

Quantum Development – Microsoft's QDK

OPEN EDITORS

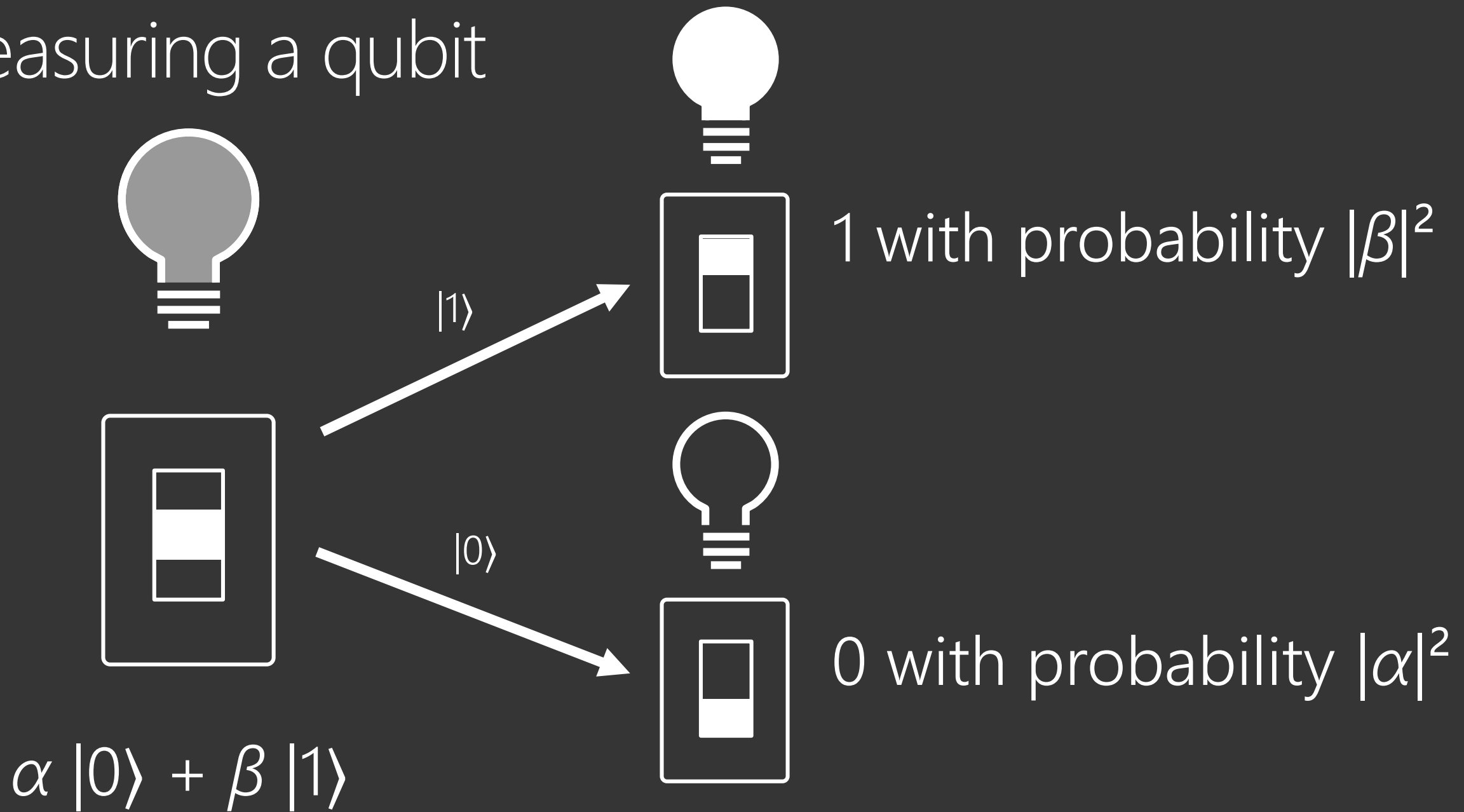
TeleportationSample.qs

SAMPLES

- .vscode
- AdiabaticIsing
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- H2SimulationGUI
- HubbardSimulation
- IntegerFactorization
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- IsingPhaseEstimation
- IsingTrotterEvolution
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- PhaseEstimation
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- SimpleIsing
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 - Program.cs
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 - 📄 TeleportationSample.qs
- UnitTesting
- ① README.md

```
32 // is unimportant.
33
34 /// Summary
35 /// Sends the state of one qubit to a target qubit by using
36 /// teleportation.
37 ///
38 /// # Input
39 /// ## msg
40 /// A qubit whose state we wish to send.
41 /// ## there
42 /// A qubit initially in the  $|0\rangle$  state that we want to send
43 /// the state of msg to.
44 operation Teleport(msg : Qubit, there : Qubit) : () {
45     body {
46
47         using (register = Qubit[1]) {
48             // Ask for an auxilliary qubit that we can use to prepare
49             // for teleportation.
50             let here = register[0];
51
52             // Create some entanglement that we can use to send our message.
53             H(here);
54             CNOT(here, there);
55
56             // Move our message into the entangled pair.
57             CNOT(msg, here);
58             H(msg);
59
60             // Measure out the entanglement.
61             if (M(msg) == One) { Z(there); }
62             if (M(here) == One) { X(there); }
63
64             // Reset our "here" qubit before releasing it.
65             Reset(here);
66         }
67     }
68 }
```

