

NDC { London }

Johnny Hooyberghs

Microsoft Q# and Azure Quantum

Johnny Hooyberghs



@djohnnieke

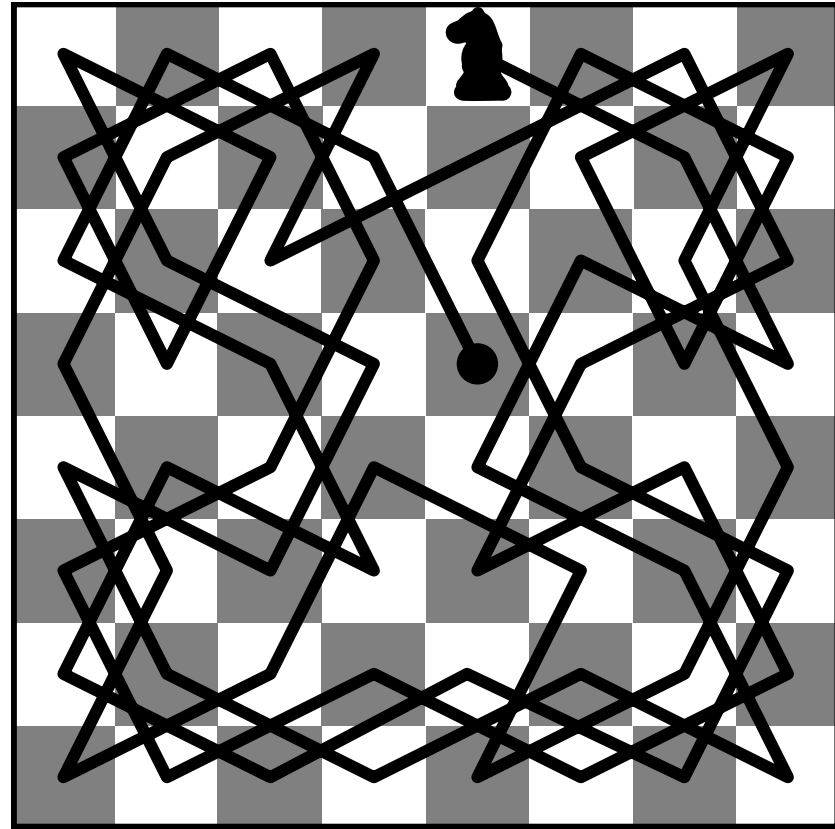
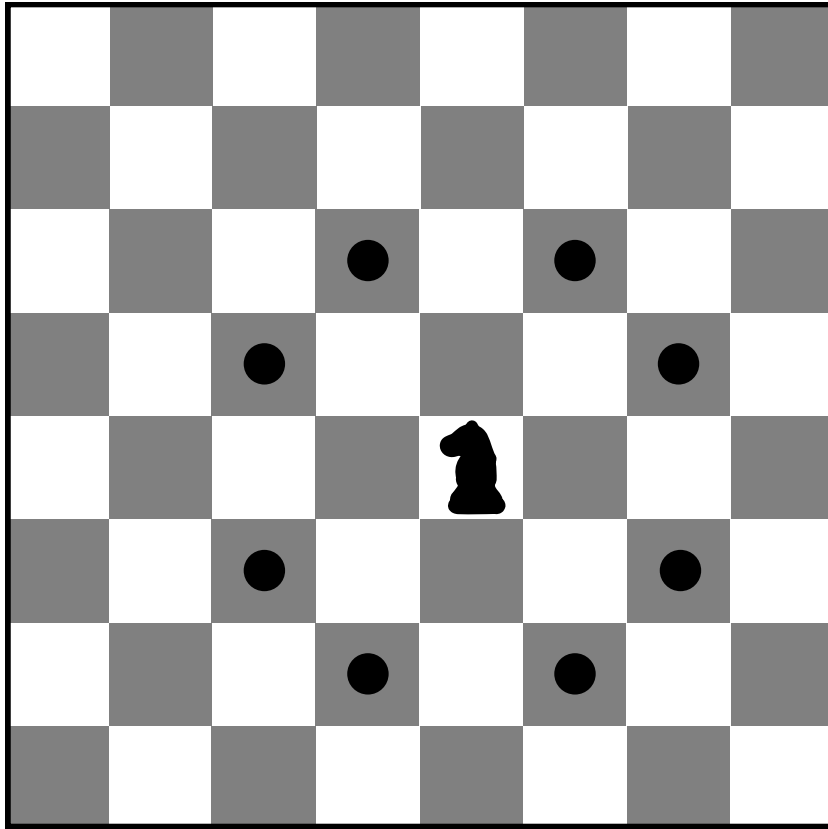
github.com/Djohnnie

johnny.hooyberghs@involved-it.be

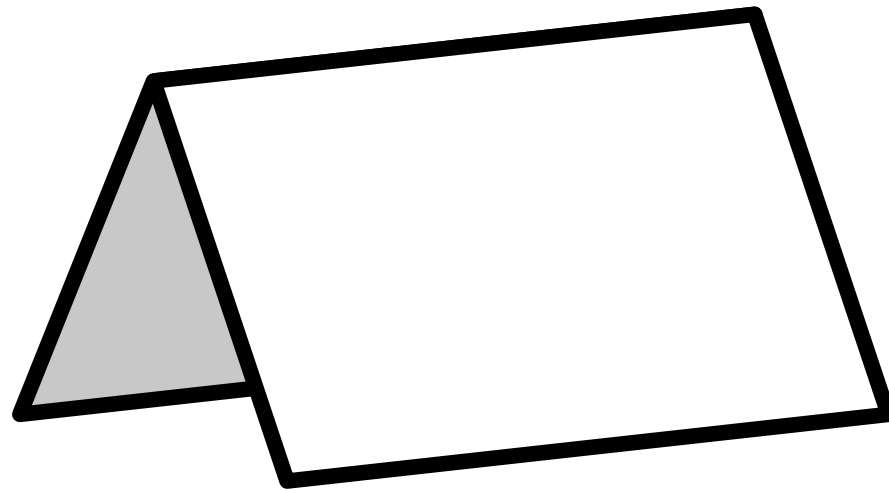


involved

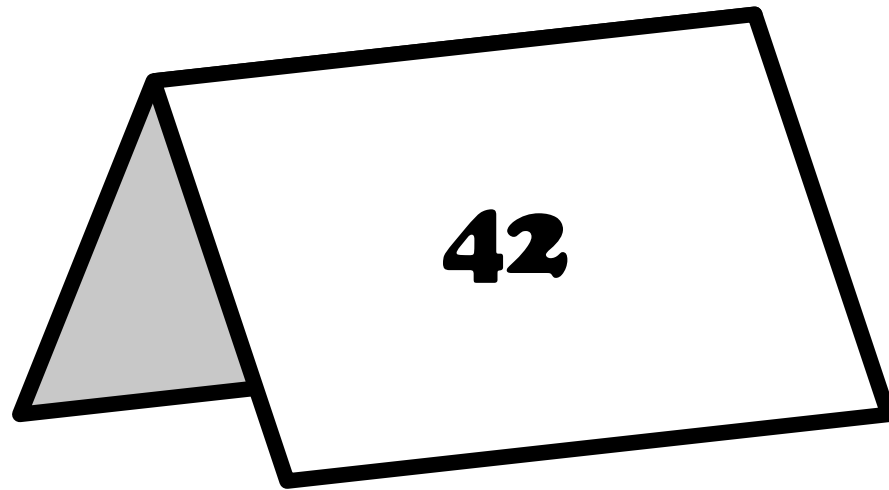
Why Quantum Computing?



Why Quantum Computing?

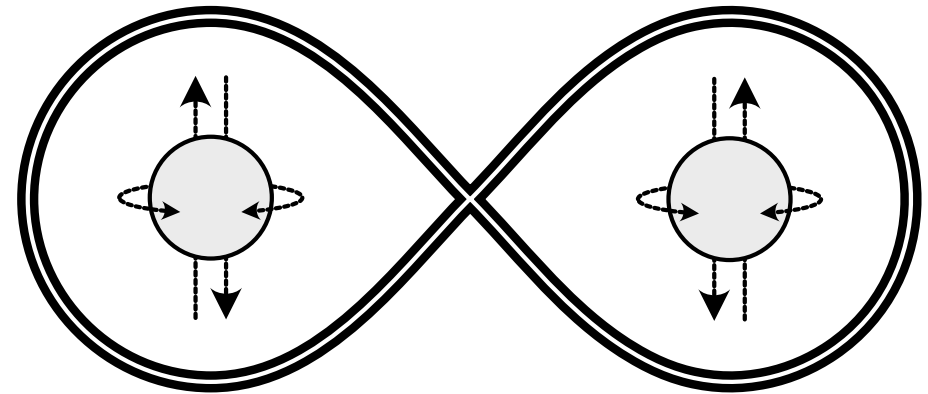
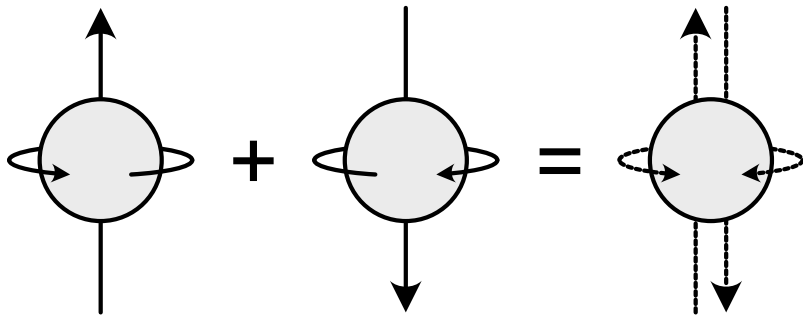


Why Quantum Computing?



