Quantum Sudoku: A Multiverse Puzzle Challenge

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# 1. Project Overview

## Project Topic:

Quantum Sudoku is an innovative twist on the traditional Sudoku puzzle, where cells can exist in a "superposition" of values until observed (selected or resolved by logic), introducing elements of quantum uncertainty and probability into the puzzle-solving process.

## Objective:

The goal of this project is to design and develop a complex AI system capable of solving and competing in Quantum Sudoku using Minimax and Alpha-Beta Pruning. This includes designing new rules for quantum cells and implementing a GUI-based game to play against an AI opponent.

# 2. Game Description

## Original Game Background:

Sudoku is a logic-based, combinatorial number-placement puzzle. The classic version consists of a 9x9 grid subdivided into 3x3 subgrids. The objective is to fill the grid so that every row, column, and subgrid contains all digits from 1 to 9 without repetition.

## Innovations Introduced:

- Introduction of "Quantum Cells": Some cells can hold 2 possible numbers at once until the player or AI makes a move or deduces the value.  
- Entangled Cells: Changing the value of one quantum cell may affect another linked cell, mimicking quantum entanglement.  
- Collapsing Mechanic: Players can collapse a superposed cell into a definite value using a special logic move or power-up.  
  
These innovations add strategic complexity, uncertainty, and probabilistic decision-making, transforming Sudoku into a semi-competitive game with potential for both single-player and two-player modes.

# 3. AI Approach and Methodology

## AI Techniques to be Used:

- Minimax Algorithm: Adapted to handle uncertainty in quantum cells.  
- Alpha-Beta Pruning: To optimize decision-making during AI moves.  
- Monte Carlo Tree Search (MCTS): Optional technique to evaluate probability-based outcomes.

## Heuristic Design:

- Quantum Heuristic Score: Based on number of resolved cells, potential collapses, and entanglement effects.  
- Positional Heuristic: Favors moves that simplify superpositions or lead to advantageous collapses.

## Complexity Analysis:

The presence of quantum states increases the state space significantly. Estimating the complexity is dependent on the number of quantum cells, typically leading to exponential growth. Efficient pruning and heuristics are crucial for feasible AI performance.

# 4. Game Rules and Mechanics

## Modified Rules:

- Some cells start in superposition (e.g., can be 2 or 5).  
- Players or AI can choose to "collapse" a superposition, revealing one value and affecting entangled cells.  
- Entangled cells change together if one is collapsed.  
- Limited "logic moves" allow forced observation/collapse.

## Winning Conditions:

For single-player: Complete the board within minimum logic moves.  
For two-player: Player with more correctly collapsed cells or completed rows/columns wins.

## Turn Sequence:

Players alternate choosing moves: either resolving a quantum cell or making a classical placement.  
AI will evaluate both the current and future potential outcomes using Minimax with heuristics.

# 5. Implementation Plan

Programming Language: Python

## Libraries and Tools:

- Pygame (for GUI)  
- NumPy (data handling)  
- TensorFlow (if using optional neural network-based heuristic evaluation)

## Milestones and Timeline:

- Week 1-2: Game design, innovation rules finalization  
- Week 3-4: AI strategy development (Minimax, MCTS, heuristics)  
- Week 5-6: Game mechanics coding and debugging  
- Week 7: AI integration and functional testing  
- Week 8: Final testing, GUI polishing, and documentation

# 6. References

- "Sudoku Solving Techniques and AI Algorithms"  
- "Quantum Computing Concepts for Game Design"  
- Pygame, NumPy, TensorFlow documentation  
- Online forums and research papers on logic-based puzzles and quantum game theory