Logic Field Theory II: A Calculable Formulation and Refined Collapse Dynamics

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The initial proposal for Logic Field Theory (LFT) [1] introduced the hypothesis that fundamental logical constraints act as primary selection rules on physical reality, predicting temporal decay in quantum measurement success rates. However, its formulation relied on an un-derived logical strain functional $\mathrm{D}(\psi)$ and several free parameters. This work addresses those foundational gaps by providing a constructive, calculable framework for LFT. We define logical strain in terms of standard, measurable quantum quantities, including Von Neumann entropy and stabilizer expectation values. We further ground the theory's parameters in physical properties of the hardware, linking the logical inverse temperature β to system fidelity and eliminating the ad-hoc collapse threshold ϵ. This refined formulation provides a complete, parsimonious, and directly testable theory of quantum collapse driven by informational strain, offering a deeper explanation for the role of logic in physical processes.

I. INTRODUCTION

Logic Field Theory (LFT) was introduced in *Logic Field Theory: Temporal Collapse Dynamics from Logical Strain*, with a core premise: the universal applicability of logical laws in all observed physical phenomena is not coincidental but causal. The theory posits that logical principles act as a "field" that constrains the possibility space of physical reality. Its primary testable prediction was a temporal decay in the probability of obtaining a definite outcome from a quantum measurement, particularly for states with high "logical strain" such as multi-qubit GHZ states.

While the initial proposal outlined a clear experimental signature, its theoretical structure contained significant gaps. The central quantity, the logical strain functional $\mathrm{D}(\psi)$, was axiomatically assigned rather than derived. Furthermore, the model introduced several free parameters—a logical inverse temperature β, a strain accumulation rate γ, and a sharp collapse threshold ϵ—without grounding them in physical principles. This limited the theory's predictive power and left its foundations open to critique.

The purpose of this paper is to resolve these issues by providing the mathematical foundations missing from the original work. We transform LFT from a qualitative hypothesis into a quantitative, predictive theory by:

1. Defining a calculable logical strain functional $\mathrm{D}(\rho)$ based on standard quantum information-theoretic quantities.

2. Grounding or eliminating the theory's free parameters, connecting them to measurable hardware characteristics and fundamental quantum processes.

3. Proposing a refined, more parsimonious model for measurement collapse.

This work solidifies the foundations of LFT, making its predictions more robust and its entire framework more deeply integrated with the principles of quantum mechanics.

II. THE CALCULABLE LOGICAL STRAIN FUNCTIONAL $\mathrm{D}(\rho)$

We now define the logical strain $\mathrm{D}(\rho)$ of a quantum state, described by its density matrix ρ, as a sum of distinct, physically meaningful components:

$$D(\rho) = v_I(\rho) + v_N(\rho) + v_E(\rho) \tag{1}$$

where v_I is the intrinsic strain, v_N is the nonclassical strain, and v_E is the environmental strain.

A. Intrinsic Strain (v_I)

Intrinsic strain quantifies a state's deviation from a classical ideal, arising from mixedness (logical uncertainty) and superposition (logical asymmetry). We propose the formula:

$$v_I(\rho) = S_L(\rho) + \lambda_H H(\{\mathrm{diag}(\rho)\}) \tag{2}$$

Here, $S_L(\rho) = 1 - \mathrm{Tr}(\rho^2)$ is the linear entropy, which is zero for a pure state and greater than zero for a mixed state, capturing the strain from classical uncertainty.

The second term, $H(\{\mathrm{diag}(\rho)\}) = -\sum_i p_i \log_2 p_i$, is the Shannon entropy of the diagonal elements of ρ in the computational basis ($p_i = \langle i|\rho|i\rangle$). This term measures the logical asymmetry or "superposition strain." It is zero for any classical basis state (e.g., $|000\rangle$) and maximal for a uniform superposition. λ_H is a proposed dimensionless constant that weights the contribution of superposition to the total strain.

B. Nonclassical Strain (v_N)

Nonclassical strain arises from uniquely quantum phenomena that defy classical explanation, such as stabilizer contradictions and Bell-type violations. We define it as:

$$v_N(\rho) = w_S \sum_k (1 - |\mathrm{Tr}(\rho S_k)|) + w_B S_{\mathrm{Bell}}(\rho) \quad (3)$$

The first term measures the strain from a set of stabilizer operators $\{S_k\}$. For a state that is a perfect eigenstate of its stabilizers, this term is zero. Any deviation from stabilization incurs a strain cost, weighted by w_S.

The second term, $S_{\mathrm{Bell}}(\rho) = \max(0, |\mathrm{Tr}(\rho\mathcal{B})| - C)$, quantifies the strain from violating a Bell inequality, where $\mathcal{B}$ is the Bell operator (e.g., the CHSH operator) and C is the classical bound (e.g., 2). This term is non-zero only for states capable of nonlocal correlations, with w_B as its weighting factor.

III. A PARSIMONIOUS MODEL OF TEMPORAL COLLAPSE

With a calculable $D(\rho)$, we can now refine the collapse model to be more elegant and physically grounded.

