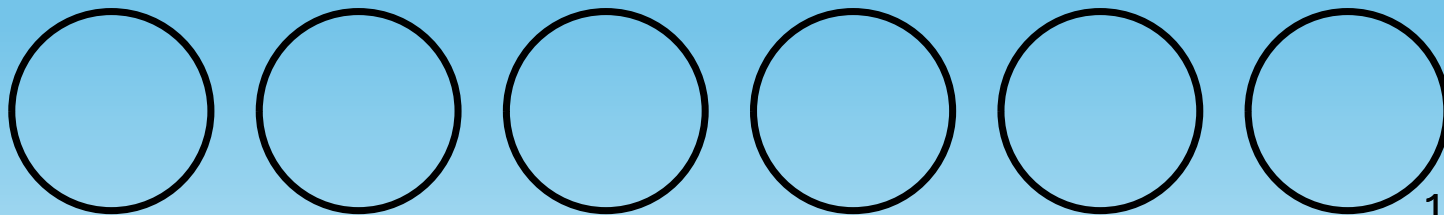




Mens Erger Je Niet with a quantum twist

**Kyrian Rahimatulla, Alexis Fimeyer, Emirhan Balban, Guo
Chuen Liu, Sjoerd Terlouw**

Delft University of Technology



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- Introduction

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- Quantum phenomena

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- The Game

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- Performing the Bell test in game

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- Running the game
- Demos

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Introduction

Goal of the project

1

Introduction

- Quantum chess
- Quantum minesweeper
- Quantum tic-tac-toe

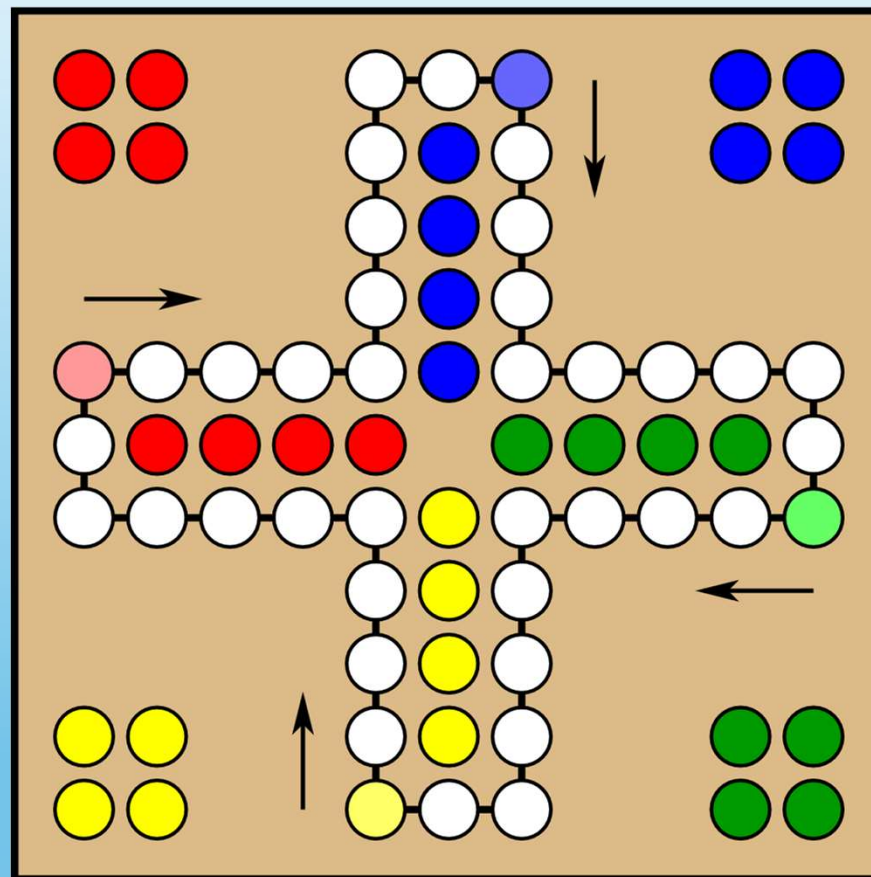
Christopher Cantwell. Quantum Chess: Developing a Mathematical Framework and Design Methodology for Creating Quantum Games. 2019. arXiv: 1906.05836 [quant-ph]. Url :<https://arxiv.org/abs/1906.05836>

Allan Goff. "Quantum tic-tac-toe: A teaching metaphor for superposition in quantum mechanics". In: American Journal of Physics 74.11 (Nov.2006), pp. 962–973. issn: 0002-9505. doi: 10.1119/1.2213635. eprint: https://pubs.aip.org/aapt/ajp/article-pdf/74/11/962/13128226/962_1_1_online.pdf. url: <https://doi.org/10.1119/1.2213635>.

