TechTrain Mechelen

Johnny Hooyberghs

Microsoft Q# and Azure Quantum

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Johnny Hooyberghs

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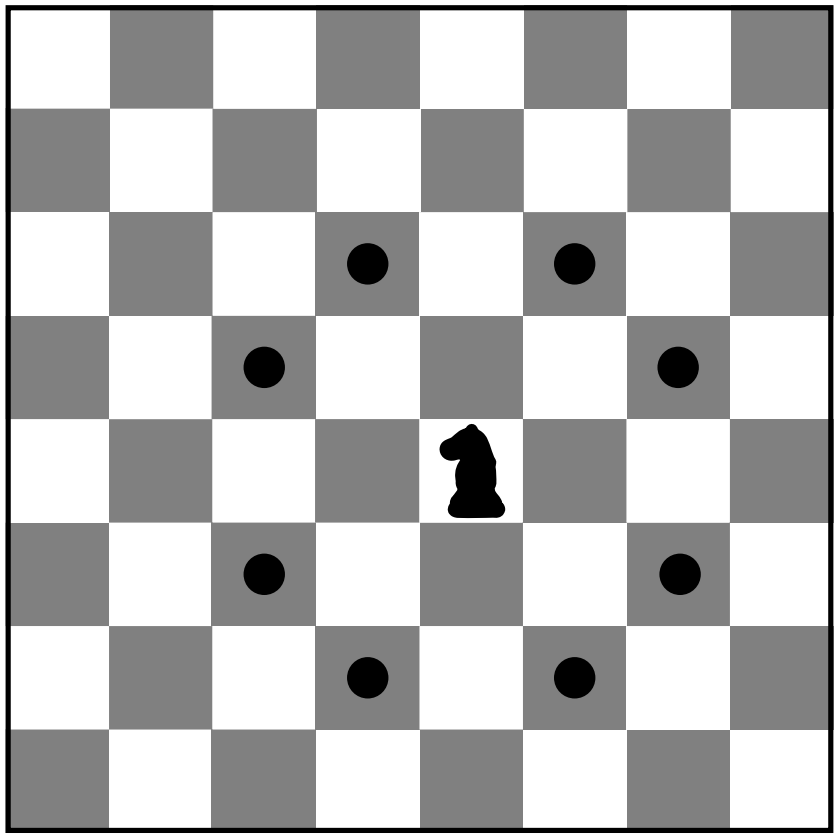
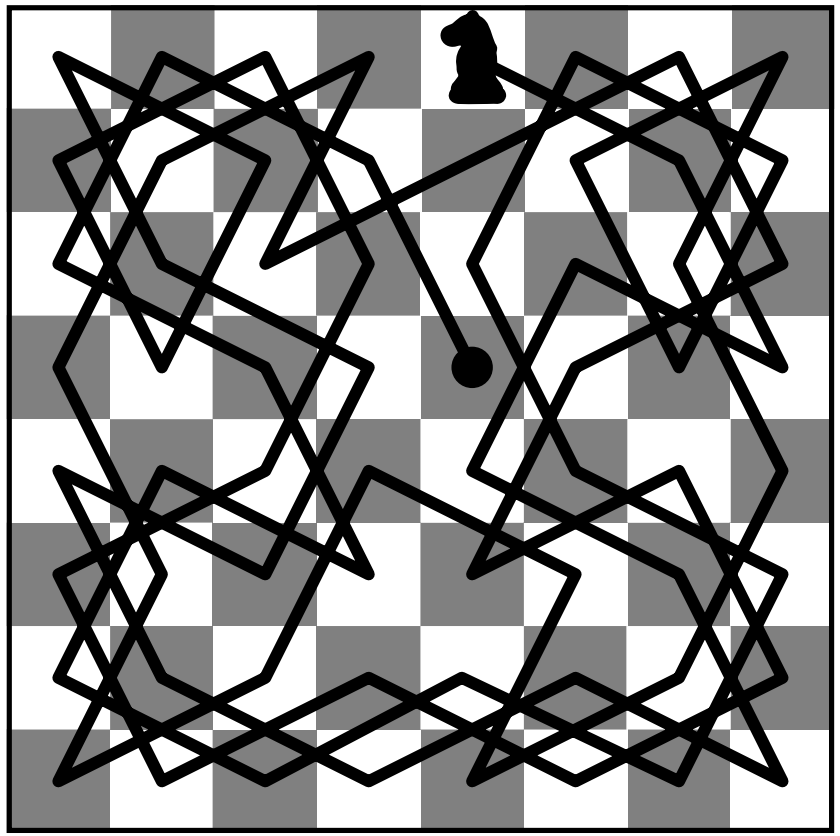
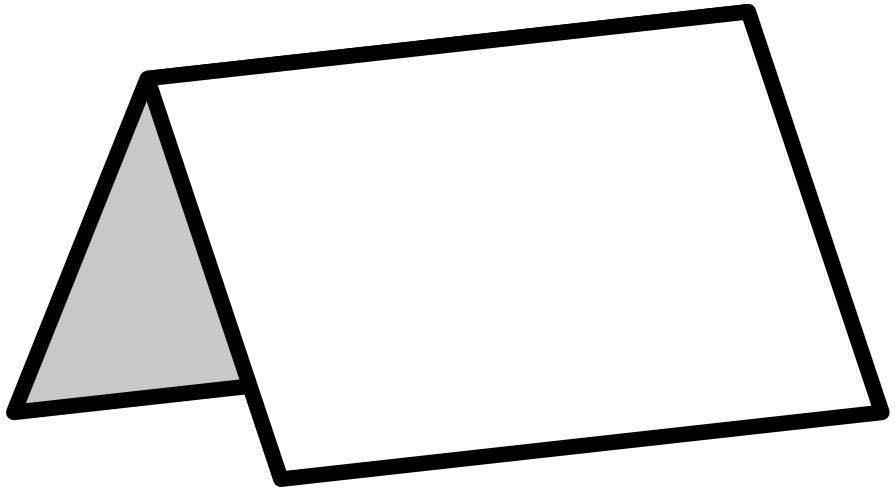
Why Quantum Computing?



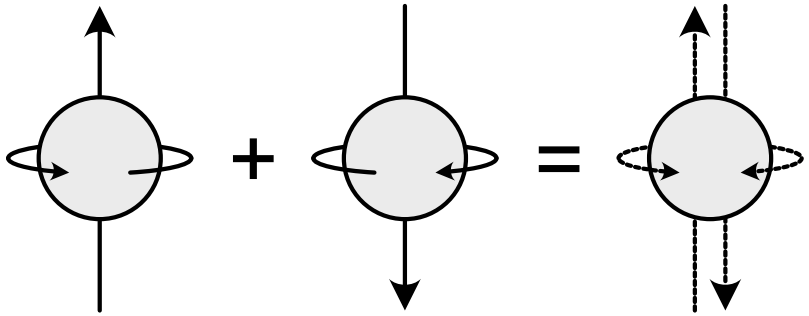


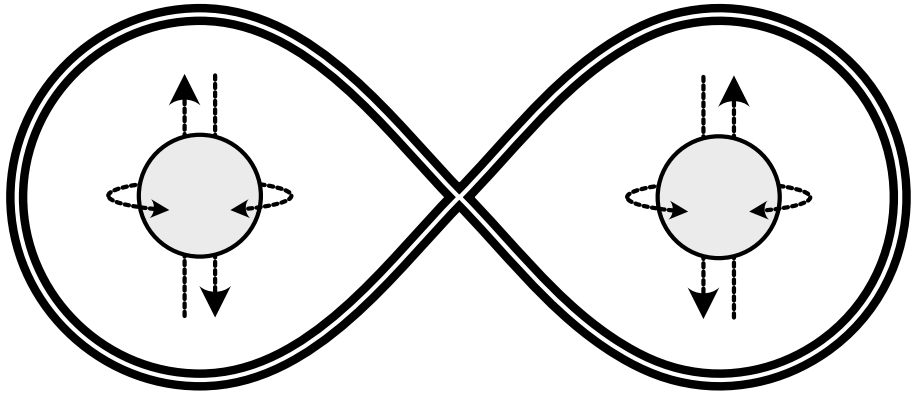
Why Quantum Computing?



