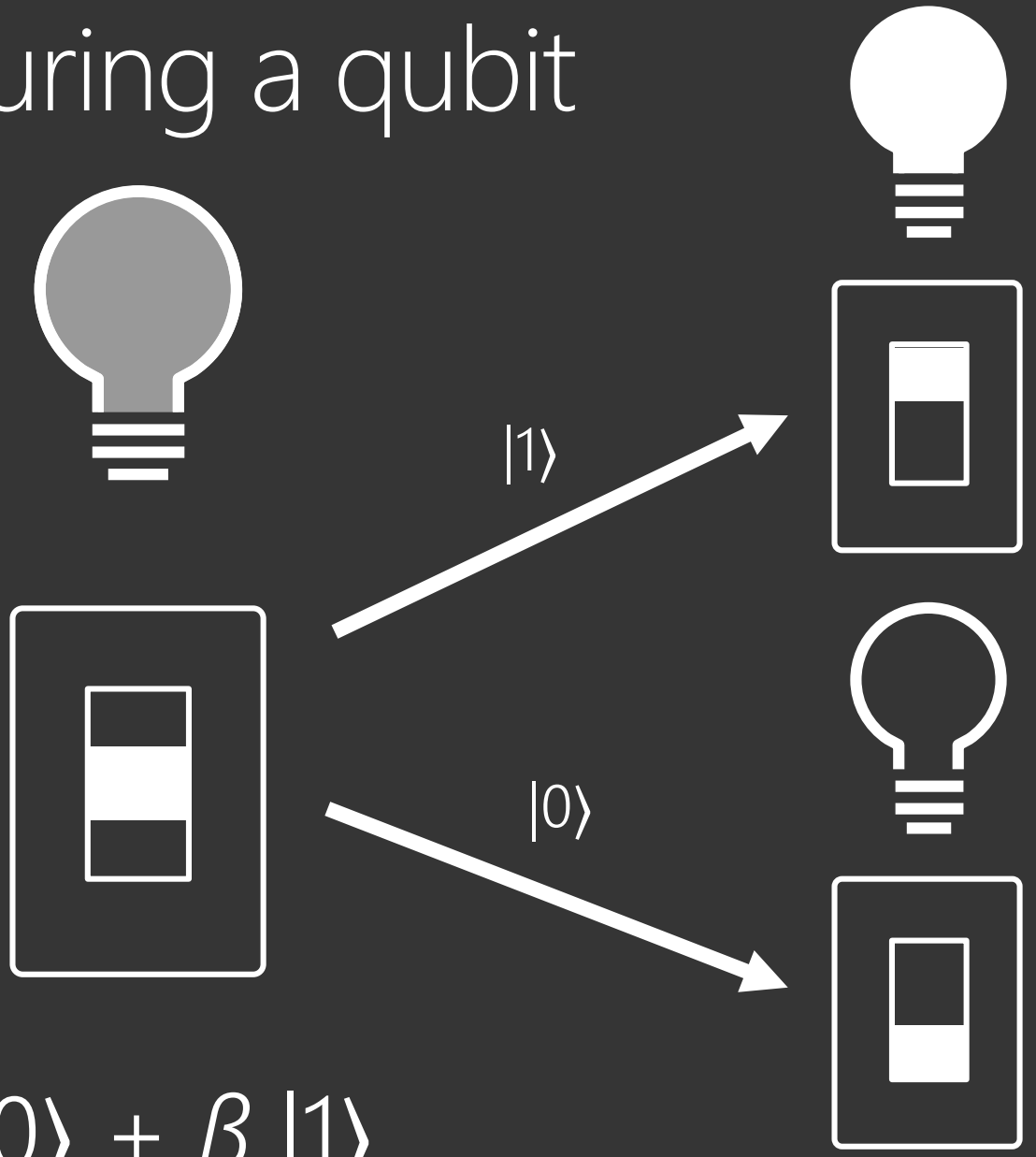
Quantum Development – Microsoft's QDK

Measuring a qubit



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

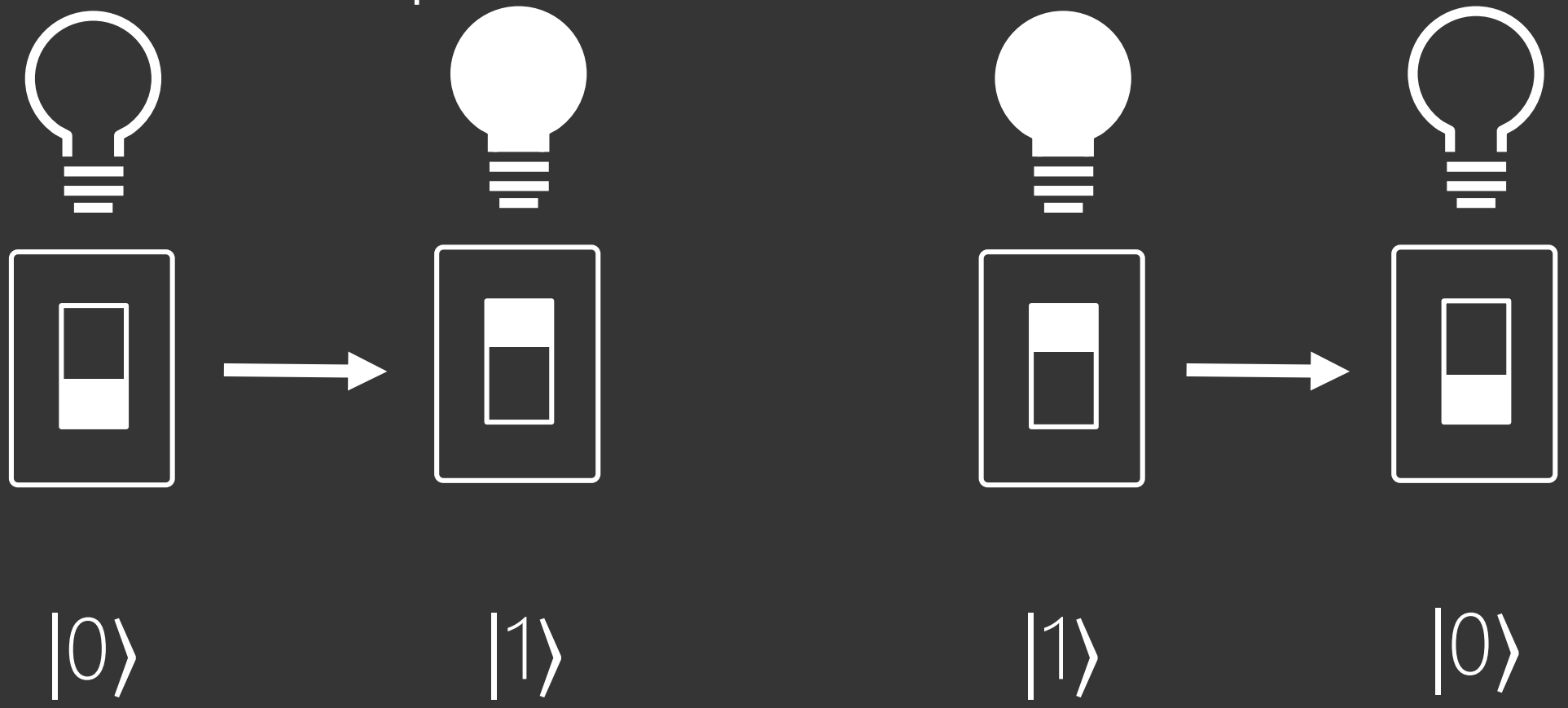
1 with probability $|\beta|^2$

0 with probability $|\alpha|^2$

Measuring a qubit

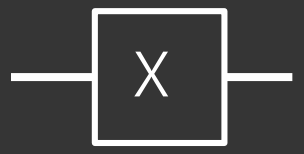
```
operation M (qubit : Qubit) : Result
```

