : ()
```



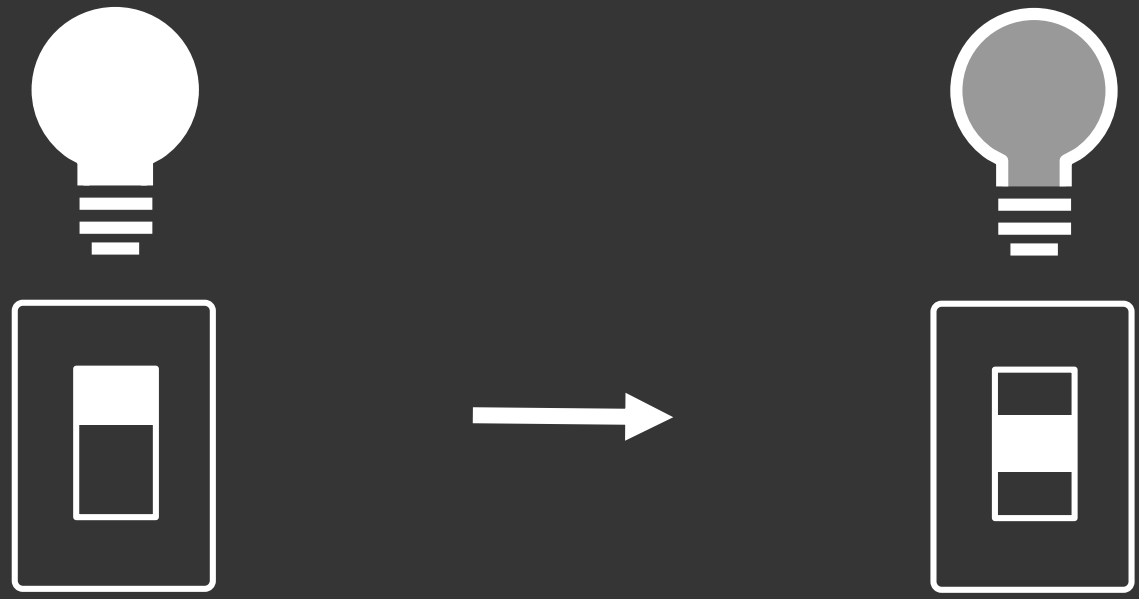
Quantum Operations - Hadamard



$|0\rangle$

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

Quantum Operations - Hadamard

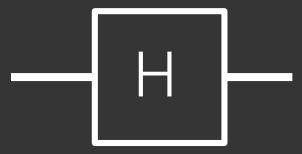


$|1\rangle$

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

Quantum Operations – Hadamard

```
operation H (qubit : Qubit) : ()
```



Our Toolbox:

NOT

Input	Output
$\|0\rangle$	$\|1\rangle$
$\|1\rangle$	$\|0\rangle$

CNOT

Input	Output
$\|00\rangle$	$\|00\rangle$
$\|01\rangle$	$\|01\rangle$
$\|10\rangle$	$\|11\rangle$
$\|11\rangle$	$\|10\rangle$

Z

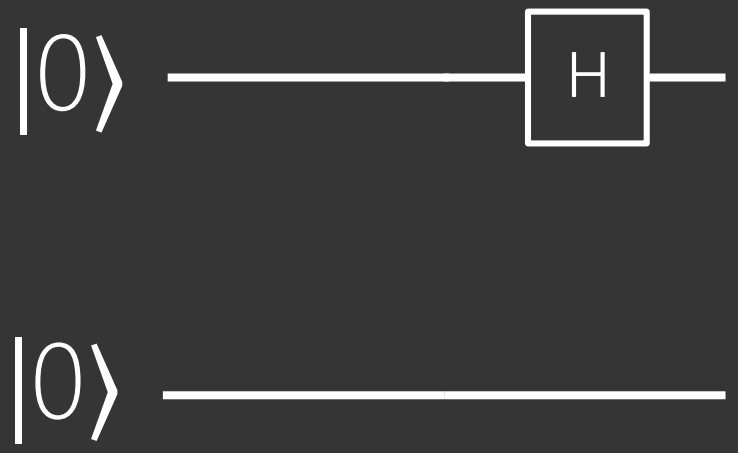
Input	Output
$\|0\rangle$	$\|0\rangle$
$\|1\rangle$	$-\|1\rangle$

Hadamard