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 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

0 1

Bits vs. Qubits

1 0 0 1 1 0

Bits vs. Qubits

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

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

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

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

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

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

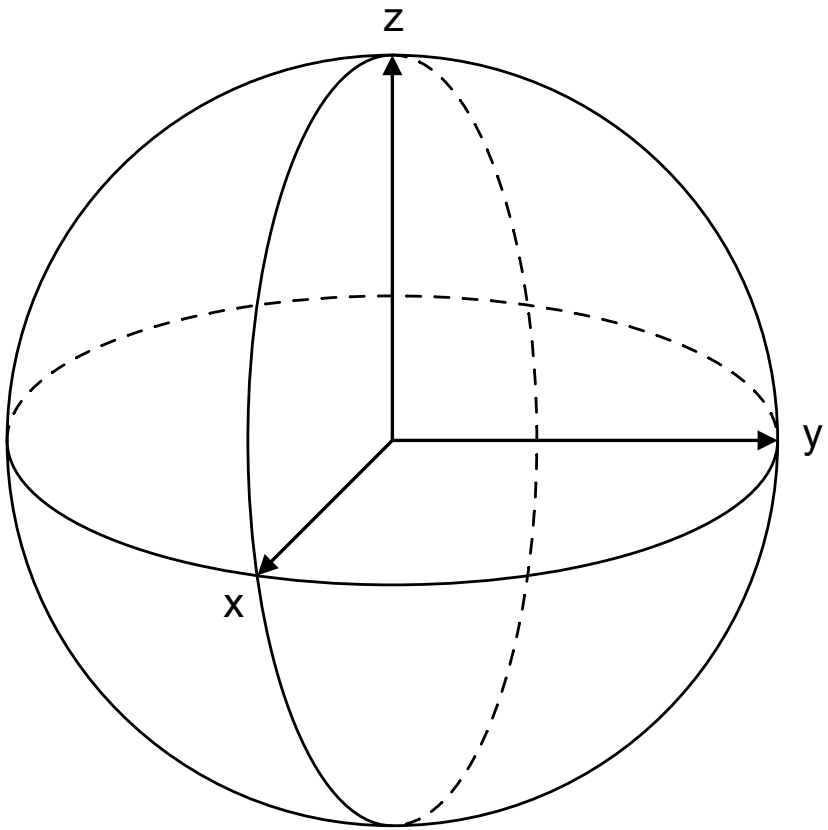
Quantum state

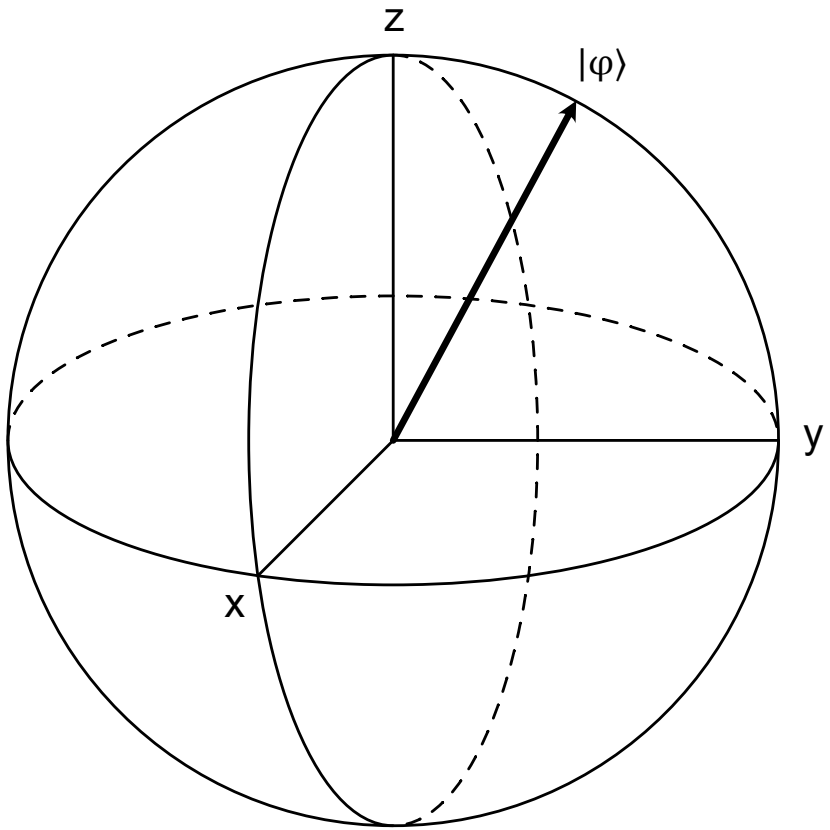
$$\frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

Quantum state

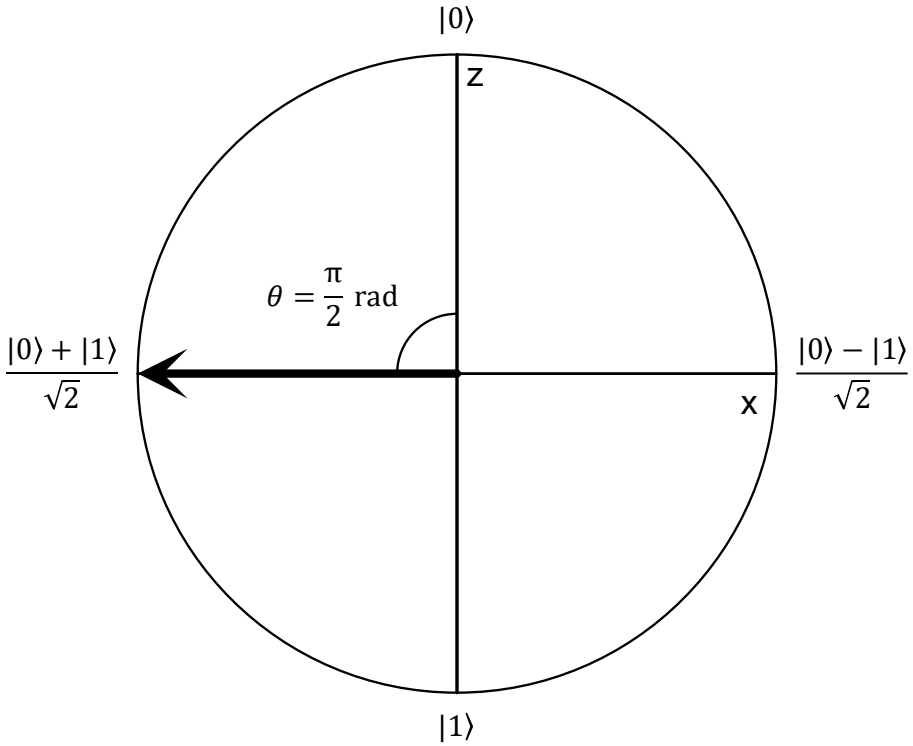
- Classical bit 0, Quantum bit $|0\rangle$
- Classical bit 1, Quantum bit $|1\rangle$
- Quantum bit in superposition
- $\boldsymbol{\alpha}|0\rangle + \boldsymbol{\beta}|1\rangle$ where $|\boldsymbol{\alpha}|^2 + |\boldsymbol{\beta}|^2 = 1$
- $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are complex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

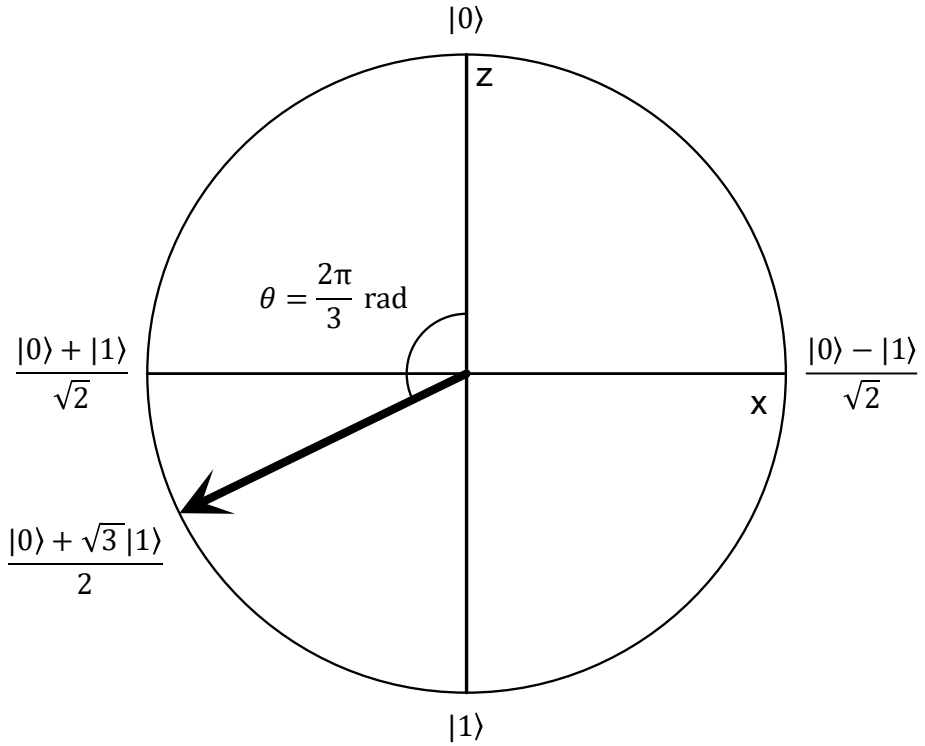
Quantum state





Quantum state





Quantum state

- 2 Qubit system (4 probabilities):

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

Quantum state

- 2 Qubit system (4 probabilities):

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

- 3 Qubit system (8 probabilities):

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

- 4 Qubit system (16 probabilities):