Quantum Operations – NOT

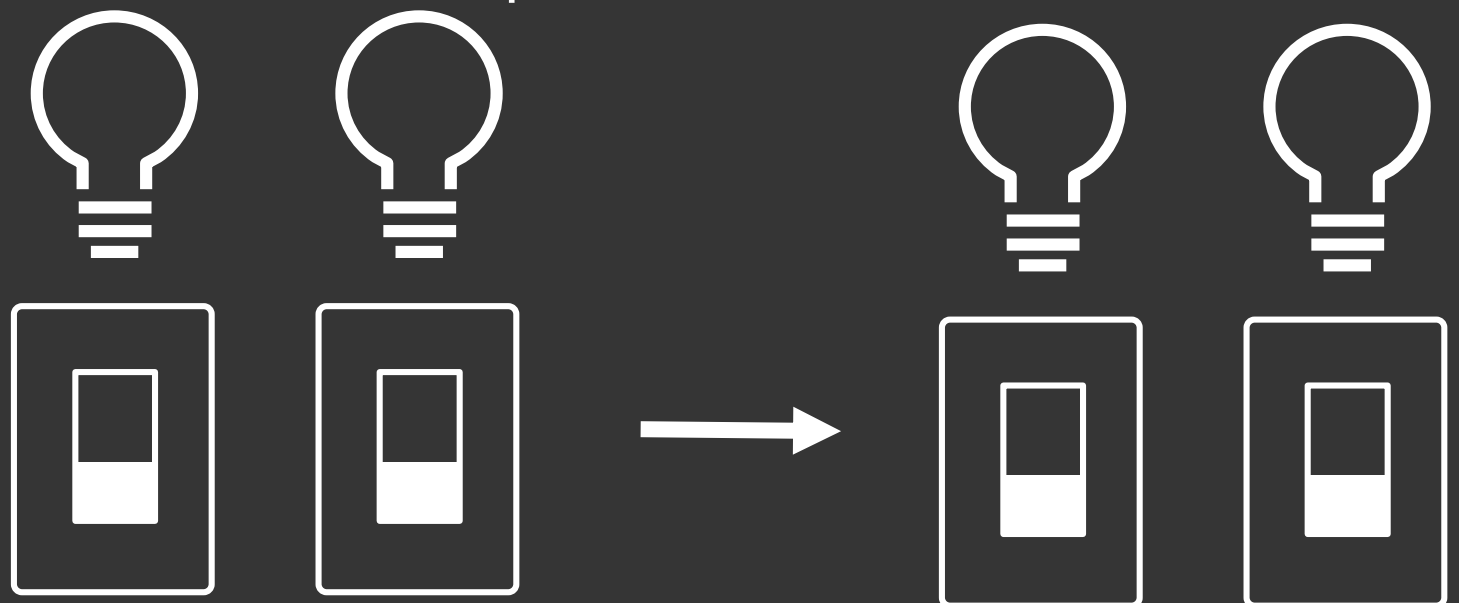


Quantum Operations – NOT

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



Quantum Operations - CNOT



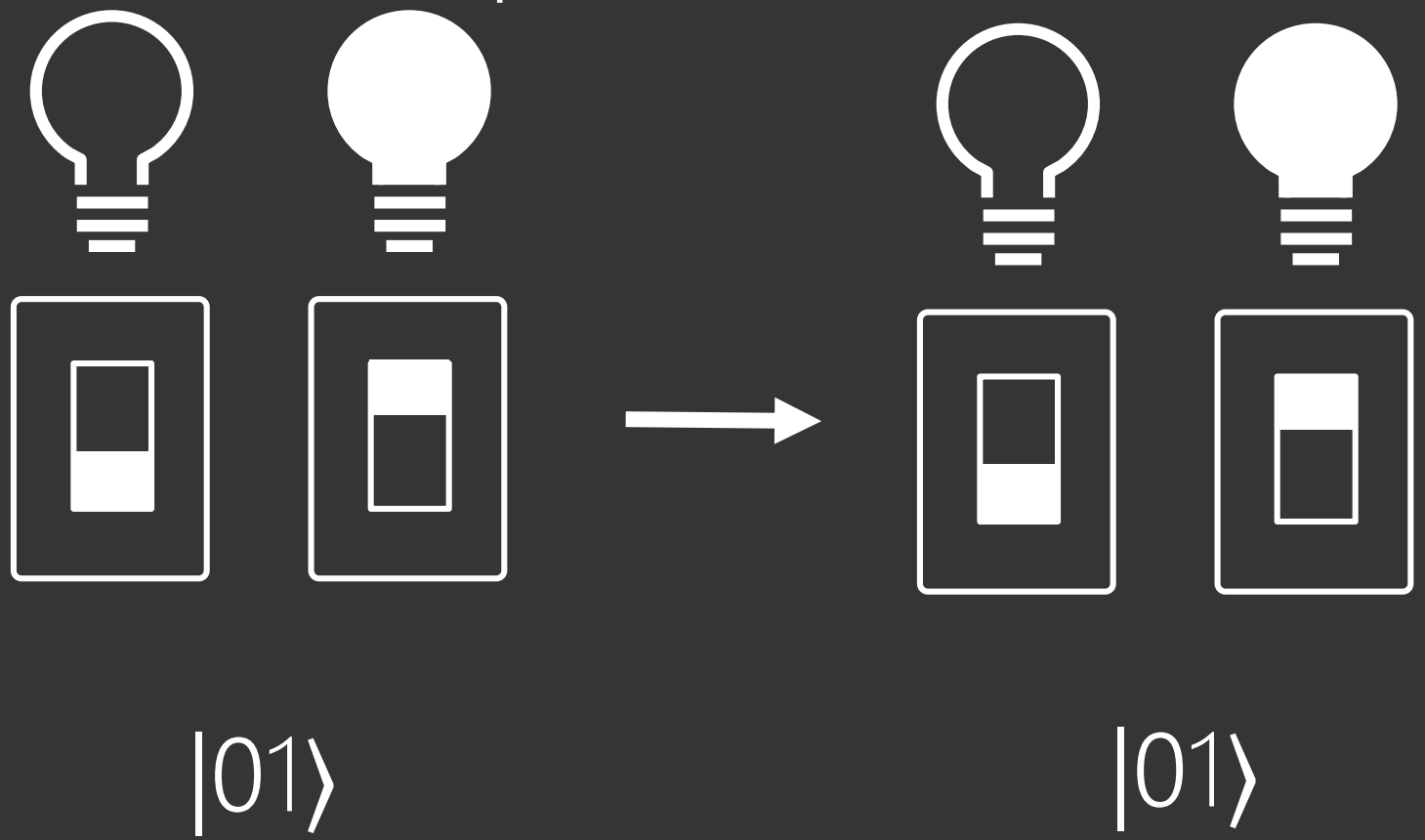
$|0\rangle|00\rangle|0\rangle$

control target

$|00\rangle$

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

Quantum Operations - CNOT