Measuring a qubit

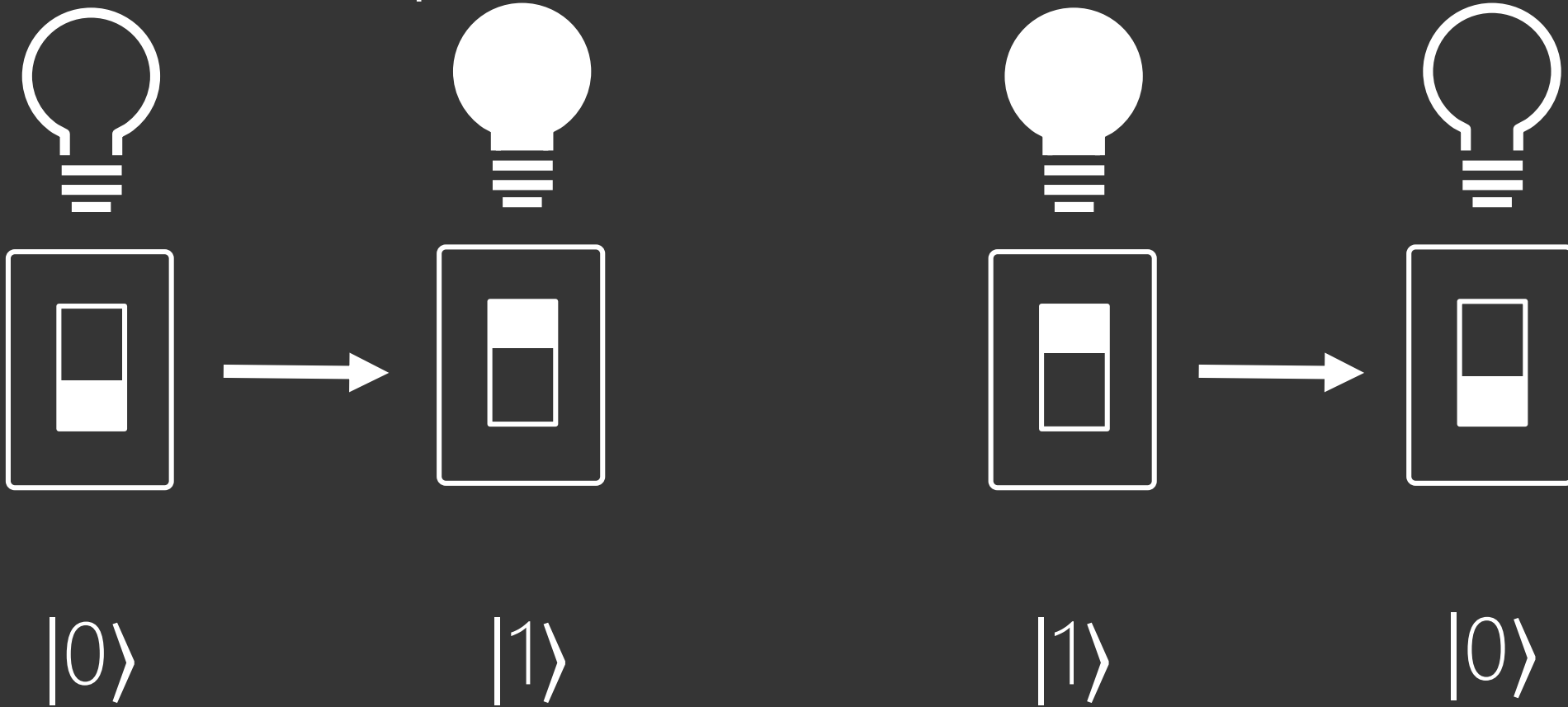


Measuring a qubit

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



Quantum Operations – NOT

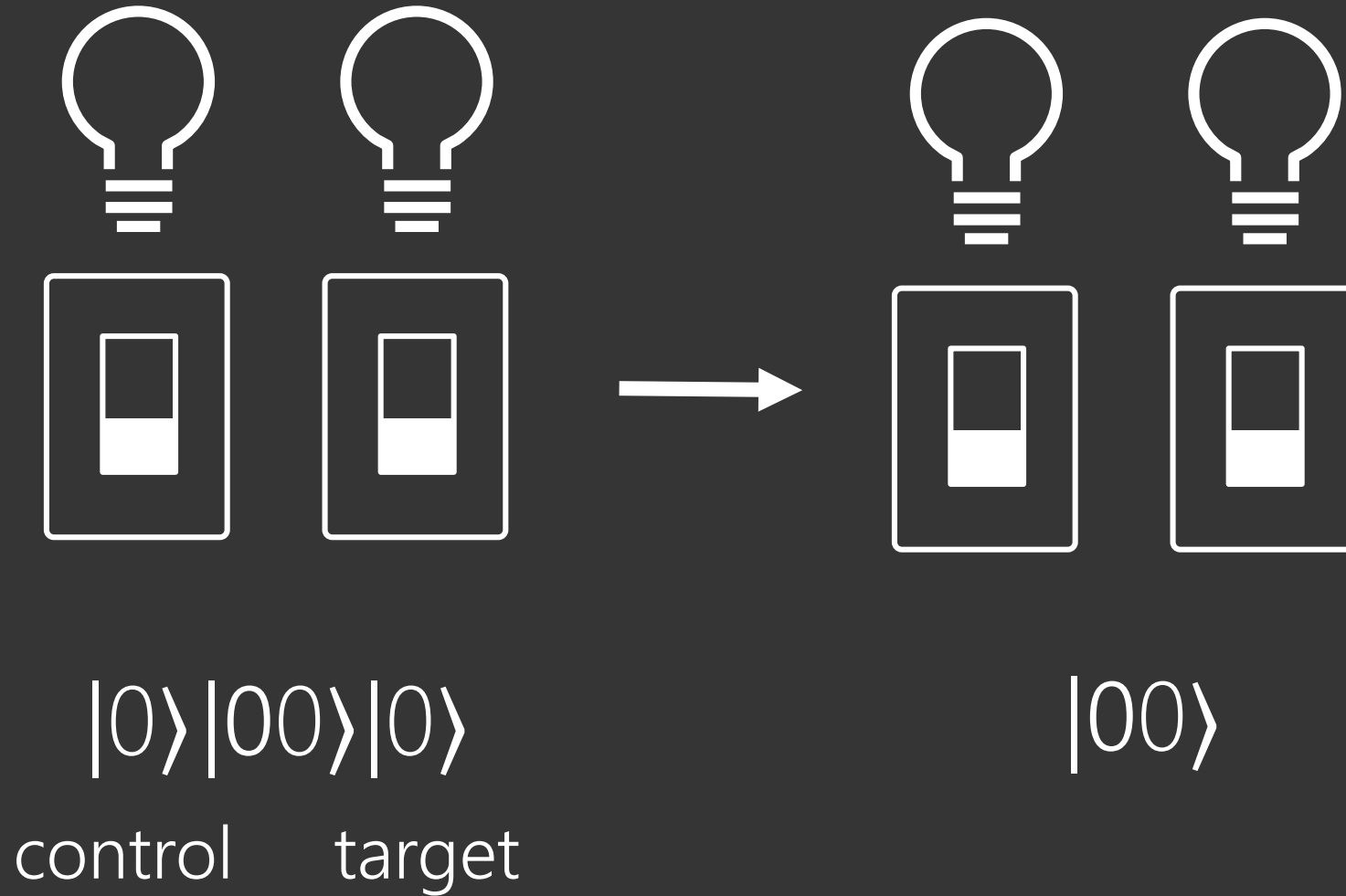