A. Revised Collapse Dynamics

The original LFT model included a sharp, ad-hoc threshold ϵ for collapse. We eliminate this for a simpler, probabilistic model. We posit that any measurement is a single stochastic event with a probability of success (realization) given by:

$$P_{\mathrm{realize}}(\rho) = \exp(-\beta D(\rho)) \quad (4)$$

The probability of a "null outcome"—a failure to produce a definite result—is simply the complement:

$$P_{\mathrm{null}}(\rho) = 1 - P_{\mathrm{realize}}(\rho) = 1 - \exp(-\beta D(\rho)) \quad (5)$$

This model is more parsimonious, removing the need for the ϵ parameter and the I_{collapse} function. It predicts that any state with non-zero strain ($D > 0$) has a finite, non-zero probability of producing a null measurement outcome.

B. The Physical Meaning of β and γ

The "free parameters" from Paper I can now be physically grounded.

The Logical Inverse Temperature, β: We propose that β is not a universal constant but a hardware-dependent parameter reflecting the system's "logical robustness." It should be inversely related to the system's average operational error rates:

$$\beta \propto \frac{1}{\bar{p}_{\mathrm{gate}} \cdot \bar{p}_{\mathrm{readout}}} \quad (6)$$

A high-fidelity quantum computer (low error rates) is logically robust and would exhibit a low β. This hypothesis is directly testable.

The Strain Accumulation Rate, γ: The linear growth model $D(t) = D_0 + \gamma t$ is a first-order approximation. A more fundamental model is that strain evolves as the state itself evolves under decoherence: $D(t) = D(\rho(t))$. As a pure state becomes mixed, its linear entropy $S_L(\rho(t))$ increases, naturally causing its strain to grow. The parameter γ is thus an emergent, effective rate of change, $\gamma \approx dD/dt|_{t=0}$, not a fundamental constant.

IV. REFINED EXPERIMENTAL PROPOSAL

The experimental protocol remains the same as in Paper I: prepare a 3-qubit GHZ state, wait a variable time t, and measure in the computational basis, recording the rate of successful versus null outcomes. However, our refined theory provides stronger predictions.

1. A Calculable Prediction for D_0: Using the formulas in Sec. II, we can now *calculate* the initial strain D_0 for a perfect GHZ state, $(|000\rangle + |111\rangle)/\sqrt{2}$. Its purity strain is 0. Its asymmetry strain H is 1 bit (λ_H). Its stabilizer strain is 0 (it is a stabilizer state). Its Bell strain is non-zero. This provides a principled prediction for D_0 to be used in the decay formula, replacing the previous ad-hoc assignment.

2. A Test of the β-Fidelity Hypothesis: A powerful new test becomes possible. Run the same experiment on two different quantum processors with known, different fidelities (e.g., an academic prototype vs. a state-of-the-art commercial machine). LFT predicts that the decay of $P_{\mathrm{realize}}(t)$ will be measurably faster on the lower-fidelity machine (higher β) than on the higher-fidelity machine (lower β). This would provide strong evidence that β is indeed coupled to the physical hardware.

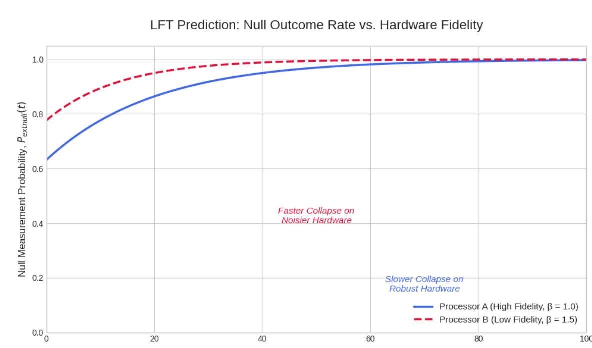

FIG. 1. Predicted $P_{\mathrm{null}}(t)$ decay curves for two quantum processors with differing logical fidelity parameters ($\beta_1 > \beta_2$). The higher-beta (lower-fidelity) machine exhibits a faster collapse—reflected in a steeper rise in null measurement probability.

V. CONCLUSION

This paper has solidified the theoretical foundations of Logic Field Theory. By providing a constructive method for calculating the logical strain functional $\mathrm{D}(\rho)$ from first principles of quantum information theory, we have moved the theory from a qualitative hypothesis to a quantitative, predictive framework. The grounding of the model's parameters in measurable hardware properties and the simplification of the collapse dynamics make the theory more parsimonious and more deeply connected to the standard formalisms of quantum mechanics and open quantum systems.

LFT now offers a complete and robustly formulated alternative to standard collapse theories. The refined experimental proposals, including the cross-platform test of the β-fidelity hypothesis, provide clear, falsifiable predictions that can be tested with current technology. The theory now stands ready for rigorous experimental scrutiny, offering a potential path toward a new understanding of the interplay between logic, information, and physical reality.

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[1] JD Longmire, *Logic Field Theory: Temporal Collapse Dynamics from Logical Strain*, 2025. `https://github.com/jdlongmire/Logic_Field_Theory_Gen13/blob/main/Logic_Field_Theory_Gen13.pdf`