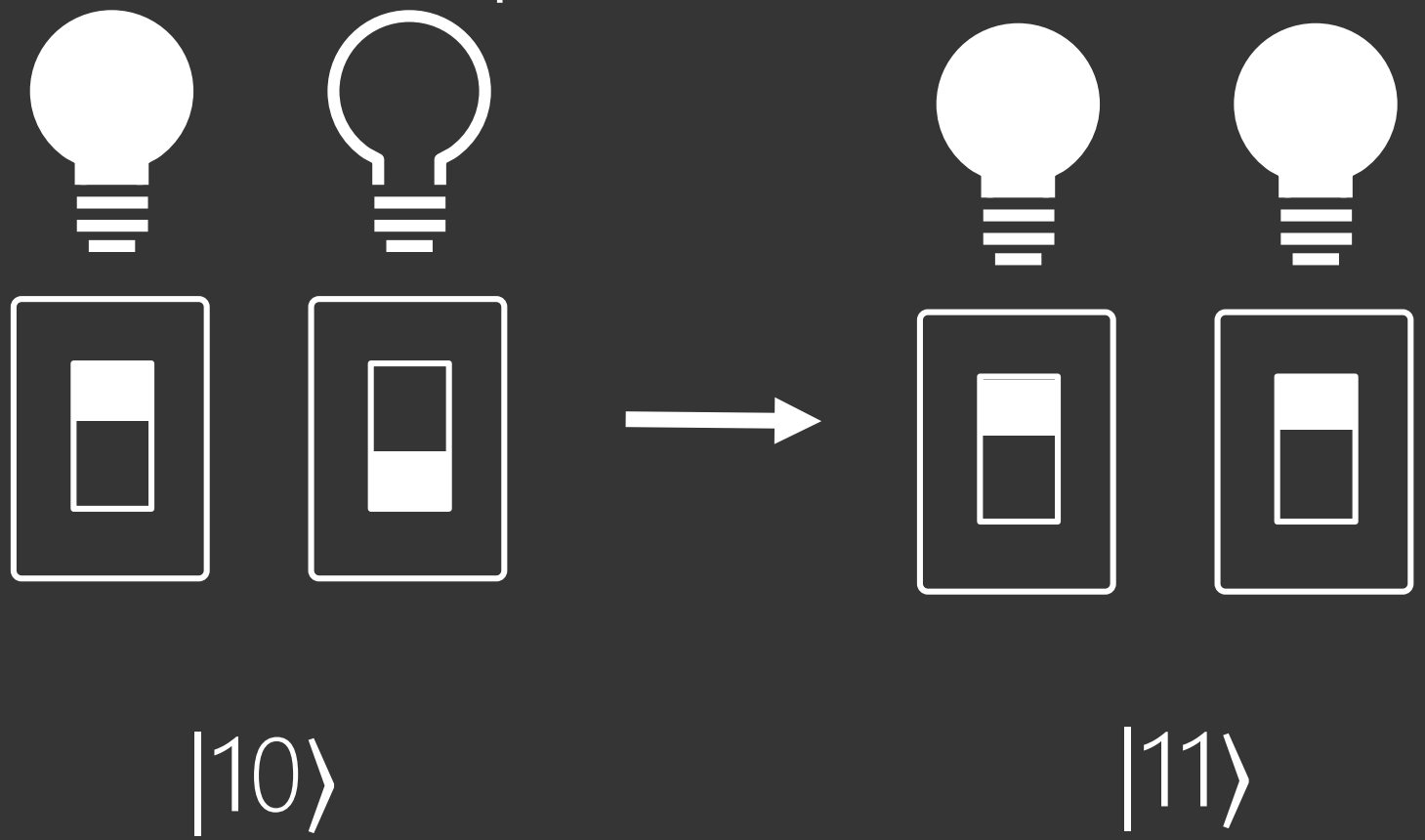


$|01\rangle$ $|01\rangle$

control target

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

Quantum Operations - CNOT

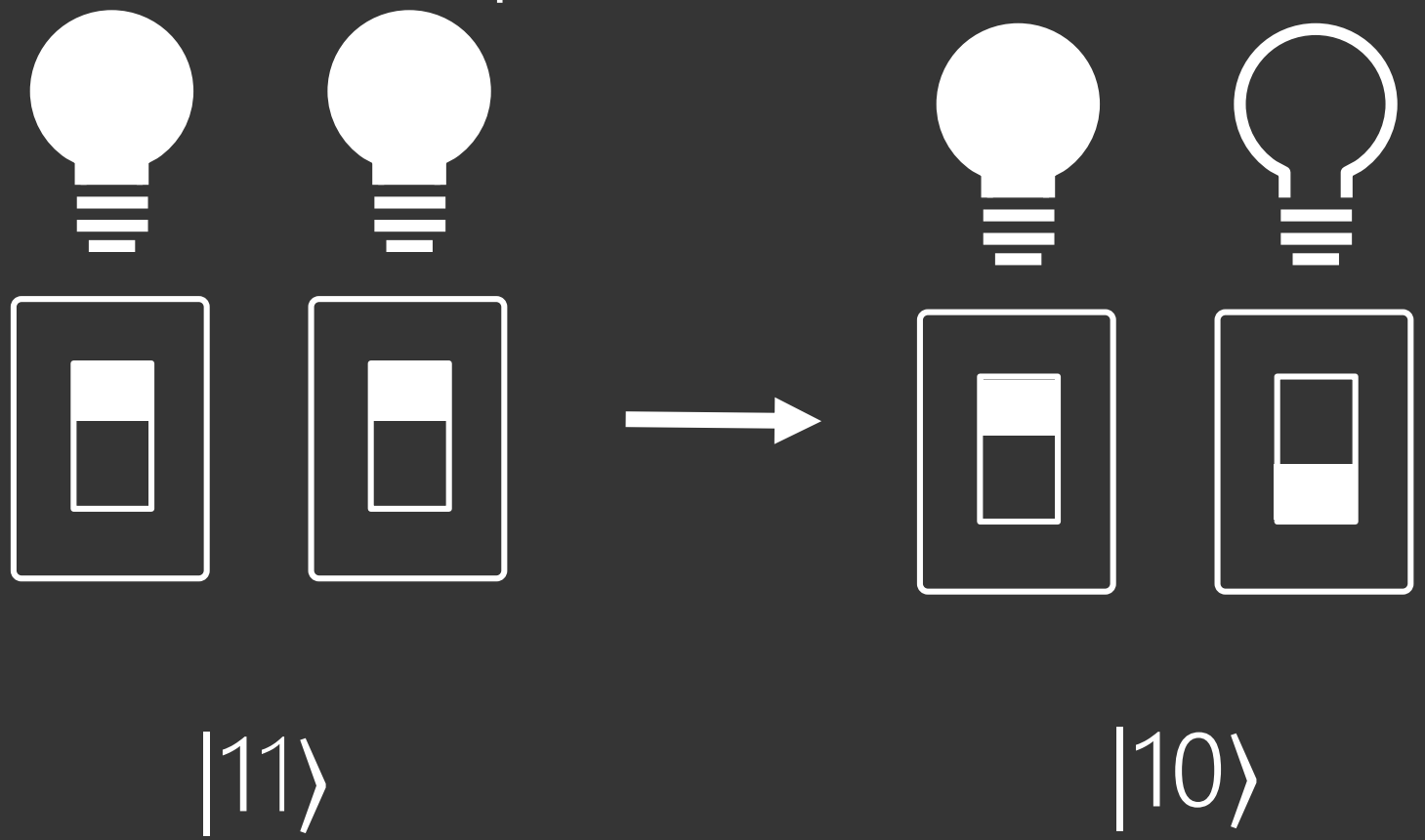


$|10\rangle$ $|11\rangle$

control target

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

Quantum Operations - CNOT



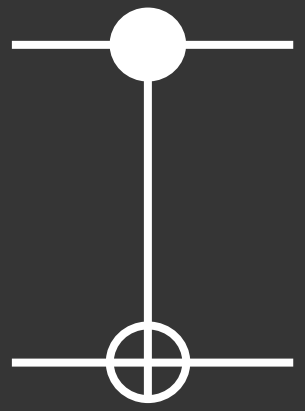