Superposition and Entanglement

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



Why Quantum Computing?

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

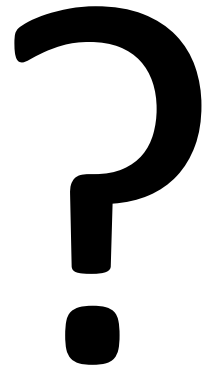
$$3.167 \times 6.301 = 19.955.267$$

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 CRYISIS?

Bits vs. Qubits

0

1

Bits vs. Qubits

1000110

Bits vs. Qubits

$|0\rangle$

$|1\rangle$

Bits vs. Qubits

$|100110\rangle$

Quantum state

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

Quantum state

$$\alpha |0\rangle + \beta |1\rangle$$
$$|\alpha|^2 + |\beta|^2 = 1$$

Quantum state

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

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

$$\alpha = a + bi$$

$$\beta = c + di$$

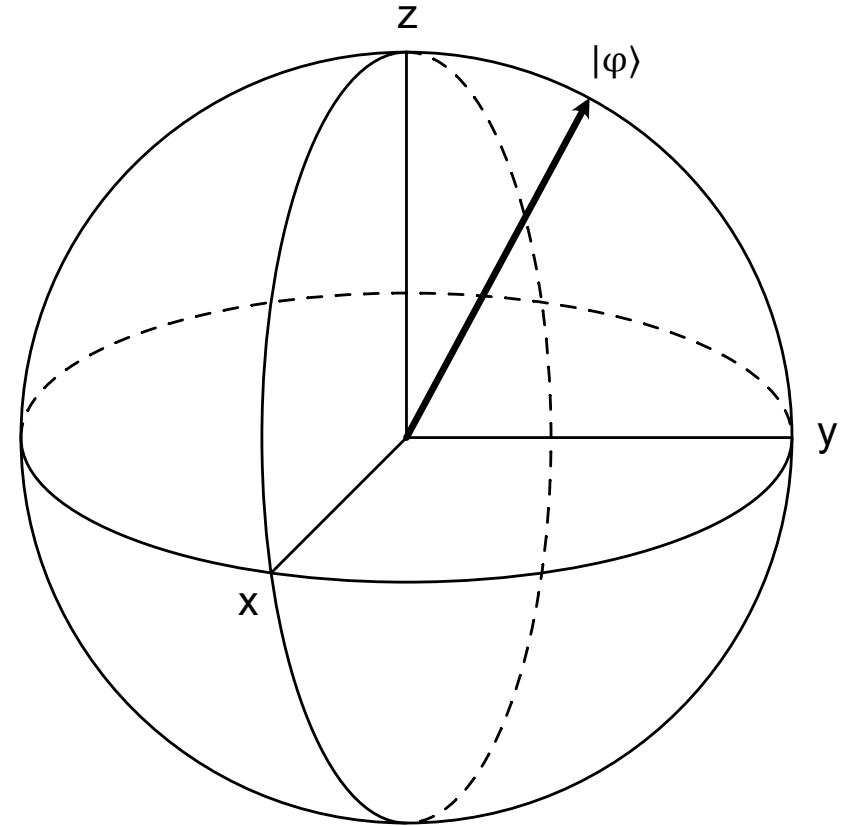
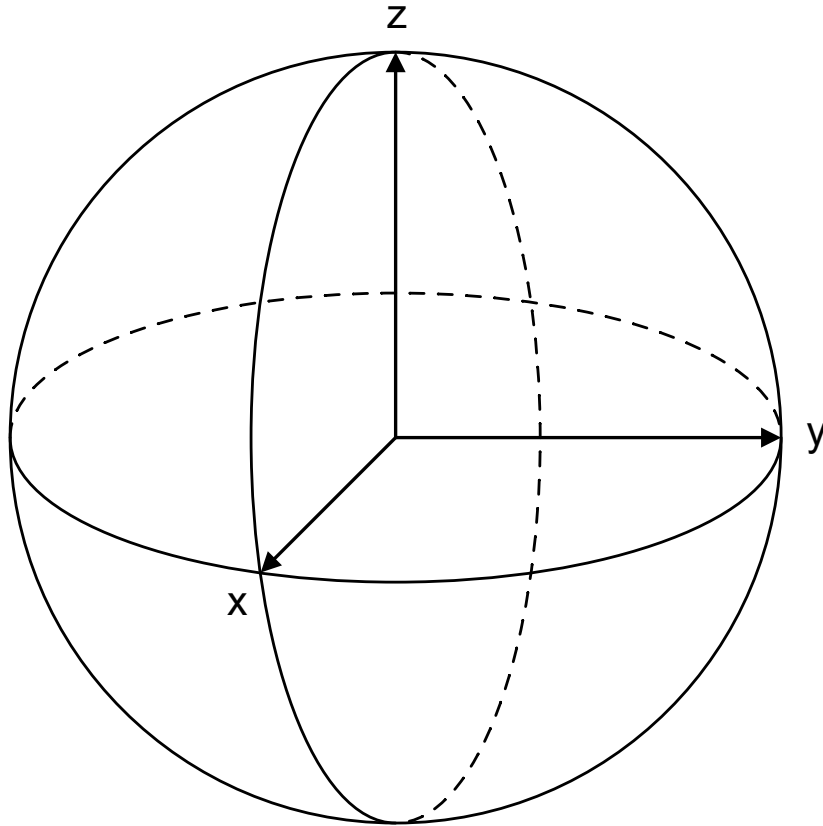
Quantum state

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

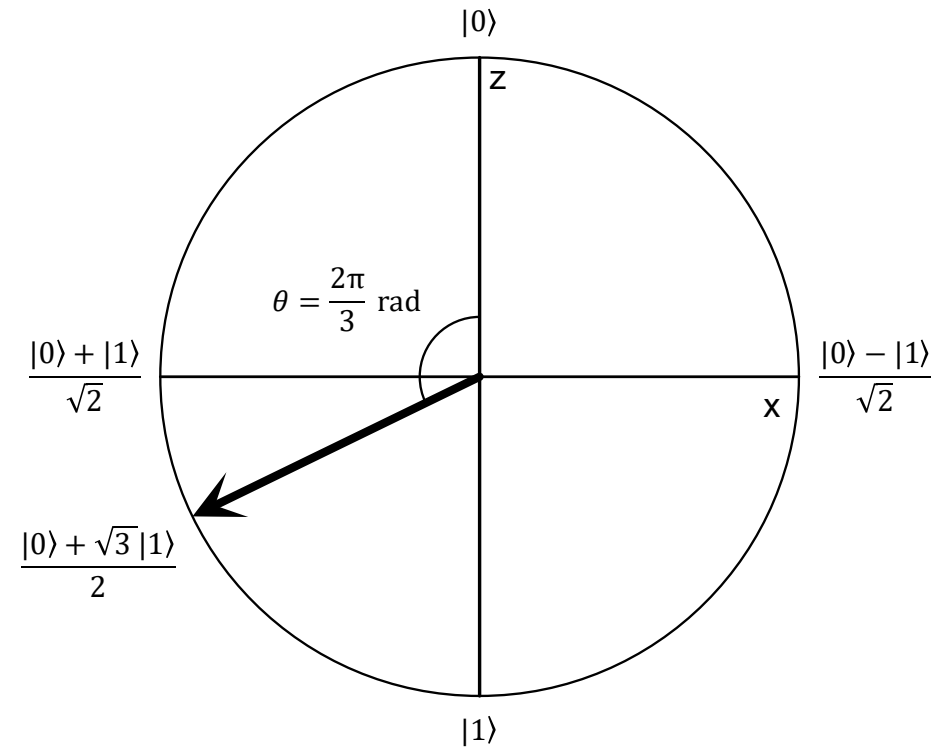
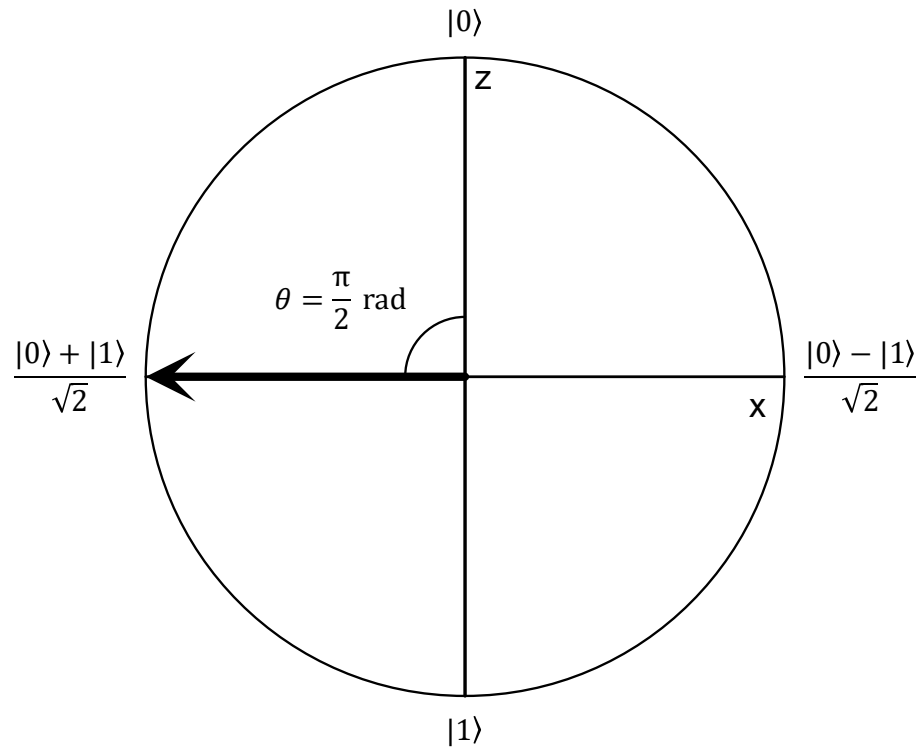
Quantum state

