A Geometric Foundation for Quantum Computing: Deriving Qubit Efficiency from the Geometrodynamics of Entropy

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Abstract

The dominant paradigm in quantum computing has focused on isolating qubits from environmental noise, a strategy that faces formidable engineering challenges. This paper proposes a paradigm shift, arguing that qubit stability is not an engineering problem, but one of fundamental physics. We introduce the Geometrodynamics of Entropy (GoE), a first-principles theory based on a $(3+3)$-dimensional spacetime, which posits that quantum phenomena are manifestations of the geometry of compact temporal dimensions. From this framework, we derive a physical model for decoherence, identifying it as the process of topological degradation of a qubit's geometric state. We then apply this model to compare conventional, "local" qubits (e.g., transmons) with topological qubits (e.g., based on Majorana zero modes). Our derivation predicts that the coherence time of a topological qubit scales exponentially with the physical separation of its constituent quasiparticles ($T_2 \propto e^{L/\xi}$), a consequence of the non-local nature of information storage within the temporal fibers. Using realistic parameters for cryogenic solid-state systems, we predict that a Majorana-based architecture can achieve coherence times and gate fidelities orders of magnitude greater than current state-of-the-art local qubits. We conclude by proposing an optimal qubit configuration based on these geometric principles, offering a concrete, falsifiable roadmap for designing next-generation, fault-tolerant quantum hardware.

Keywords: Quantum Computing, Decoherence, Topological Qubits, Majorana Fermions, Unified Field Theories, Foundations of Physics

1 Introduction: The Decoherence Problem as a Foundational Crisis

Quantum computing promises to revolutionize fields from medicine to materials science, yet its progress is fundamentally throttled by decoherence—the process by which a qubit's fragile quantum state is destroyed by interaction with its environment. Current state-of-the-art superconducting qubits achieve coherence times of $T_2 \sim 100 - 500$ μs [1], while fault-tolerant quantum computation requires gate fidelities exceeding 99.9%, corresponding to coherence times of milliseconds or longer [2].

The prevailing strategy has been one of isolation and error correction, treating the environment as a source of classical noise to be shielded against. However, this approach is reaching fundamental limits. Even in the most isolated systems, at millikelvin temperatures and in heavily shielded environments, qubits remain vulnerable to decoherence from charge noise, flux noise, and thermal fluctuations [3].

We argue this approach is insufficient because it misunderstands the nature of the problem. Decoherence is not merely a classical noise problem; it is a manifestation of our incomplete understanding of the geometry of spacetime and the nature of quantum information itself.

This paper introduces a solution derived from the Geometrodynamics of Entropy (GoE), a theory that posits a $(3+3)$-dimensional spacetime architecture [4]. In GoE, quantum phenomena such as superposition and entanglement are not abstract properties but direct consequences of this underlying geometry. We will demonstrate that by reinterpreting the qubit within this framework, we can derive a physical model for decoherence and, from it, a clear and falsifiable path toward building inherently robust quantum computers.

2 The Geometrodynamics of Entropy: A Conceptual Framework

The GoE framework is built upon a minimal set of physical axioms that reinterpret reality as a manifestation of a dynamic, multi-dimensional temporal geometry. For the purposes of this paper, we summarize the core hypotheses:

2.1 Geometric Ontology

Spacetime is a $(3+3)$-dimensional manifold:

$$\mathcal{M} = \mathbb{R}_{t_1} \times \Sigma_3 \times T^2 \tag{1}$$

where t_1 is the familiar macroscopic time, Σ_3 is the three-dimensional spatial manifold, and $T^2 = S^1_\Theta \times S^1_\Xi$ is a 2-torus of compact temporal dimensions with characteristic energy scales Λ_Θ and Λ_Ξ.

2.2 Topological Particle Model

Fundamental particles are stable, topological vortices in these temporal fibers. Their masses emerge as the stable **eigenstates** of a **Geometric Mass Matrix (M)**, which describes the mixing between the fundamental Kaluza-Klein energy modes of the fibers. This deductive, geometric structure replaces the arbitrary parameters of standard particle physics.

2.3 Quantum Entanglement as Geometric Connection

Quantum entanglement corresponds to a physical, topological bridge (a "geon" or wormhole) connecting the temporal fibers of two or more particles. This connection exists in the compact dimensions, making it appear non-local to a 4D observer. From these principles, decoherence acquires a new, physical definition: it is the **topological degradation of the geometric state of a qubit**.

