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Analysis of Quantum Inspired AI for Grid-Based Puzzle Solving

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Abstract: *This research presents a Quantum-Inspired AI model designed to solve grid-based puzzles like Sudoku more efficiently. By combining classical AI techniques with quantum-inspired optimization methods such as QAOA and VQE, the model enhances problem-solving speed and accuracy. It integrates deep learning, reinforcement learning, and symbolic reasoning to mimic human cognitive processes. The system is capable of handling structured logic and adapting across various puzzle formats. Results show improved performance over traditional AI Models.*

This approach has applications in education, cybersecurity, and AI-assisted decision-making. The model also incorporates Quantum Neural Networks (QNNs) for better pattern recognition and learning in ambiguous or incomplete puzzle states. A modular framework built with tools like Qiskit and TensorFlow Quantum allows for easy experimentation and hybrid integration. Performance evaluations highlight gains in both computational efficiency and interpretability.

The system demonstrates robustness across different puzzle complexities and constraint types. Its scalability and adaptability make it suitable for real-world problem-solving in logistics, planning, and intelligent tutoring systems.

Key Word: *Quantum-Inspired AI; Quantum Optimization (QAOA, VQE); Deep Learning; Artificial General Intelligence (AGI).*

I.INTRODUCTION

The convergence of Artificial Intelligence (AI) and Quantum Computing represents a frontier in computational innovation, opening transformative avenues for tackling highly structured and computationally intensive problems. Among these, grid-based problem-solving—exemplified by puzzles like Sudoku—presents a unique blend of combinatorial explosion and rigid constraint satisfaction, often pushing the boundaries of classical algorithmic efficiency. Traditional AI techniques, while successful in narrow domains, often struggle with generalization, adaptability, and scalable reasoning when faced with the intricate logic and high-dimensional solution spaces inherent in such problems.

In response to these limitations, this research introduces a novel paradigm by harnessing Quantum-Inspired Artificial Intelligence (QIAI)— a field that mimics core quantum phenomena such as superposition, entanglement, and quantum tunneling within classical hardware architectures. These quantum analogs enable the creation of powerful optimization and learning algorithms that traverse complex solution landscapes more intelligently and efficiently. Techniques like the Quantum Approximate Optimization Algorithm (QAOA) and Variational Quantum Eigensolver (VQE), when combined with classical deep learning, reinforcement learning, and symbolic AI,establish a hybrid framework capable of emulating adaptive cognition and logical inference.

This project specifically focuses on the application of QIAI to grid-based puzzle solving, with Sudoku serving as the primary use case due to its high constraint density and well-defined success criteria. By encoding the puzzle into a structured matrix representation and applying quantum-inspired solvers, the system aims to significantly reduce the search space and improve solution accuracy and speed. Beyond mere puzzle completion,the architecture integrates symbolic reasoning, constraint-aware validation, and multi-modal processing, enabling the system to interpret and solve a wide range of puzzle formats—whether they are textual, numerical, or even visual representations.

II.MATERIAL AND METHODS

Solving Logic Grid Puzzles with an Algorithm that Imitates Human Behavior⋆ Guillaume Escamocher and Barry O'Sullivan Insight Centre for Data Analytics University College Cork, Cork, Ireland {guillaume. escamocher, barry.osullivan}@insight-centre.orgAuthors: Mitchell, Ryan; Libeskind-Hadas, Ran

This novel approach to solving logic grid puzzles using an algorithm that mimics human reasoning. Unlike traditional solvers that rely on exhaustive computation, this method employs step-by-step heuristics similar to the way humans eliminate possibilities and make deductions. Each solving step is accompanied by a natural-language explanation, making the process transparent and interpretable. Grounded in Constraint Programming, the approach emphasizes both efficiency and explainable reasoning, providing a framework that is not only effective in puzzle-solving but also accessible for educational purposes and the study of human-like problem-solving strategies.

Learning to Automatically Solve Logic Grid Puzzles Arindam Mitra SCIDSE Arizona State University amitra7@asu.edu Chitta Baral SCIDSE Arizona State University chitta@asu.edu

a system designed to automatically solve logic grid puzzles by translating natural language clues into Answer Set Programming (ASP) representations. The system first extracts entities and identifies relationships mentioned in the clues, then converts this information into ASP rules that can be processed by a solver. LOGICIA achieves 81% accuracy in clue translation and successfully solves approximately 71% of puzzles in the evaluated dataset. This work highlights the potential of combining natural language understanding with formal reasoning techniques, enabling automated deduction while maintaining interpretable and structured solutions. It represents a significant step toward AI systems capable of mimicking human-like reasoning in puzzle-solving tasks.