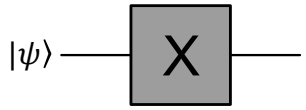
…

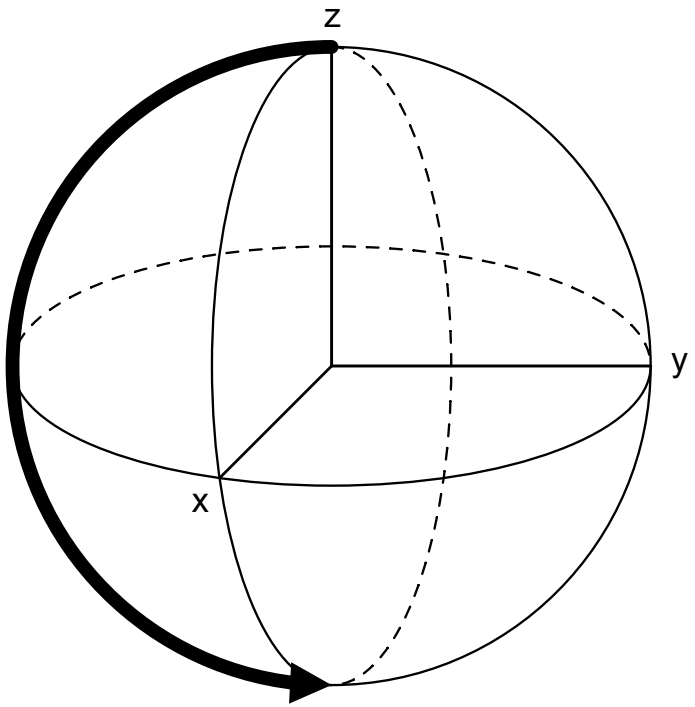
Quantum state

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

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

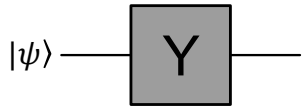
X-gate

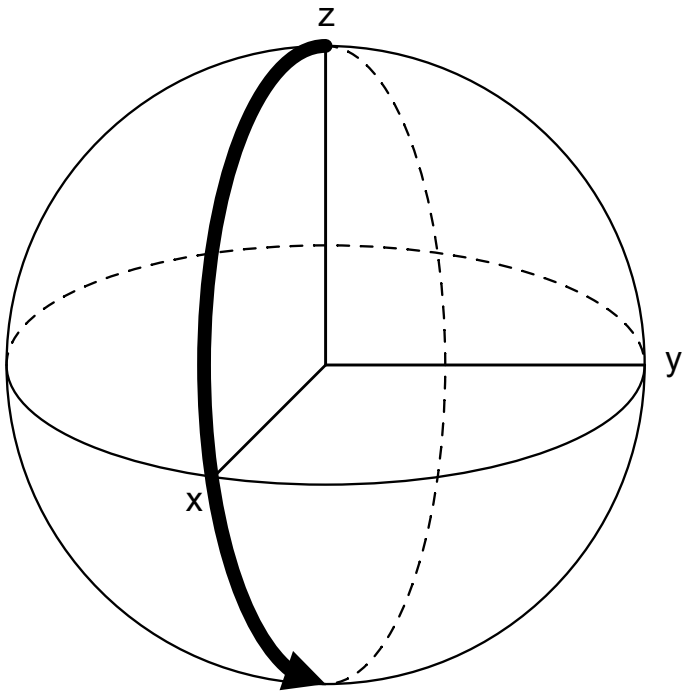




$$\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

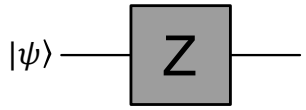
Y-gate

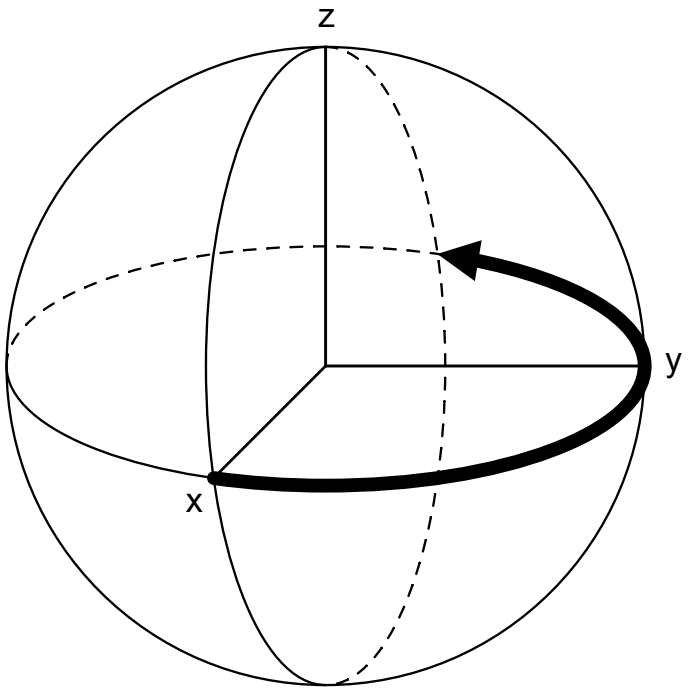




$$\begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$$

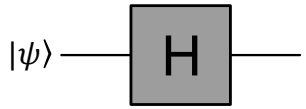
Z-gate

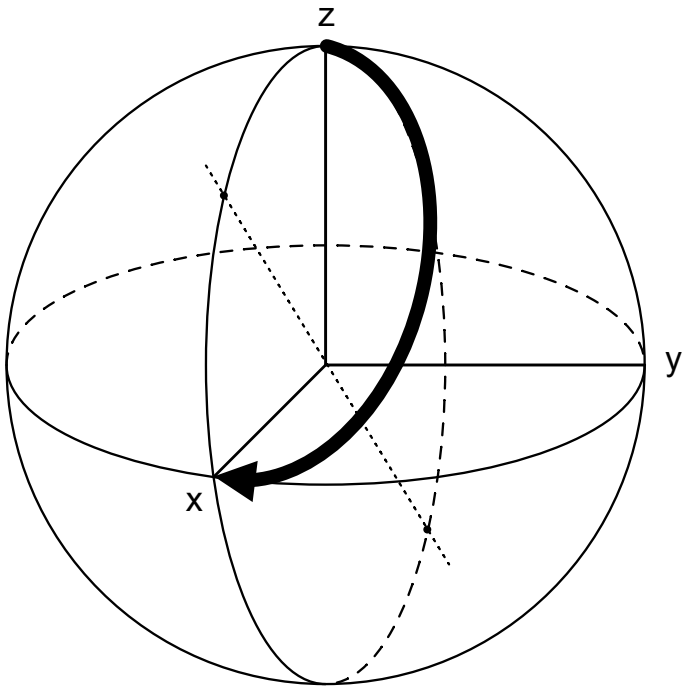




$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

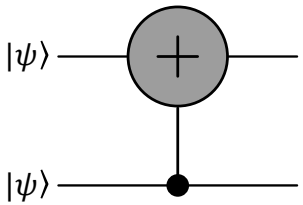
H-gate





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

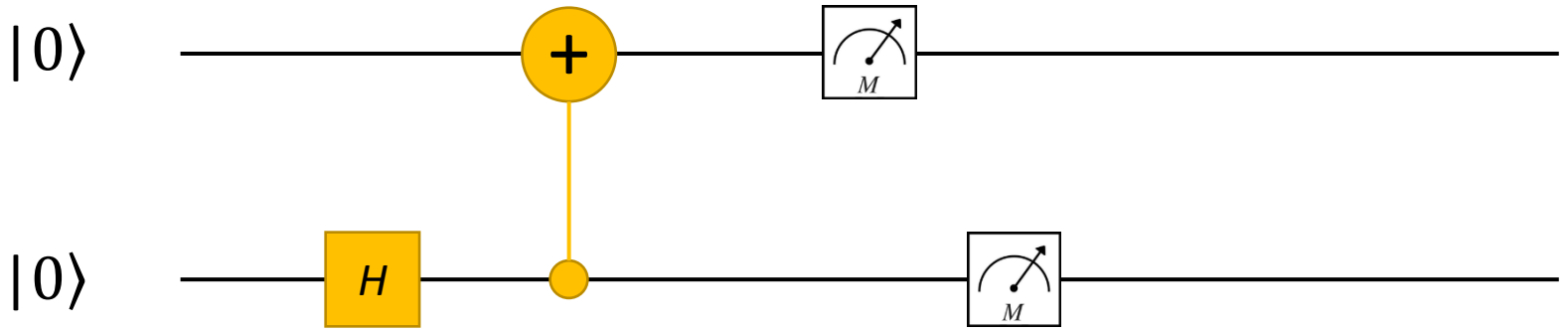
CNOT-gate



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