Michal Gordon and Goren Gordon. "Quantum computer games: Quantum minesweeper". In: Physics Education 45 (June 2010), p. 372. doi:10.1088/0031-9120/45/4/008.

1

Introduction



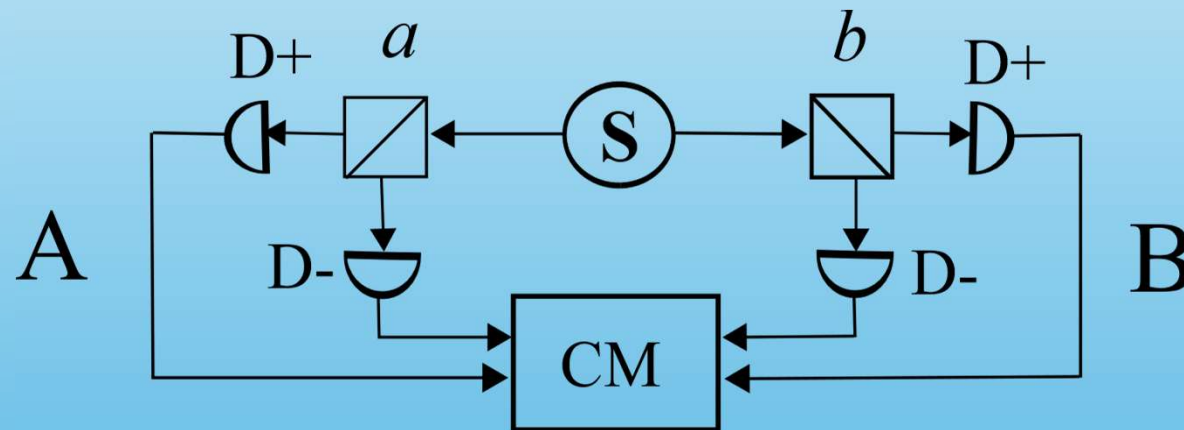
Source: Mens erger je niet! -
Wikipedia

2

Quantum phenomena

Quantum elements

- Superposition
- Entanglement
- Measurement
- Phase
- Interference



- $|0\rangle \rightarrow -1$
- $|1\rangle \rightarrow +1$

2

- Quantum phenomena

Bell test (classical)

$$S = \langle A_1 \otimes B_1 \rangle - \langle A_1 \otimes B_2 \rangle + \langle A_2 \otimes B_1 \rangle + \langle A_2 \otimes B_2 \rangle$$

$$S = A_1(B_1 - B_2) + A_2(B_1 + B_2)$$

- Local realism

Classically: $|S| \leq 2$

2

Quantum phenomena

Bell test

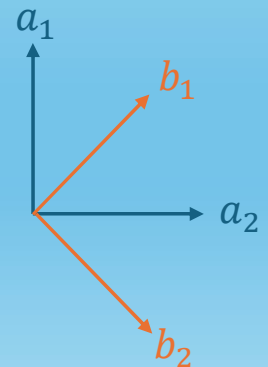
$$S = \langle A_1 \otimes B_1 \rangle - \langle A_1 \otimes B_2 \rangle + \langle A_2 \otimes B_1 \rangle + \langle A_2 \otimes B_2 \rangle$$

$$|\Psi^-\rangle = \frac{1}{\sqrt{2}}(|10\rangle - |01\rangle)$$

$$\langle A_1 \otimes B_2 \rangle = 1/\sqrt{2}$$

$$\langle A_1 \otimes B_1 \rangle = \langle A_2 \otimes B_1 \rangle = \langle A_2 \otimes B_2 \rangle = -1/\sqrt{2}$$