$|11\rangle$ $|10\rangle$

control target

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

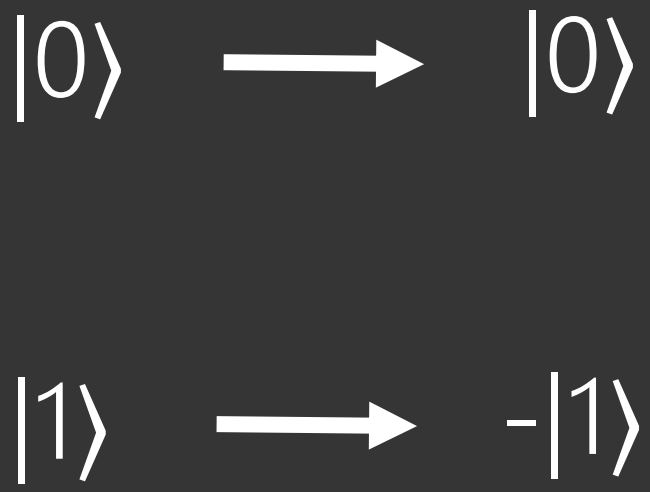
Quantum Operations – CNOT

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



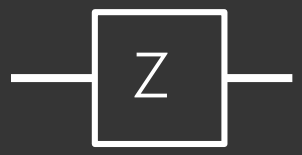
Quantum Operations - Z

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