https://github.com/Djohnnie/QSharp-and-AzureQuantum-CanaryWharf-2020

Entanglement



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

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

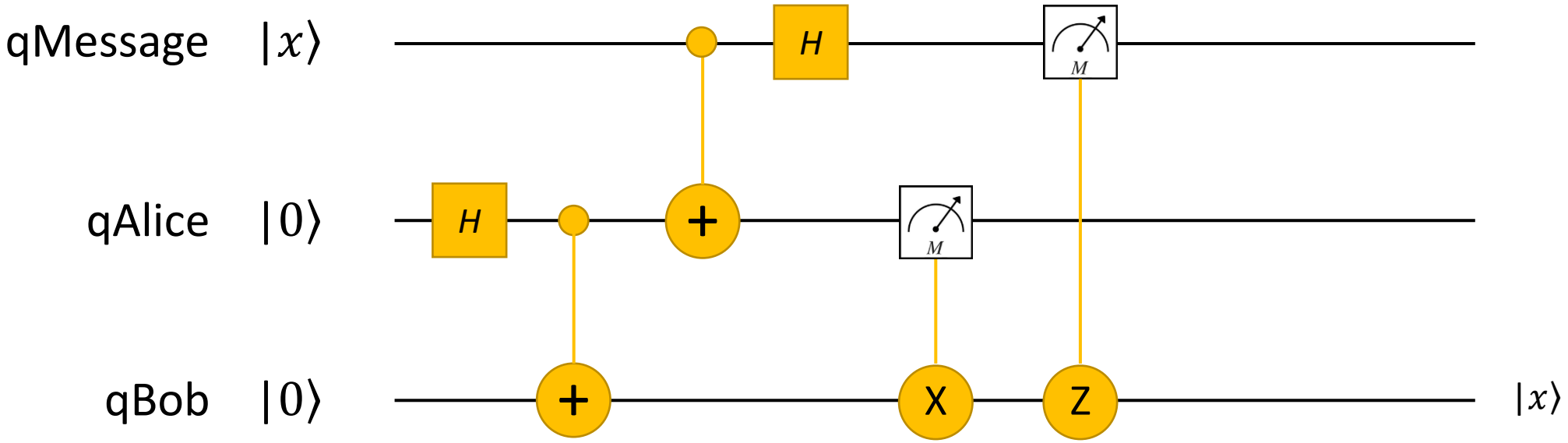
Entanglement

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

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

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

Teleportation



https://github.com/Djohnnie/QSharp-and-AzureQuantum-TechTrainMechelen-2021

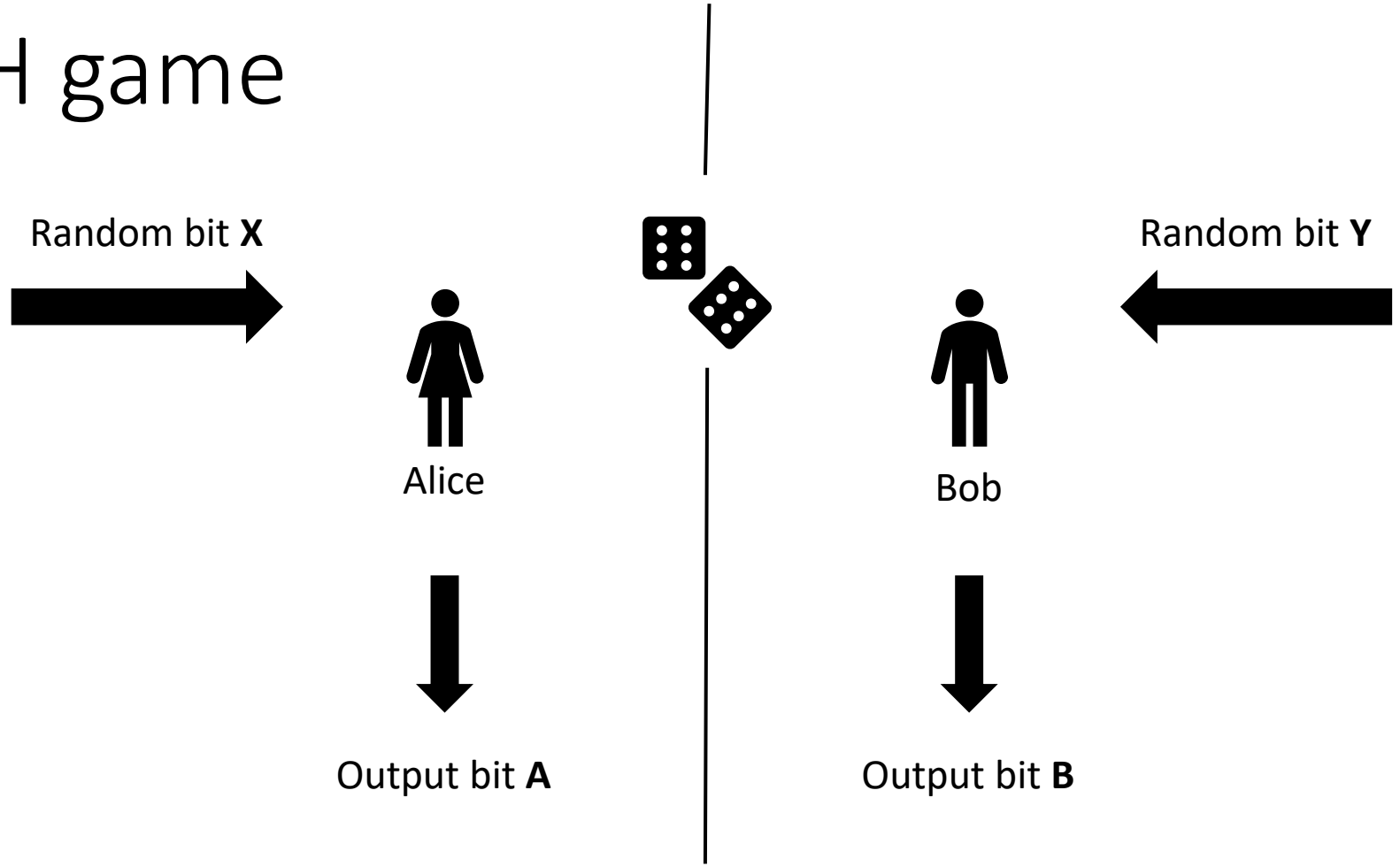
Microsoft Q#

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

Azure Quantum

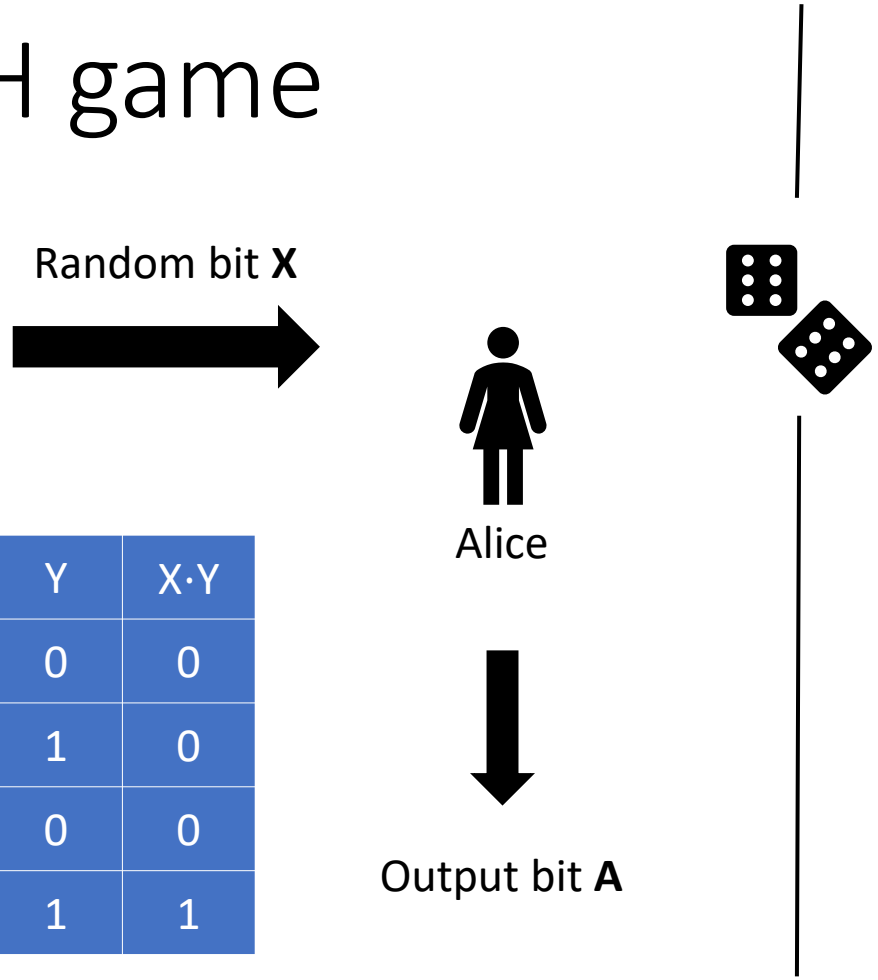
- Quantum in the cloud
  - Optimization
  - Machine Learning
  - Quantum Simulation
- Access to quantum hardware
  - Microsoft (Topological)
  - IonQ & Honeywell (Ion Traps)
  - QCI (Superconducting)
- Q# & QDK
  - Quantum Intermediate Representation (QIR)