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

Entanglement

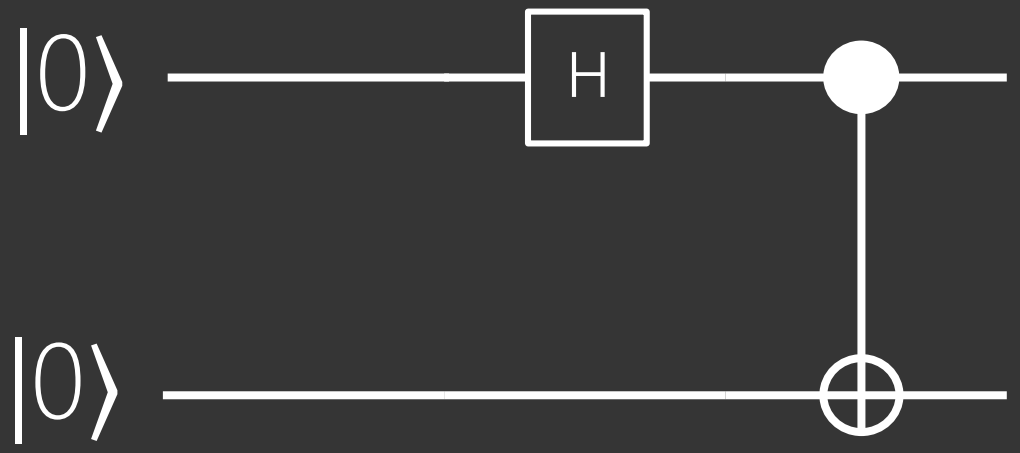
$$\frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$



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

Entanglement

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



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

Input	Output
$\|00\rangle$	$\|00\rangle$
$\|01\rangle$	$\|01\rangle$
$\|10\rangle$	$\|11\rangle$
$\|11\rangle$	$\|10\rangle$

Entanglement - Summary

$$|00\rangle \longrightarrow \frac{1}{\sqrt{2}}|00\rangle + \frac{1}{\sqrt{2}}|11\rangle$$

Quantum Teleportation - Motivation

$|\psi\rangle$

$|0\rangle$

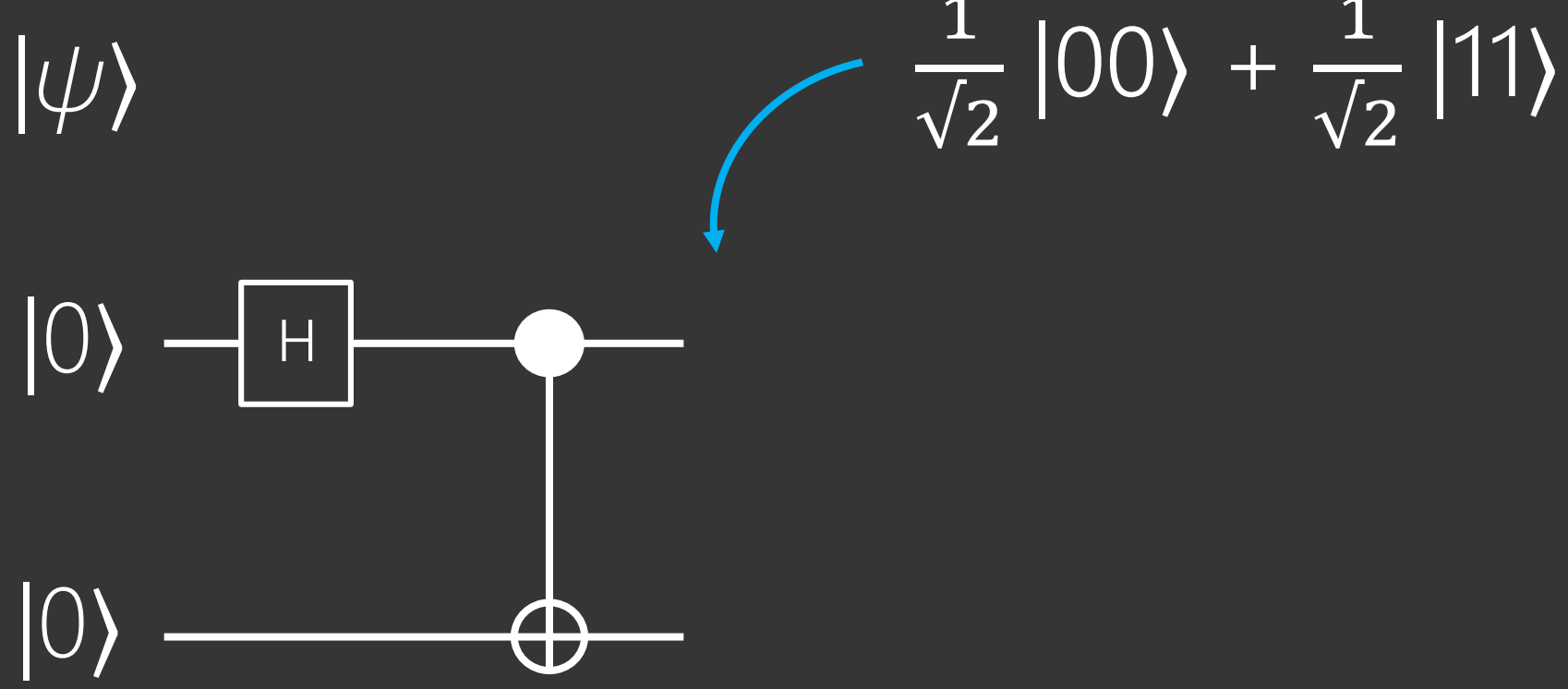
$|0\rangle$

Physically?

Classically?

