

# Ambitions and Challenges in Digital Quantum Computing

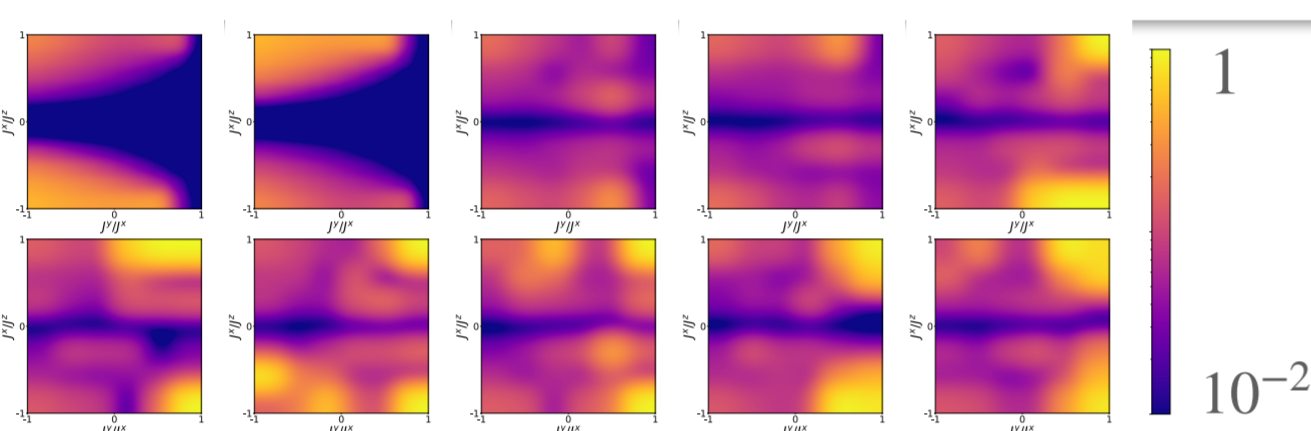
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ABSTRACT

Quantum computing is often presented as a route to solving classically intractable problems, yet this promise is fundamentally constrained by limited hardware resources. This poster explores how this tension can be addressed across quantum simulation, quantum chemistry, and quantum machine learning. In quantum simulation, key challenges lie in the efficient preparation of physically relevant many-body states and the reliable estimation of observables. Quantum chemistry represents a distinct and industrially relevant challenge, where accurately modelling molecular systems requires balancing algorithmic design with resource constraints. Similar issues arise in quantum machine learning: While variational approaches are well suited to near-term devices, their performance typically degrades at larger system sizes. A central goal is therefore to identify tasks that may exhibit genuine quantum advantage, such as scalable learning on sets. We present algorithmic strategies designed to exploit quantum hardware while targeting relevant problems.

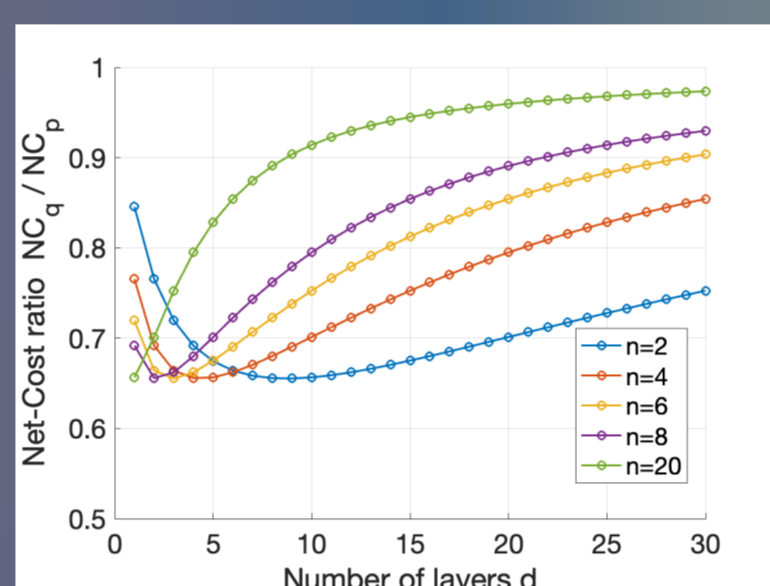
## Enhancement of Adiabatic Quantum-State Preparation [1,2]

Quantum-state preparation is among the most challenging tasks in digital quantum computing. **Adiabatic state preparation** is a physically motivated approach to this problem, but it suffers from well-known limitations. In this work, we **accelerate** the conventional adiabatic procedure and introduce a novel method that exploits group-theoretic principles to **leverage the symmetries** of the simulated system.