- Classical bit 0, Quantum bit $|0\rangle$
- Classical bit 1, Quantum bit $|1\rangle$
- Quantum bit in superposition
- $\alpha|0\rangle + \beta|1\rangle$ where $|\alpha|^2 + |\beta|^2 = 1$
- α and β are complex numbers ($ai + b$)
- Value known after measurement
- Collapses to $|0\rangle$ with probability $|\alpha|^2$ or $|1\rangle$ with probability $|\beta|^2$

Quantum state



Quantum state



Quantum state

- 2 Qubit system (4 probabilities):

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

Quantum state

- 2 Qubit system (4 probabilities):

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

- 3 Qubit system (8 probabilities):

$$\alpha|000\rangle + \beta|001\rangle + \gamma|010\rangle + \delta|011\rangle + \epsilon|100\rangle + \zeta|101\rangle + \eta|111\rangle$$

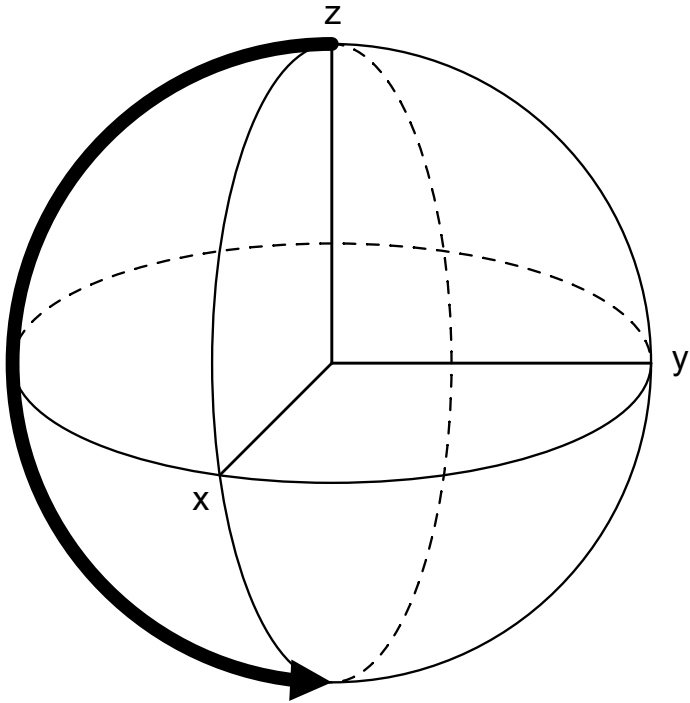
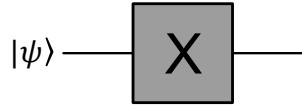
- 4 Qubit system (16 probabilities):

...

Quantum state

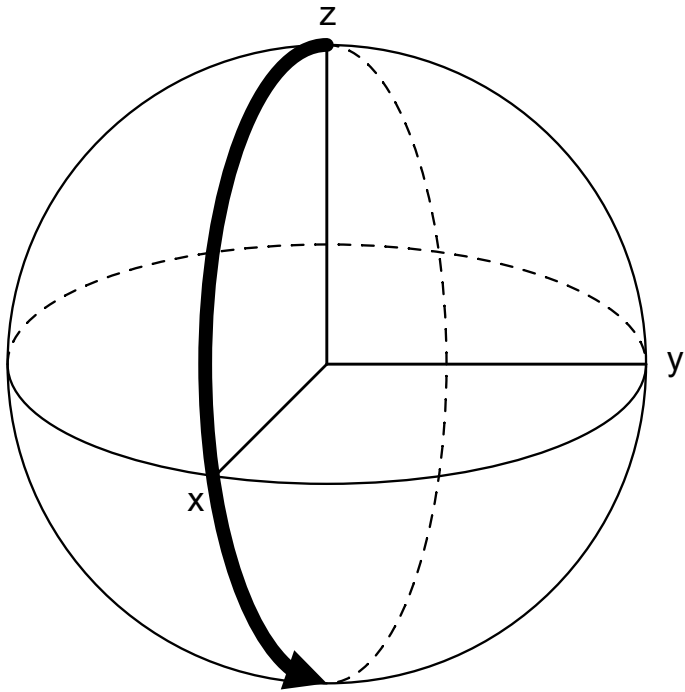
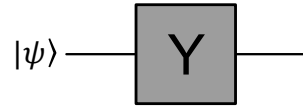
 $|0\rangle$ $\begin{pmatrix} 1 \\ 0 \end{pmatrix}$ $|1\rangle$ $\begin{pmatrix} 0 \\ 1 \end{pmatrix}$

X-gate



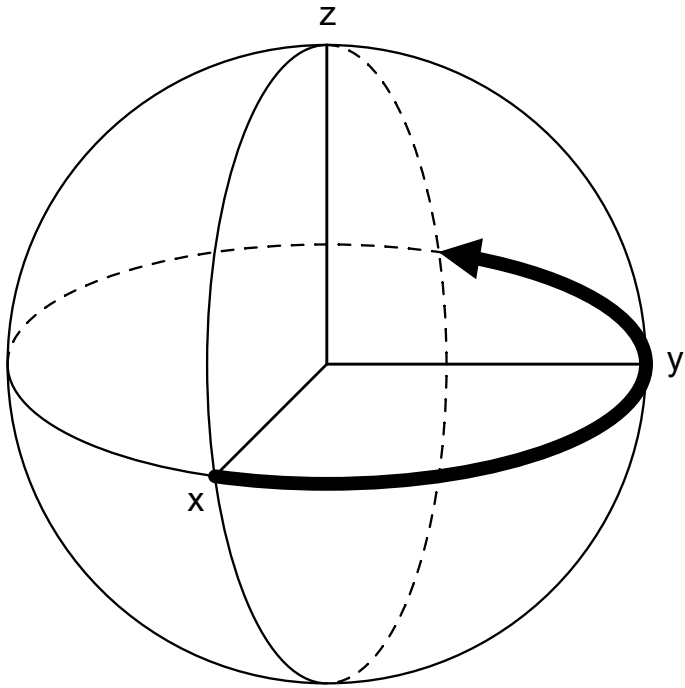
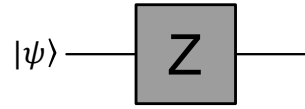
$$\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

Y-gate



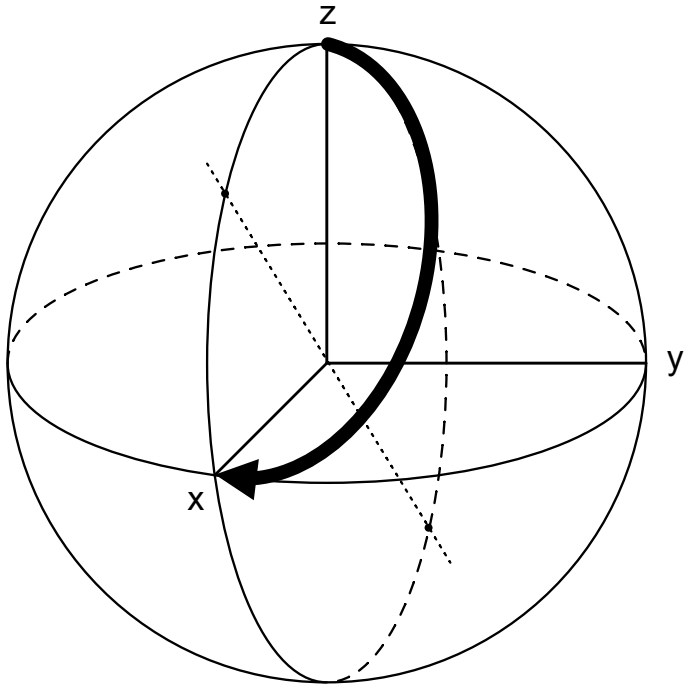
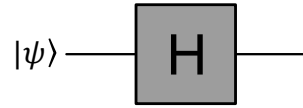
$$\begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$$

Z-gate



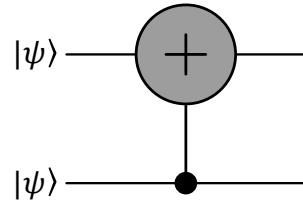
$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

