Advancing Quantum-Classical Hybrid Workflows: Algorithm Selection, Circuit Generation, and Optimization for NISQ Processors

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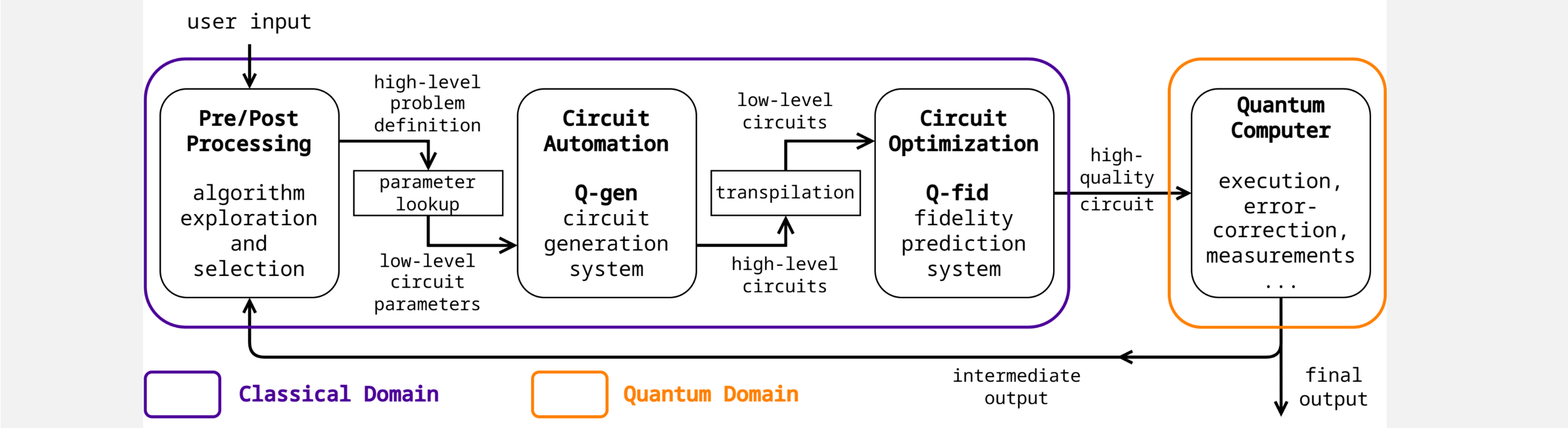
INTRODUCTION

