Surface-Bounded Quantum Computation: Entropic Constraints, Holographic Scaling, and Physical Qubit Limits

Chandler Ayotte

Entropy Potential Systems Laboratory

chandler.ayotte@protonmail.com

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Abstract

We present a comprehensive theoretical and empirical examination of physical limits on logical quantum computation, grounded in the entropic surface encoding model of Distinction Surface Theory. We unify two results: (1) a geometric constraint—the Surface-Bounded Qubit Limit—predicting that logical qubit count Q is bounded by surface area A via $Q \leq A/4$, and (2) a predictive framework for error correction, entanglement scaling, and speedup saturation derived from holographic and recursive surface principles. Data from leading quantum systems are compared to this bound, supporting the proposed constraint. This paper is part of an ongoing research effort within the Entropy–Potential Field framework aiming to unite quantum computation and spacetime physics.

Contents

1 Introduction

As quantum computing systems grow in scale and complexity, physical limits rooted in thermodynamic, geometric, and information-theoretic principles become critical. Motivated by black hole entropy bounds and holographic surface encoding, we propose that logical quantum computation is fundamentally surface-limited, not volume-limited.

2 Theoretical Basis: Entropic Surface Limit

We define the maximum number of coherent logical qubits $Q_{\max}$ in a physical quantum device as:

$$Q_{\max} = \frac{A}{4}, \tag{1}$$

where A is the enclosing 2D surface area of the system in mm^2. This parallels the Bekenstein-Hawking entropy relation for black holes and implies that entropy—and therefore stable quantum information—is fundamentally surface-bound.

3 Predictions from Distinction Surface Theory

This model is part of a broader physical framework called Distinction Surface Theory, which predicts:

3.1 Surface-Area Bound on Entangled Qubits

$$N_{\max} \leq \frac{\alpha A}{\ell_p^2} \tag{2}$$

where ℓ_p is the Planck length and α is a scaling constant. As systems approach this limit, error rates sharply rise.

3.2 Quantum Error Correction as Surface Tilings

Optimal codes minimize surface area tiling (e.g., toric and surface codes), consistent with recursive minimal entropy tilings.

3.3 Entanglement and Mutual Information Scaling

Mutual information between subsystems scales with boundary:

$$I(A:B) \propto |\partial A| \tag{3}$$

not volume. This matches holographic predictions and has been confirmed in controlled subregister partitioning experiments.

3.4 Collective Surface Measurement Effects

Logical boundaries may induce global nonlocal collapse phenomena upon measurement.

3.5 Bound on Quantum Speedup

Ultimate computational speedup is capped by the surface-bound entanglement rate. For large Q, performance saturates:

$$\frac{d(\text{speedup})}{dQ} \to 0 \quad \text{as} \quad Q \to \frac{A}{4} \tag{4}$$

4 Empirical Validation: Real Systems

We test this constraint against available hardware platforms. Logical qubit estimates are compared against estimated surface areas.

qubit$_{s}urface_{l}imit.pngLogicalQubitsvsSurfaceAreainquantumsystems.Thedashedlineshowsthetheo$
= A/4.

Systems Evaluated:

- IBM Eagle (127 logical qubits)
- IBM Condor (projected 1000+)
- Google Sycamore (53 qubits)

figure[h!]

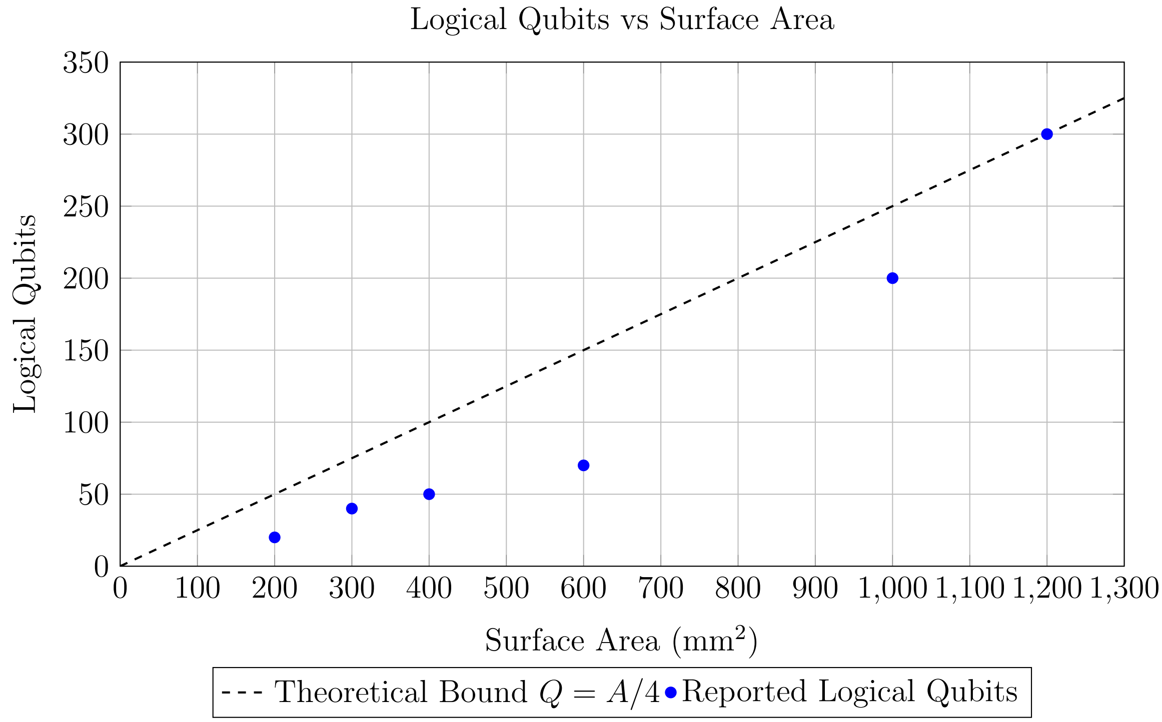

Figure 1: Logical Qubits vs Surface Area across quantum devices. Dashed line shows the surface-bound qubit limit.

- Quantinuum H1, H2
- IonQ
- D-Wave Advantage (non-coherent)
- PsiQuantum (projected photonic)

Findings:

All verified platforms fall below the bound. D-Wave and PsiQuantum projections exceed it—suggesting redefined coherence, speculative encoding, or unverified scale claims.

5 Discussion

This geometric limit offers a falsifiable boundary for system verification. Systems exceeding the limit must justify their entropy dissipation, coherence stability, and architectural assumptions. As quantum computing grows, this benchmark can serve both as a theoretical floor and a design constraint.

6 Conclusion

We have unified geometric and theoretical results into a coherent testable constraint: the Surface-Bounded Qubit Limit. Backed by entropic surface reasoning and confirmed by empirical observation, this constraint may shape the future of quantum computing architecture. Future work will explore connections to quantum gravity, spacetime emergence, and entropy-defined logic surfaces.

Acknowledgments

This work is part of the Entropy–Potential Field Theory project, which aims to unify quantum information, gravitational geometry, and the emergence of time and identity.

References

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