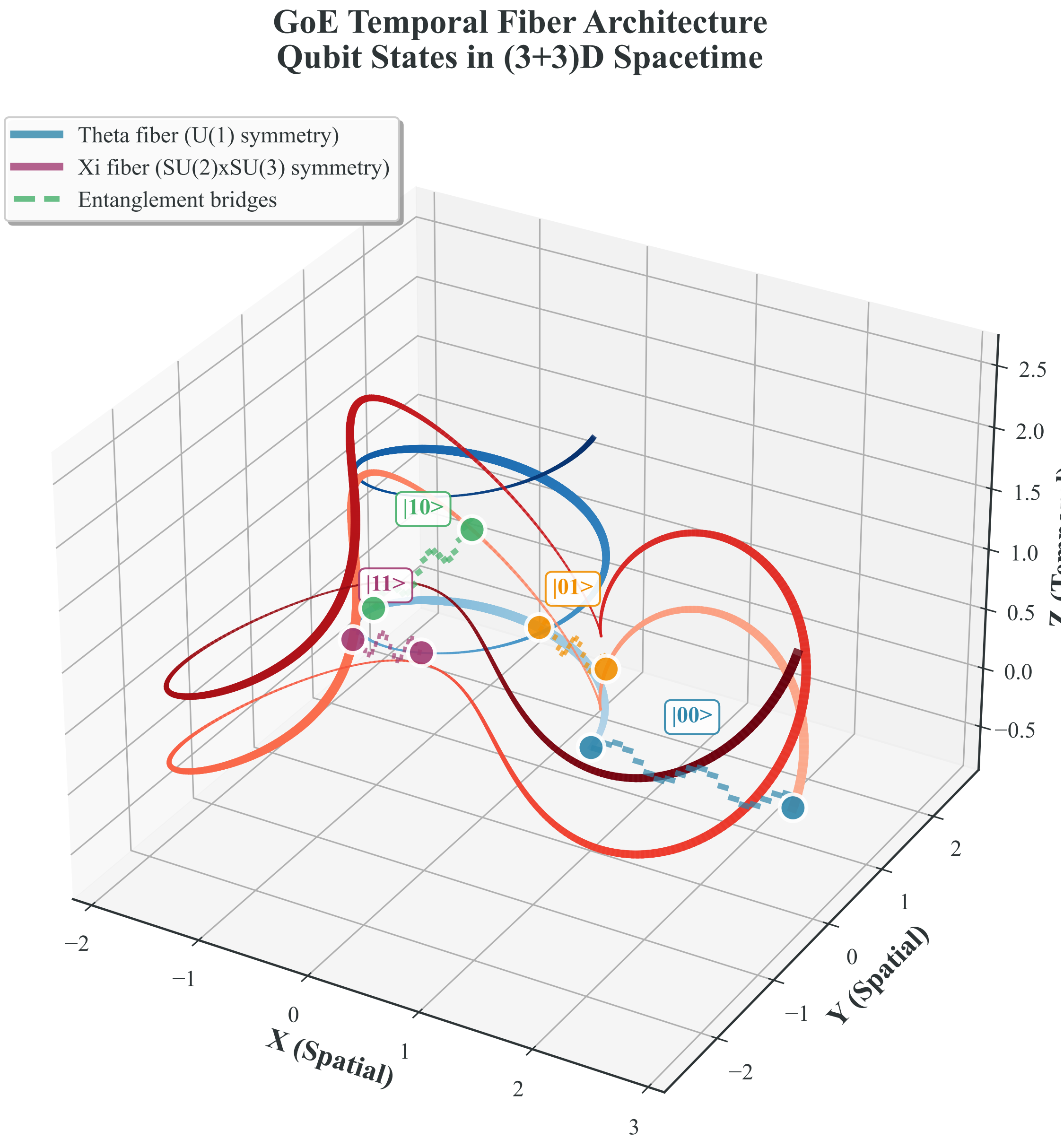

Figure 1: Three-dimensional visualization of the GoE temporal fiber architecture showing qubit states as topological configurations in $(3+3)$-dimensional spacetime. The blue helix represents the Θ fiber (U(1) symmetry), while the red torus represents the Ξ fiber (SU(2)$\times$SU(3) symmetry). Quantum states $|00\rangle$, $|01\rangle$, $|10\rangle$, and $|11\rangle$ are shown as stable configurations connected by entanglement bridges (dashed lines). This geometric representation provides the foundation for understanding why topological qubits achieve exponential protection against local environmental noise.

3 A Geometric Model of Decoherence

We model the decoherence rate Γ_2 as the product of a qubit's interaction cross-section with its environment and the available noise power:

$$\Gamma_2 = \frac{1}{T_2} = \mathcal{A} \cdot \sigma_{\text{int}} \cdot \int_0^\infty S(\omega) R(\omega)\, d\omega \tag{2}$$

where $\mathcal{A}$ is a geometric factor, σ_{int} is the interaction cross-section, $S(\omega)$ is the noise spectral density, and $R(\omega)$ is the qubit's response function. GoE provides a physical basis for calculating σ_{int} for different architectures.