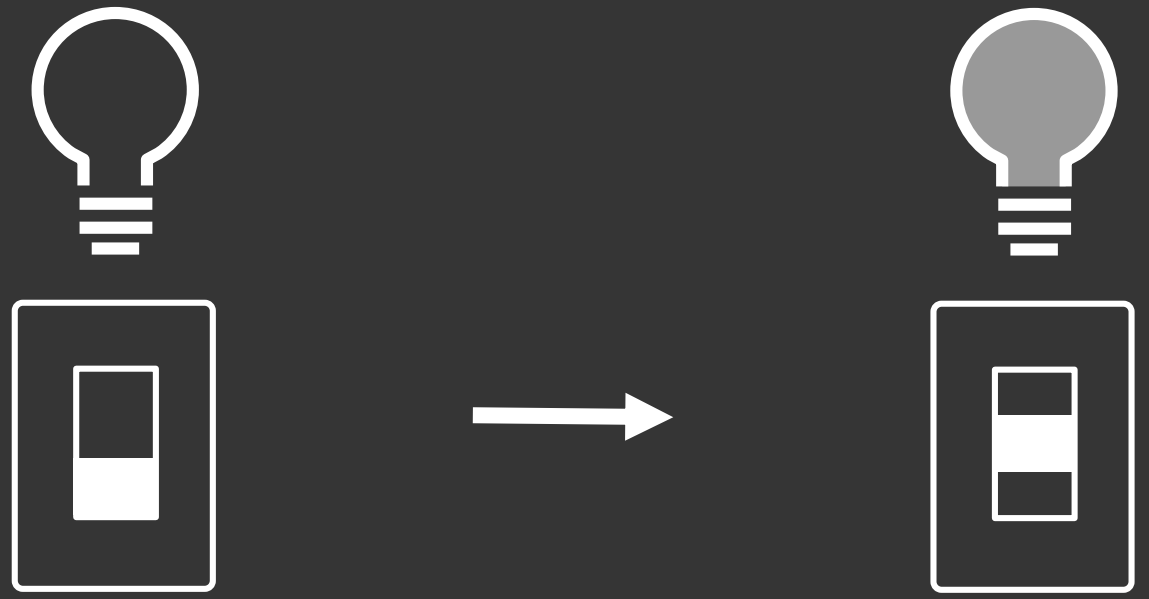


Quantum Operations – Z

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



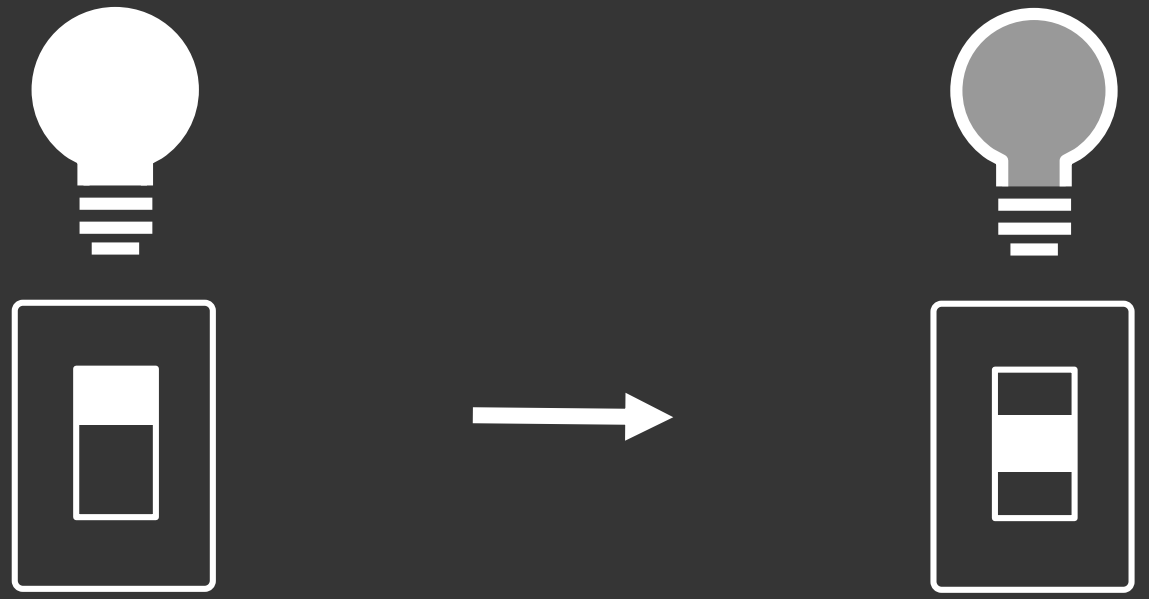
Quantum Operations - Hadamard



$|0\rangle$

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

Quantum Operations - Hadamard

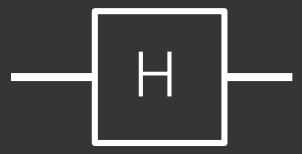


$|1\rangle$