Quantum Operations – NOT

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

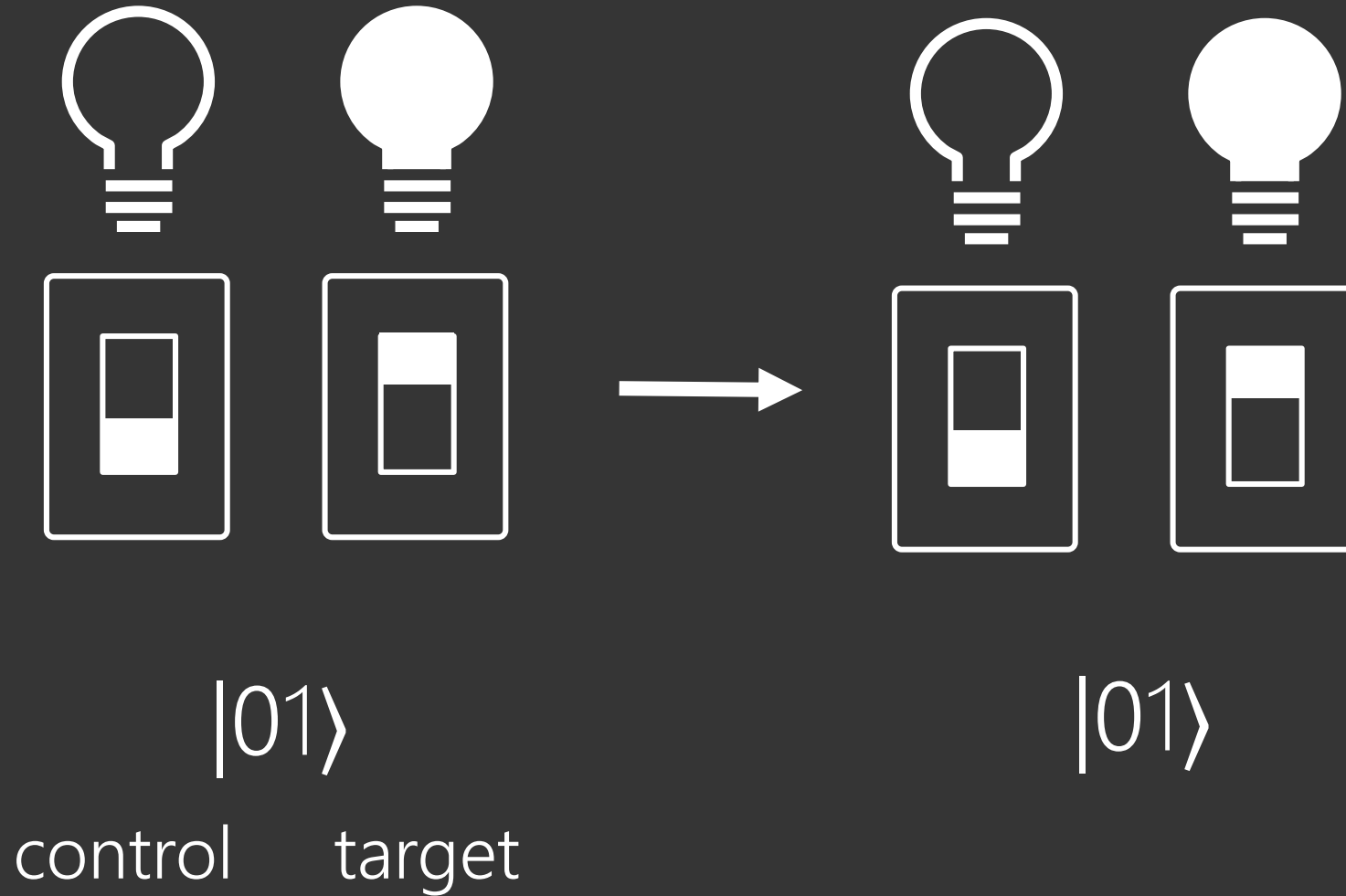


Quantum Operations - CNOT



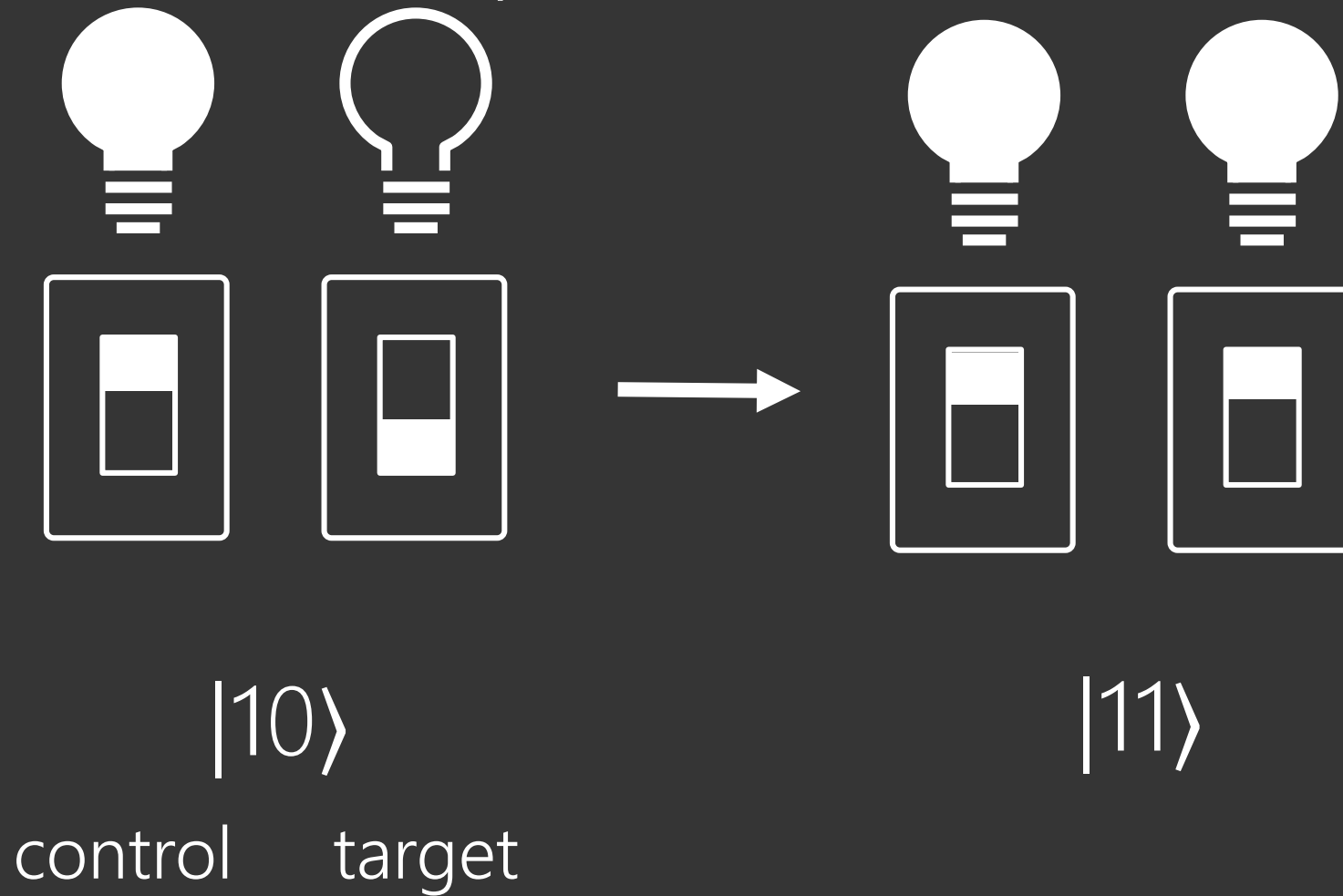