H-gate



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

CNOT-gate



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

Microsoft Q#

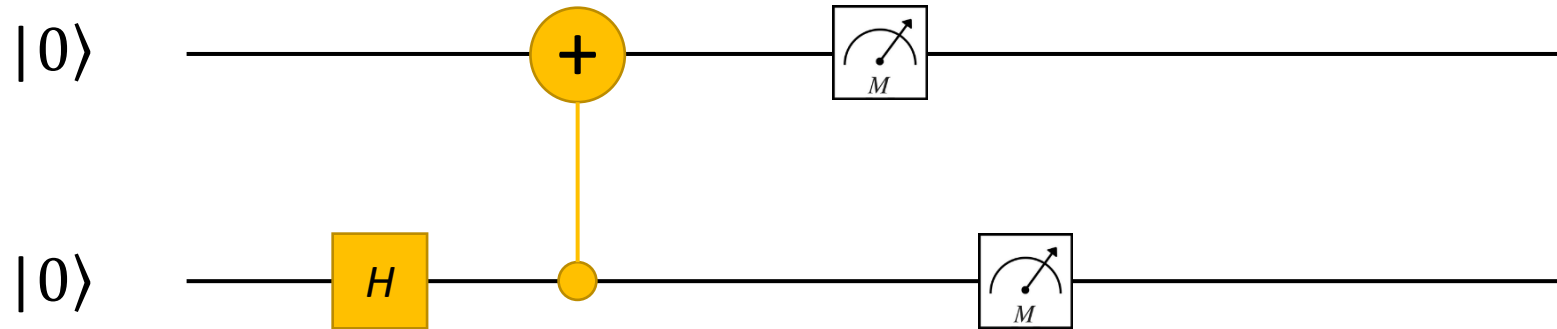
<https://www.microsoft.com/en-us/quantum/development-kit>



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



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

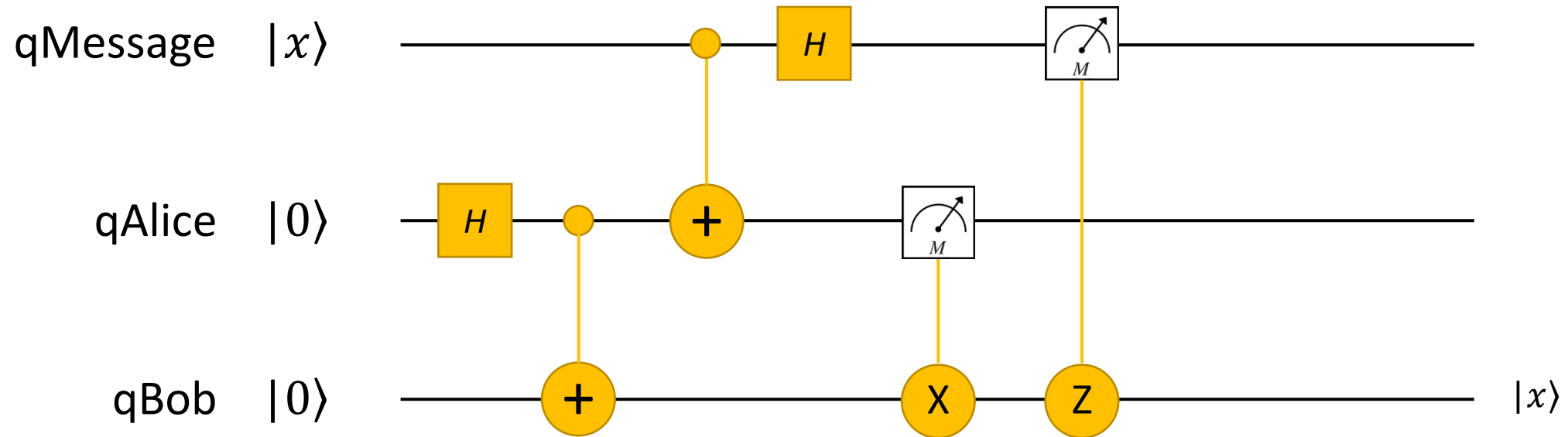
Entanglement

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

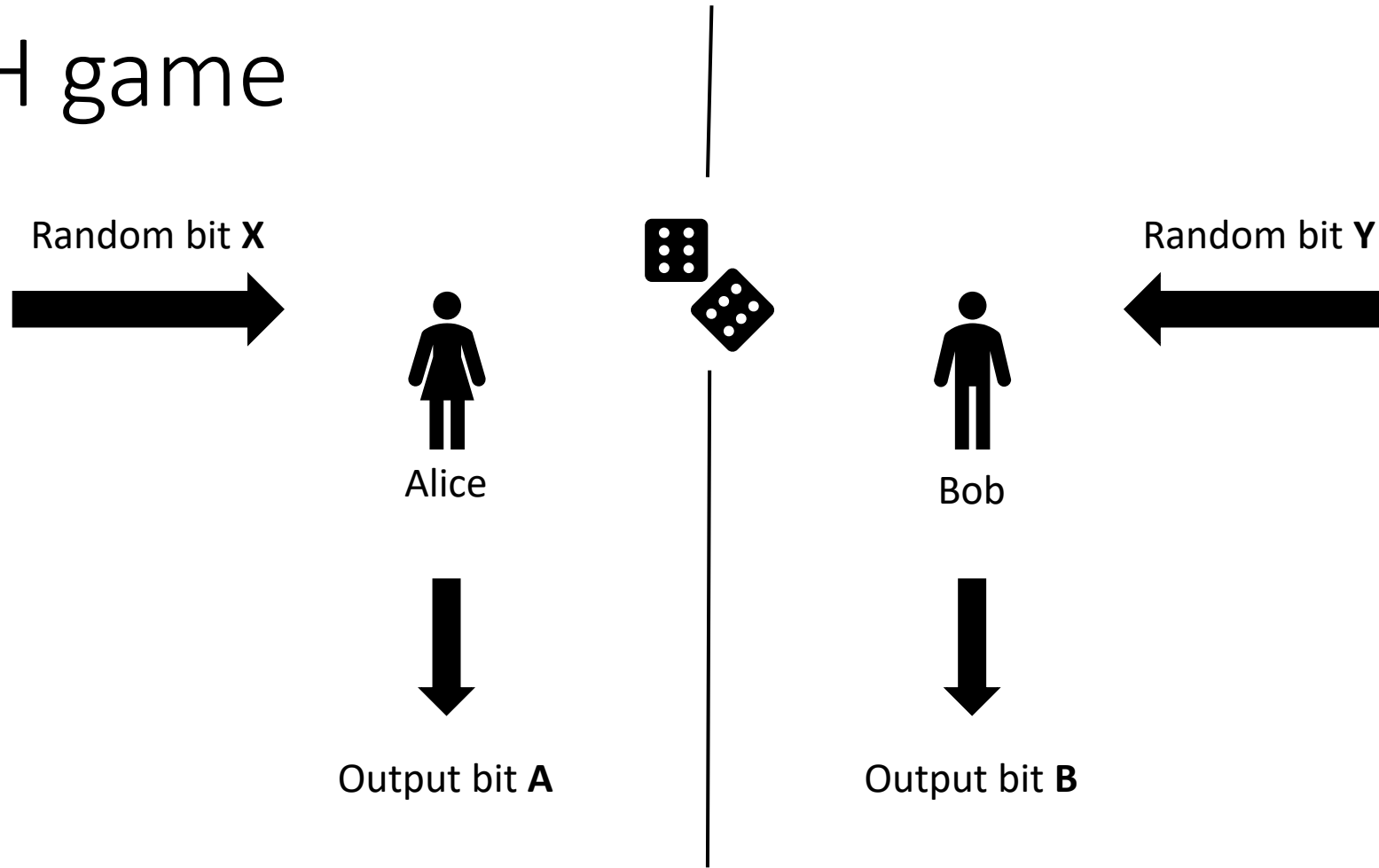
$$\begin{pmatrix} \frac{1}{\sqrt{2}} \\ 0 \\ 0 \\ \frac{1}{\sqrt{2}} \end{pmatrix} = \begin{pmatrix} a \\ b \end{pmatrix} \otimes \begin{pmatrix} c \\ d \end{pmatrix} \rightarrow \begin{aligned} ac &= \frac{1}{\sqrt{2}} \\ ad &= 0 \\ bc &= 0 \\ bd &= \frac{1}{\sqrt{2}} \end{aligned}$$