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

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

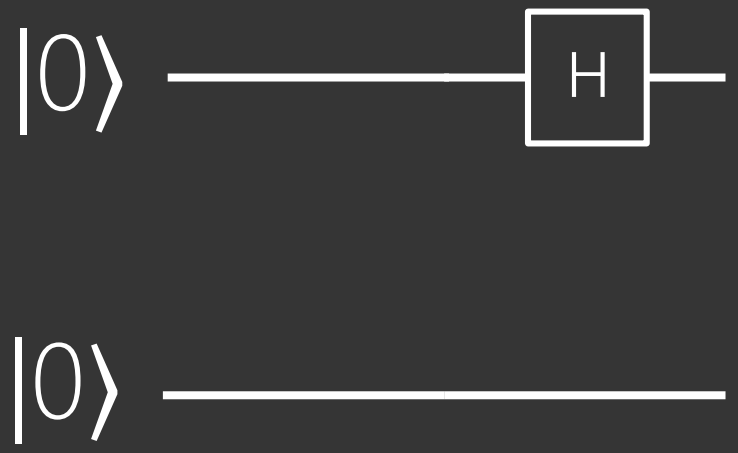
Input	Output
$\|0\rangle$	$\|0\rangle$
$\|1\rangle$	$-\|1\rangle$

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

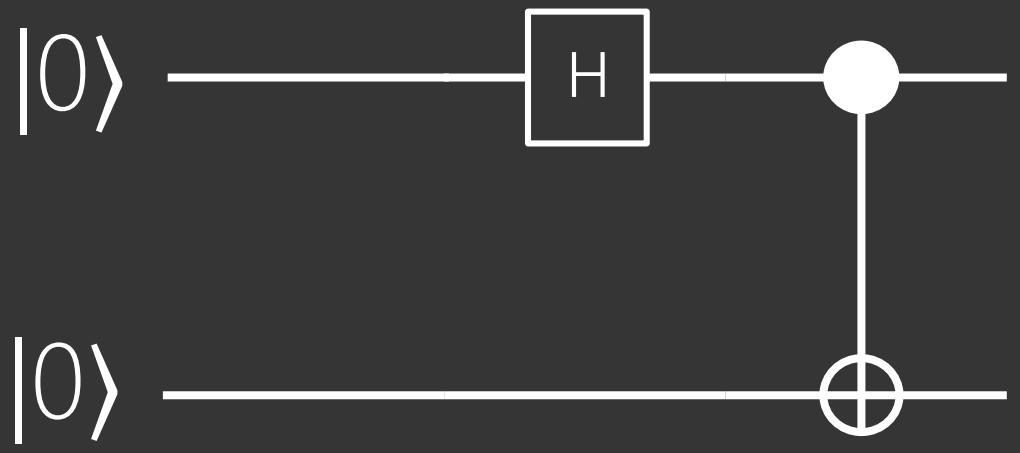
$$\frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$