Input	Output
$ 00\rangle$	$ 00\rangle$

Quantum Operations - CNOT



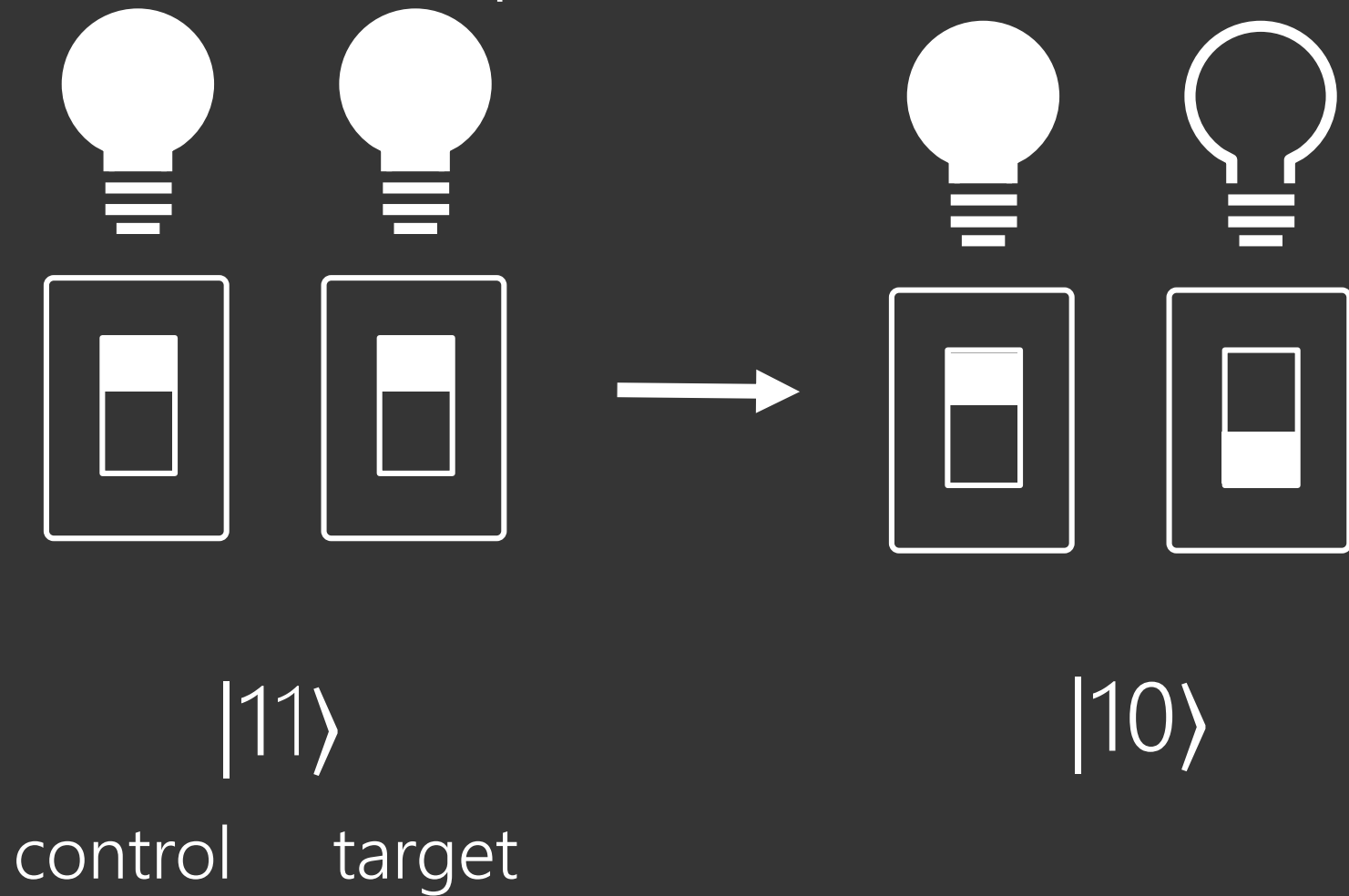
Input	Output
$ 00\rangle$	$ 00\rangle$
$ 01\rangle$	$ 01\rangle$