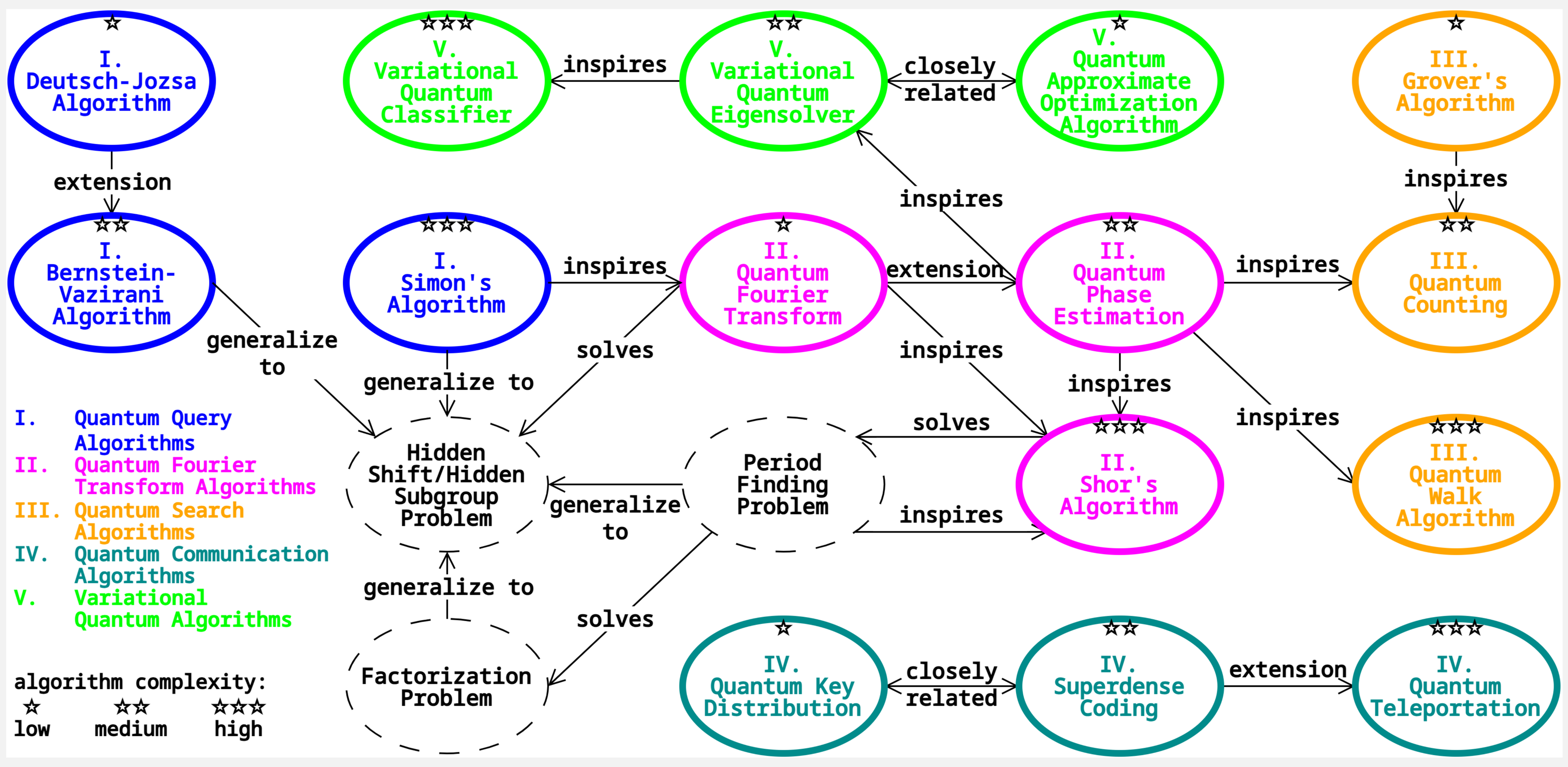
- While quantum computing holds the potential to **revolutionize** certain fields, classical computing will remain **indispensable** for **building**, **optimizing**, and **utilizing** quantum technologies.
- Specifically, classical systems **prepare input data** for quantum computations and **analyze output data** generated by quantum systems, as quantum computers are **not suited** for general-purpose data handling.
- This work envisions the full quantum computing process as a **quantum-classical hybrid ecosystem**.
- Under this concept, we introduce an innovative **workflow** tailored specifically for **circuit model** quantum computing, addressing the **challenges** of **designing** and **optimizing** quantum circuits.

BACKGROUND



- Proposed the **Quantum-Classical Hybrid Workflow** with **3** major components.
- Focused on **classical automation** and **optimization** techniques for quantum computing.

