QUANTUM TIC-TAC-TOE

Comparative study of 2 different quantum versions of the tic-tac-toe game. First approach was described by Prof Sai Sagole, Prof Anurit Dey, Prof Bikash K. Behera, and Prof Prasanta K. Panigrahi, of IISER Kolkata and published on December 2019. The second approach was described by Allan Goff (Novatia, California), Dale Lehmann (DST Output, California) and Dr. Joel Siegel (Sierra Community College), published on March 2003.

FIRST APPROACH SUMMARY

At the start of the game the board is set up. Each box is in a superposition state of $|0\rangle$ and $|1\rangle$. This state is called the quantum state and has equal probability of collapsing into a classical state.

The game allows two types of moves: classical or quantum. When a classical move is applied the box collapses to either of the classical states with equal probabilities. A quantum move requires 2 boxes, a control box (in quantum state) and a target box such that when a classical move is applied to the control box, if it collapses to the player's favored classical state, it automatically flips the state of the target box).

A classical move can only be applied to a box that is in a quantum state, i.e., a classical move cannot be applied to the same box twice. Quantum move's target should be in classical state and control in quantum state. Player X's favored state is $|1\rangle$, and player O's favored state is $|0\rangle$.

The condition for winning is the same as it is in the regular classical version of Tic-Tac-Toe. The first player to get three of his marks (i.e. 'X' or 'O') in a single row, column or diagonal wins the game.

The quantum state is set-up by applying Hadamard gate to $|0\rangle$. Whenever a classical move is applied, if it collapses to $|1\rangle$, the box is marked 'X', if it collapses to $|0\rangle$, it is marked 'O'. The result of the measured qubits is fixed with the RESET gate (for $|0\rangle$) and RESET+NOT (for $|1\rangle$). Whenever a quantum move is applied, an anti-control NOT (when player O apples the move) or control NOT (when player X applies the move) gate is applied from control to target qubits. This step changes the target qubit when control is in their favor, but cannot change the same when control is not in their favor. The code is run in the jupyter notebook, and quantum moves are performed by sending the qubits to the qiskit library.

SECOND APPROACH SUMMARY

This version of the game is played on the exact same board as classical tic-tac-toe.

The rules for the game are same as the classical form, except that the players make quantum moves, in which two different squares are marked at once. A quantum move looks like a classical move that is half in one square and half in the other square. Quantum moves may entangle by sharing squares. An entanglement arises when two or more quantum moves share a square. On a cyclic entanglement, the other player chooses the collapse to classical moves. A cyclic entanglement occurs whenever there is a path from one square back to itself. In a collapse the quantum moves are replaced with classical moves.

First player to get 3 of same classical symbol in a row, column, or diagonal, wins. There is a chance of simultaneous matching or row, columns or diagonals, in which case, the earlier in time to get the match, i.e., one who gets the match in lesser number of moves, gets a full point, the opponent a half point.

The measurement process begins with a cyclic entanglement. However complicated the cyclic entanglement, there are only 2 possible ways to collapse to classical moves. Whoever creates the entanglement, it falls to his opponent to decide which way the moves collapse. A player only gets to make a classical (collapse) move if their opponent’s last quantum move creates a cyclic entanglement. While there must be at least one collapse move in every game, it turns out that there cannot be more than four such moves. Except at the conclusion of the game, a player who makes a collapse move gets to make their next quantum move immediately afterward.

Some quantum moves can lie off the cyclic portion and are called “stems”. Regardless of which way a cycle collapses, the stems are determined by their very structure to collapse in only one way. Any attempt to select a stem square to specify a collapse in, leads either to not resolving the cyclic part, or to making its resolution impossible.