Quantum Operations - CNOT



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

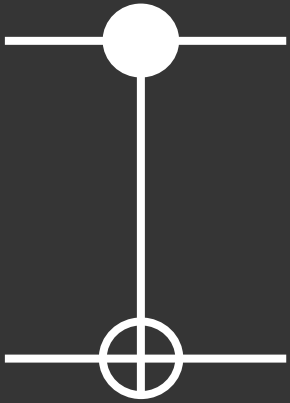
Quantum Operations - CNOT



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

Quantum Operations – CNOT

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



Quantum Operations - Z

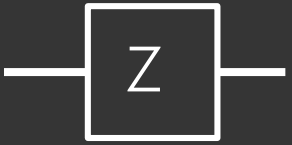
$$|0\rangle \longrightarrow |0\rangle$$

$$|1\rangle \longrightarrow -|1\rangle$$

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



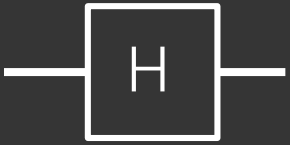
$|1\rangle$



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

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$

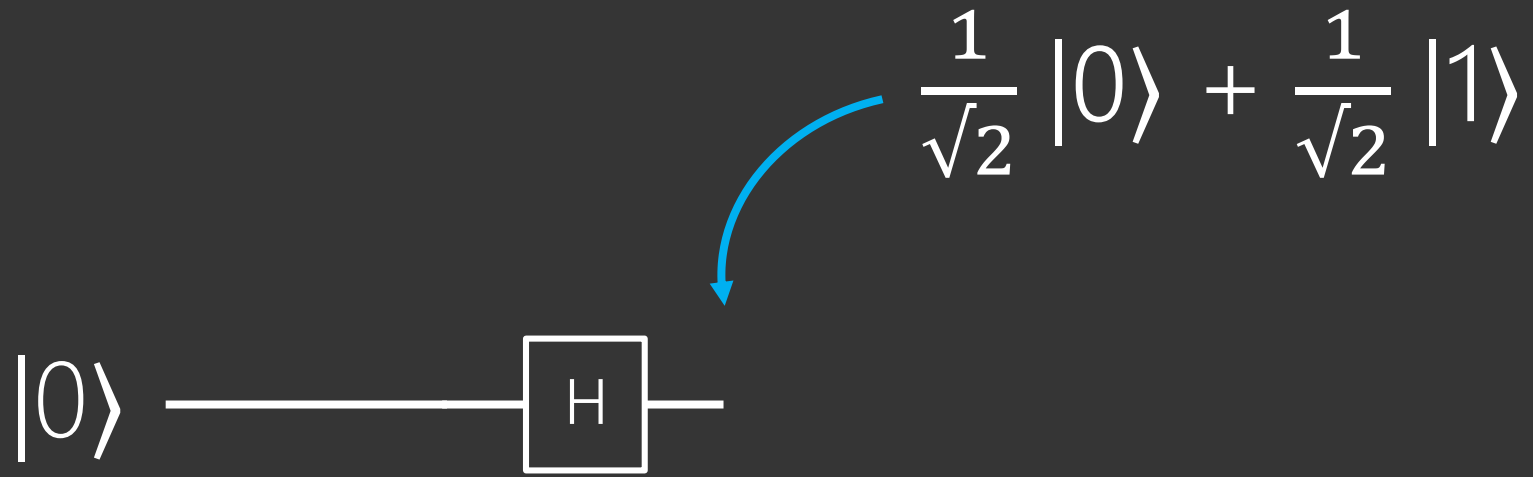
Z

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

Hadamard

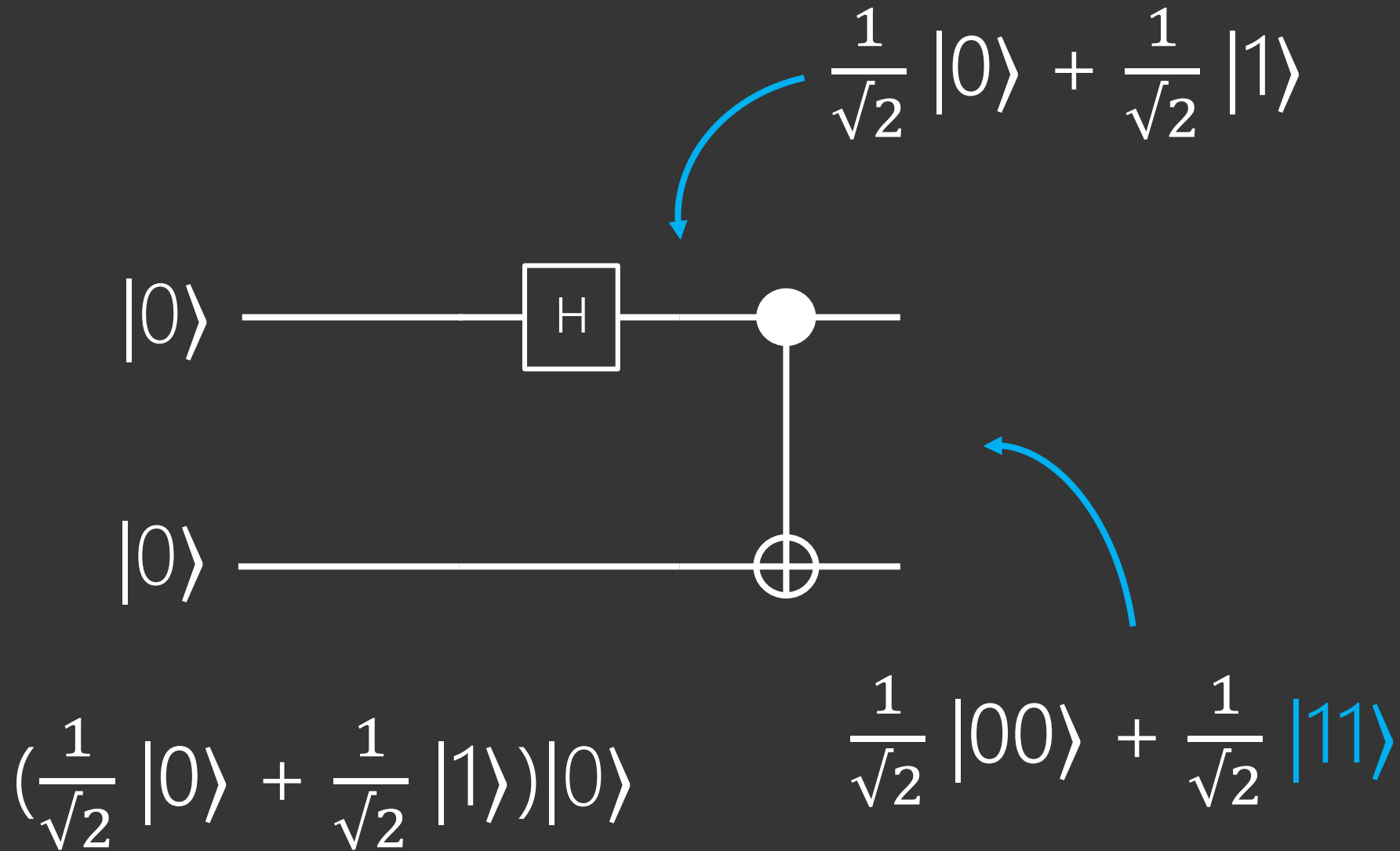
Input	Output
$ 0\rangle$	$\frac{1}{\sqrt{2}} 0\rangle + \frac{1}{\sqrt{2}} 1\rangle$
$ 1\rangle$	$\frac{1}{\sqrt{2}} 0\rangle - \frac{1}{\sqrt{2}} 1\rangle$

Entanglement



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



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

$|\psi\rangle$

Physically?