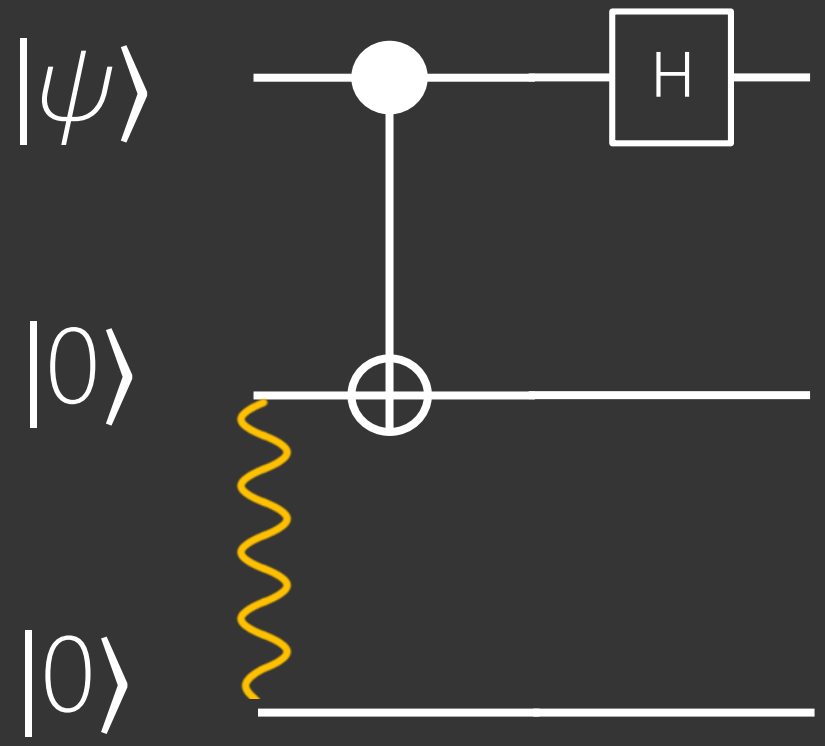
Quantum teleportation!

Quantum Teleportation - Explained



Step 0: Entangle our qubits

Quantum Teleportation - Explained



?

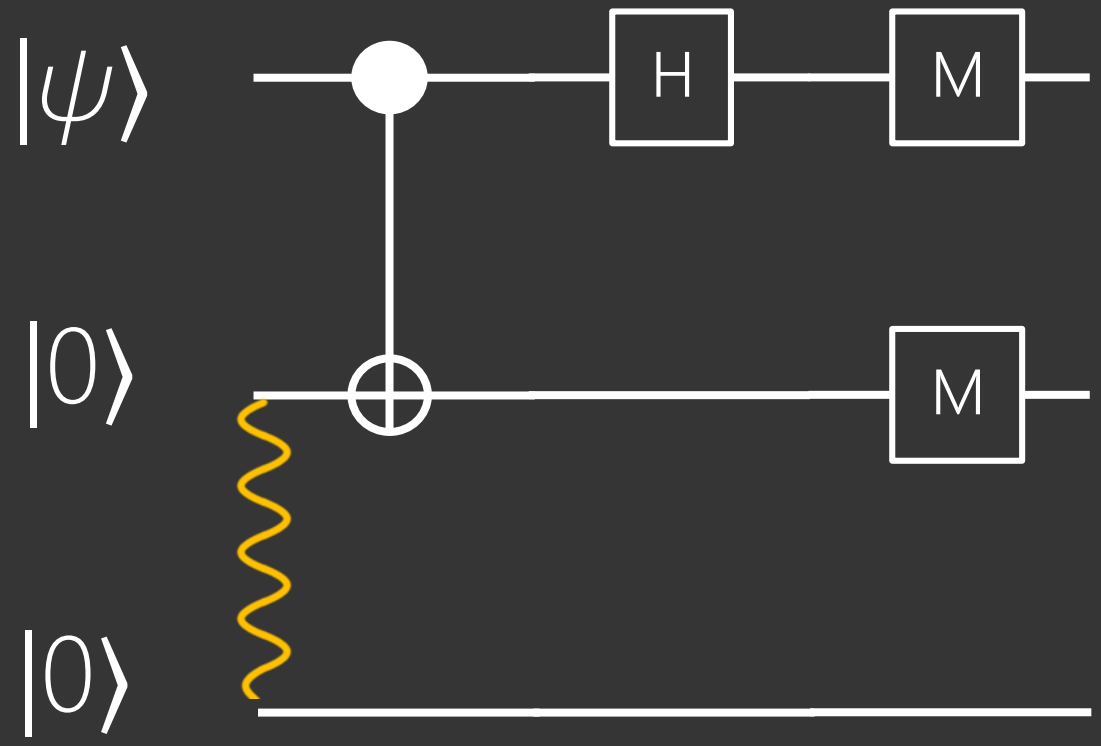
$$|\psi\rangle = \alpha\,|0\rangle + \beta\,|1\rangle$$

Step 1: Entangle my qubit with the state to be sent

Quantum Teleportation - Explained

$$\frac{1}{2}[|00\rangle(\alpha|0\rangle + \beta|1\rangle) + |01\rangle(\alpha|1\rangle + \beta|0\rangle) + |10\rangle(\alpha|0\rangle - \beta|1\rangle) + |11\rangle(\alpha|1\rangle - \beta|0\rangle)]$$

Quantum Teleportation - Explained



Step 2: Measure the first two qubits (mine, message)

Quantum Teleportation - Explained

$$\frac{1}{2}[|00\rangle(\alpha|0\rangle + \beta|1\rangle) + |01\rangle(\alpha|1\rangle + \beta|0\rangle) + |10\rangle(\alpha|0\rangle - \beta|1\rangle) + |11\rangle(\alpha|1\rangle - \beta|0\rangle)]$$

$$|00\rangle(\alpha|0\rangle+\beta|1\rangle)$$

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

Step 3: Interpret the result

Quantum Teleportation - Explained

$$\frac{1}{2}[|00\rangle(\alpha|0\rangle + \beta|1\rangle) + |01\rangle(\alpha|1\rangle + \beta|0\rangle) + |10\rangle(\alpha|0\rangle - \beta|1\rangle) + |11\rangle(\alpha|1\rangle - \beta|0\rangle)]$$

