From Quantum Chess to Games of the Future

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Goal of this activity

Will play this cool new quantum video game on the second half of the workshop:

- We will use the quantum chess to explain quantum mechanics concepts
- We will use these understand the technology of the future, quantum computers
- We will also show the connection to chemistry
- By the end, should be possible to answer the connection between chemistry, chess and quantum computers
How to play chess?

- How to move pieces in chess?
- How to perform quantum moves in quantum chess?
- Playing puzzles
How does a quantum computer look like?

Not quite like a laptop or desktop...
How to operate a quantum computer?

Can be done remotely! Demonstrating using the IBM circuit composer:
Why chess?

- Centuries-old game with a significant global presence
- Is played in schools, clubs, tournaments, online platforms, and even at professional levels
- 600 million chess players globally, with players spanning across all age groups, cultures, and skill levels
In the US, Bobby Fischer (US Chess Champion x8, age 14; World Chess Champion 1972-1975)

How many people in this room play chess?
How is chess played?

- 16 pieces for each player
- Players alternate play turns and can only make one move
- Each trying to trap and capture the opposite king (checkmate)
- Often easier by one player have more pieces than the other
- Goal: Achieve a positional/material advantage to achieve checkmate
- Chess notation
How to move the pieces?

Six piece types, with different allowed movements.
How to capture a piece?

Capture by taking on a square with a piece of the opposite player.
How to checkmate? - The Ultimate Goal

Left: One move before checkmate: there are multiple ways to checkmate here! Right: A final checkmate position: the dark king cannot move towards the white king (as kings cannot be adjacent in a game of chess).
Conceptual check

- How does the rook move?
How is a complete game of chess played?

All information is visible, but hard to follow even if knowing the rules...

Donald Byrne vs Bobby Fischer 1956 ("Game of the Century")
Workshop will focus on simpler scenarios.
How many ways to go from A to B?

How did you solve this problem?
How many possible B after 3 branches

How did you solve this problem?
How many possible moves for 1 pawn at the beginning?
How many possible moves for 1 knight at the beginning?
Chess is complex, but how much?

From the starting position:
Exponential growth of possibilities with number of moves

- After 7 moves: 3,195,901,860 possible games
- One human life: 2,524,608,000 seconds (80 years)

OEIS Integer Sequence A048987
Can you think of any reason that make chess complex?
Quantum Chess vs Chess

Parallels between allowed moves in chess and quantum chess:

Quantum chess uses this move called **superposition** (more on this later)
Example of a knight in an uniform superposition of two (left) and eight squares (right)

Does this mean I can make a single piece occupy the entire chess board?
How to play Quantum Chess?

Quantum chess is available online, through a web browser at https://quantumchess.net/play/

We will play the tutorial and one example together.
When do we play?

This portion of the workshop would have you solving the Quantum Chess Puzzles.

- Working in pairs; can and should ask questions
- Eight total puzzles, but we will focus on #3, #5, #7 and discuss those
- Winning the puzzle is probabilistic, due to the presence of superpositions
- Having the right idea is the goal (moves that maximize probability of winning)
Any suggested moves to maximize chance of capturing one of the rooks?
Puzzle Example 2 cont.

Superposition for the win!
Right Idea: Two outcomes

Measurement outcomes...

[Image of quantum chess game interface showing 'Success' and 'Try Again' messages]
Hint towards right idea

Don’t be discouraged!
Beyond these puzzles

- Try the other quantum chess puzzles
- Play quantum chess with your friends (select 'Sandbox', then press 'New', 'Play'; if the pieces appear all good to play otherwise, press 'Stop' followed by 'New' and 'Play'
- Other quantum games (quantum checkers, whac-a-mole...); links in the handout
What is a superposition?

Consider the following problem of finding a person at a particular place:
How do we typically describe position?

Classical (when size is big) description of position:

- House
- School
- Store

100%
How do we typically describe position?

Classical (when size is big) description of position:

House

School

Store

100%
How do we typically describe position?

Classical (when size is big) description of position:

- House
- School
- Store

100%
How do we describe position in quantum mechanics?

Quantum description of position, (when size is very small):

House

School

Store

100%

0%

0%
What is a superposition?

Quantum description of position (probability split into two places)

House

School

Store

50%

50%

0%
How would I know the outcome? - Scenario 1

Measuring the probability of being at the house, outcome 1 (at the house)
How would I know the outcome? - Scenario 2

Measuring the probability of being at the house, outcome 2 (not at the house)
A different superposition

Quantum description of position (probability split into three places):

- **House**: 33%
- **School**: 33%
- **Store**: 33%
How to check for superpositions?

(1) Measurements
- House: 100%
- School: 0%
- Store: 0%

(2) Measurements
- House: 50%
- School: 50%
- Store: 0%

(3) Measurements
- House: 33%
- School: 33%
- Store: 33%
A quantum measurement...

IT'S A DEAD HEAT

AND THE WINNER IS

NUMBER 3, IN A QUANTUM FINISH

THEY'RE CHECKING THE ELECTRON MICROSCOPE

NO FAIR!

YOU CHANGED THE OUTCOME BY MEASURING IT!!
Try to explain in your own words what superposition is.
Connecting chess to chemistry

- Chess is not a solved game just as quantum mechanics is not.
- Both are exponentially complex due to the number of possibilities for state evolution.

- The game state of chess evolves according to the rules of chess; chemical systems evolve according to the principles of quantum mechanics.
Quantum computing gives exploratory power by considering a larger range of possibilities (states) simultaneously (using superposition).
Connection to Chemistry

Molecules on a surface, pieces on a chess board...

Atom Types
- Silver
- Hydrogen
- Carbon
- Nitrogen
- Oxygen

Molecule
A real quantum circuit

Demonstrating superposition, using the https://quantum-computing.ibm.com/composer
How to share my thoughts on today’s activity?

www.tinyurl.com/QuantumChessActivity