CODE REPORT

SM-204 Physics-2

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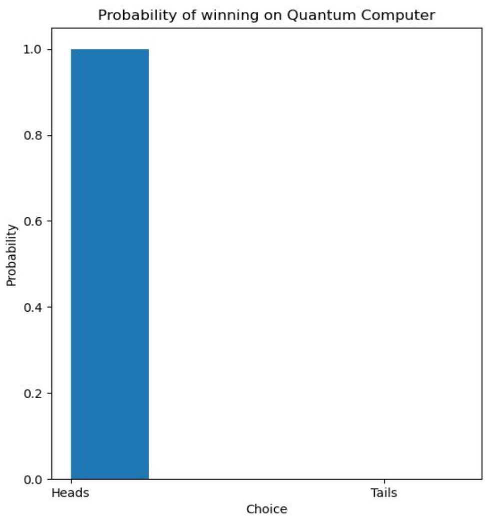
Implementing the concepts of Qubits and Gates using a small Coin Flipping game

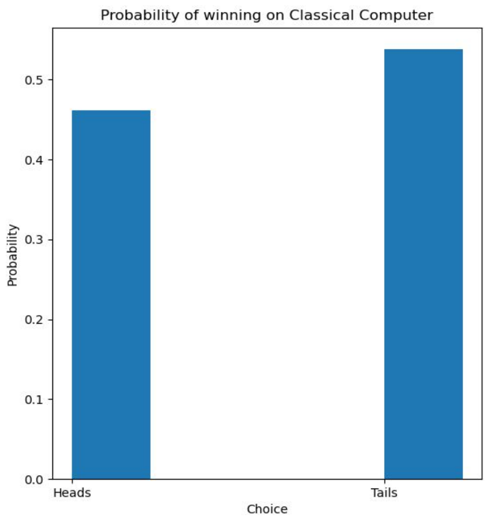
Once we understood what Qubits are, we wanted to practically try it out on a quantum computer to check how the concept of superposition works. For this, we used Qiskit, which is a python framework that simulates the results by a quantum computer. Alternatively, we could have used IBM Quantum Experience for running the code on an actual Quantum Computer like Melbourne, but we instead chose to stick to the simulation.

This is a simple coin flipping simulator. The game goes as follows. You have a fair and unbiased coin. You have a computer playing against you. Initially assume that the coin is in Heads position. The computer first chooses to either turn the coin or leave it as is. Note that all the moves are hidden, ie. a computer doesn't know what humans choose and humans doesn't know what computers do. The second turn would be yours. You may also now turn the coin or leave it as it is. Computer then plays the final move, where it can choose to flip the coin or leave it as it is. After these three steps the final position of the coin is revealed. If Heads is the face, computer wins, else Player wins.

We have a csv form *inputs.csv* which contains random boolean values 0 and 1 depicting the user's moves.

We had 2 different opponents, one was a classical computer and other was a quantum computer. If the player played against a classical computer he/she had an approximate 50-50 chance(see figure below) to win the game. But, if we played this on the Quantum Computer, the player loses in almost all the cases. Even if there are a few cases, it might occur due to some noise, but since we are using a Theoretical Simulator here, we might not be bound to such errors. In order to see these errors, you can alternatively check this on IBM Quantum Experience.





What does this experiment teach us? The basic analogies in the experiment are as follows, the coin is a register. And it has a place to be filled in with, either a bit or a qubit, which depends on the computer the player is playing against. A bit here is a head or a tail, where 0 represents head and 1 represents tail. In a classical computer, it is certain that the bit will be either 0 or 1 but not both, hence there is a 50-50 chance to win. So if a player chooses to keep it as Heads, Identity gate is applied, if he/she chooses to flip it to Tails, a Pauli-X gate is applied. But when we look at the quantum computer, the qubit can exist in superposition of both Heads and Tails, so a new gate needs to be introduced to identify this state. It is the Hadamard gate.

A quantum gate acting on a single qubit can be defined by its action on basis vectors $|0\rangle$ and $|1\rangle$.

Identity gate maps $|0\rangle$ to $|0\rangle$ and $|1\rangle$ to $|1\rangle$

X-Gate maps $|0\rangle$ to $|1\rangle$ and $|1\rangle$ and $|0\rangle$

Hadamard-Gate maps $|0\rangle$ *to* $|0\rangle+|1\rangle)/\sqrt{2}$ and $|1\rangle$ to $(|0\rangle-|1\rangle)/\sqrt{2}$

So now we have 2 cases.