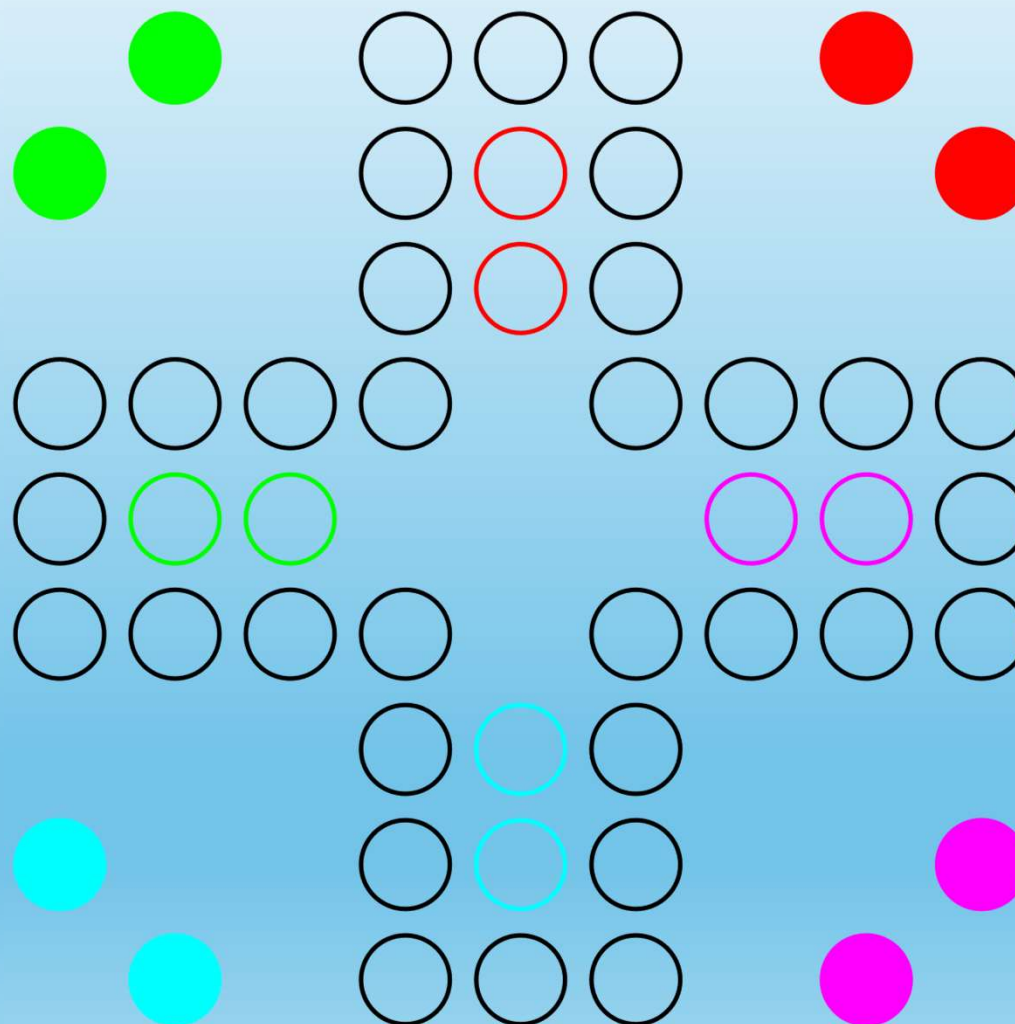
In quantum mechanics: $|S| \leq 2\sqrt{2}$



3

The Game

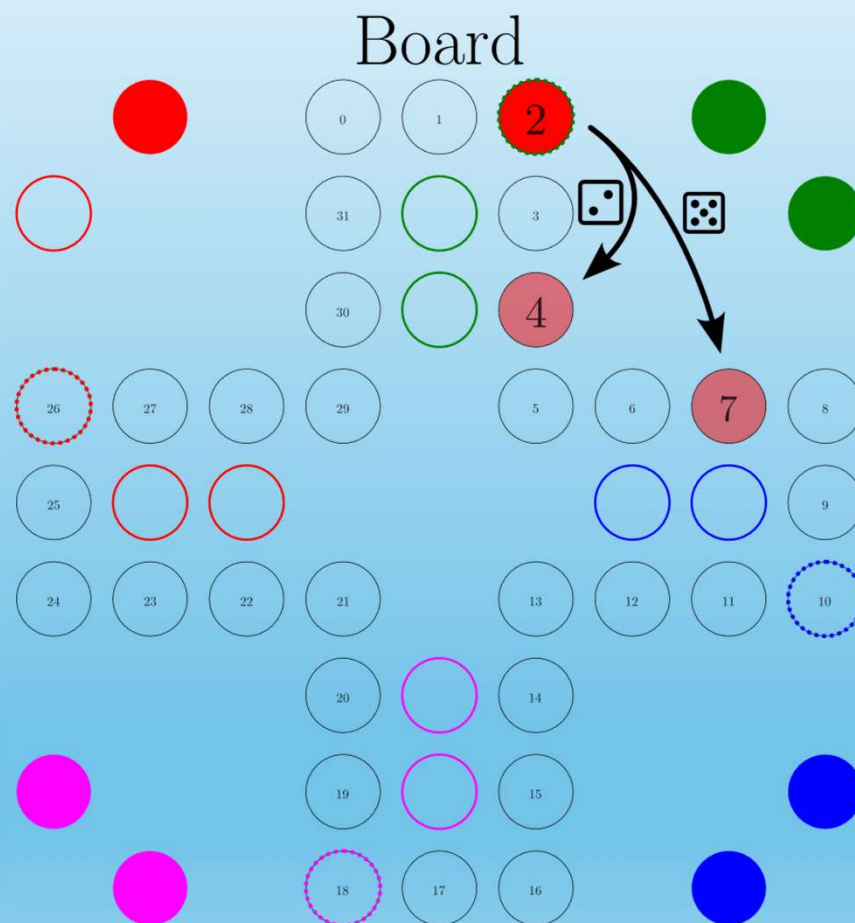
The Board:



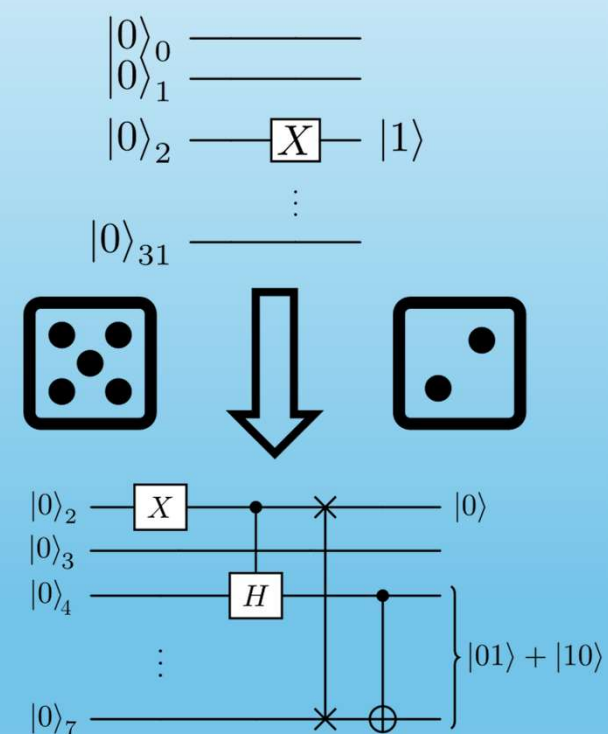
3

The Game

Rules & Mechanics:



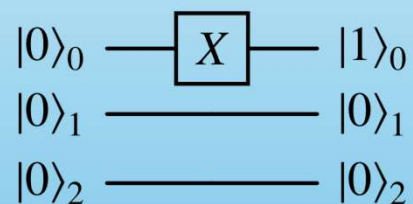
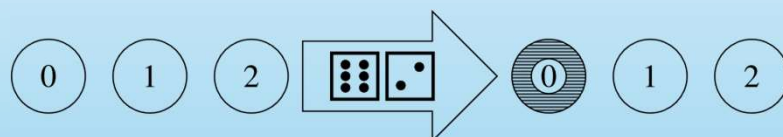
Quantum circuit



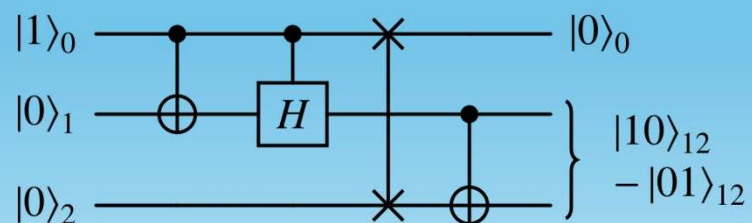
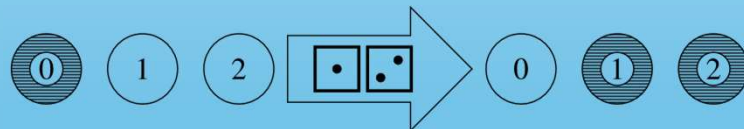
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Rules & Mechanics:

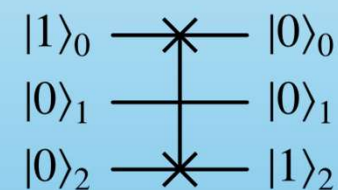
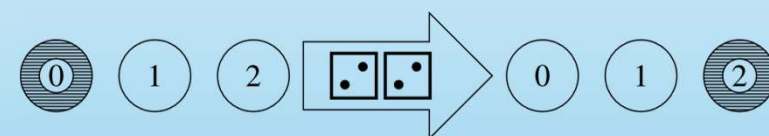
Placing a pawn:



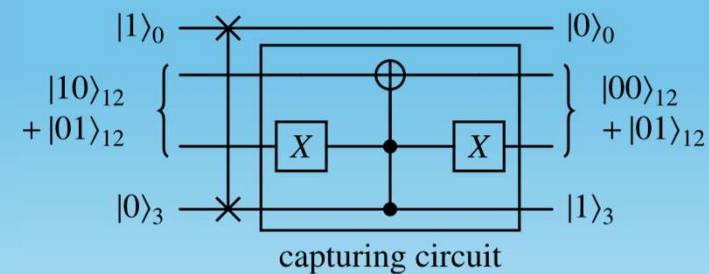
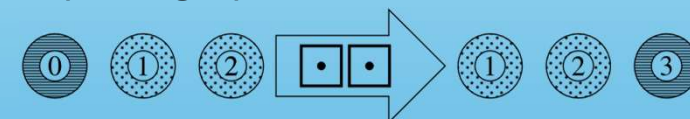
Superposition play:



Moving a pawn



Capturing a pawn:



3

- The Game

Rules & Mechanics:

- No double occupancy
- Capturing moves the capturer one further, also leads to entanglement
- Measurement:
 - 20 Pawns are on the board \Rightarrow Z basis
 - Pawn reaches winning spot \Rightarrow different basis

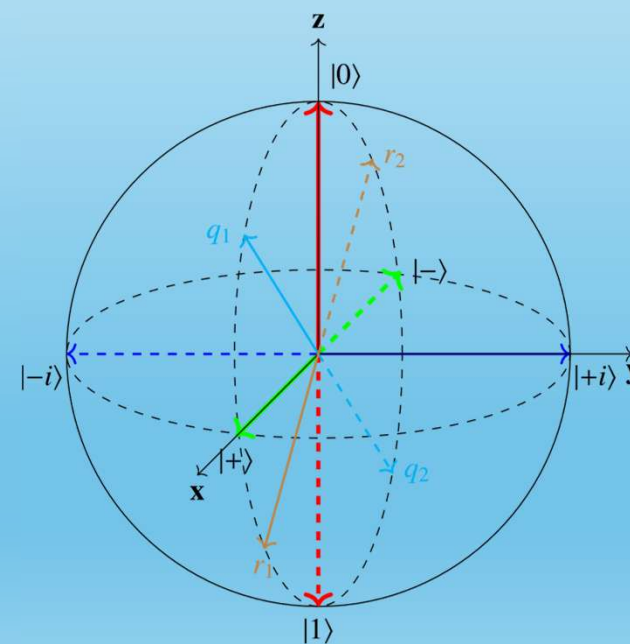
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Rules & Mechanics:

Q-basis: The diagonal between the Z-basis' $|0\rangle$ state and the X-basis' $|+\rangle$ state.

R-basis: The diagonal between the X-basis' $|-\rangle$ state and the Z-basis' $|1\rangle$ state.

Pawn\Basis	Z	Q	X	R
Red 1	R	G	B	P
Red 2	R	P	B	G
Blue 1	B	P	R	G
Blue 2	B	G	R	P
Green 1	G	R	P	B
Green 2	G	B	P	R
Purple 1	P	B	G	R
Purple 2	P	R	G	B

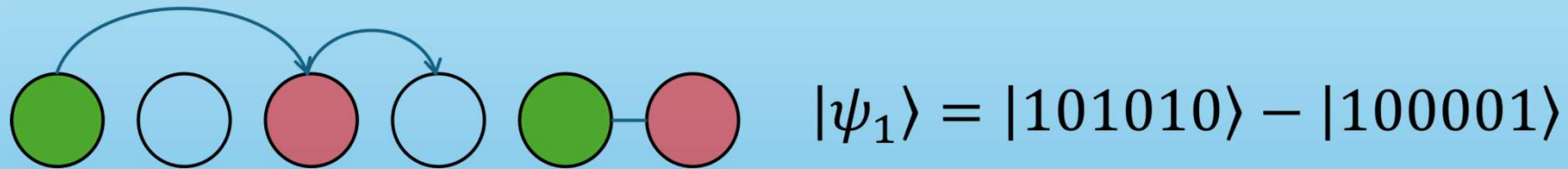
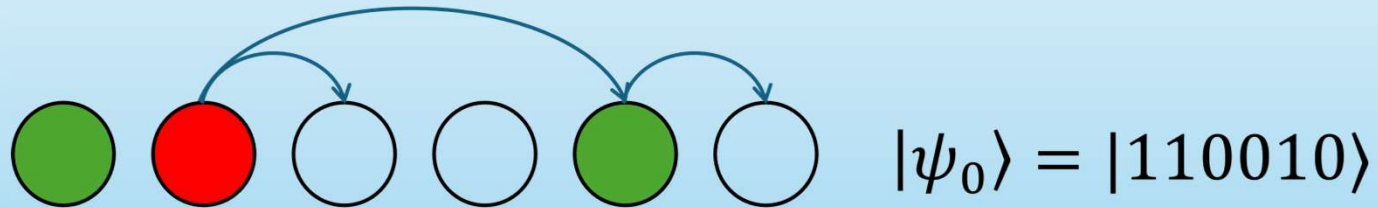