## Optimal Importance Sampling for Randomized Quantum Circuits

**Randomized circuits** are quantum circuits whose gates are sampled from a classical probability distribution. We employ **importance sampling** to construct an equivalently biased estimator of the measured observable while **minimizing** the overall **computational cost** required to achieve a target precision.



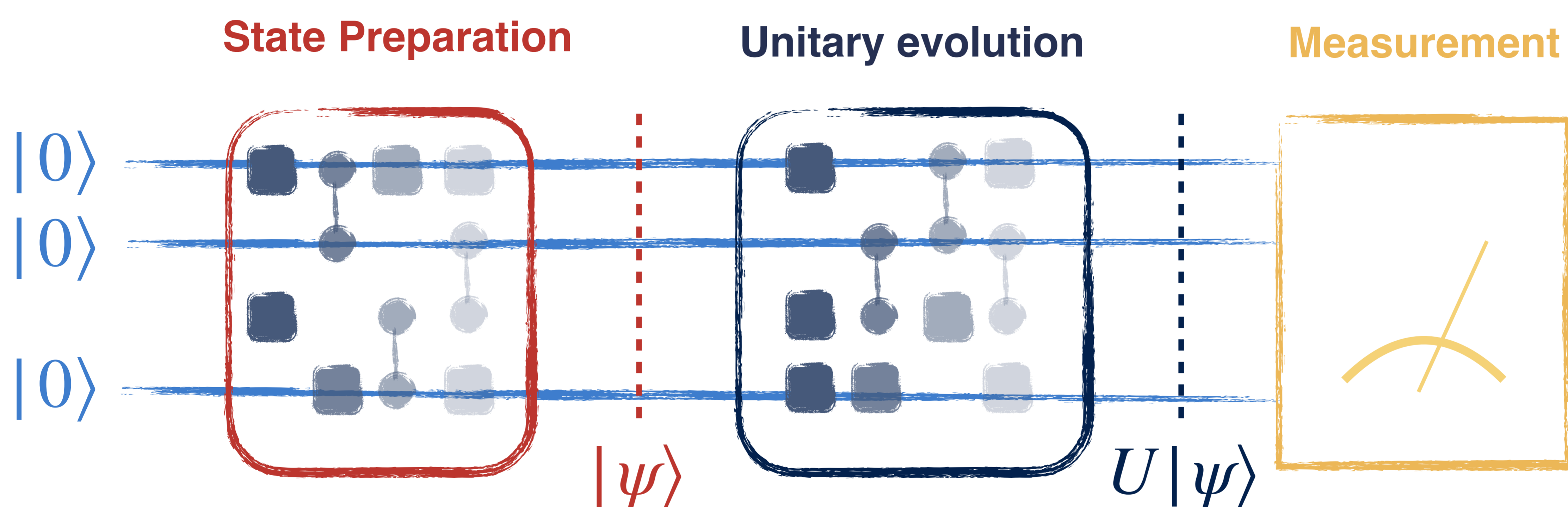
## Spectral Gap Estimation via Adiabatic Preparation [3]

Estimating spectral gaps via energy differences can be **computationally demanding** for some Hamiltonians. Here, we propose an alternative approach that circumvents this difficulty by exploiting the preparation of specially tailored **superposition states**.