1. If player chooses not to flip the coin
2. If player chooses to flip the coin

Case 1

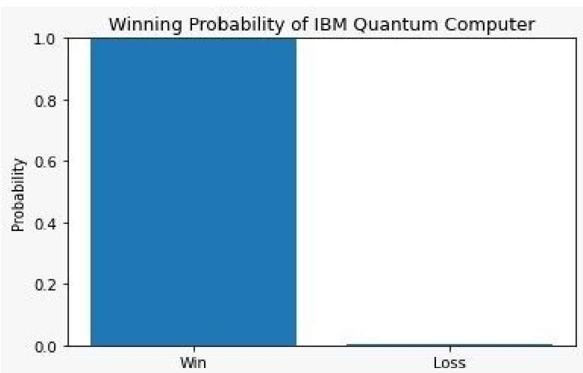
Firstly, Hadamard gate is applied on initial $|0\rangle$ state which gives, $|0\rangle+|1\rangle/\sqrt{2}$. Now we apply the user's choice to use the Identity gate. It will return the same output. Now apply Hadamard gate on this output as it is the computer's choice and it will be in superposition. Hence $H(|0\rangle+|1\rangle/\sqrt{2})$, will return $|0\rangle$ on calculations, which is Heads.

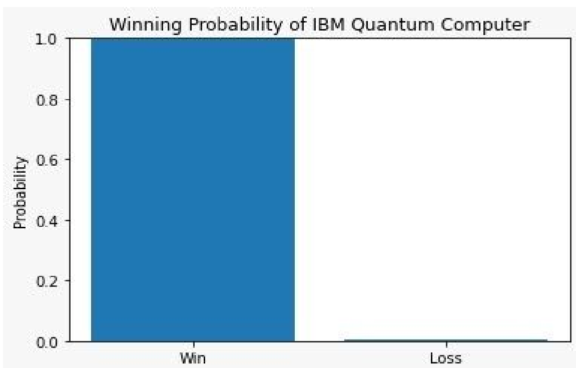
Case 2

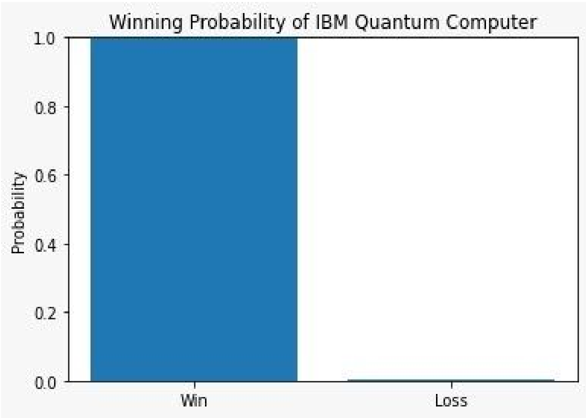
Firstly, Hadamard gate is applied on initial $|0\rangle$ state which gives, $|0\rangle+|1\rangle/\sqrt{2}$. Now we apply the user's choice to use Pauli-X gate. It will return the same output since $X(|0\rangle+|1\rangle/\sqrt{2}) = |1\rangle+|0\rangle/\sqrt{2}$. Now apply Hadamard gate on this output as it is in superposition. Hence $H(|1\rangle+|0\rangle/\sqrt{2})$, will return $|0\rangle$ on calculations, which is Heads.

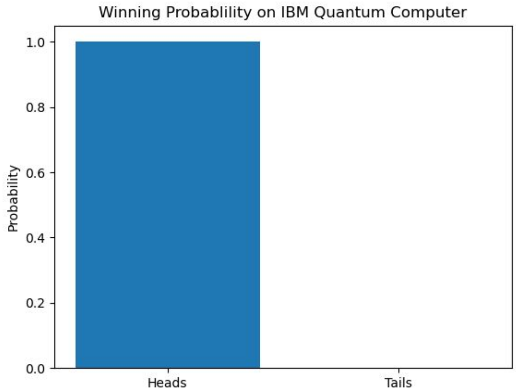
Hence due to the principle of superposition, it is always a Heads as an output.

We did the experiment on IBM Quantum Computer as well. For the inputs 1(Tails), 0(Heads) and 1(Tails), 0(Heads) the following graphs were observed.









Conclusion:

From the above graphs, we clearly see that the probability of a quantum computer winning a game against a human is very high(~99%). The slight error observed is due to the noise in the actual quantum computer as compared to the simulation.

Bibliography

This code is inspired from the TED Talk

https://www.ted.com/talks/shohini_ghose_a_beginner_s_guide_to_quantum_computing

Other helpful links

https://github.com/MackEdweise/TEDCoinToss

https://github.com/qiskit-community/qiskit-community-tutorials/blob/master/games/Quantum-Coin-Game.ipynb

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