Step-by-Step Reasoning to Solve Grid Puzzles: Where do LLMs Falter? Nemika Tyagi1∗ Mihir Parmar1∗ Mohith Kulkarni1 Aswin RRV1 Nisarg Patel1 Mutsumi Nakamura1 Arindam Mitra2 Chitta Baral1 1Arizona State University 2Microsoft Research {ntyagi8, mparmar3, chitta}@asu.edu

The paper introduces GridPuzzle, a dataset comprising 274 logic grid puzzles of varying complexities, designed to evaluate the reasoning capabilities of large language models (LLMs). Unlike previous studies that focus solely on the final answers, this research delves into the models' reasoning chains to identify specific areas where they falter. The authors propose a novel error taxonomy, categorizing reasoning failures into five types:

- WW: Wrong Premise and Wrong Conclusion
- WR: Wrong Premise and Right Conclusion
- RW: Right Premise and Wrong Conclusion
- RR: Right Premise and Right Conclusion
- NC: No Conclusion

“Using Grid Puzzle to Solve Constraint-Based Scheduling Problem” by Noppon Choosri, affiliated with SMART Research Centre, College of Arts Media and Technology, Chiang Mai University, Thailand.

The paper explores the application of logic grid puzzles as a framework for addressing constraint-based scheduling problems. By representing scheduling constraints in a structured grid format, the approach allows systematic reasoning to assign tasks, resources, or time slots without conflicts. This method leverages the inherent properties of grid puzzles—such as elimination, deduction, and logical inference—to simplify complex scheduling scenarios. The proposed technique demonstrates how human-like step-by-step reasoning can be mapped onto computational algorithms, enabling more efficient and interpretable solutions for scheduling problems in domains such as education, project management, and resource allocation.

Designing Grid-based Problem Solving Environments and Portals Gregor von Laszewski, Ian Foster, Jarek Gawor, Peter Lane, Nell Rehn, Mike Russell Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439, U.S.A. gregor@mcs.anl.govt:

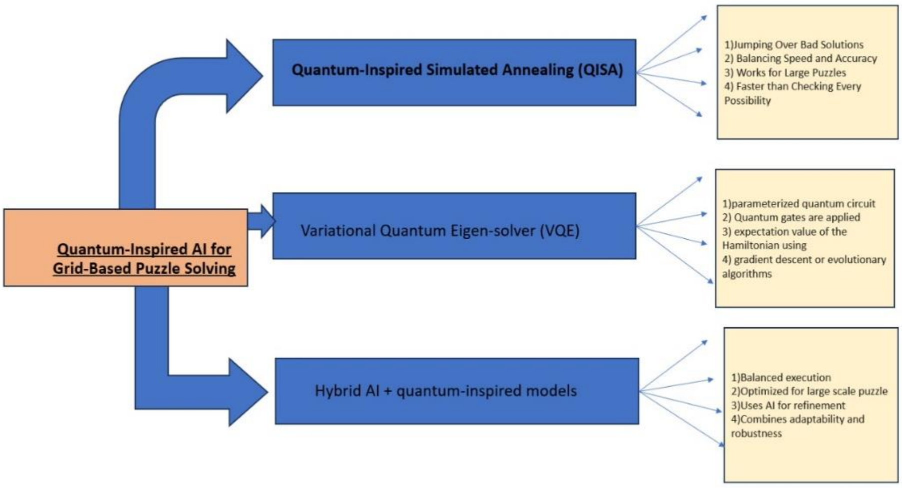
Presents an exploration of how Grid computing technologies can be leveraged to create user-friendly, efficient, and scalable problem-solving environments. It emphasizes the need for portals that provide seamless access to distributed resources, tools, and applications while masking underlying technical complexities from end-users. The authors highlight design principles, architectural considerations, and implementation strategies that enable researchers and practitioners to utilize Grid infrastructures effectively. By integrating advanced computational resources with intuitive interfaces, the paper contributes to the broader understanding of how Grid-based systems can support collaborative scientific research and large-scale problem solving

Quantum Optimization and Quantum Learning: A Survey YANGYANG LI , (Senior Member, IEEE), MENGZHUOTIAN, GUANGYUAN LIU ,CHENG PENG , AND LICHENG JIAO , (Fellow, IEEE) Key Laboratory of Intelligent Perception and Image Understanding of Ministry of Education, Xidian University, Xi'an 710071, China Corresponding author: Yangyang Li (yyli@xidian.edu.cn)

