AI-Driven Discovery of Physics-Native Quantum Information Units

Author: Tom Stevns — Independent Research Contributor

Date: December 2025

Abstract

Current quantum computing architectures rely on qubits and gates that are derived from human-designed logical models rather than emerging naturally from physical symmetries or dynamical constraints. This misalignment between mathematical abstractions and physical realizations is a primary cause of noise, decoherence, and the need for extreme redundancy—often requiring ~1,000 physical qubits for a single logical qubit.

This whitepaper proposes a paradigm shift: an AI-driven search across Hamiltonian space to discover physics-native quantum information units, i.e., information-bearing states and operations that arise directly from the fundamental laws of quantum mechanics rather than being imposed externally. Such an approach has the potential to eliminate the need for large-scale error correction, reduce circuit depth, and enable computational processes inaccessible to classical intuition.

1. Introduction

The current qubit model originates from abstract quantum information theory, which treats quantum states as vectors in a Hilbert space and gates as unitary transformations chosen for logical universality. While mathematically elegant, this framework assumes idealized, geometry-free operations that are largely incompatible with real quantum hardware.

Superconducting circuits, trapped ions, spins in semiconductors, photonic qubits, and topological prototypes all struggle with decoherence, crosstalk, leakage, and operational noise. These problems arise not merely from engineering limitations but from a more fundamental issue:

We impose human-designed logical structures upon physical systems instead of discovering the information structures that physics naturally supports.

2. Background and Problem Statement

Quantum computing today faces three core challenges:

1. Fragile qubit implementations
2. Misaligned gate operations
3. Extreme error correction overhead

2.3 Human-Designed Quantum Gates as Physically Misaligned Operations

The Hadamard gate is conceptually simple but physically destructive. It amplifies phase noise, amplitude noise, and leakage to non-computational states.

CNOT introduces crosstalk, unintended entanglement, decoherence during coupling, and frequency drift.

T-gates are mathematical idealizations requiring magic-state distillation.

Phase gates suffer from timing jitter and phase drift.

Controlled-Z assumes symmetric interactions that real hardware cannot guarantee.

Arbitrary rotations rely on unrealistic Bloch-sphere symmetry.

Conclusion of Section 2.3:

The current gate set is logically efficient but physically incompatible. It amplifies noise because it violates the natural symmetries of real quantum systems.

3. Motivation: Why Physics-Native Qubits

A physics-native information unit is a quantum state or subspace that is naturally stable, symmetry-protected, topologically robust, energetically gapped, and requires minimal external control.

4. Methodology: AI-Driven Hamiltonian-Space Exploration

Build a Hamiltonian library.

Use AI to evolve candidate systems.

Simulate candidates.

Evaluate stability.

Filter for realizability.

5. Proposed System Architecture

Quantum physics database

AI discovery engine

Quantum dynamics simulator

Stability scoring system

Candidate realization layer

6. Evaluation Metrics

Logical error rate

Coherence time

Leakage suppression

Spectral gap

Noise sensitivity

Scalability

7. Potential Physics-Native Information Units

Non-Abelian anyons

Majorana modes

Collective excitations

Symmetry-protected subspaces

Topologically ordered phases

8. Implications for Quantum Computing

Reduced error correction

New gate sets

AI-generated algorithms

New computational paradigms

9. Discussion and Limitations

Hamiltonian space is large, but AI + HPC makes exploration feasible.

10. Conclusion

Current architectures are limited by misalignment between logical abstractions and physical realities. AI-driven discovery of physics-native information units offers a fundamentally more robust and scalable path forward.

References (representative):

Preskill (2018); Kitaev (2003); Wen (2013); McClean et al. (2018); Kandala et al. (2019); Motta et al. (2020); Lidar & Brun (2013).