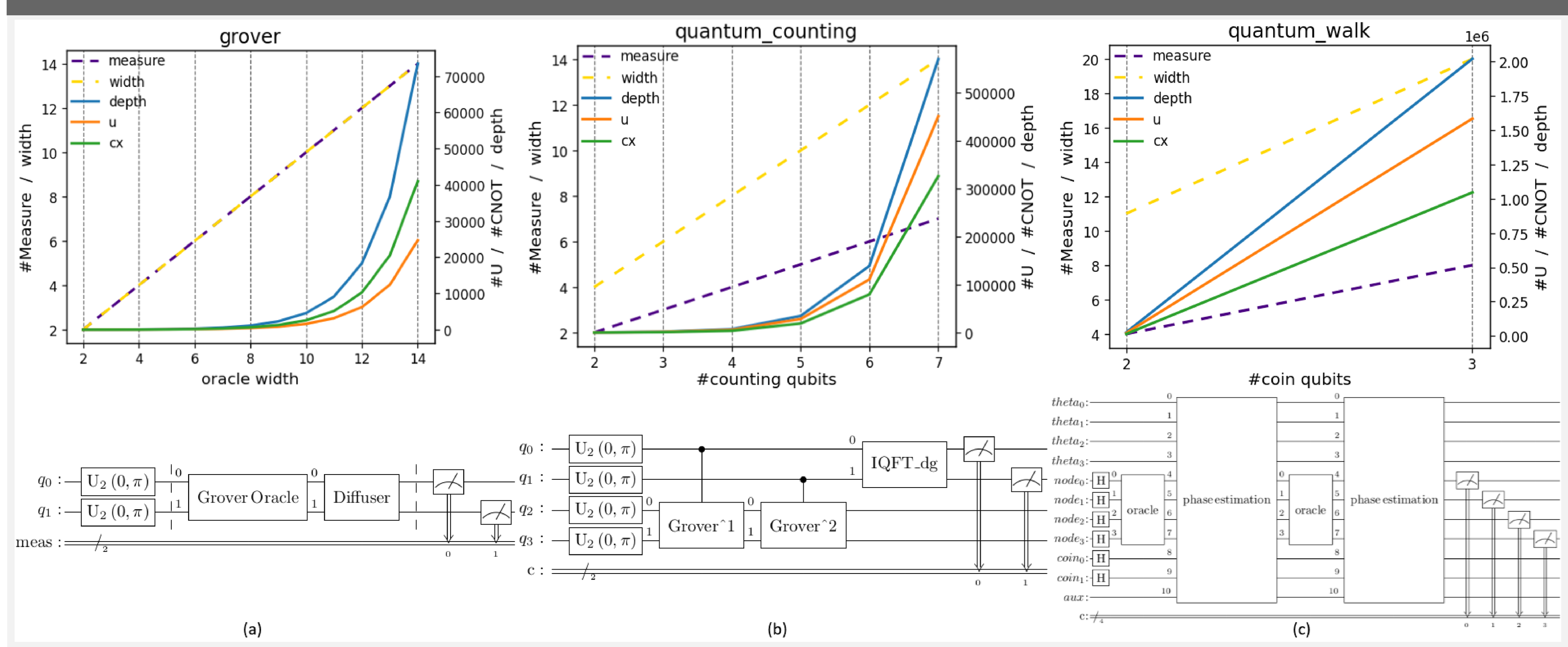
METHODS

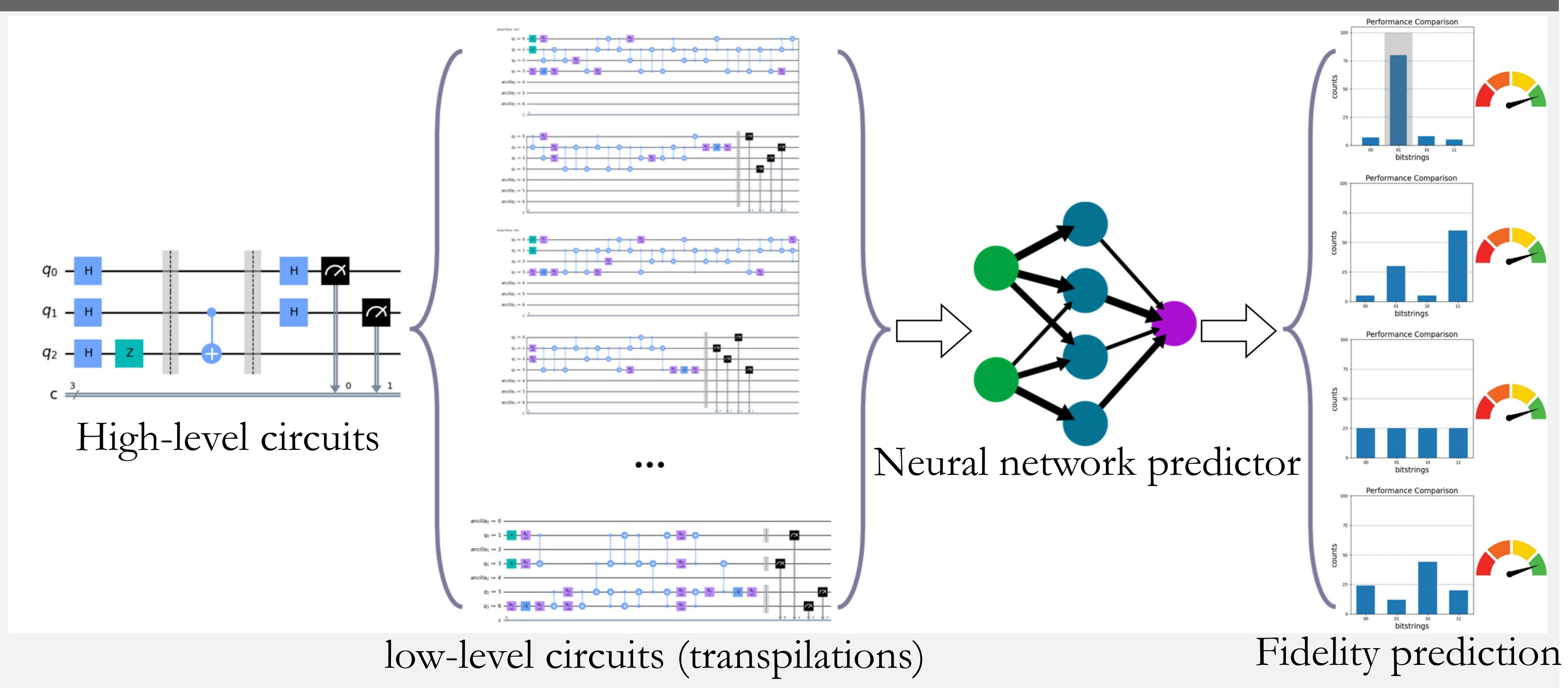


1st component of the workflow: an organized quantum algorithm system

- The **core** of the proposed **Quantum-Classical Hybrid Workflow** is the theoretical framework for organizing quantum algorithms, aimed at enhancing the efficiency of algorithm selection.
- This **structured** approach ensures that the most suitable algorithms are chosen for **specific quantum tasks**, maximizing resource **utilization** and **performance**.
- To solve a quantum computing problem, we need a **comprehensive understanding** of the quantum algorithms, so we know **which** algorithm to implement, and **prepare** the hardware accordingly.
- **15** quantum algorithms organized into a structured system to facilitate algorithm **selection**, define circuit generation **parameters**, and guide effective circuit **design**.