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

Teleportation

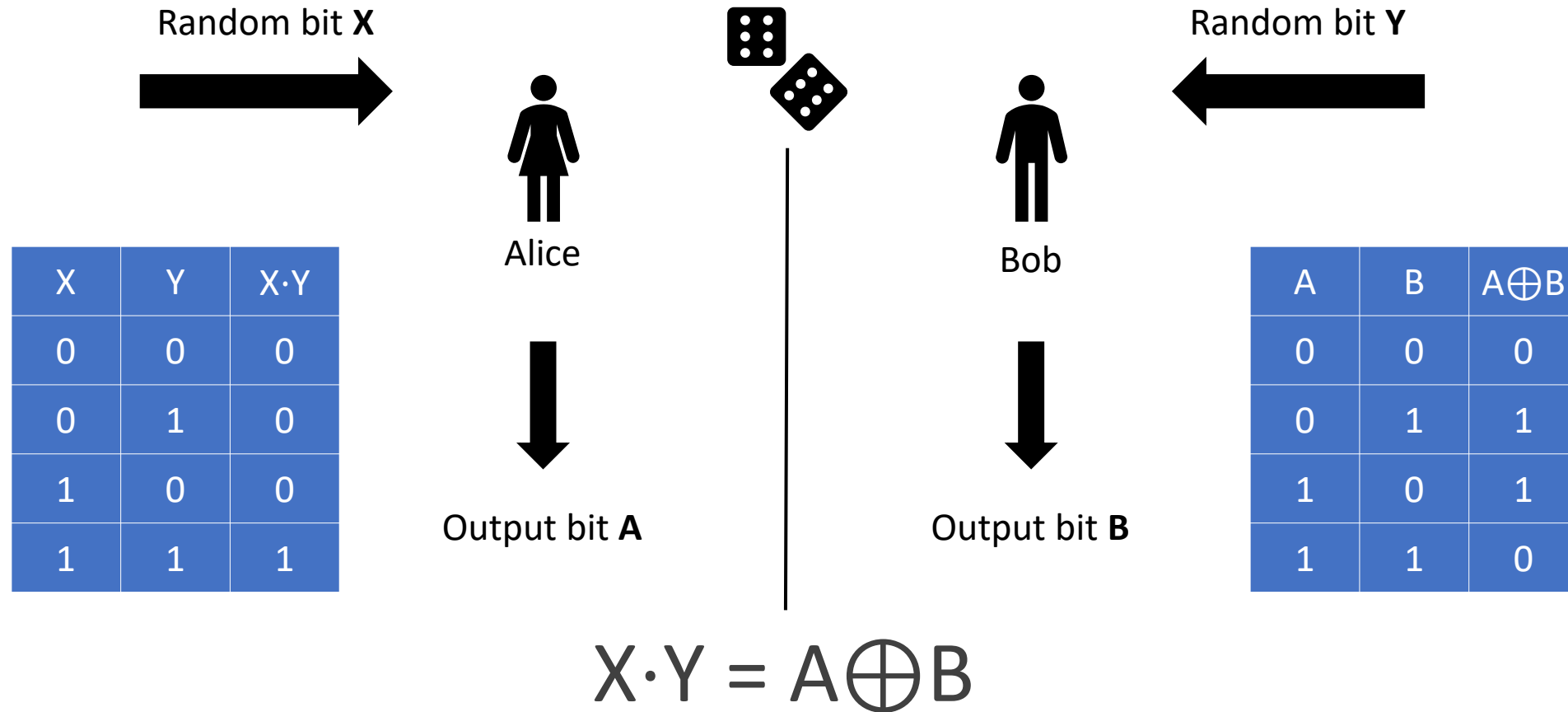


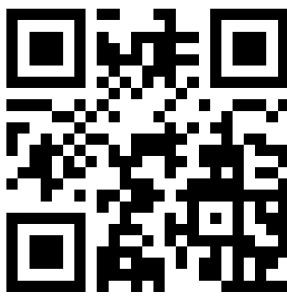
CHSH game



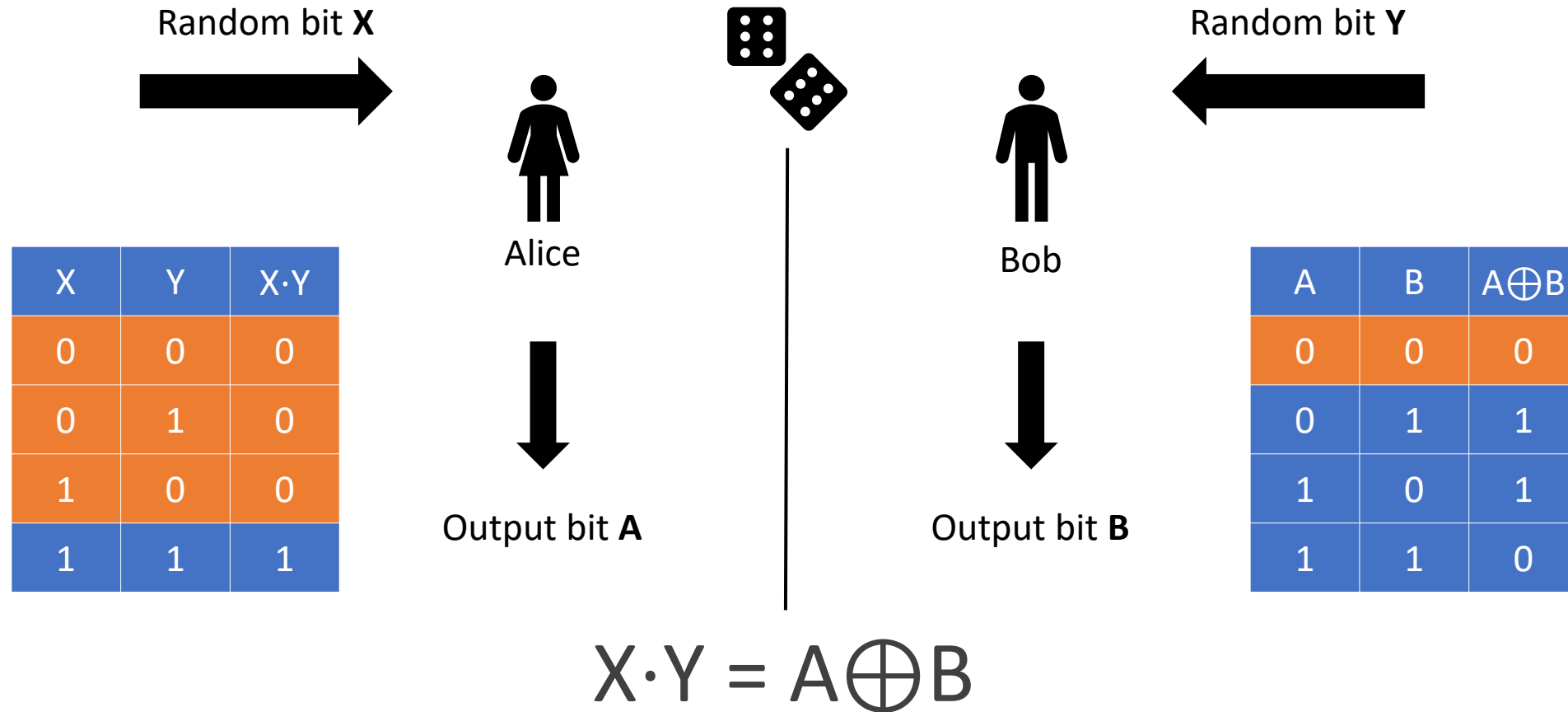
$$X \cdot Y = A \oplus B$$

CHSH game

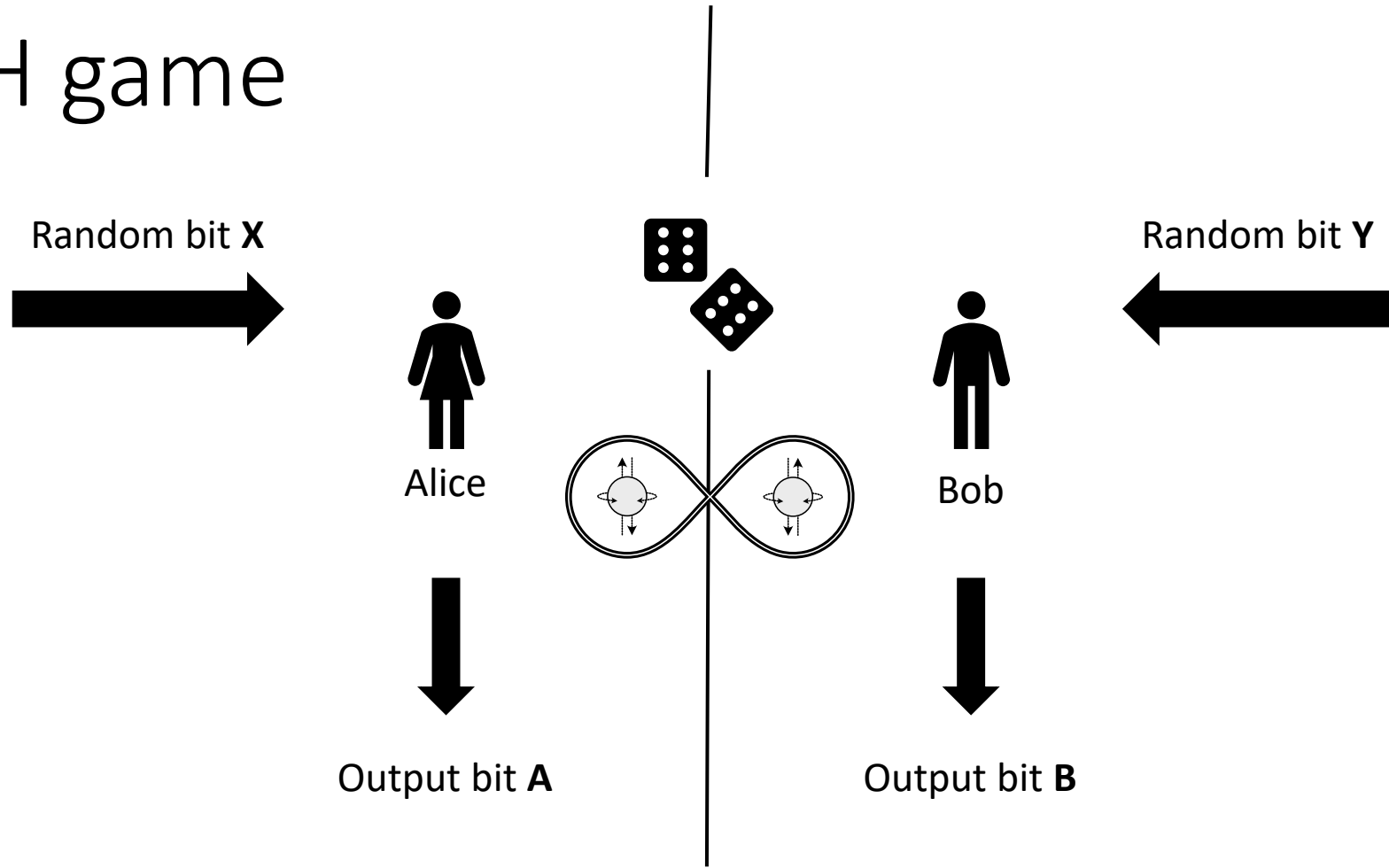




CHSH game