$$|\psi\rangle = \frac{1}{\sqrt{2}} (|E_1\rangle + |E_2\rangle)$$

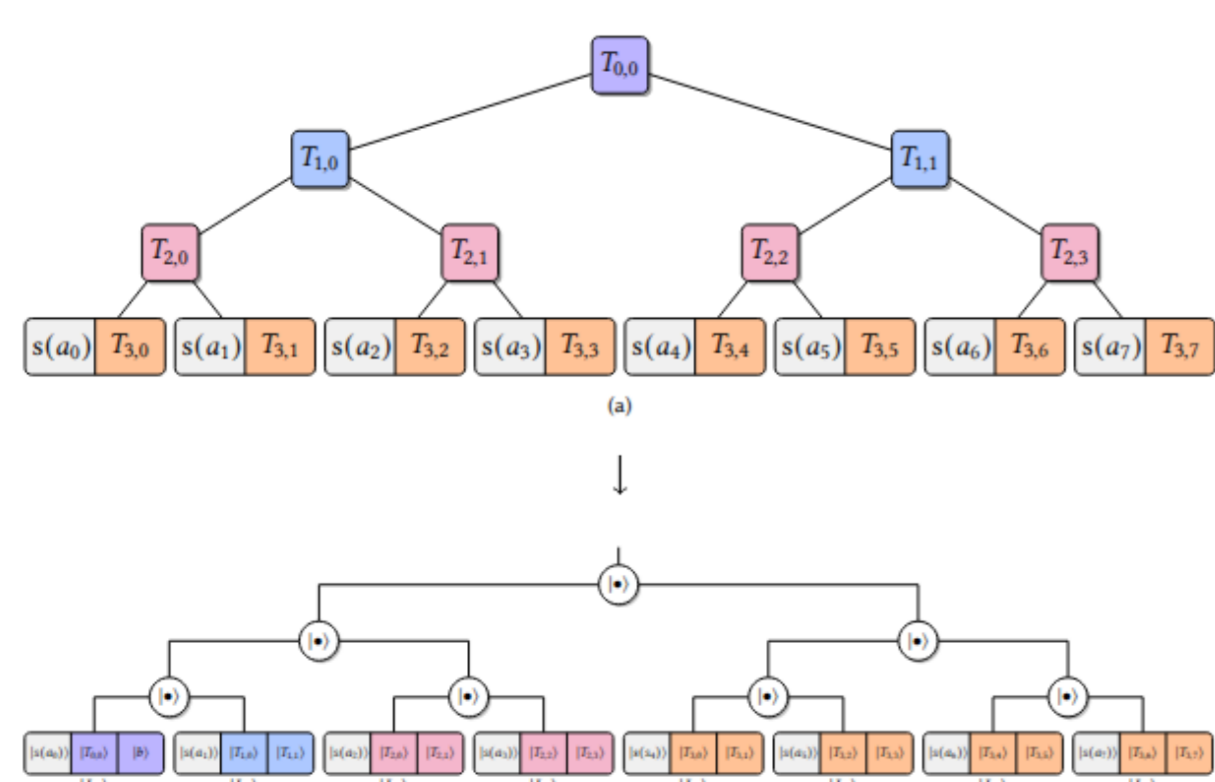
$$\langle\psi|O(t)|\psi\rangle = \bar{O} + \rho\cos(\Delta E \cdot t)$$

GENERAL ALGORITHM  
STRUCTURE



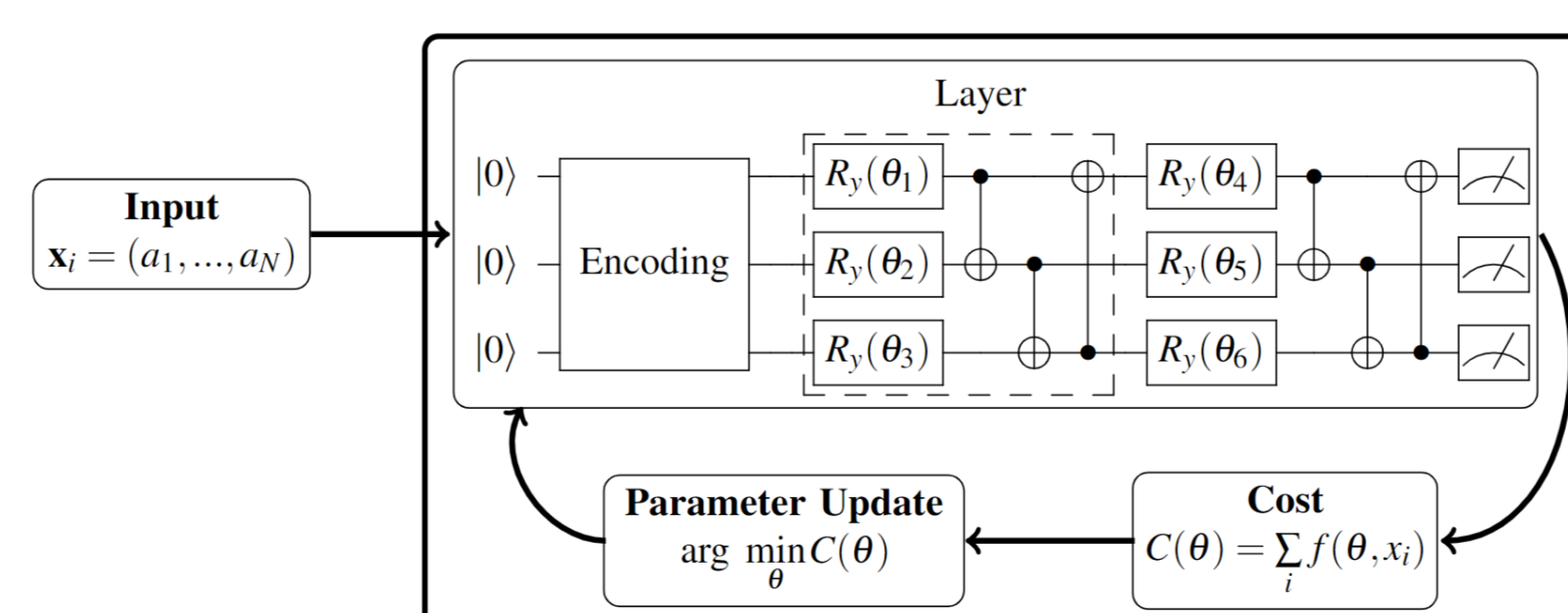
## Efficient State Preparation with BBQRAM [4]