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

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



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

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

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

$|\psi\rangle$

$|0\rangle$

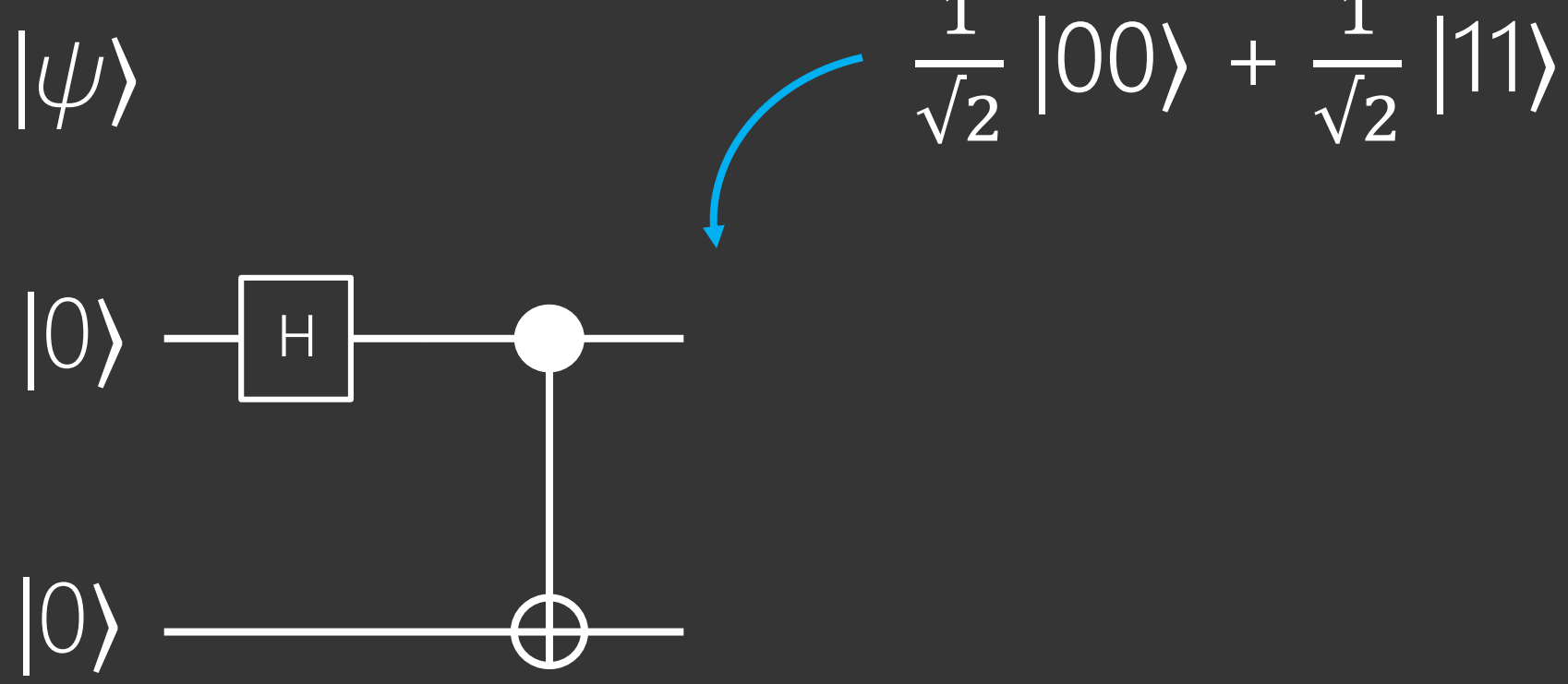
$|0\rangle$

Physically?

Classically?

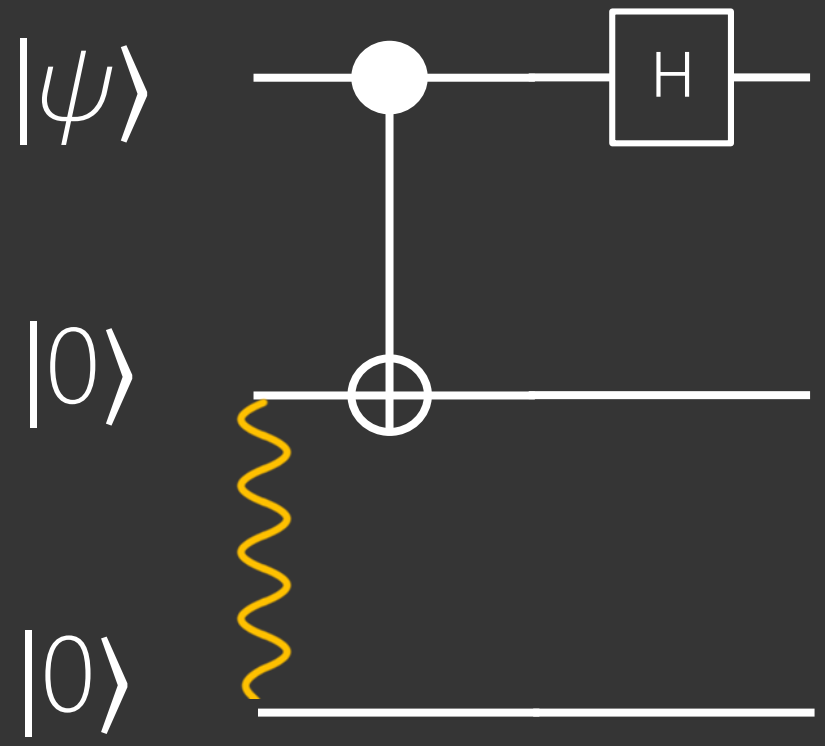
Quantum teleportation!

Quantum Teleportation - Explained



Step 0: Entangle our qubits

Quantum Teleportation - Explained



?