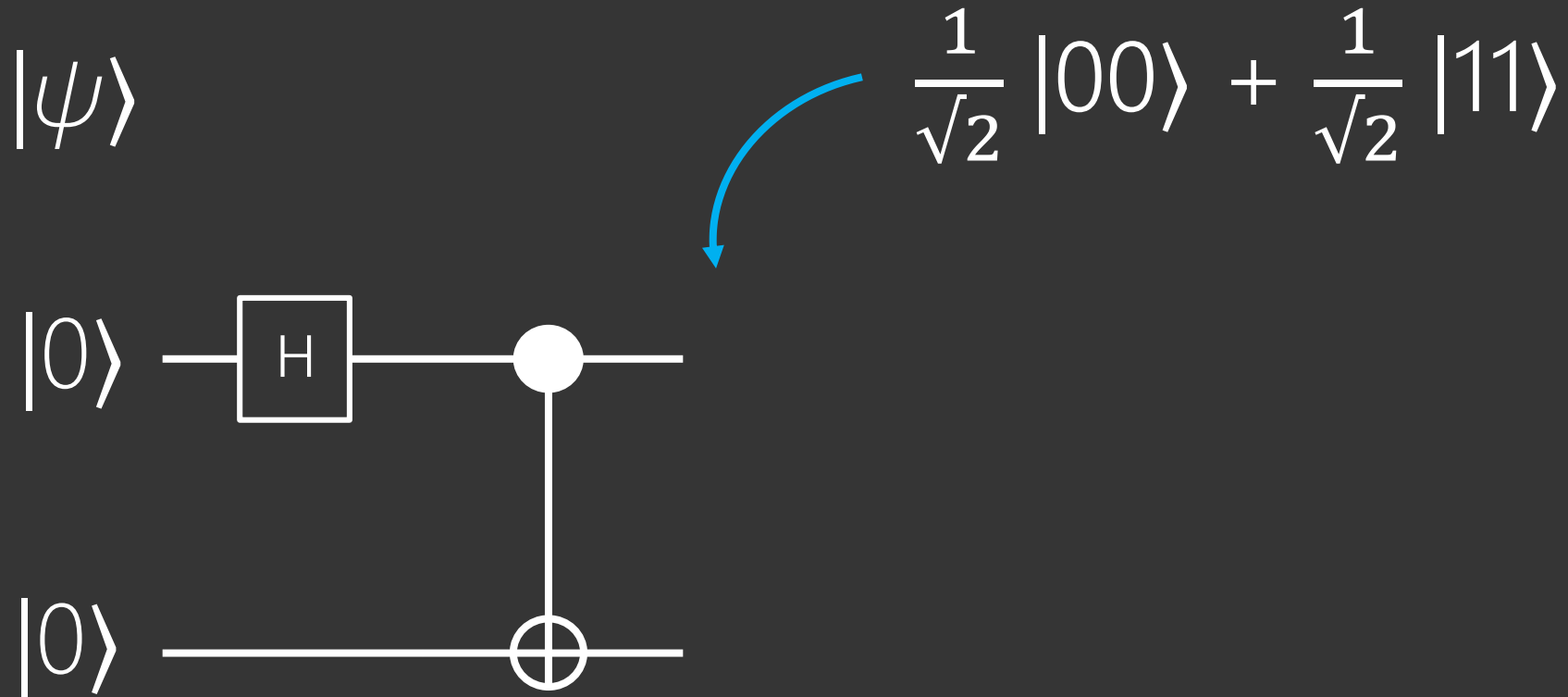
$|0\rangle$

Classically?

$|0\rangle$

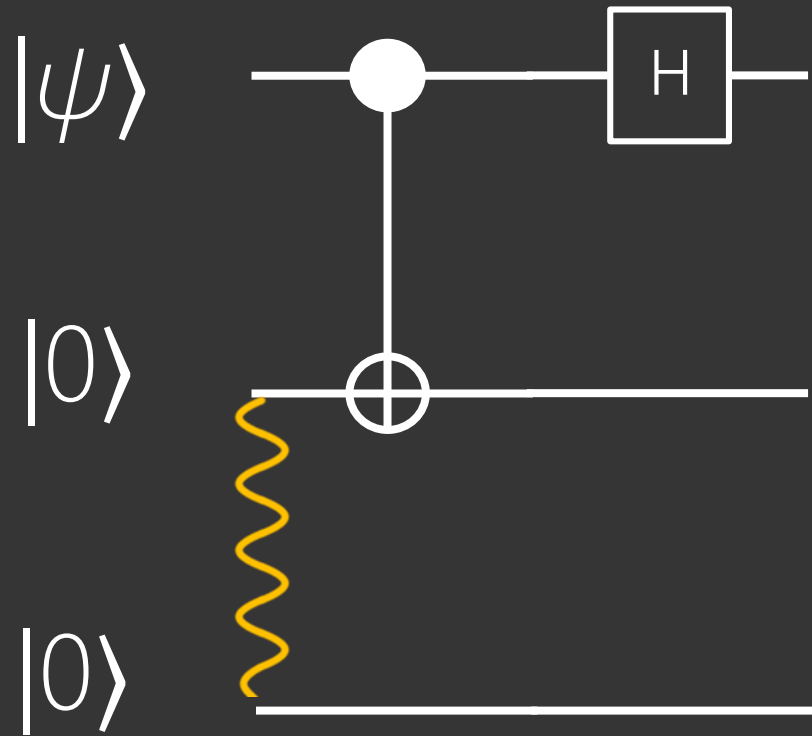
Quantum teleportation!

Quantum Teleportation - Explained