**Efficient data preparation** is essential for realizing quantum advantage in areas like machine learning and chemistry. This work presents a framework combining the physical model of **Bucket Brigade QRAM (BBQRAM)** with the classical **Segment Tree data structure** to achieve efficient quantum state preparation. Our explicit  $O(\log^2(MN))$  time bound sharpens previous results and provides implementers with concrete guidance for resource planning.



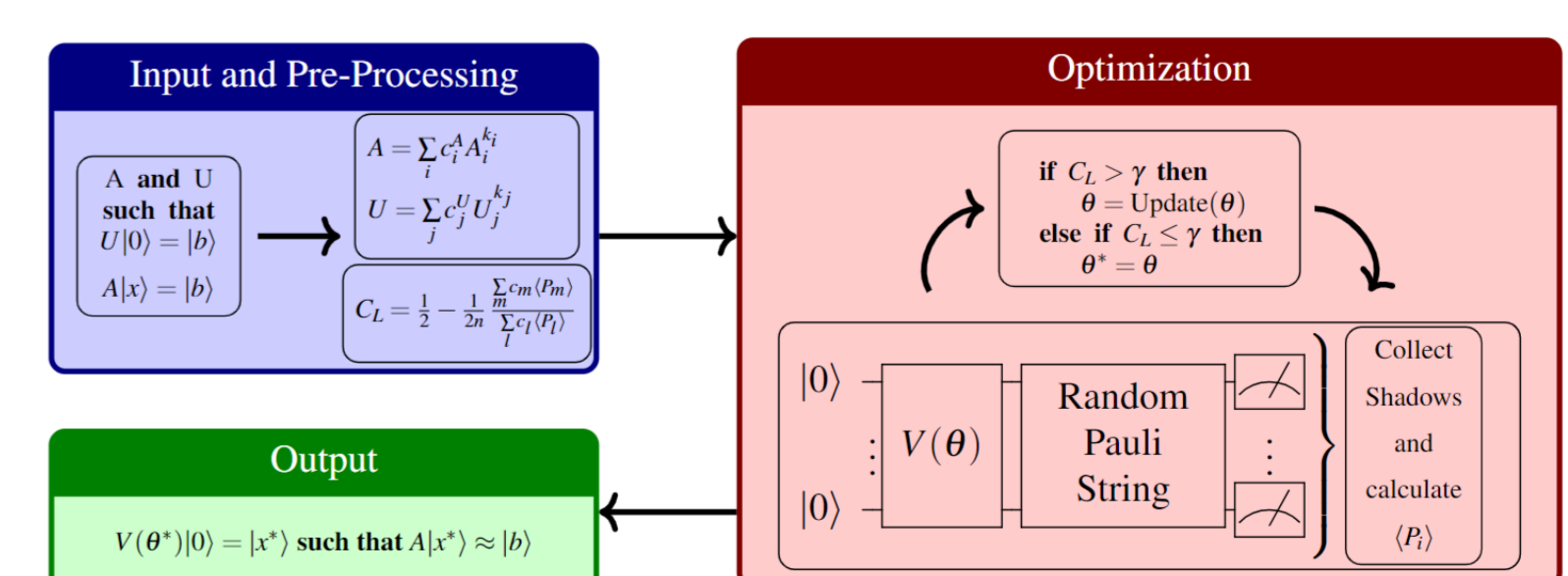
## Large Scale Benchmarking of Quantum and Classical Neural Networks [5]

Most **benchmarks** in the literature between classical and quantum neural networks have been **limited** to a small number of qubits and architectures. In this work we employ just over **400 days of HPC compute time**, running highly optimized code, to compare **460 QNNs** against **4460 NNs** for the classification of medical data. We find comparable results between the two models, with the QNNs showing a slight advantage in the low data regime.



## Shadow Quantum Linear Solver [6]

The solution to a **linear system** of equation represents a promising avenue for quantum computing to offer a computational speedup when compared to its classical counterpart. Yet most quantum algorithms for linear systems are too demanding for the current available quantum devices. In this work, by **combining** the framework of **variational quantum algorithms** and **classical shadows**, we propose a **resource efficient** quantum algorithm for linear systems of equations.



## BIBLIOGRAPHY

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