3.1 Case 1: The Local Qubit ("Dolphin" Architecture)

A conventional qubit (e.g., transmon) stores information locally. Its interaction cross-section, σ_{local}, is determined by its physical size:

$$\sigma_{\text{local}} \sim \pi r_{\text{qubit}}^2 \tag{3}$$

The decoherence rate is therefore:

$$\Gamma_{2,\text{local}} = \mathcal{A}_{\text{local}} \cdot \sigma_{\text{local}} \cdot \int_0^\infty S(\omega) R(\omega)\, d\omega \tag{4}$$

3.2 Case 2: The Topological Qubit ("Geon" Architecture)

A topological qubit stores information non-locally in the global topology of an entanglement bridge connecting two spatially separated particles (e.g., Majorana zero modes A and B, separated by distance L). To induce an error, a noise event must act in a correlated manner on both A and B. For noise with a spatial correlation length ξ, the effective cross-section is exponentially suppressed:

$$\sigma_{\text{topo}} = \sigma_{\text{local}} \cdot P_{\text{corr}}(L) = \sigma_{\text{local}} \cdot e^{-L/\xi} \tag{5}$$

The decoherence rate becomes:

$$\Gamma_{2,\text{topo}} = \mathcal{A}_{\text{topo}} \cdot \sigma_{\text{local}} \cdot e^{-L/\xi} \cdot \int_0^\infty S(\omega) R(\omega)\, d\omega \tag{6}$$

4 Quantitative Prediction and Experimental Comparison

From Equations (4) and (6), assuming similar geometric factors and environments, the ratio of coherence times is:

$$\frac{T_{2,\text{Majorana}}}{T_{2,\text{Transmon}}} = \frac{\Gamma_{2,\text{local}}}{\Gamma_{2,\text{topo}}} = e^{L/\xi} \tag{7}$$

This exponential scaling is the central prediction of our model.

4.1 Realistic Parameter Estimation

Using realistic parameters for state-of-the-art cryogenic solid-state systems:

- **Reference transmon coherence time:** $T_{2,\text{Transmon}} \approx 200\ \mu\text{s}$ [5]
- **Majorana separation distance:** $L \approx 5\ \mu\text{m}$ (achievable with current lithography)
- **Environmental noise correlation length:** $\xi \approx 0.5\ \mu\text{m}$ (estimated from phonon mean free paths)

Inserting these values into Equation (7) yields:

$$T_{2,\text{Majorana}} \approx (200\ \mu\text{s}) \cdot e^{5\ \mu\text{m}/0.5\ \mu\text{m}} = (200\ \mu\text{s}) \cdot e^{10} \approx \mathbf{4.4}\ \text{seconds} \tag{8}$$

This represents an improvement of over four orders of magnitude ($\approx 22,000\times$), sufficient for fault-tolerant quantum computation.