Step 0: Entangle our qubits

Quantum Teleportation - Explained



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

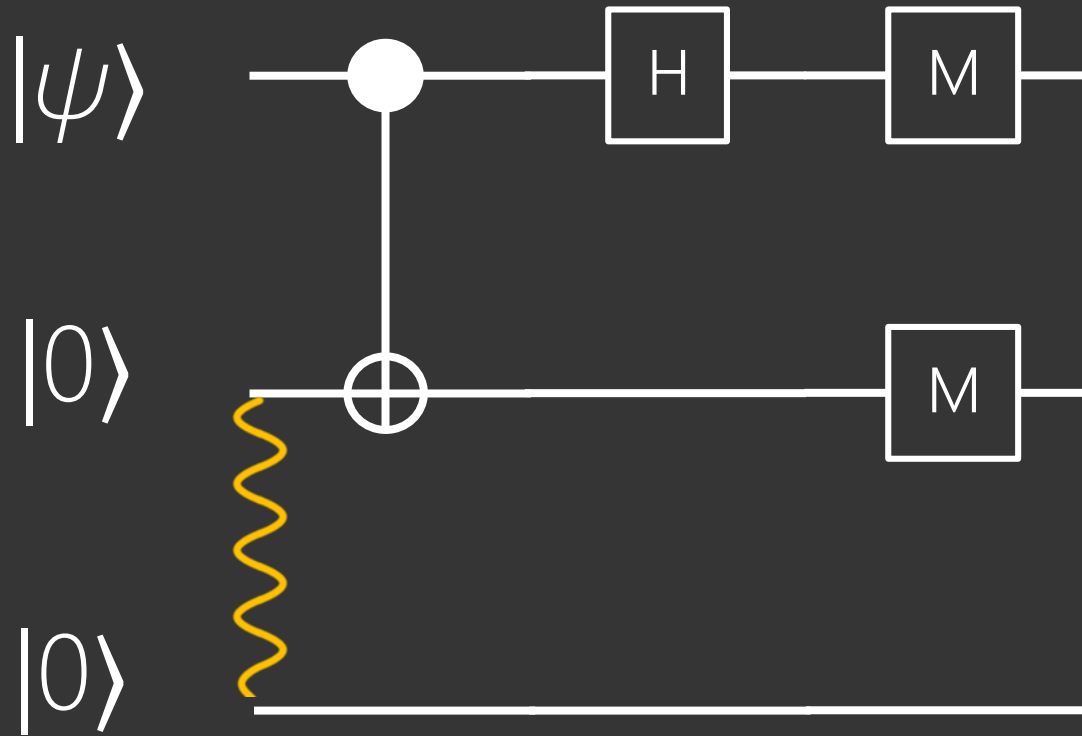
?