- This **organized** algorithm system ensures that the circuit generation parameters can be accurately **prepared**, laying the **foundation** for the Q-gen quantum circuit generation system.

RESULTS

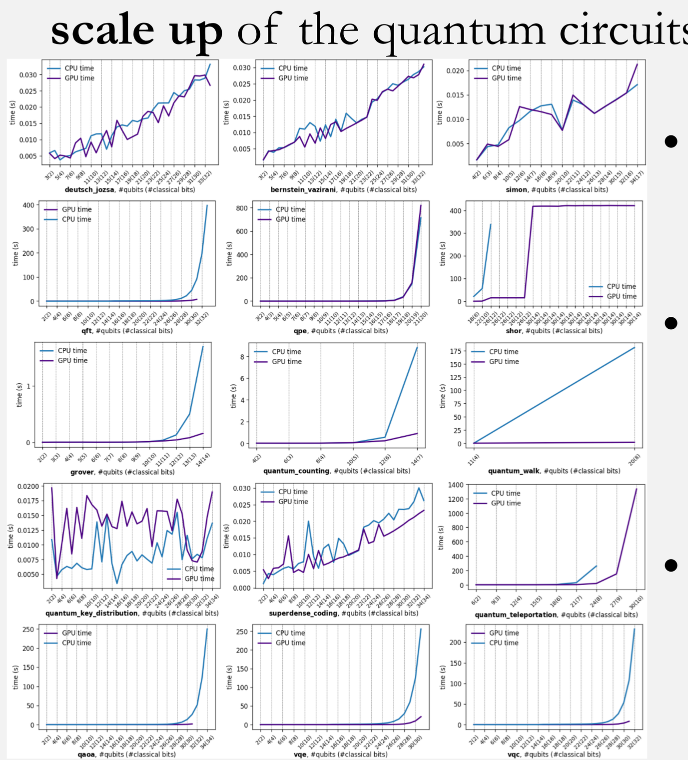




2nd component of the workflow: Q-gen for circuit automation

- **Simplifies** the creation of quantum circuits for **practical** applications.
- Quantum circuits are highly **structured** and usually includes **reusable** elements to preserve reversibility, which leaves a good opportunity for automation.
- Q-gen provides **algorithm-specific** generation parameters for easy **scale up** of the quantum circuits.

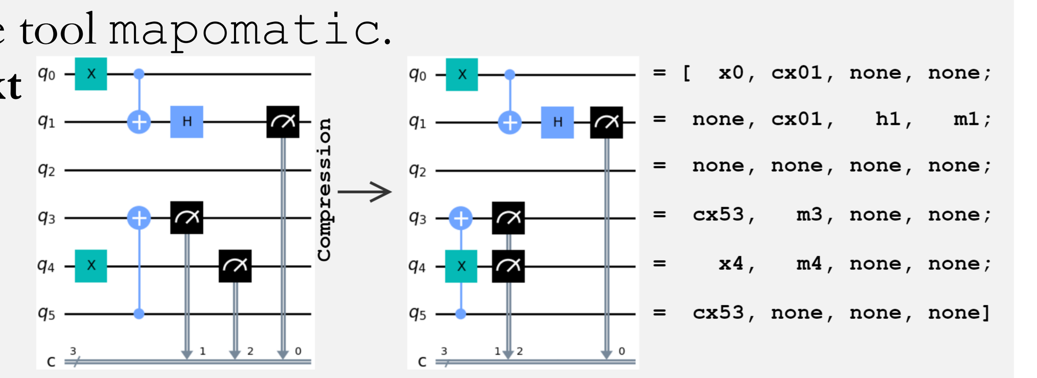
Algorithm	Available Parameters (* = problem size)
Grover's	oracle width* oracle content #solution #iteration
Quantum Counting	#counting qubits* #searching qubits #solution
Quantum Walk	#theta qubits #node qubits #coin qubits* #iterations #solutions