CHSH game



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

CHSH game



X	Y	X·Y
0	0	0
0	1	0
1	0	0
1	1	1

A	B	A⊕B
0	0	0
0	1	1
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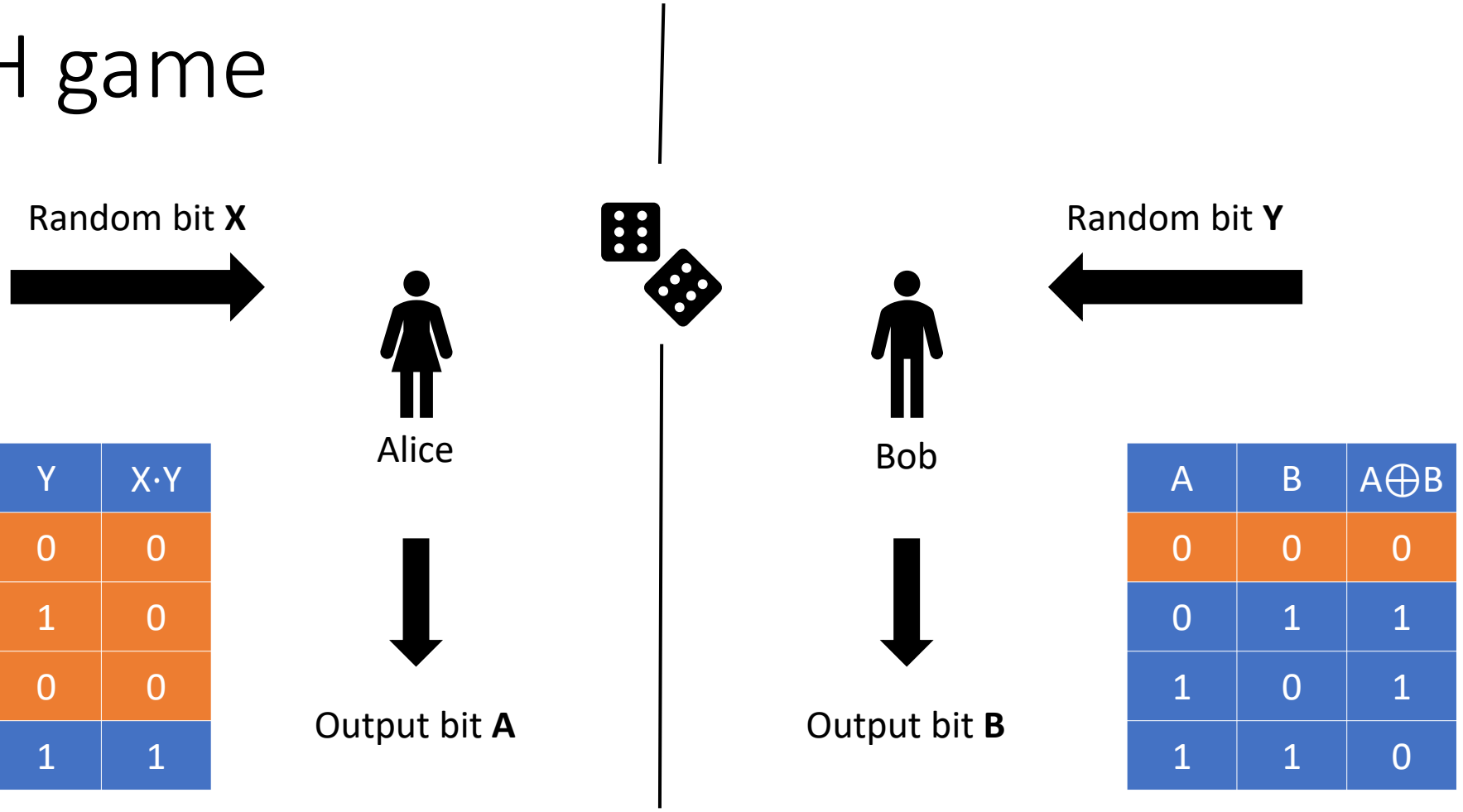

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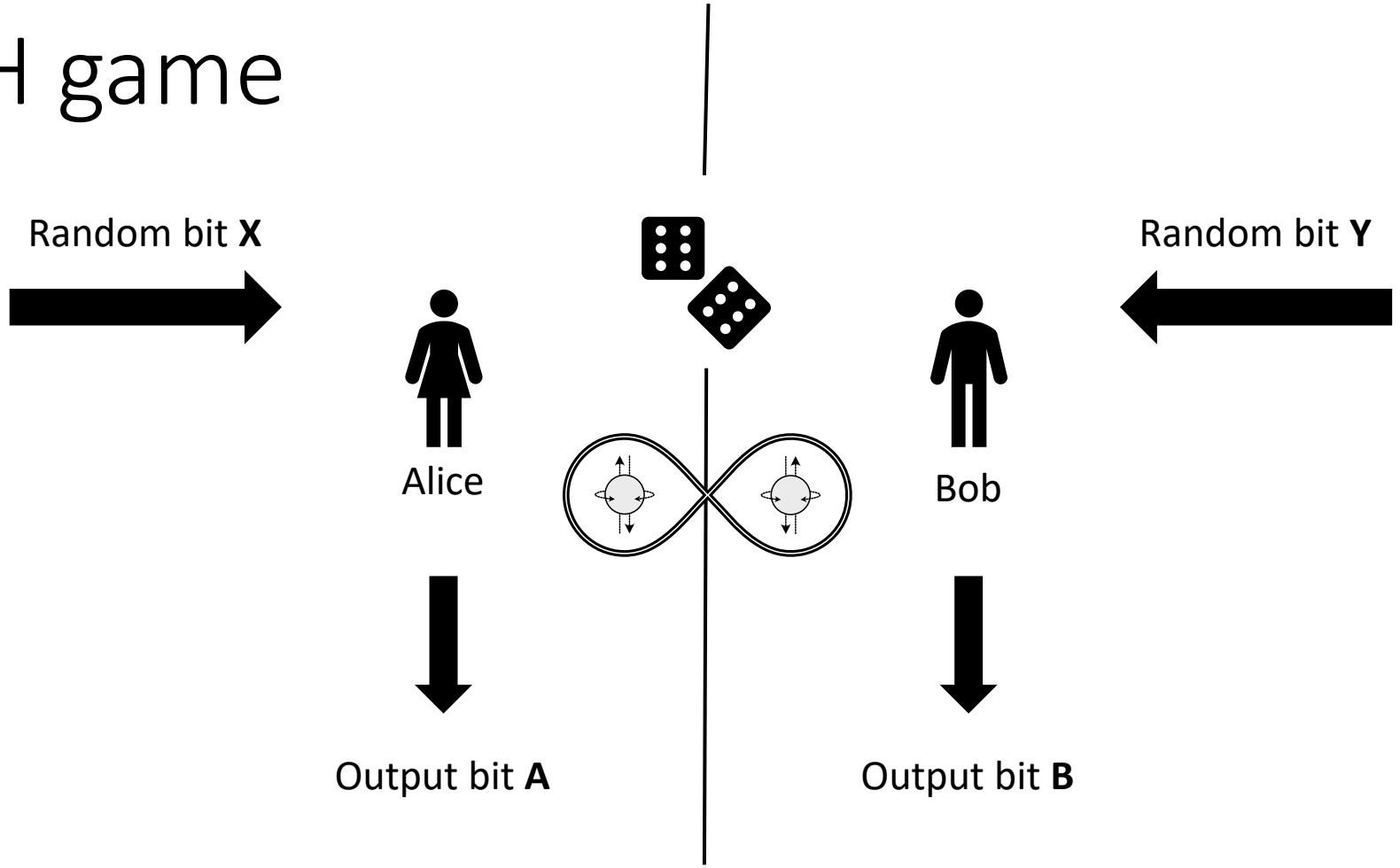