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

Quantum Teleportation - Explained

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

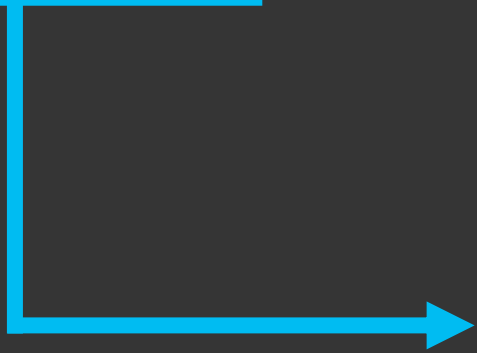
Quantum Teleportation - Explained



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

Quantum Teleportation - Explained

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



Do nothing

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

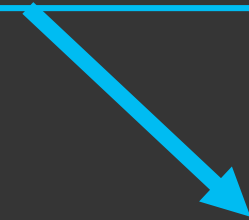


$$|\psi\rangle = \alpha |0\rangle + \beta |1\rangle$$

Step 3: Interpret the result

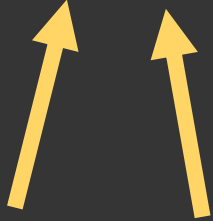
Quantum Teleportation - Explained

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



Apply a NOT gate

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



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

Step 3: Interpret the result

Quantum Teleportation - Explained

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


Apply a Z gate

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

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

Step 3: Interpret the result

Quantum Teleportation - Explained

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


Apply a Z gate and a NOT gate

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


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

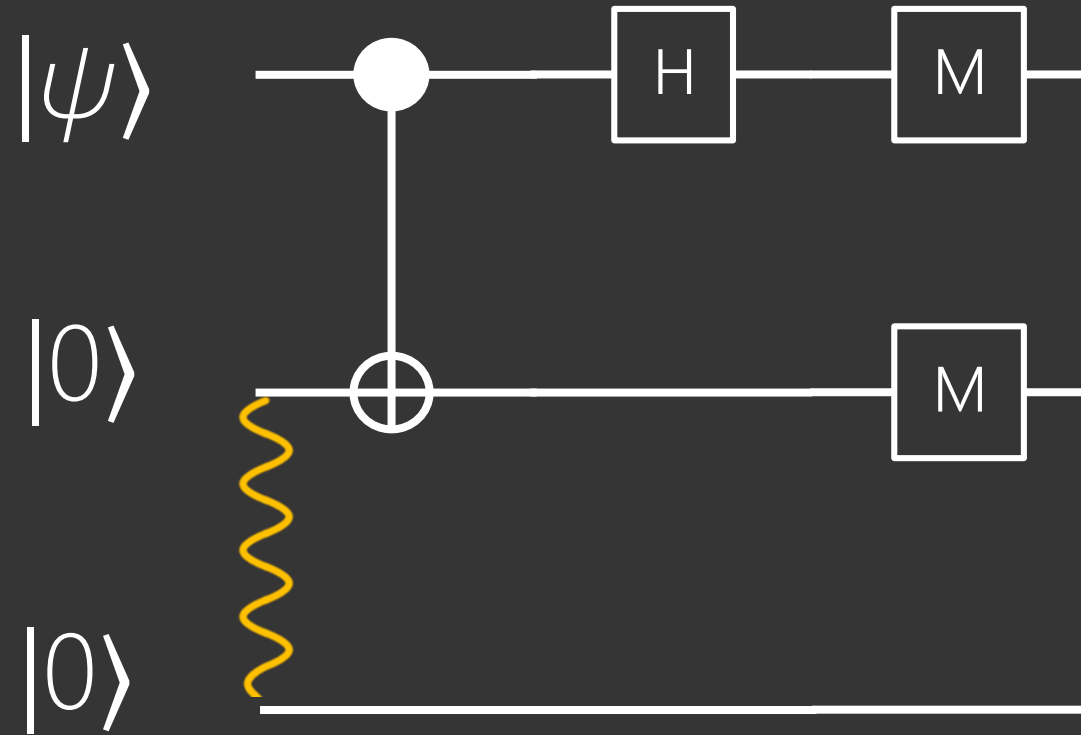
Step 3: Interpret the result

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!



Q&A?

Q. Do you follow Microsoft Quantum on Twitter?

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

A. Yes? Go to aka.ms/QuantumAdventures



Anita Ramanan | Frances Tibble

<https://aka.ms/quantumadventures>

@whywontitbuild | @frances_tibble

anraman@microsoft.com | frtibble@microsoft.com