Semiclassical Mastermind

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MOTIVATION

Quantum computing and information is poised to be an incredibly lucrative in the near future with over $1 billion in funds committed from both government and industry. From an academic standpoint, a lot of important and interesting work remains in the field: quantum error correction, quantum networking, quantum algorithms, quantum applications, etc.

One significant issue? Quantum mechanics is notoriously challenging, with prohibitively difficult mathematics. Additionally, students have trouble with a lack of physical intuition. This has prompted the following subfield of research:

Promote classical games to *quantum games* to
(i) build intuition before advanced math, and
(ii) as objects of study in their own right

We will focus on the game "Mastermind"

BACKGROUND

The relevant background involves
(i) Quantum mechanical ideas, and
(ii) Mastermind (the classic board game)

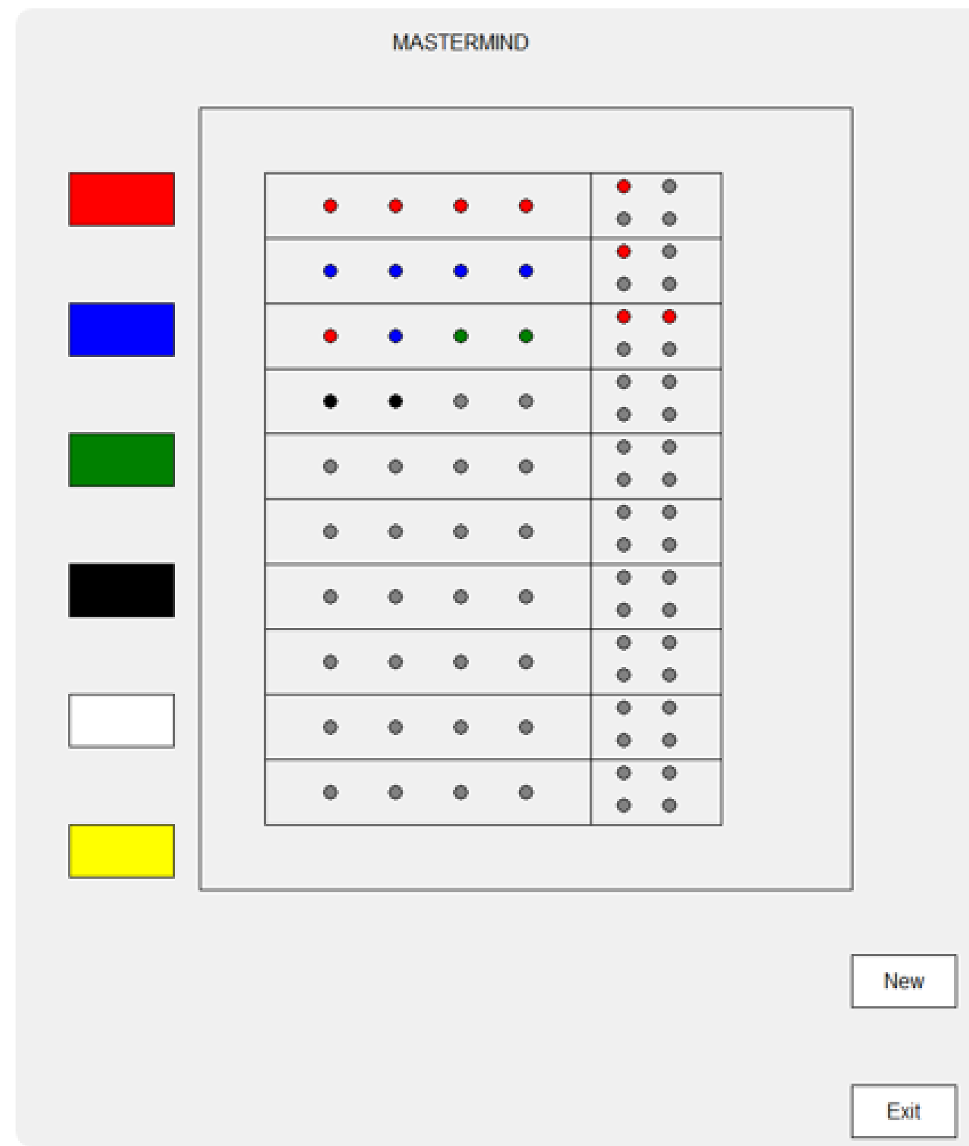
QUANTUM MECHANICS

Classical bits are replaced with QUANTUM BITS / "QUBITS". Instead of either a 0 or a 1 like a classical bit, qubits exhibit the following these quantum mechanical properties:

(1) SUPERPOSITION - When a qubit is in a "combination" of multiple states (such as 1 and 0 in equal measures) that could then be measured to be in any of these states
(2) COLLAPSE – When, upon measurement, a superposition reduces irreversibly and probabilistically (depending on in what ratios the states are superposed) to one classical state
(3) ENTANGLEMENT – When one part of a quantum state cannot be described or measured without influencing another

MASTERMIND

Use logic to guess a random combination of colored pegs; feedback pegs give clues on how close the guess is. Several optimal methods have been found for solving Mastermind games optimally



BUILDING THE GAME

Mastermind uses system of colored pegs, so replace pegs with qubits – two-component normalized complex vectors
|q > = a |0> + b |1> |a|^2 + |b|^2 = 1
P(measure in 0 state) = |a|^2
P(measure in 1 state) = |b|^2

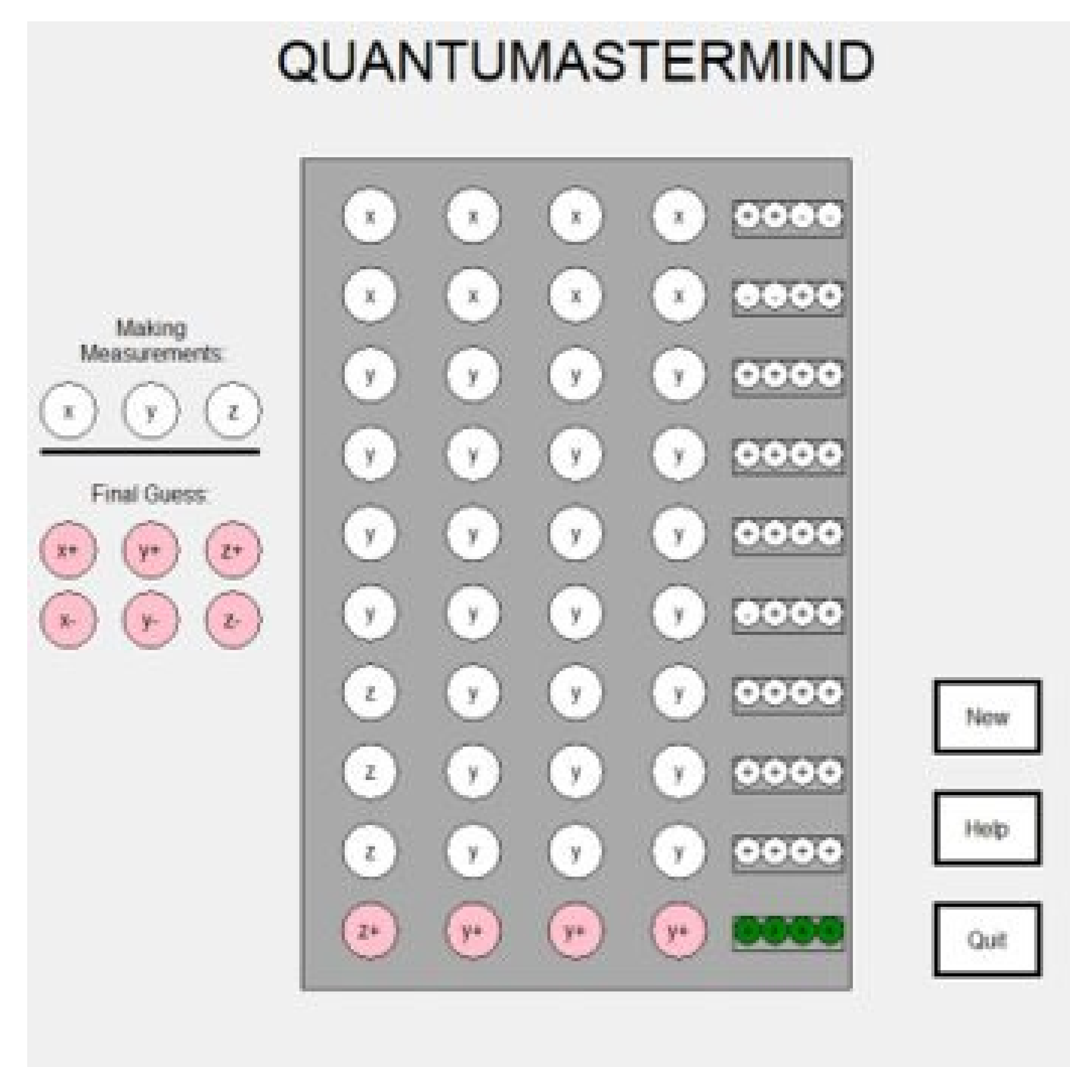
|+z> along z-axis, will (always) measure +
|+x> along x-axis, will (always) measure +
(expressed in z-basis)