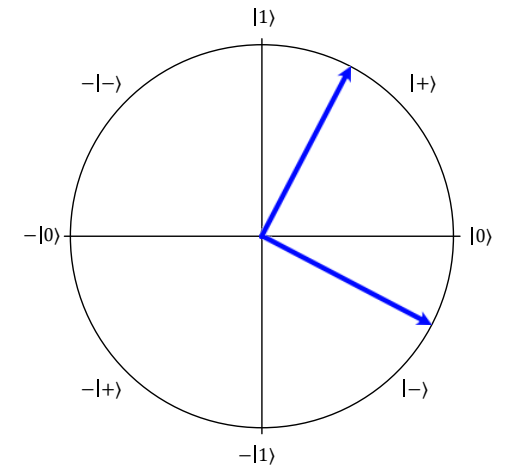
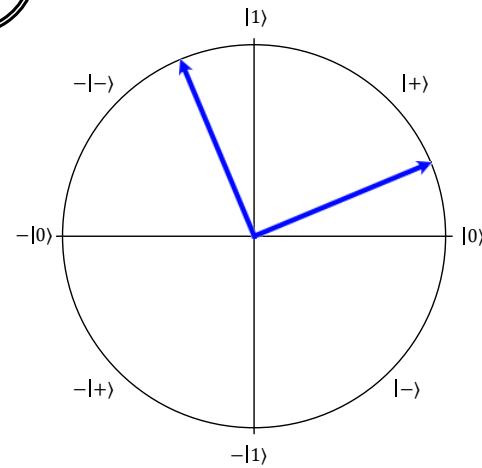
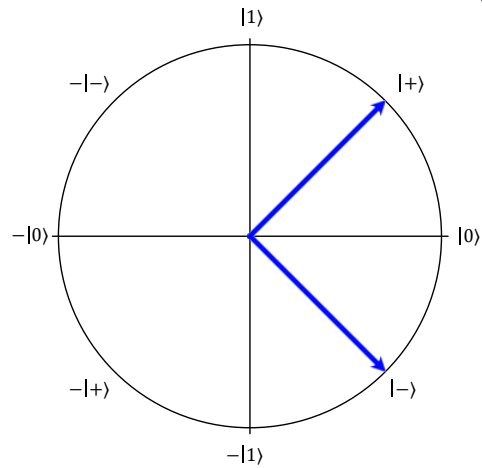
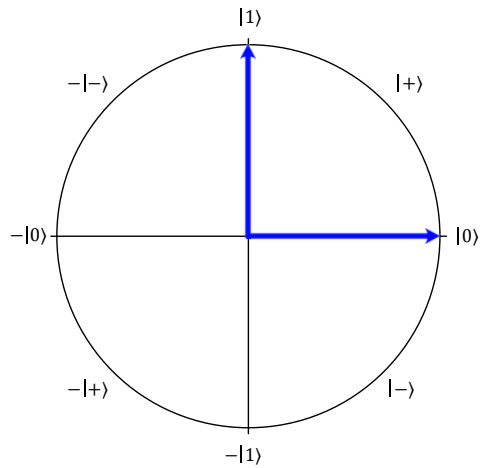
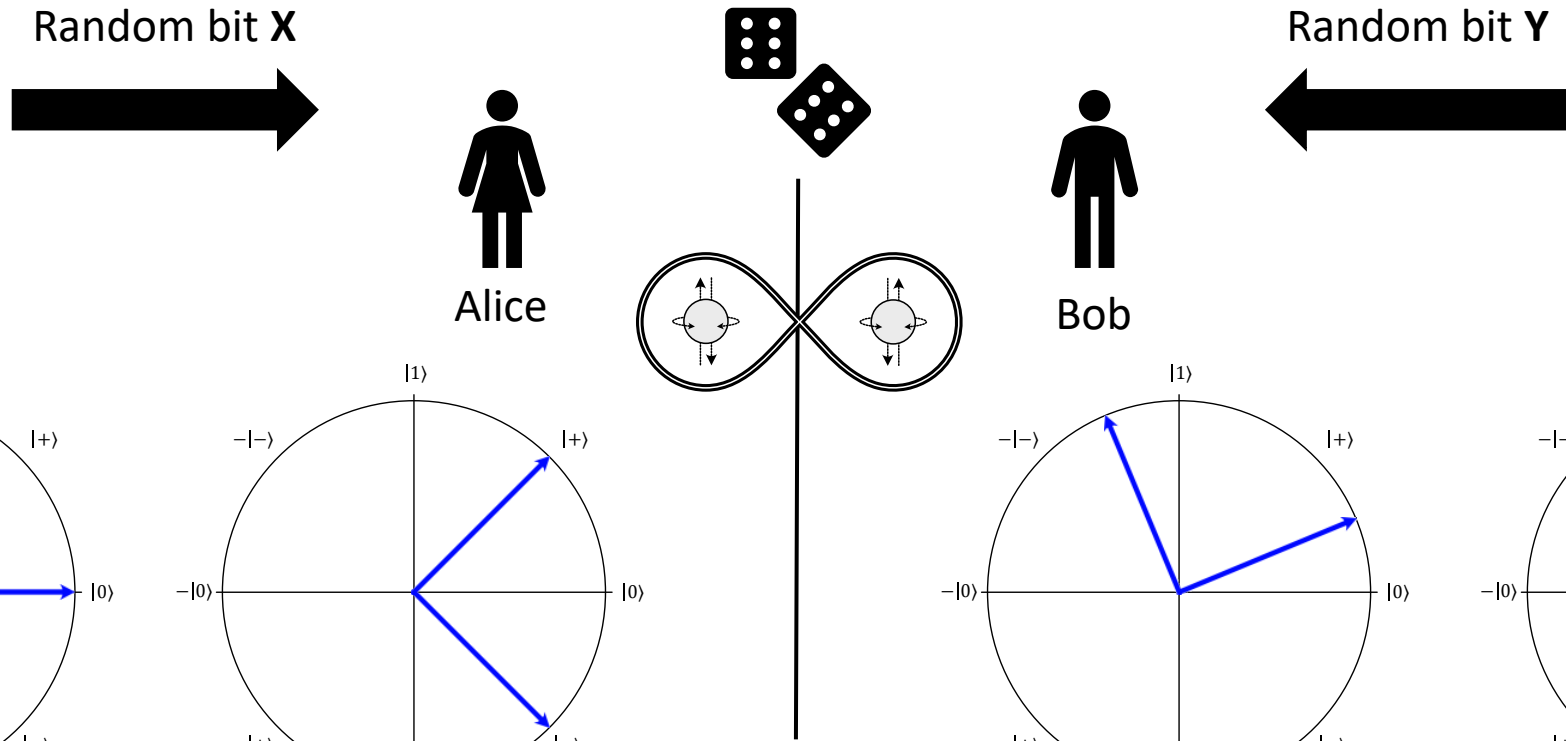


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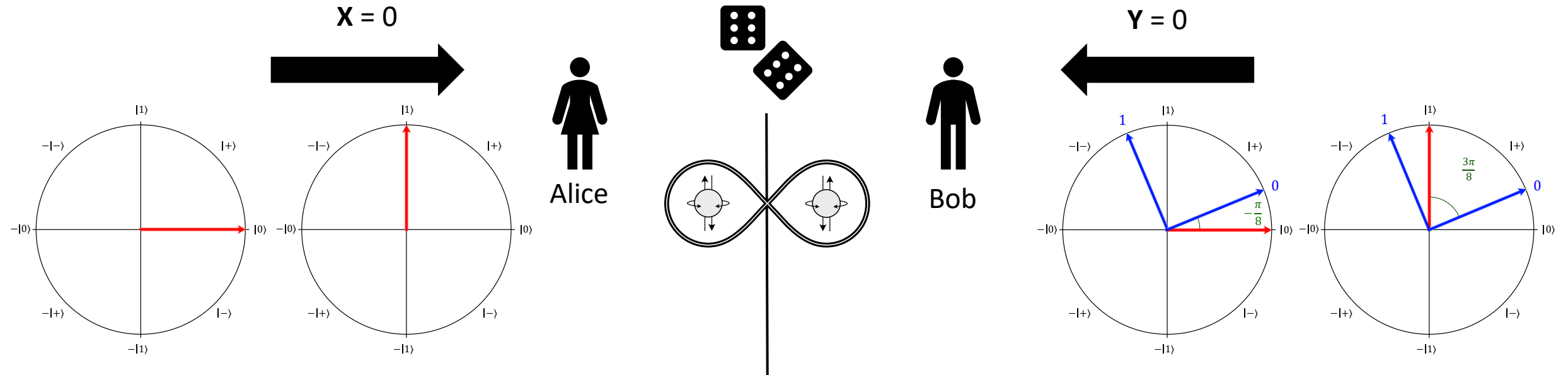