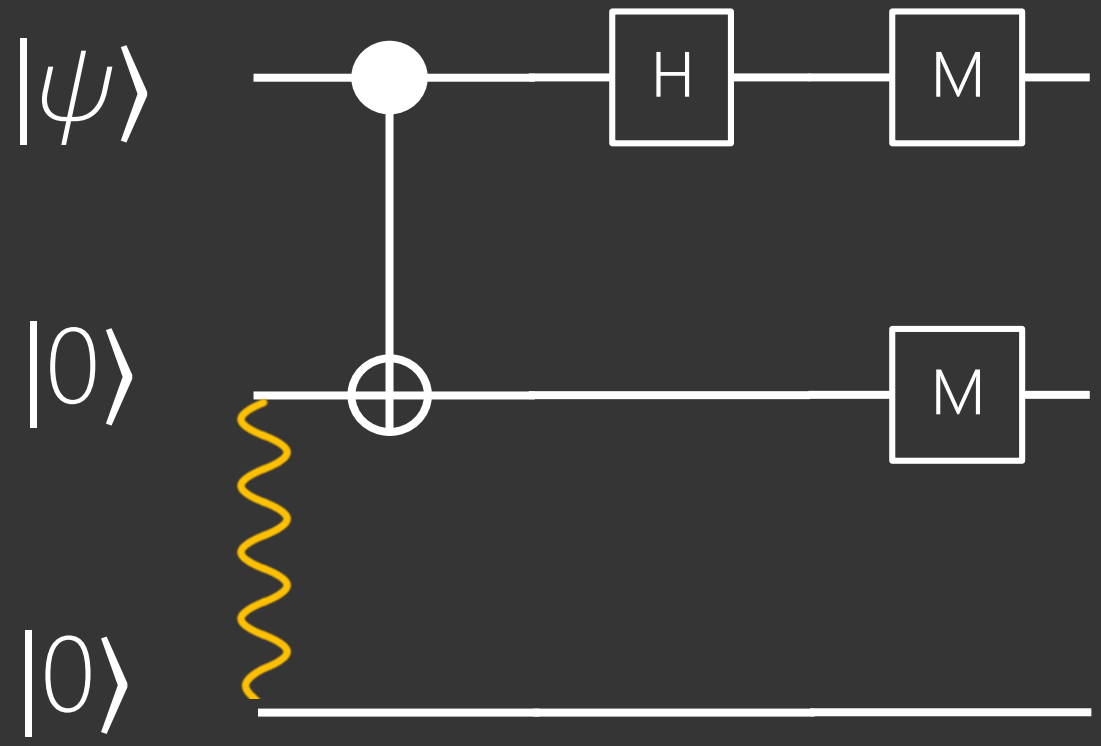
$$|\psi\rangle = \alpha\,|0\rangle + \beta\,|1\rangle$$

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

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

Do nothing

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

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

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 a NOT gate

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

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

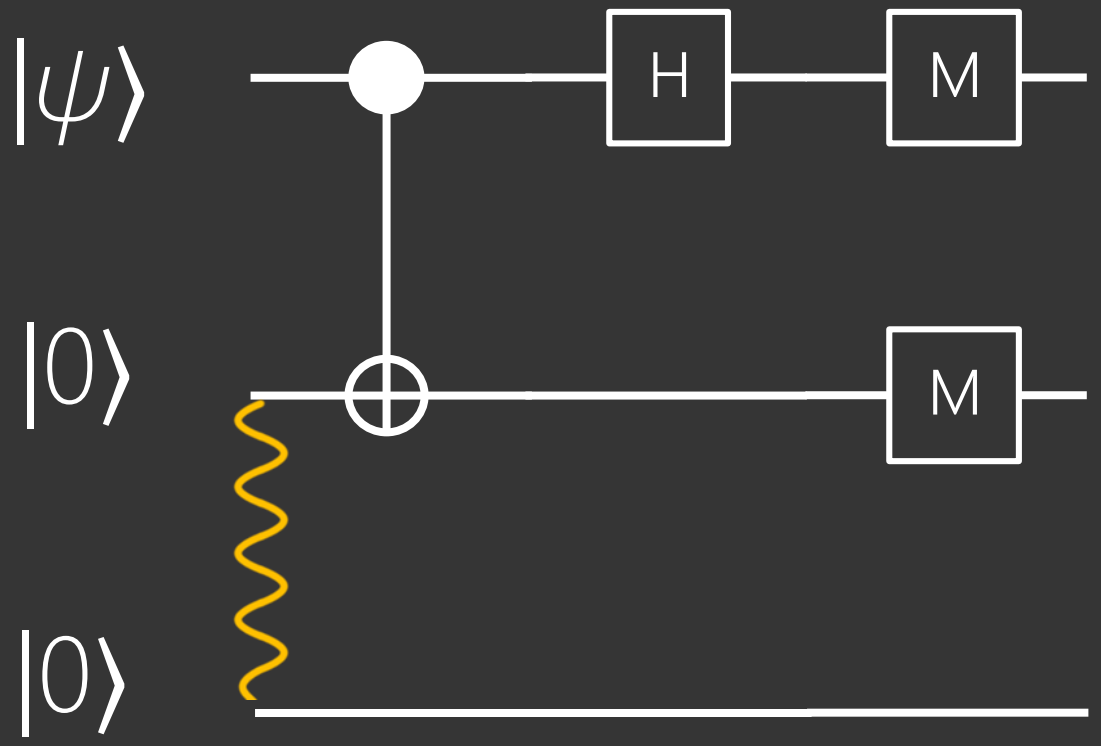
Step 3: Interpret the result

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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Anita Ramanan | Frances Tibble

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