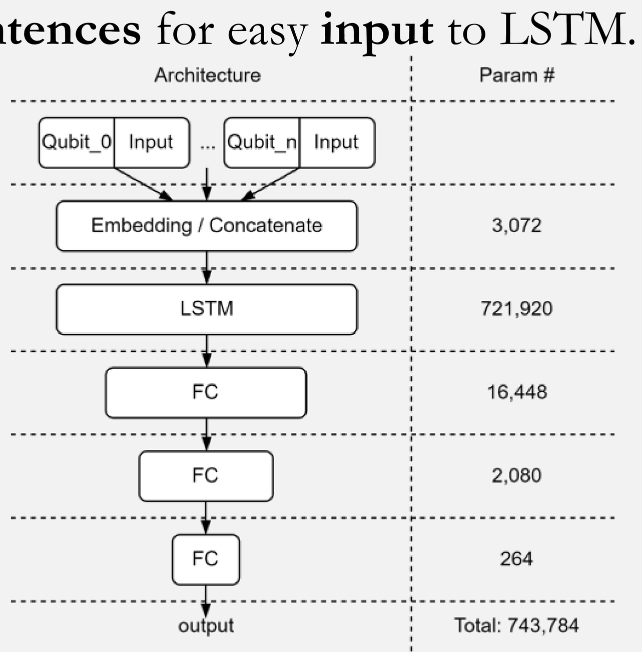


- To demonstrate the **capability** of Q-gen, we present the Q-gen quantum circuit **dataset** consisting of **1000+** circuits.
- These circuits are produced with **various** generation parameters from all **15 available** algorithms, ranging from shallow circuits with **no** CNOT gates to deep circuits with **more than** 50,000 CNOT gates.
- We also provide **open-source**, **ready-to-use** dataset including **Simulation times**, circuit **dimensions**, gate **statistics**…

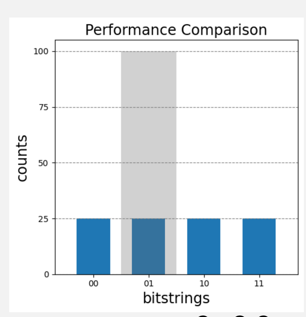
3rd component of the workflow: Q-fid for circuit optimization

- Leveraging **LSTM** neural network and **novel** modeling methods to optimize low-level quantum circuit layout and transpilations with **fidelity predictions**.
- Q-fid achieves a high prediction **accuracy** with an average RMSE of **0.0515**, up to **24.7x** more accurate than the Qiskit transpile tool `mapomatic`.
- Model quantum gates/qubits using **text labels**. Treat full circuits like human **sentences** for easy **input** to LSTM.



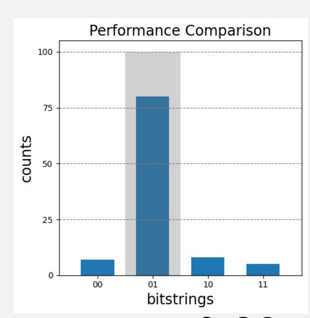


- **Lightweight** LSTM architecture.



score = 0.00

- Prediction score (0~1) shows the **comparison** between the **noise-free distribution** and the **noisy distribution.**



score = 0.98

CONCLUSIONS

- Quantum computing heavily relies on classical computing as the two computing paradigms are **complementary.**
- By leveraging the two classical tools: **Q-fid** and **Q-gen**, the hybrid workflow bridges the gap between current quantum hardware limitations and the growing demands for efficient quantum solutions.
- The **organized algorithm system** proposed in this work also shows a clear mind map for users who want to learn about quantum computing in general.
- Together, these contributions offer a **comprehensive solution** for advancing the capabilities of circuit model quantum computing, combining the strengths of classical computation with emerging quantum technologies.

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