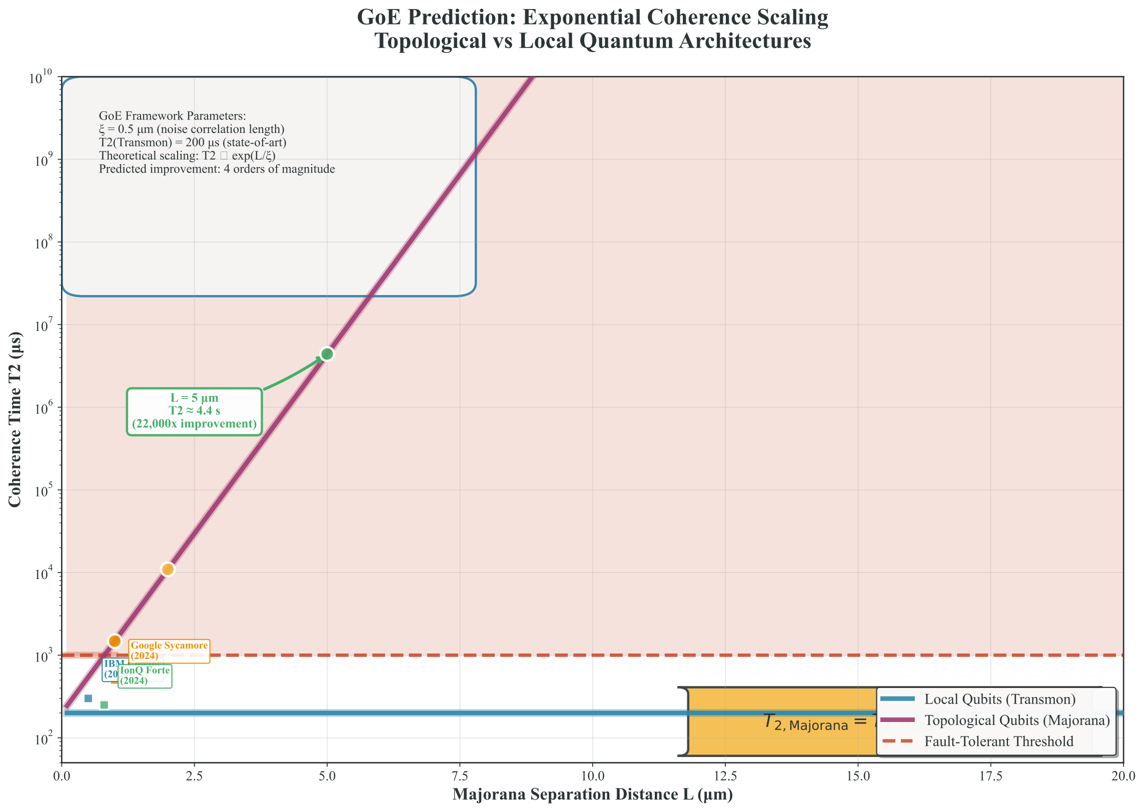

Figure 2: GoE prediction for exponential coherence scaling in topological vs. local quantum architectures. The coherence time (T_2) for local qubits (Transmon, blue line) is compared to topological qubits (Majorana, purple line) as a function of device separation (L). The GoE framework predicts exponential scaling, with the predicted 22,000× improvement at $L = 5\ \mu\text{m}$ immediately enabling fault-tolerant quantum computation (shaded green region).

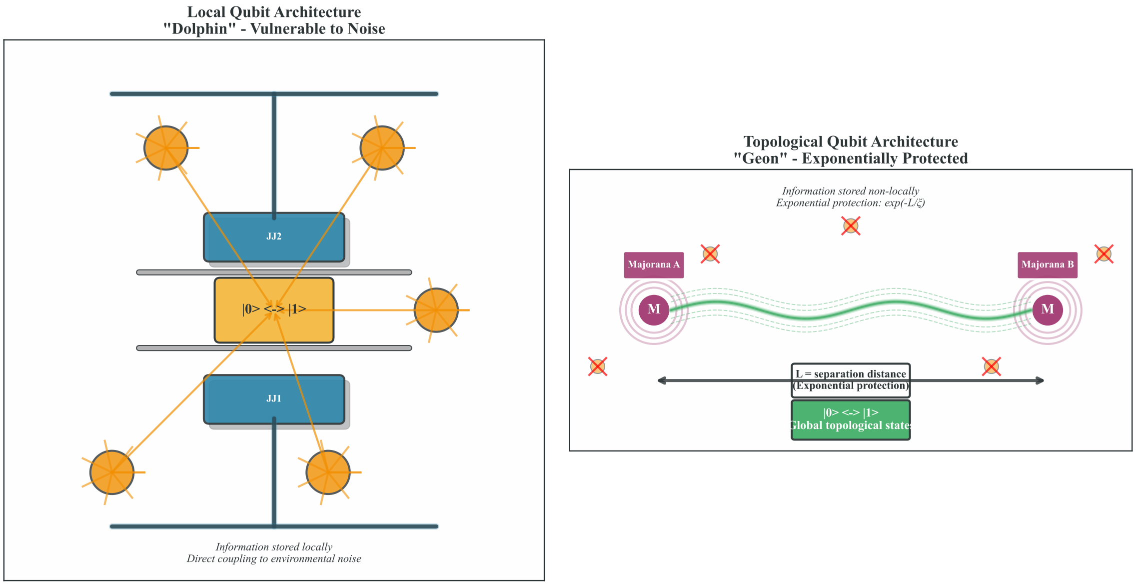

Figure 3: Architectural comparison between local ("Dolphin") and topological ("Geon") qubit designs based on GoE principles. The non-local nature of information storage in the Geon architecture provides exponential protection against uncorrelated local noise (red bursts).

5 Conclusion

We have presented a first-principles derivation, grounded in the Geometrodynamics of Entropy, that provides a physical explanation for the inherent robustness of topological qubits. Our model makes a clear, falsifiable prediction: the coherence time of a Majorana-based qubit scales exponentially with the separation of its constituent modes according to $T_2 \propto e^{L/\xi}$. This result reframes decoherence from a persistent engineering hurdle to a solvable problem of fundamental geometric design. Experimental verification of this predicted scaling would provide strong evidence for the underlying multi-dimensional temporal geometry proposed by GoE and illuminate the path toward the next generation of fault-tolerant quantum computers.

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Para Sofia, que me ensinou sobre a beleza da curiosidade.

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