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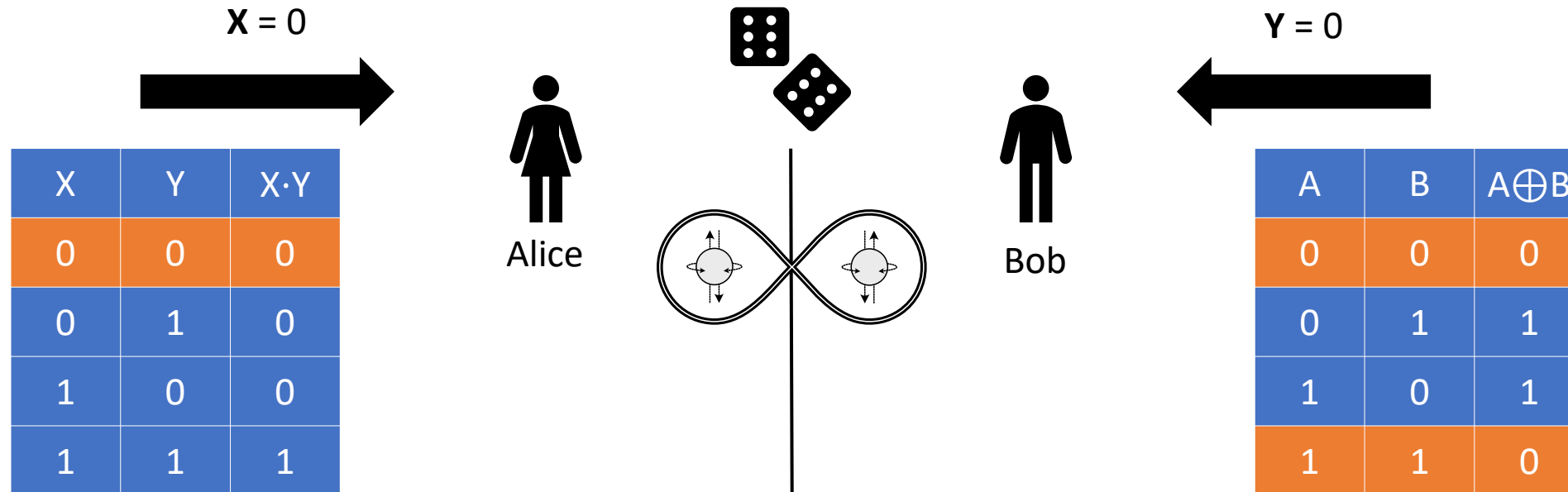


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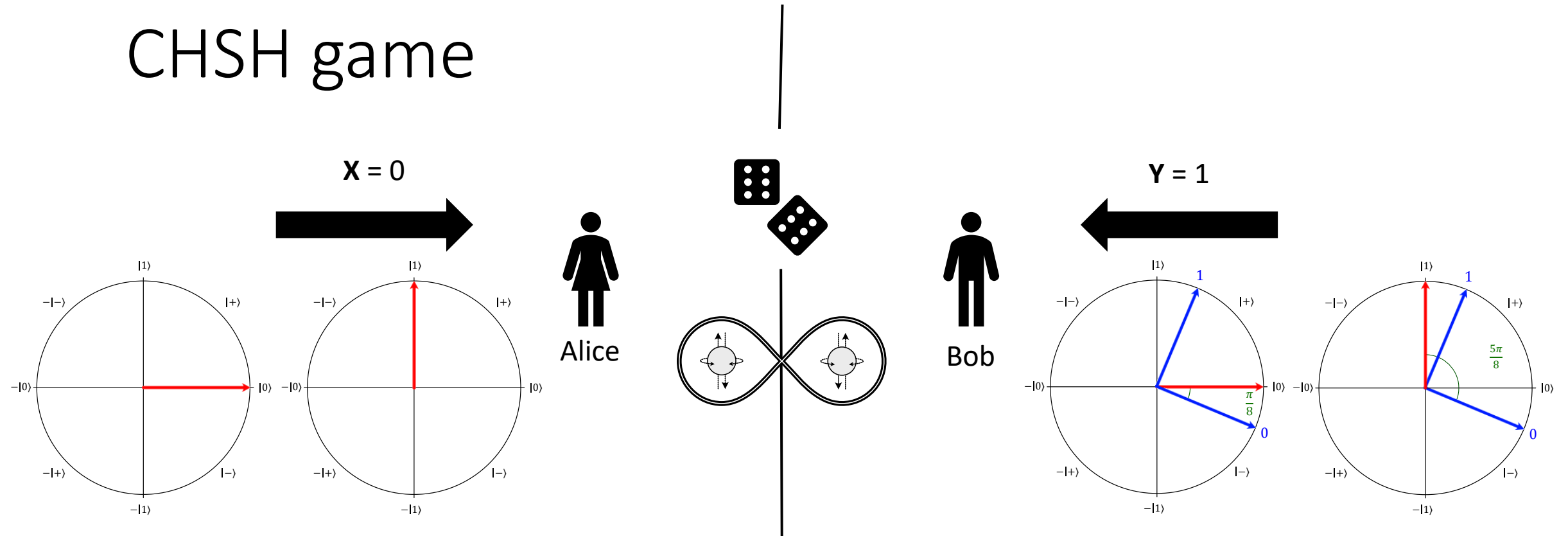
Alice outputs	Bob's qbit	Bob outputs 0 with probability	Bob outputs 1 with probability
0	$ 0\rangle$	$\cos^2\left(-\frac{\pi}{8}\right) \approx 0.85$	$\sin^2\left(-\frac{\pi}{8}\right) \approx 0.15$
1	$ 1\rangle$	$\cos^2\left(\frac{3\pi}{8}\right) \approx 0.15$	$\sin^2\left(\frac{3\pi}{8}\right) \approx 0.85$