Apply a NOT gate

$$|01\rangle(\alpha|1\rangle+\beta|0\rangle)$$

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

Step 3: Interpret the result

Quantum Teleportation - Explained

$$\frac{1}{2}[|00\rangle(\alpha|0\rangle + \beta|1\rangle) + |01\rangle(\alpha|1\rangle + \beta|0\rangle) + |10\rangle(\alpha|0\rangle - \beta|1\rangle) + |11\rangle(\alpha|1\rangle - \beta|0\rangle)]$$

Apply a Z gate

$$|10\rangle(\alpha|0\rangle - \beta|1\rangle)$$

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

Step 3: Interpret the result

Quantum Teleportation - Explained

$$\frac{1}{2}[|00\rangle(\alpha|0\rangle + \beta|1\rangle) + |01\rangle(\alpha|1\rangle + \beta|0\rangle) + |10\rangle(\alpha|0\rangle - \beta|1\rangle) + |11\rangle(\alpha|1\rangle - \beta|0\rangle)]$$

Apply a Z gate and NOT gate

$$|11\rangle(\alpha|1\rangle - \beta|0\rangle)$$

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

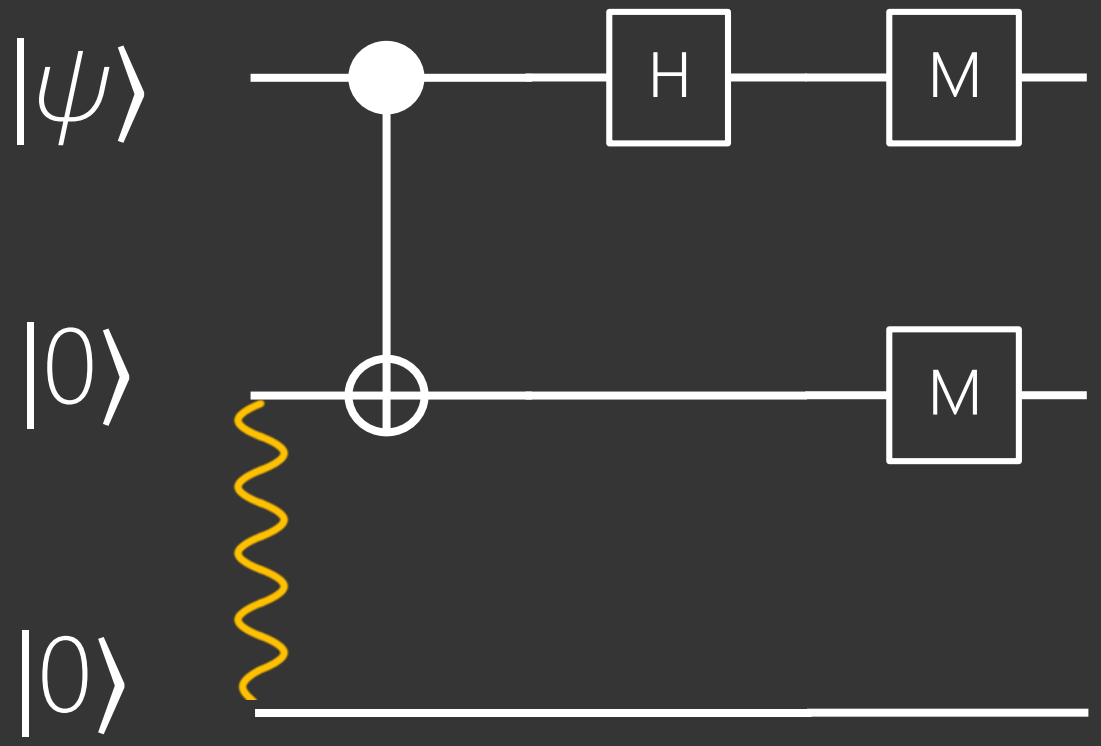
Step 3: Interpret the result

Quantum Teleportation - Summary

Measurement	Operation
$\|00\rangle$	Do nothing
$\|01\rangle$	Apply NOT
$\|10\rangle$	Apply Z
$\|11\rangle$	Apply NOT, Z

Step 4: Apply the gates

Quantum Teleportation – Code!