The Game

4

Performing the Bell test in game

Creating the Singlet state



4

Performing the Bell test in game

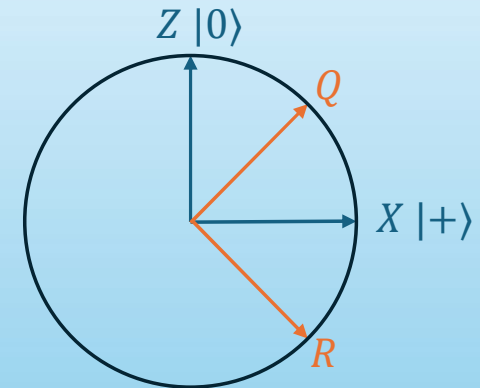
Mapping the axes

Trigger

Pawn\Basis	Z	Q	X	R
Red 1	R	G	B	P
Red 2	R	P	B	G
Blue 1	B	P	R	G
Blue 2	B	G	R	P
Green 1	G	R	P	B
Green 2	G	B	P	R
Purple 1	P	B	G	R
Purple 2	P	R	G	B

Red = Alice

Green = Bob



4

Performing the Bell test in game

Mapping the outcomes

$$\begin{aligned} \bigcirc &= +1 = \lambda \text{ of } |0\rangle \\ \bigcirc &= -1 = \lambda \text{ of } \frac{1}{\sqrt{2}}(|10\rangle - |01\rangle) \end{aligned}$$

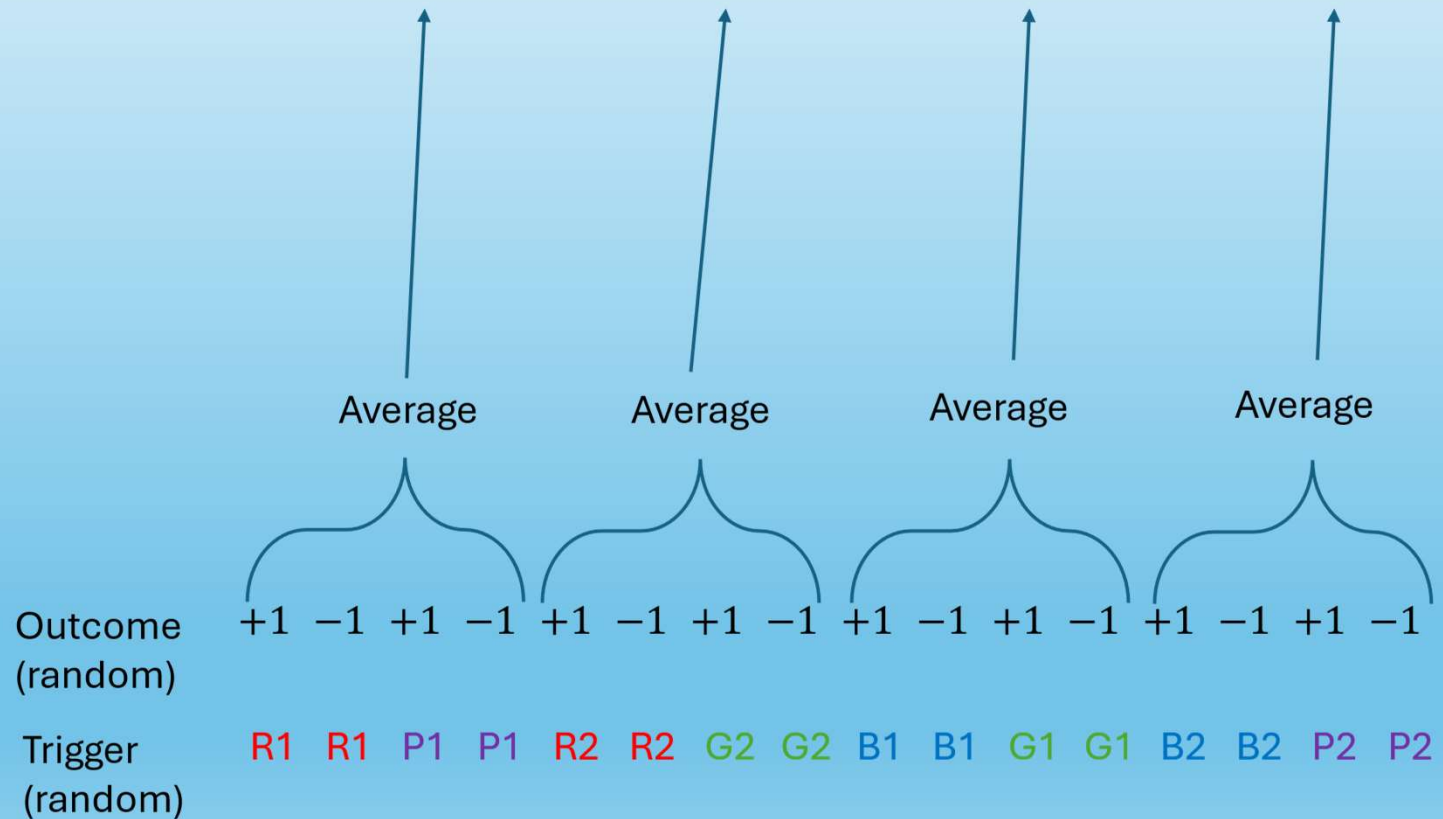
$$\begin{aligned} \bigcirc \quad \bigcirc &= 1 \cdot 1 = 1 \\ \bullet \quad \bigcirc &= -1 \cdot 1 = -1 \\ \bigcirc \quad \bullet &= -1 \cdot 1 = -1 \\ \bullet \quad \bullet &= -1 \cdot -1 = 1 \end{aligned}$$