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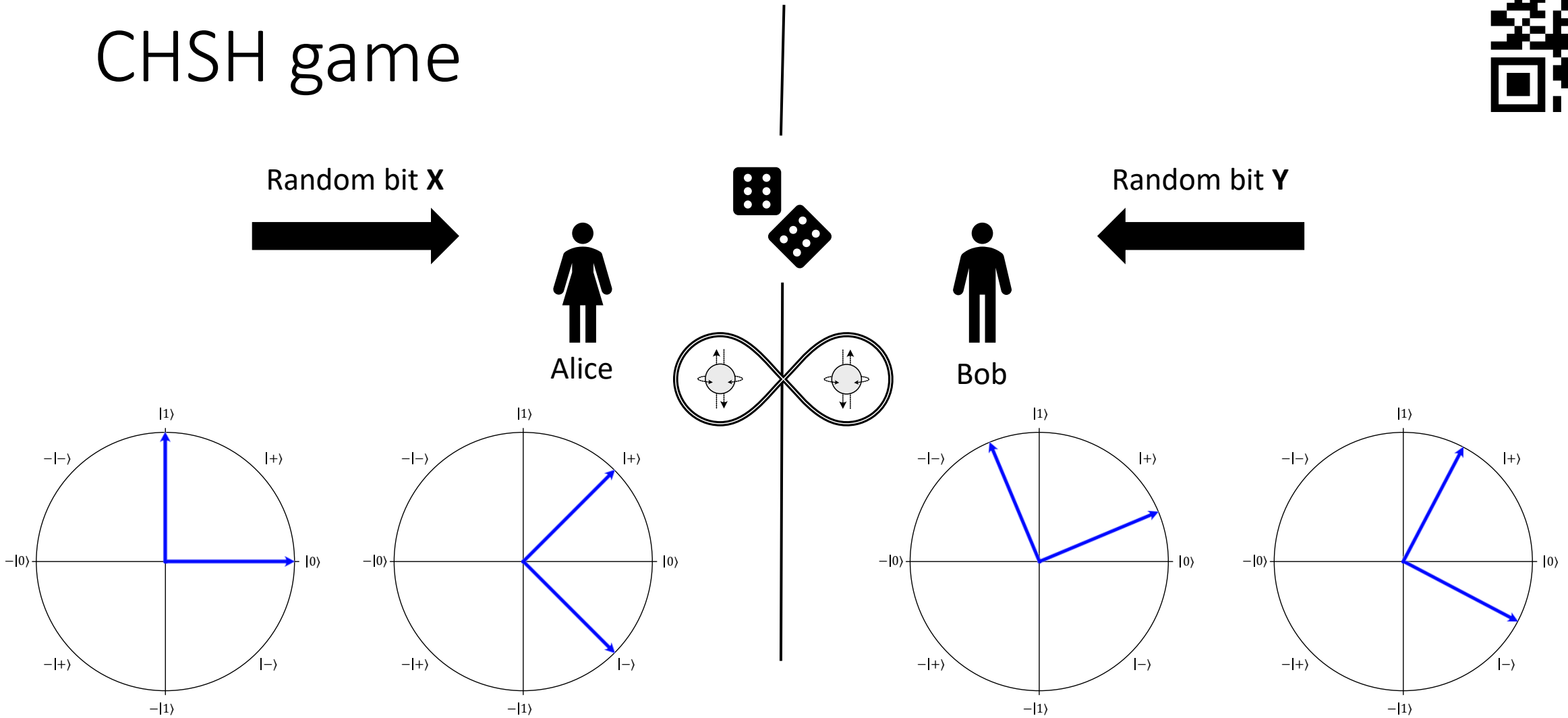

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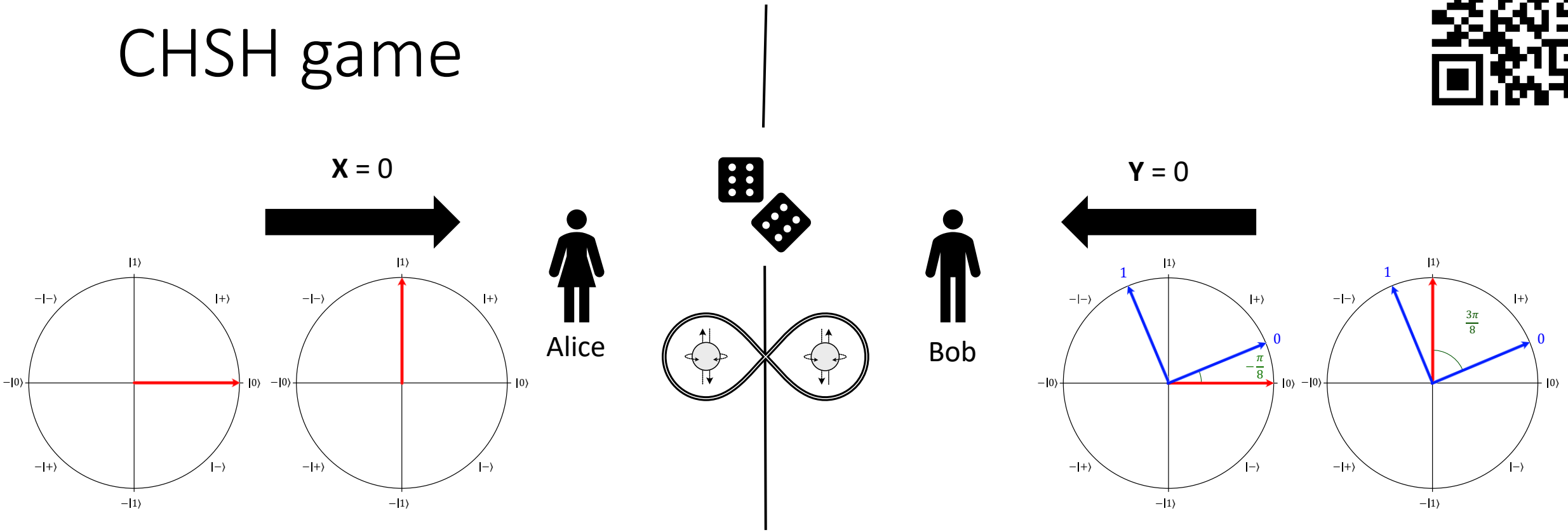

Alice outputs	Bob's qbit	Bob outputs 0 with probability	Bob outputs 1 with probability
0	$\|0\rangle$	$\cos^2\left(-\frac{\pi}{8}\right) \approx 0.85$	$\sin^2\left(-\frac{\pi}{8}\right) \approx 0.15$
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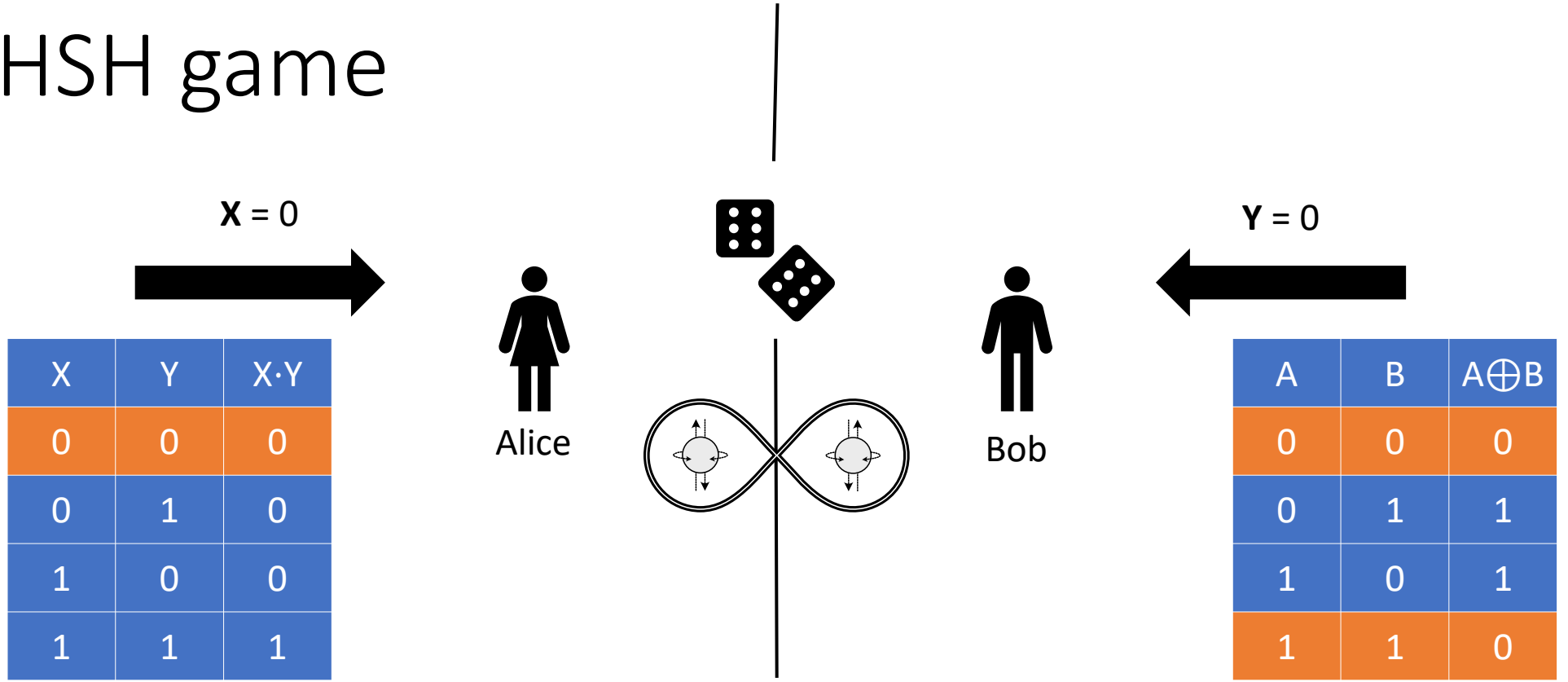