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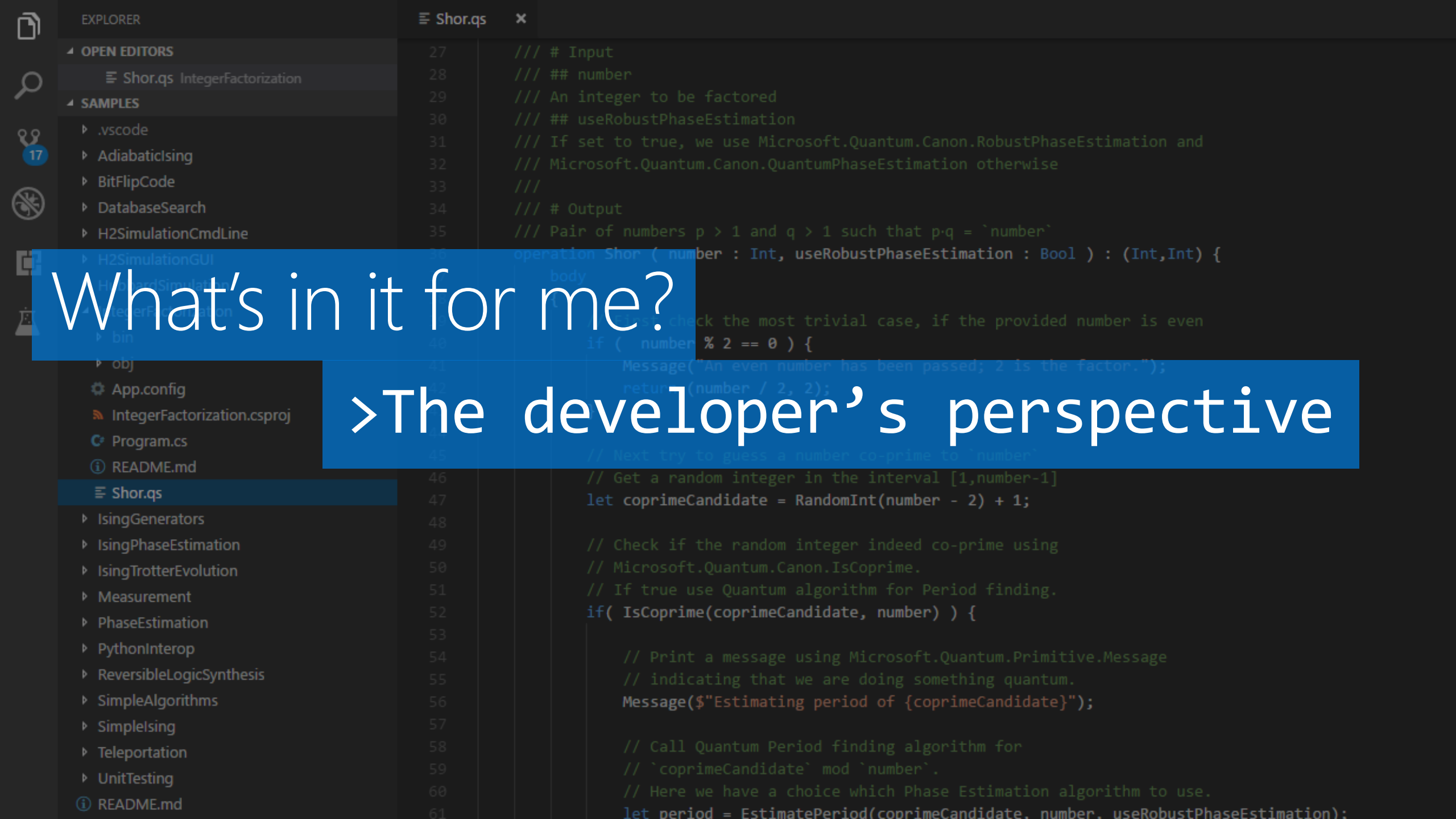
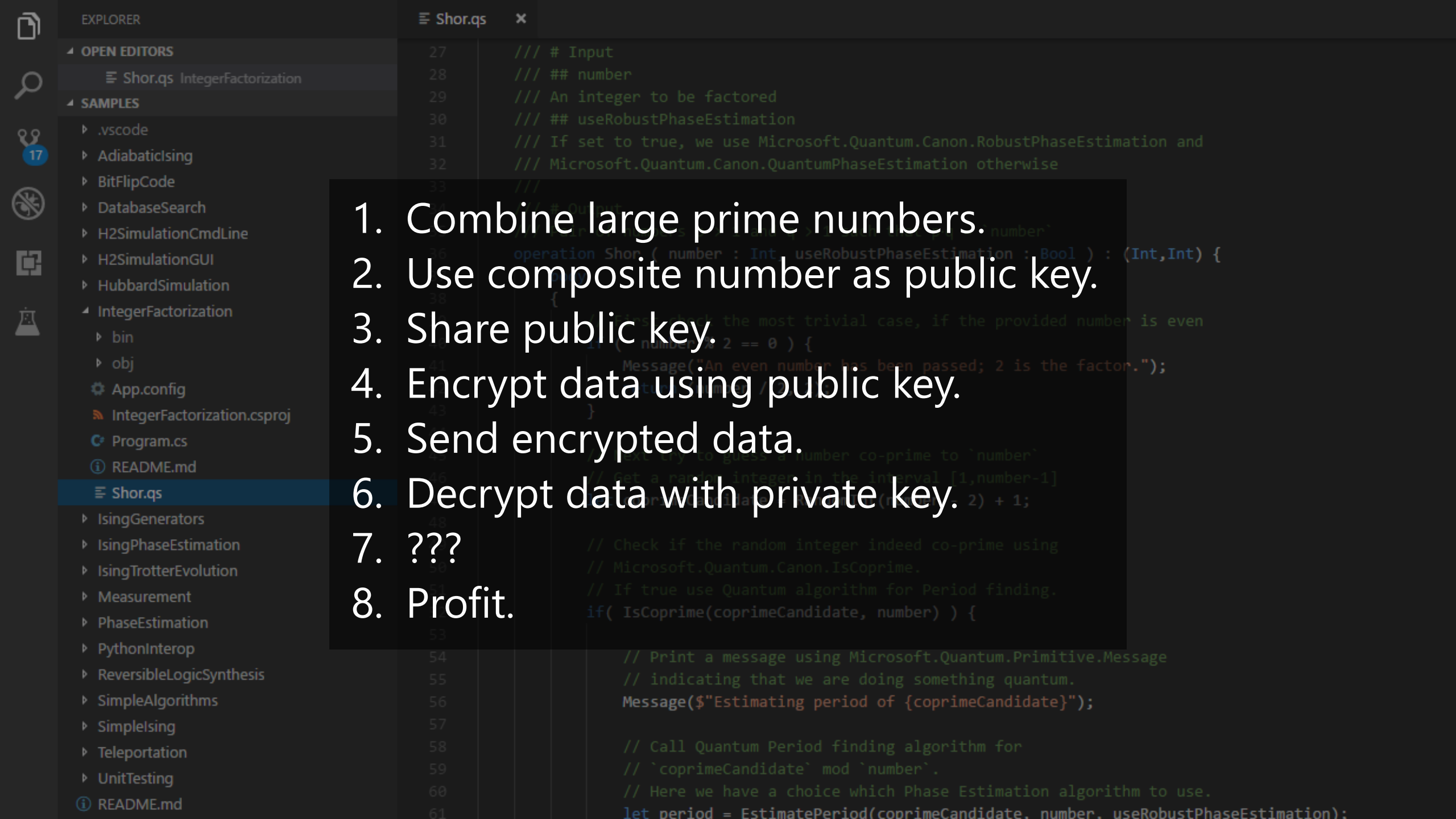
So are classical computers obsolete then?

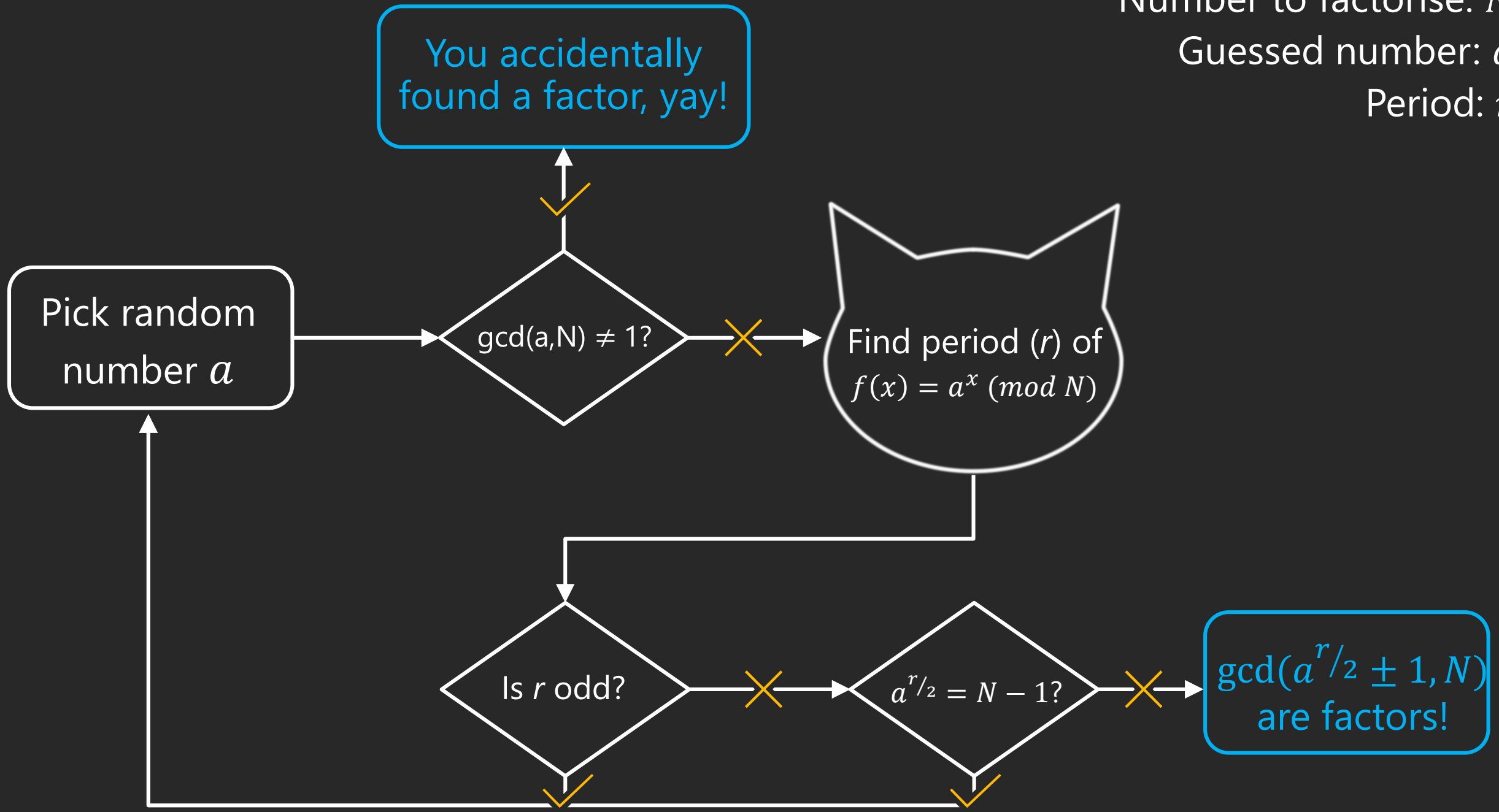
What's in it for me?

>The developer's perspective



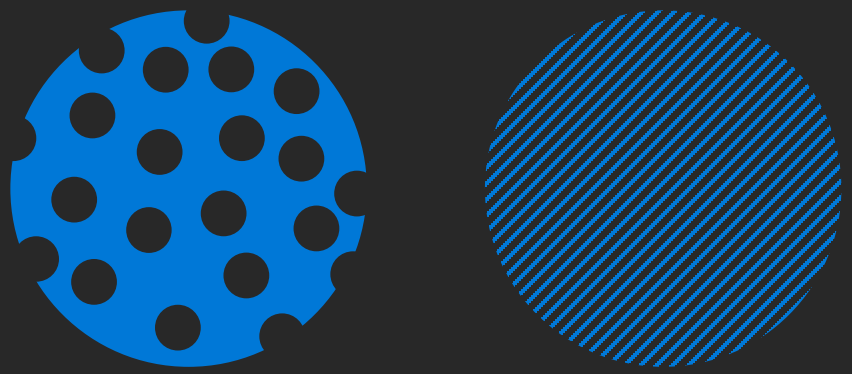

EXPLORER
OPEN EDITORS
Shor.qs IntegerFactorization
SAMPLES
.vscode
AdiabaticIsing
BitFlipCode
DatabaseSearch
H2SimulationCmdLine
H2SimulationGUI
HubbardSimulation
IntegerFactorization
bin
obj
App.config
IntegerFactorization.csproj
Program.cs
README.md
Shor.qs
IsingGenerators
IsingPhaseEstimation
IsingTrotterEvolution
Measurement
PhaseEstimation
PythonInterop
ReversibleLogicSynthesis
SimpleAlgorithms
SimpleIsing
Teleportation
UnitTesting
README.md
Shor.qs
1. Combine large prime numbers.
2. Use composite number as public key.
3. Share public key.
4. Encrypt data using public key.
5. Send encrypted data.
6. Decrypt data with private key.
7. ???