4

Performing the Bell test in game

Bringing it all together

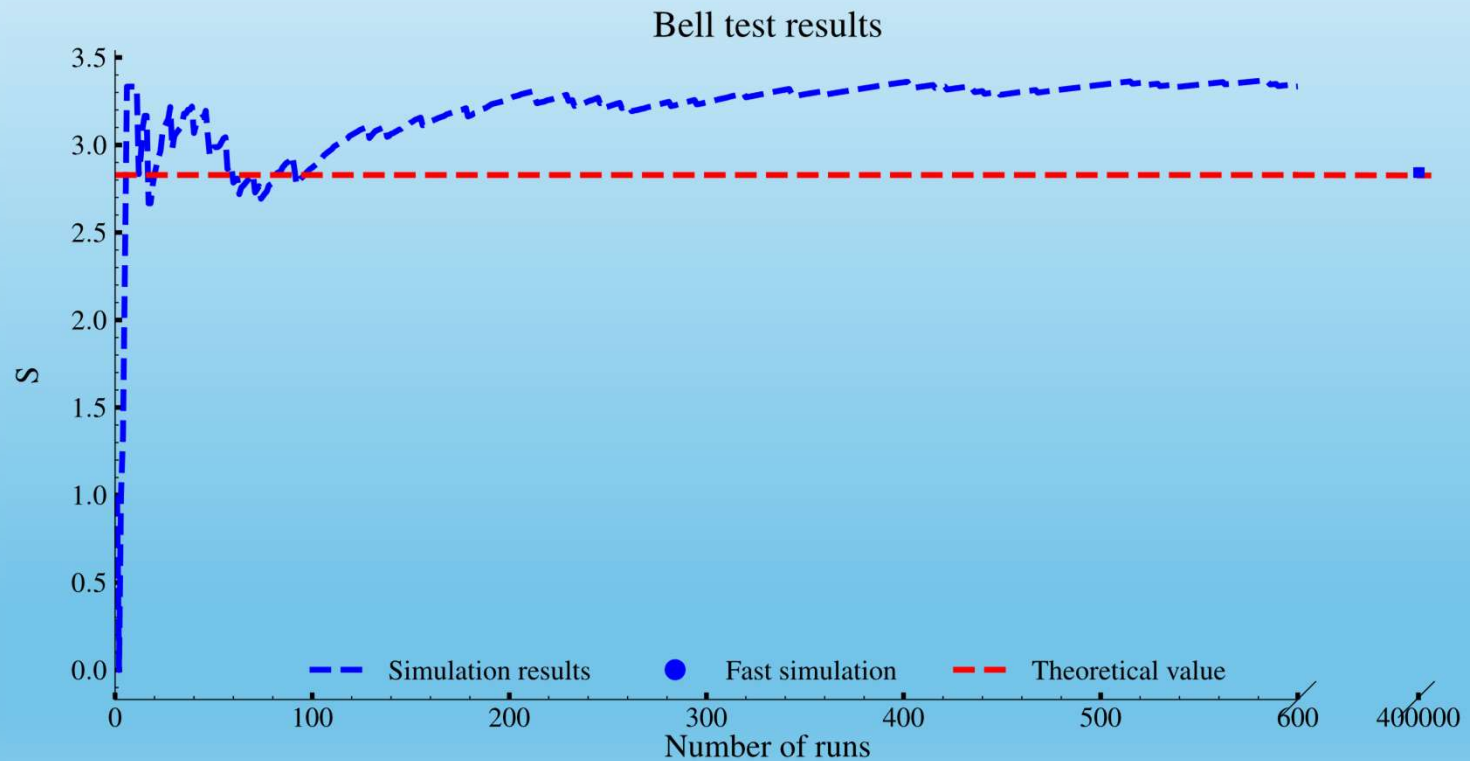
$$S = \langle A_1 \otimes B_1 \rangle - \langle A_1 \otimes B_2 \rangle + \langle A_2 \otimes B_1 \rangle + \langle A_2 \otimes B_2 \rangle$$