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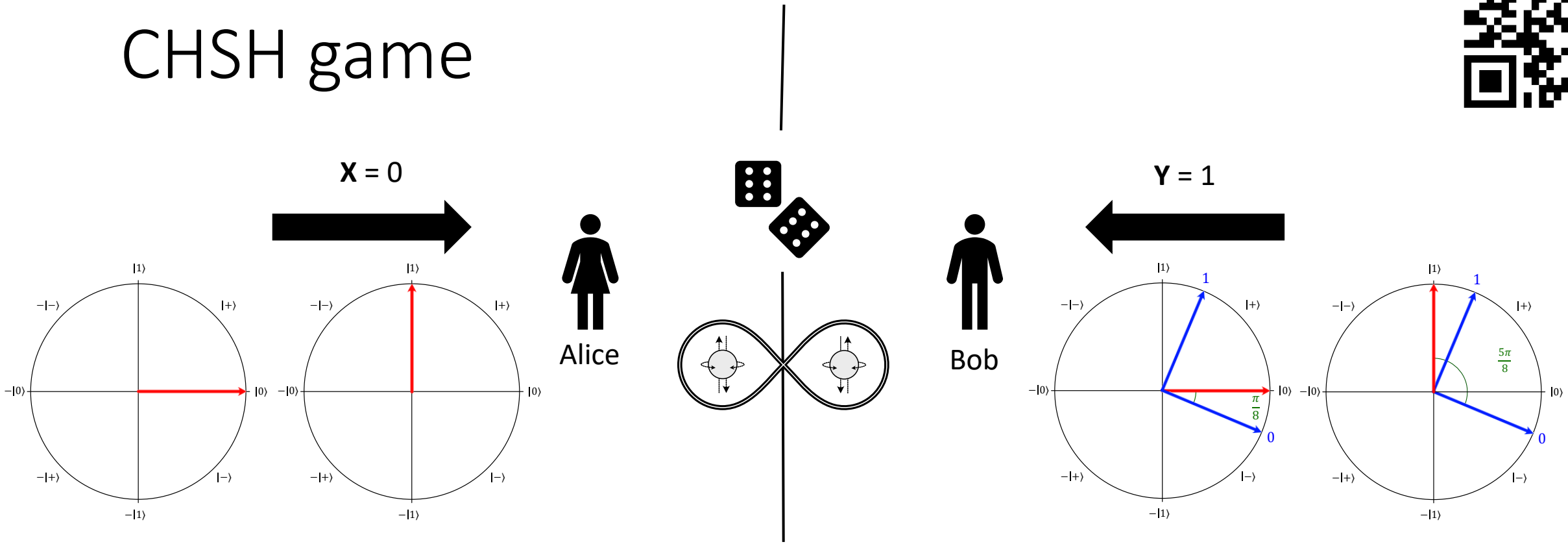

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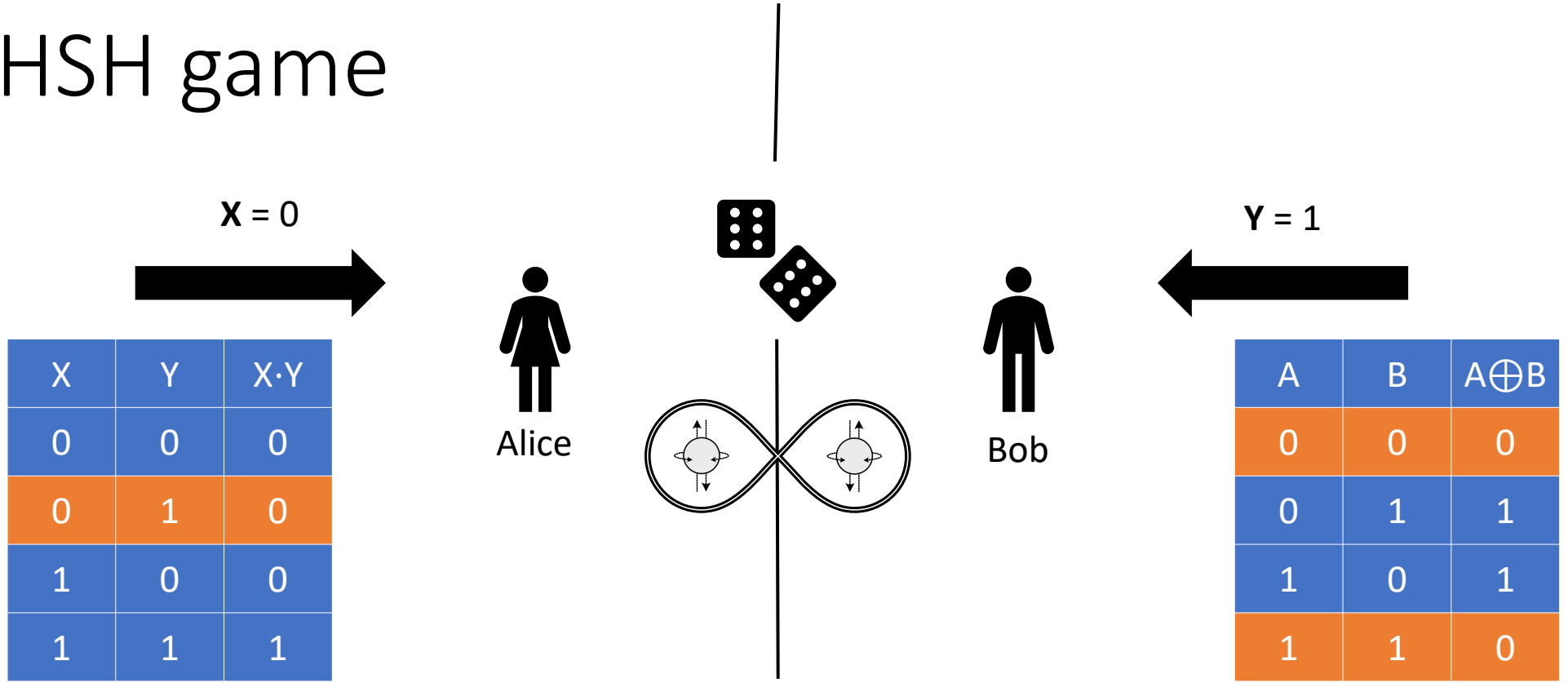

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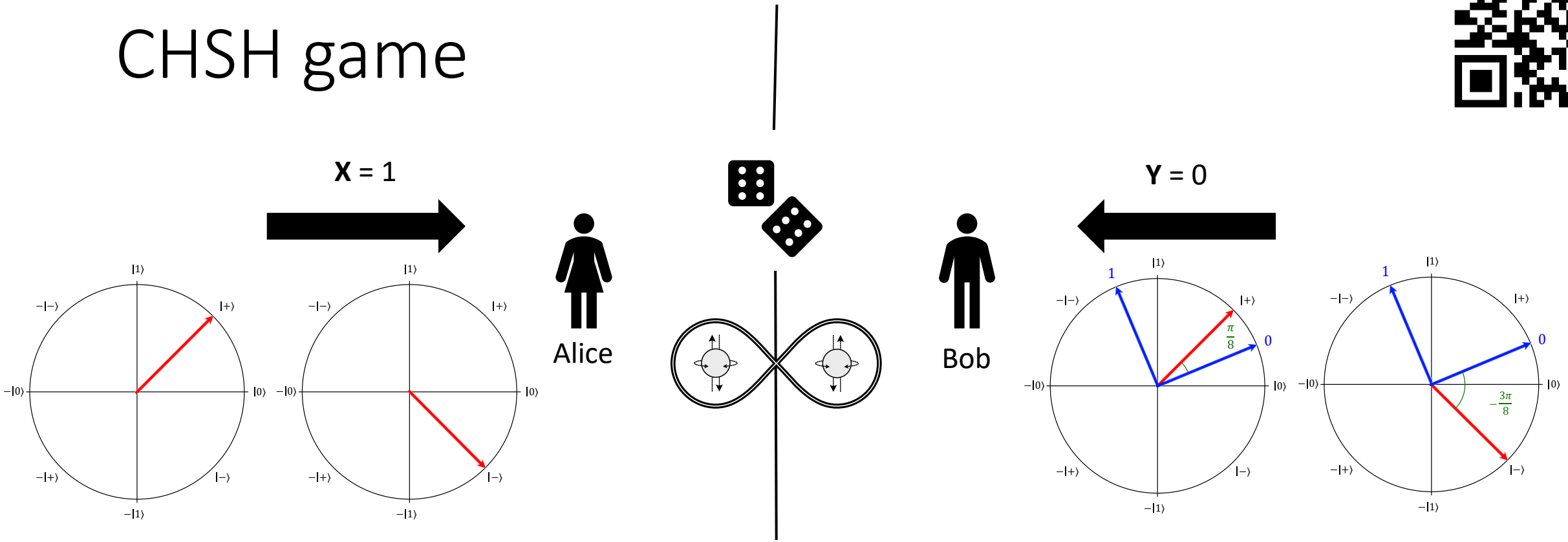