What if we measure |+x> along z-axis? It's a superposition of states:
|+x> = (|0> + |1>) / sqrt(2)

Measuring different |+x> qubits might give opposite of first measurement

INVESTIGATIONS

Player picks four axes along which to measure and receives outcomes of measurements. The goal is to correctly determine orientations of qubits based on measurement feedback



Method 1

Choose x-axis 3x, then y-axis 3x, then z-axis 3x. Guess final answer using info from previous guesses.
Pros: easy / **Cons:** "wasted" moves

Method 2

Input xxxx for guesses; if feedback contradicts, replace offending x with y, or replace offending y with z
Pros: no wasted guesses / **Cons**: more complicated to simulate

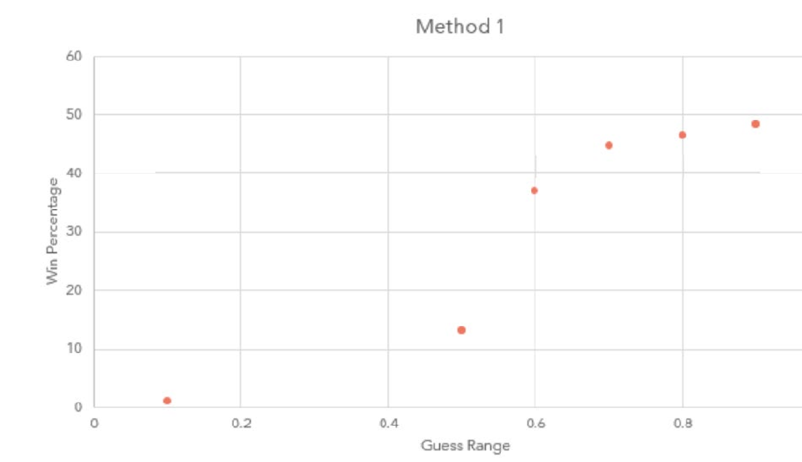
Method 3

Randomly guess axis 9 times; guess the final answer using info from these guesses
Pros: even easier / **Cons**: seems really terrible

For each method, specify a "range" at which to make the final guess

RESULTS

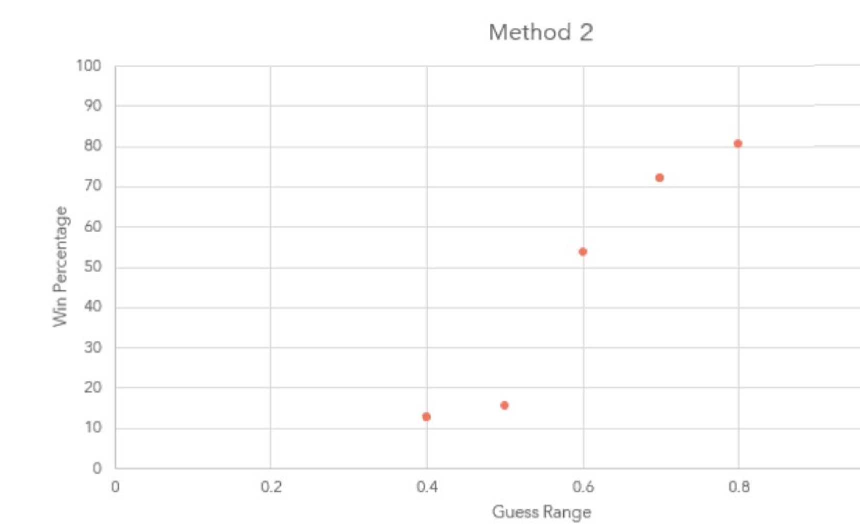
With 50000 simulations, results of each method are below:

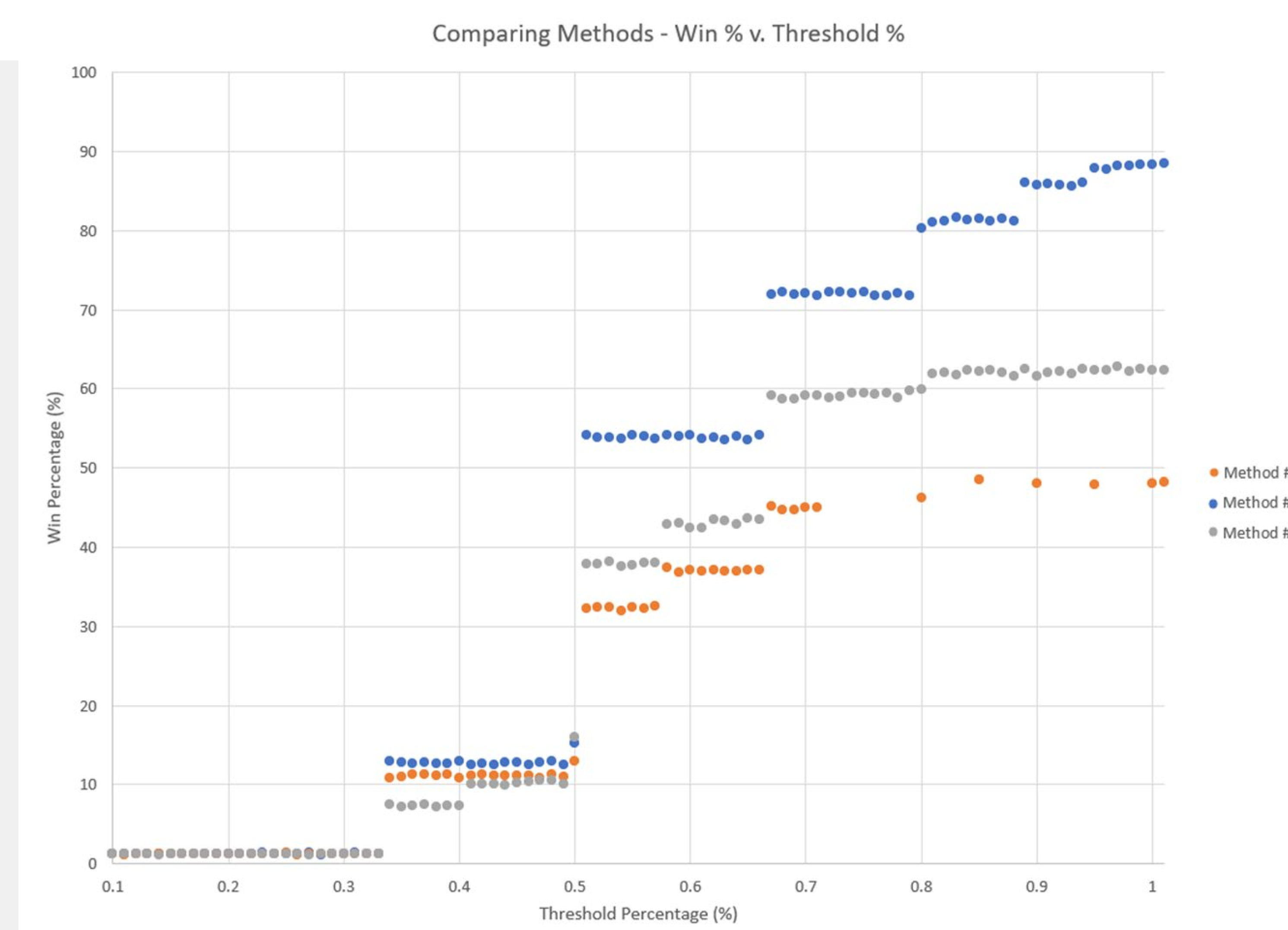


Method #1:
88.34%

Method #2:
48.19%

Method #3:
62.36%





CONCLUSIONS

Method 2 has shown the best results with the game we created. Also performed work showing how win percentage increases when final guess is made after round "N".

This game only uses superposition and collapse, but we have now laid the foundation for future work of promoting games to a fully "quantum" form involving entanglement.

Finally, we want to use this game to develop simple quantum ideas with people who benefit from non-traditional learning.