4

Performing the Bell test in game

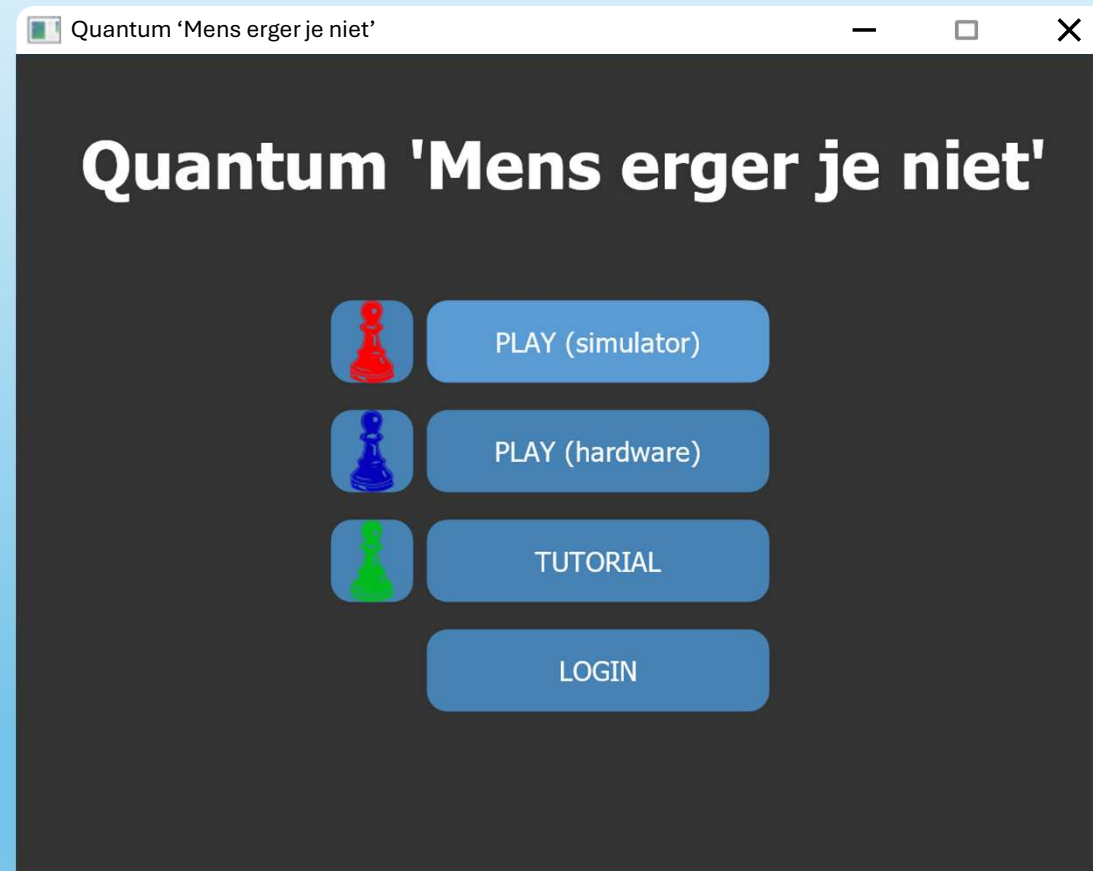
Results



5

The game

- Running the game
- Demos



Q&A