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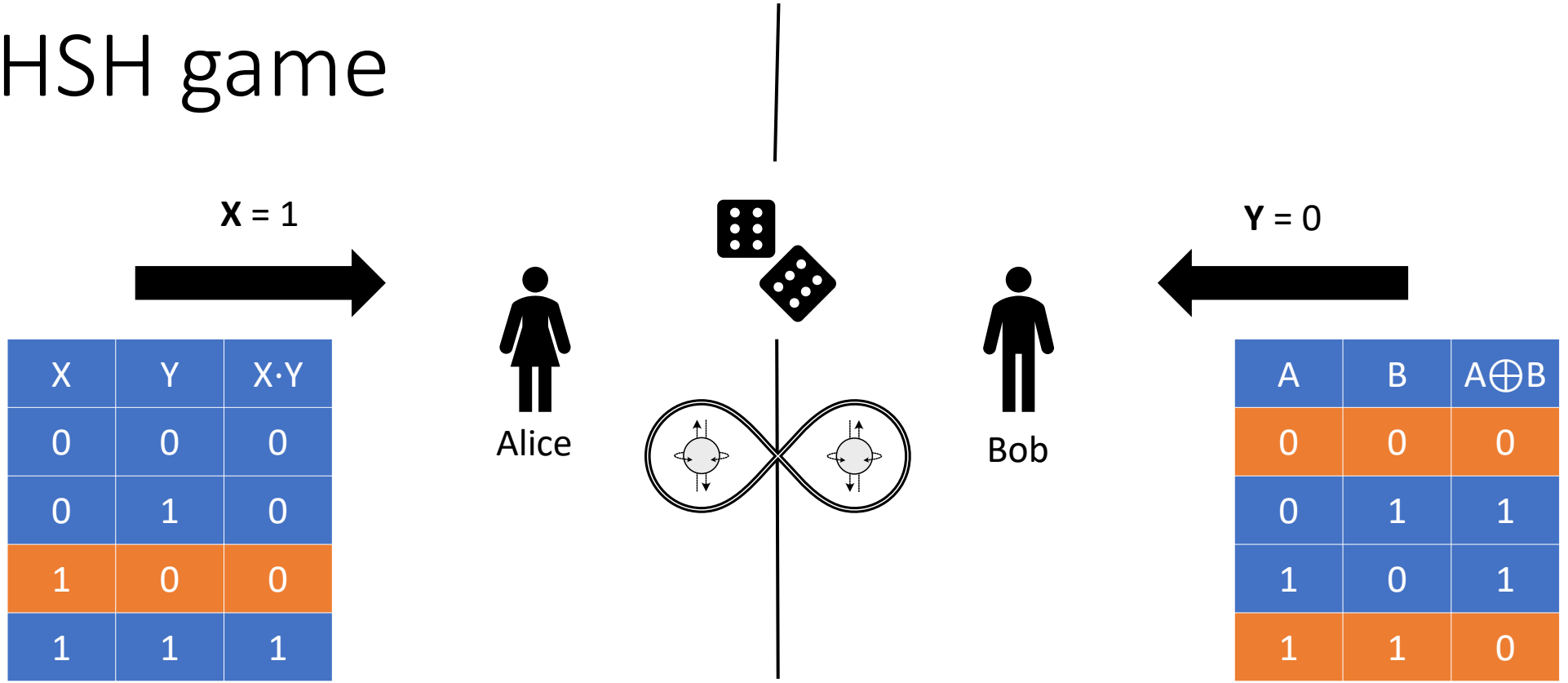

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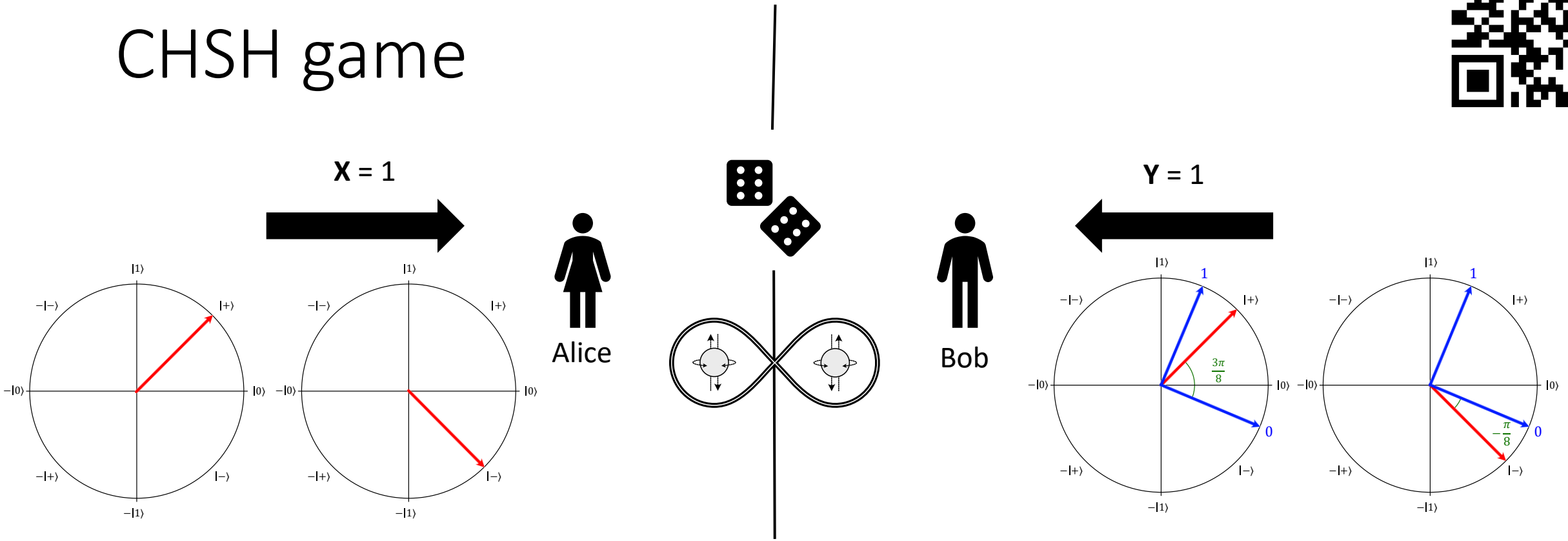

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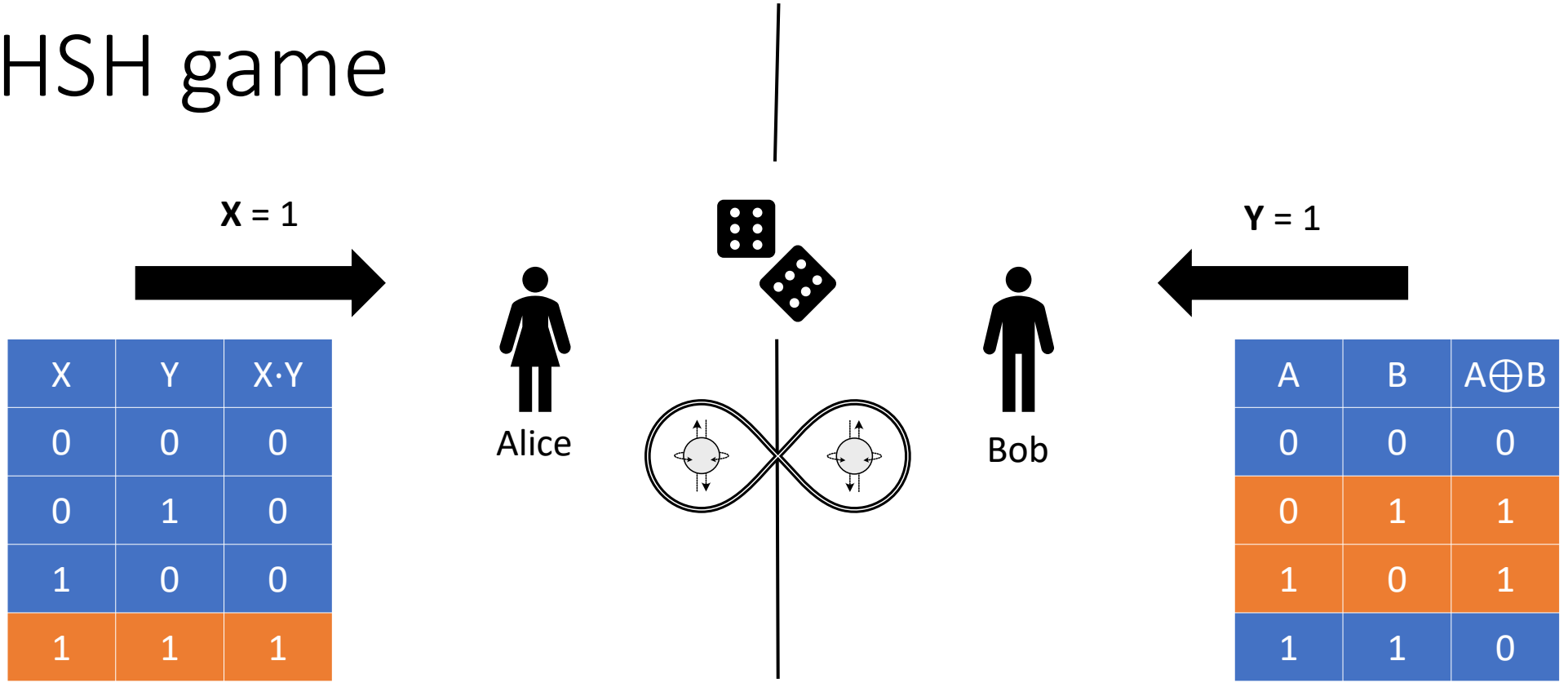

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