The paper highlights that quantum optimization and quantum learning are deeply interconnected, as many learning tasks can be reformulated as optimization problems. By leveraging quantum principles such as superposition and entanglement, quantum algorithms promise significant improvements in solving high-dimensional and computationally intensive problems. Given the limitations of current noisy intermediate-scale quantum (NISQ) hardware, the authors emphasize the importance of hybrid quantum-classical approaches, particularly variational quantum algorithms like VQE and QAOA, which provide practical pathways to real-world applications. The paper also points out that these methods hold great potential in domains such as finance, chemistry, logistics, and image processing, although large-scale implementation remains constrained by issues of noise, scalability, and hardware efficiency. Overall, the insights suggest that quantum optimization and learning are in a formative stage but carry transformative potential for artificial intelligence and scientific computing, with future progress dependent on advances in both quantum hardware and algorithm design.

III.METHODS

This project focuses on leveraging Quantum-Inspired Artificial Intelligence(QIAI) methodologies to enhance the efficiency and effectiveness of solving grid-based puzzles such as Sudoku, surpassing the limitations of traditional AI approaches. Central to our methodology are advanced quantum-inspired algorithms including the Quantum Approximate Optimization Algorithm (QAOA), Variational Quantum Eigensolver (VQE), and hybrid quantum-classical frameworks. These techniques emulate key quantum mechanical phenomena—such as superposition and entanglement—within classical computational environments, enabling a substantial reduction in the combinatorial search space and more effective constraint satisfaction during puzzle resolution.



The diagram illustrates an architectural overview of how **Quantum-Inspired AI techniques** can be leveraged for **grid-based puzzle solving**, such as logic puzzles or constraint-based problems. The central block, titled **"Quantum-Inspired AI for Grid-Based Puzzle Solving"**, branches into three major methodologies thatrepresent distinct approaches: **Quantum-Inspired Simulated Annealing (QISA)**, **Variational Quantum Eigen-solver (VQE)**, and **Hybrid AI + Quantum-Inspired Models**.

The **QISA** path focuses on mimicking the behavior of quantum tunneling to solve puzzles efficiently. This technique allows the system to **"jump over" bad or suboptimal solutions**, unlike classical algorithms that may get stuck in local minima. It's particularly suited for large puzzles because it balances speed and accuracy well and is significantly **faster than brute-force approaches** that check every possible combination.

The second branch highlights the **Variational Quantum Eigen-solver (VQE)** method, which uses **parameterized quantum circuits** to estimate the optimal solution to a problem. This approach applies quantum gates and evaluates the expectation value of the problem's Hamiltonian. It then optimizes these values using **gradient descent or evolutionary algorithms**, making it suitable for complex logical structures where energy minimization reflects constraint satisfaction.

Finally, the **Hybrid AI + Quantum-Inspired Models** strategy combines classical AI techniques with quantum-inspired reasoning for **balanced execution**. These models are **optimized for large-scale puzzles** and use AI components to refine or guide the solution process. This hybridization brings together the **adaptability of AI** and the **robustness of quantum optimization**, making it a powerful solution for dynamic and high-dimensional problem spaces.

In essence, the diagram showcases a flexible framework for solving puzzles by integrating innovative quantum principles with traditional AI methods. Each method contributes unique strengths to improve accuracy, scalability, and computationa efficiency in constraint-based puzzle domains.

IV. CONCLUSION

This project explores the powerful synergy between Quantum-Inspired Artificial Intelligence and classical computing for solving complex grid-based puzzles like Sudoku. By employing advanced algorithms such as the Quantum Approximate Optimization Algorithm (QAOA), Variational Quantum Eigensolver (VQE), and Quantum Neural Networks (QNNs), the approach significantly enhances constraint satisfaction and solution efficiency. Through tools like Qiskit and TensorFlow Quantum, puzzles are encoded into matrix formats and processed within a modular framework that ensures accuracy, robustness, and flexibility. This hybrid design not only improves performance but also supports explainability— crucial for real-world applications.

A standout feature is the use of QNNs for adaptive learning and dynamic search strategy refinement, especially in puzzles with ambiguous or incomplete data. The framework's extensibility allows it to scale across diverse constraint-satisfaction domains such as logistics and network optimization. By approximating quantum behavior on classical hardware, the project offers a practical bridge until fully quantum systems mature, paving the way for next-generation AI capable of addressing increasingly complex, high-stakes challenges with clarity and confidence.

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