CHSH game



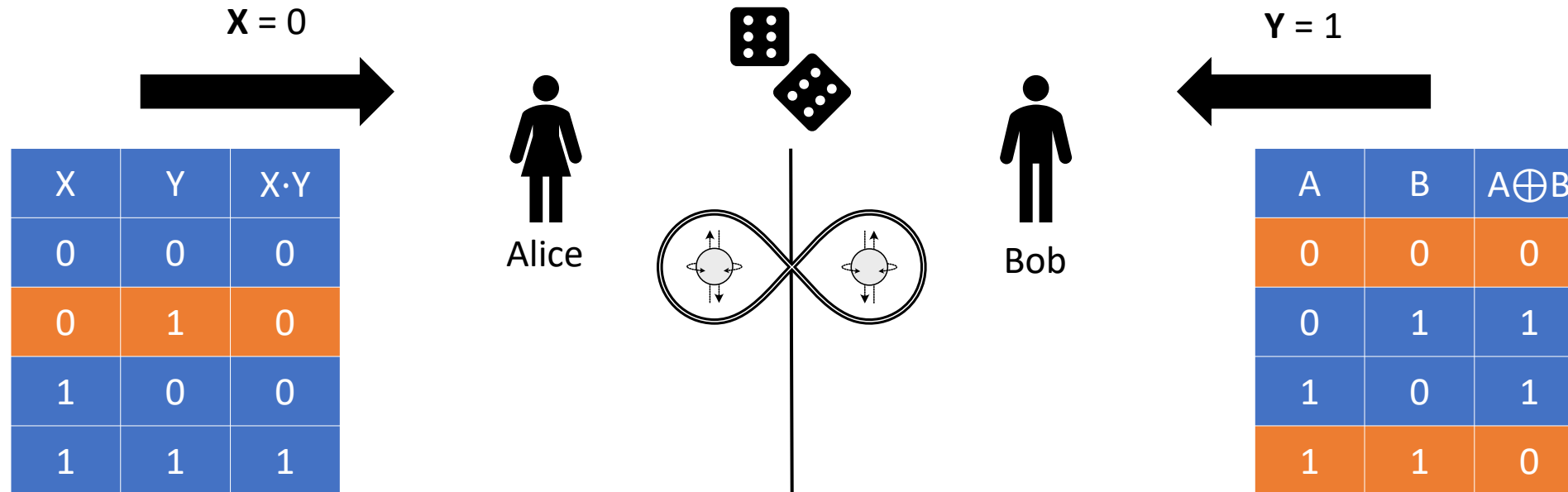
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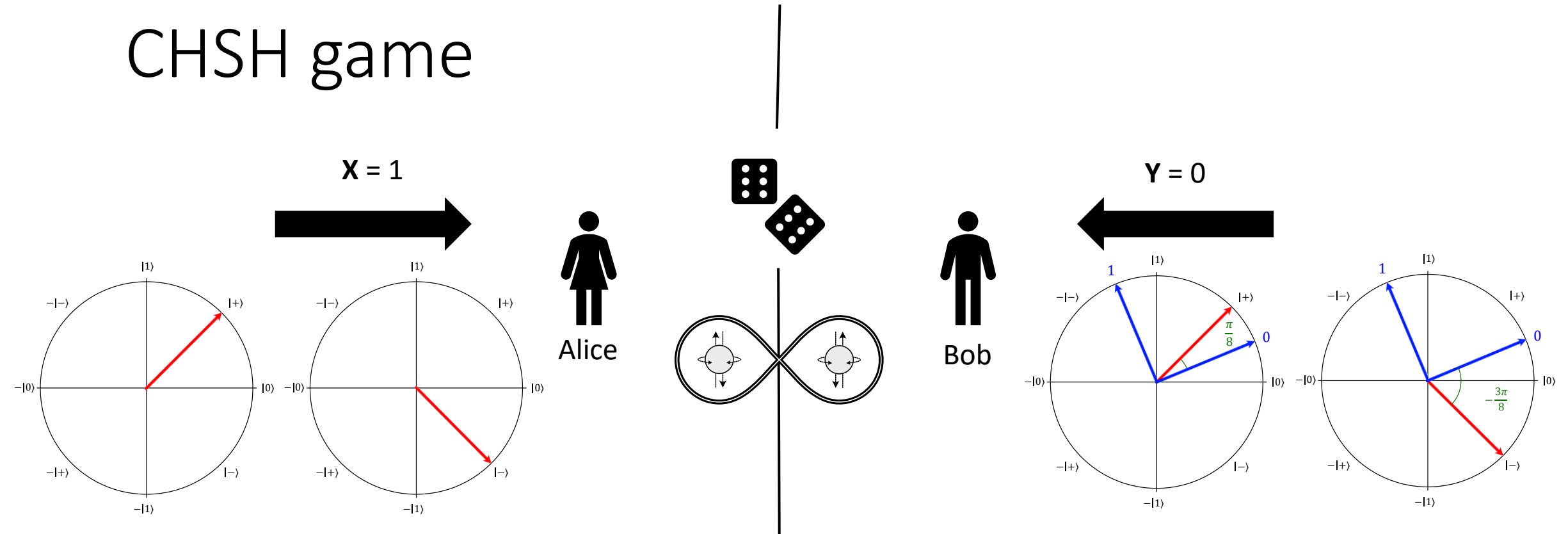
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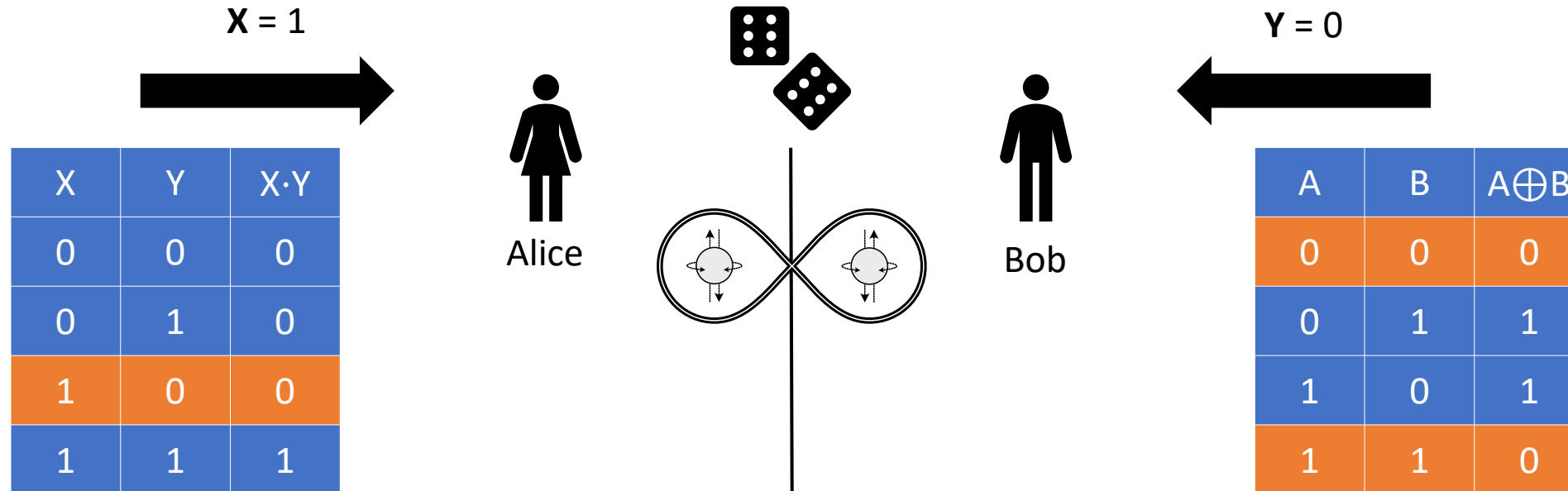
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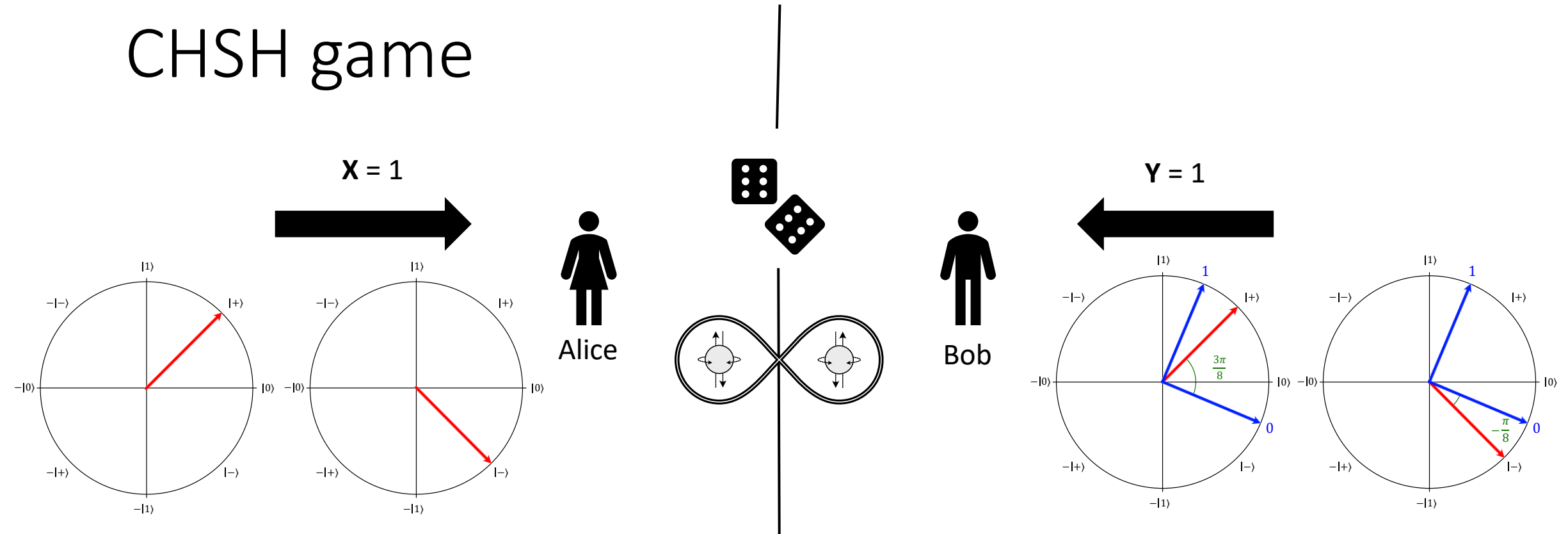
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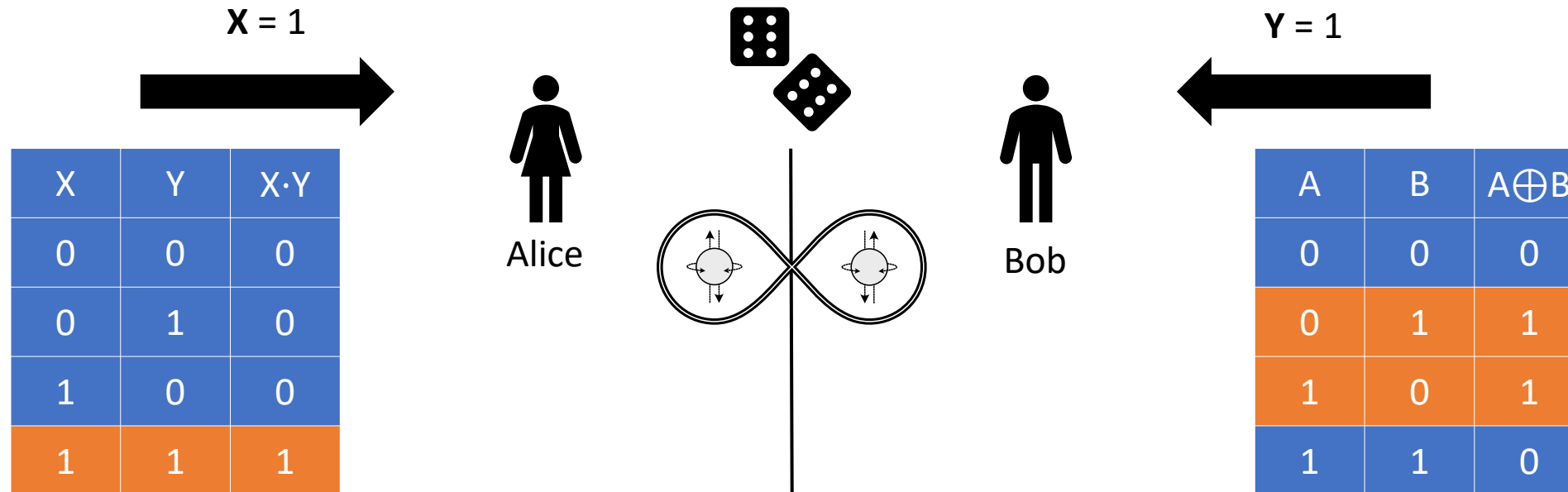
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CHSH game



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<https://github.com/Djohnnie/QSharp-and-AzureQuantum-NDCLondon-2021>