8. Profit.

Number to factorise: N
Guessed number: a
Period: r



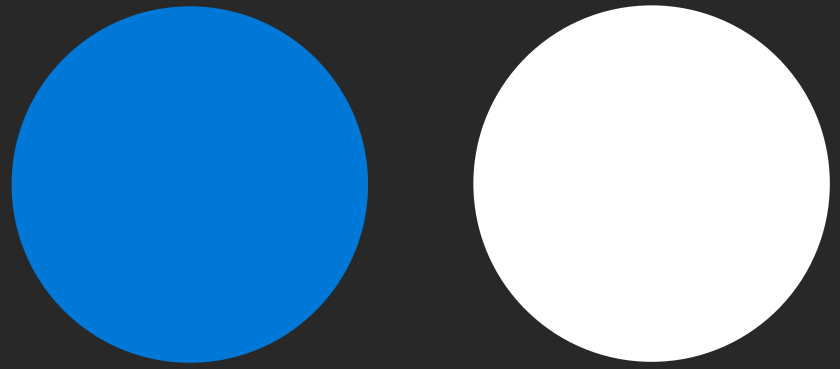
Satya Nadella (CEO)

0 1



Spotty/stripy mode (basis)

0 1



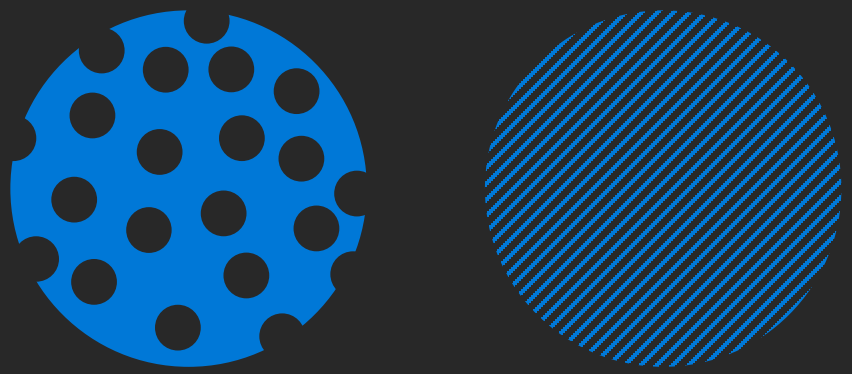
Blue/white mode (basis)

Frances

Key

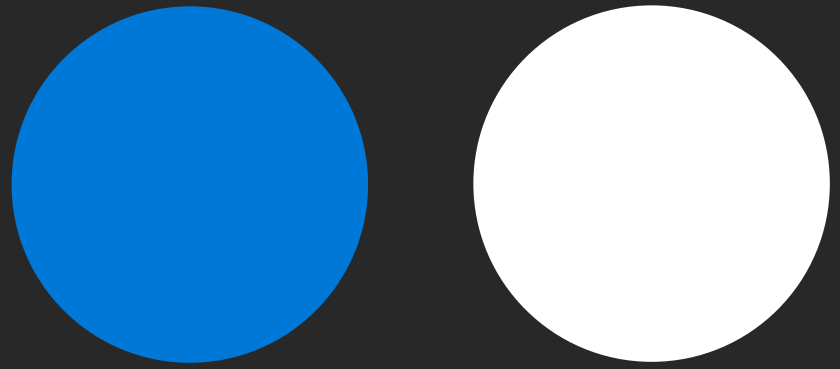
Anita

0 1



Spotty/stripy mode (basis)

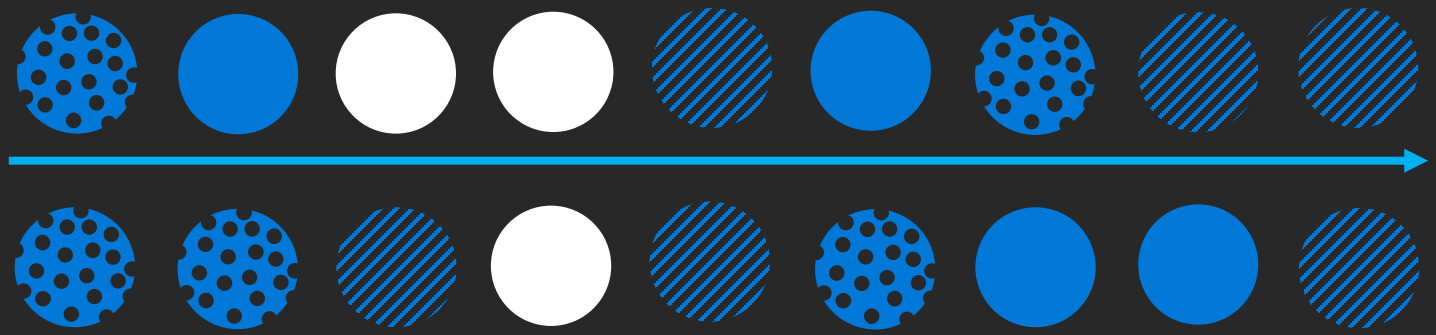
0 1



Blue/white mode (basis)

Frances

Frances sends



Anita measures

Anita

0 1 0 1

Spotty/stripy mode (basis)

Blue/white mode (basis)

Frances

0

0

1

1

Anita

Grover’s search:

N/2 on average, N at worst – hence O(N)

Using Grover’s: O(√N)

QUANTUM COMPUTING

- What is quantum computing? Why is it important?
- How do we build a quantum computer?
- What kinds of physical systems are already in development?
- What is Q#/the QDK and why would you use it?
- Can we use Q# to teleport a quantum state?

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Q&A?

Q. Do you follow Microsoft Quantum on Twitter?

A. No? Go to aka.ms/QuantumTwitter

Q. Do you receive the Microsoft Quantum newsletter?

A. No? Go to aka.ms/QuantumNewsletter

Q. Interested in learning more about quantum computing from the ground up?

A. Yes? Go to aka.ms/QuantumAdventures
Bonus! github.com/frtibble/QuantumWorkshop

Anita Ramanan | Frances Tibble

https://aka.ms/quantumadventures

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