The Attralucian Essays:

Exploring the Finite

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The Attralucian Essays

On Quantum Decoherence: A Geofinitist Interpretation

Re-examining the Church-Turing Thesis

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The Geofinite Decoherence Thesis

Overview

Quantum decoherence is often presented as the bridge between quantum superposition and classical appearance. It explains how interactions between a quantum system and its environment suppress observable interference terms, allowing stable classical records to emerge. Yet decoherence does not, by itself, select a single metaphysical outcome. It does not fully resolve the measurement problem; rather, it describes the finite dynamical conditions under which quantum alternatives become experimentally indistinguishable.

This paper presents the *Geofinite Decoherence Thesis*. Through the lens of Geofinitism, decoherence is reframed not as a metaphysical collapse, but as a measured transition in which coherences fall below the resolution, recoverability, and redundancy thresholds of a finite observational system. The central claim is that the quantum–classical boundary is not an absolute ontological division, but a finite measurement boundary arising from interaction, coarse-graining, environmental record formation, and loss of operational recoverability.

Introduction

The quantum measurement problem arises because the formalism of quantum mechanics permits superpositions of states, while measurement yields definite records. A microscopic system may be represented as a coherent combination of alternatives, yet an apparatus records one stable outcome. Schrödinger's cat dramatized this tension by extending quantum superposition into the macroscopic domain.

Decoherence theory provides a powerful partial explanation. When a system interacts with its environment, phase relations between components of the quantum state become dispersed into environmental degrees of freedom. In a suitable basis, the off-diagonal terms of the density matrix become suppressed, and the system appears classical for practical purposes.

However, decoherence alone does not say that one outcome metaphysically replaces all others. It explains why interference becomes inaccessible and why some bases become dynamically stable. Interpretations such as Copenhagen, Many-Worlds, objective collapse, and relational accounts add further philosophical commitments. Geofinitism avoids this interpretive leap. It asks instead: what is measured, with what tolerance, by what apparatus, over what finite interval?

Classical Decoherence and Its Limits

Let a system be described by a density operator ρ_t. In a chosen basis $B = \{b_i\}$, decoherence is commonly associated with the suppression of off-diagonal terms:

$$\rho_t^{(ij)} = b_i \rho_t b_j, \qquad i \neq j.$$

If these coherences decay toward zero, the density matrix becomes approximately diagonal in that basis, and the system behaves as though it occupies a classical mixture of alternatives.

A standard model expresses this through exponential decay:

$$\rho_{01}(t) = \rho_{01}(0) e^{-\Gamma t},$$

where Γ is a decoherence rate.

The difficulty is not that this model fails. The difficulty is that its interpretation is often extended beyond what is measured. Infinite Hilbert spaces, exact states, ideal measurements, continuous time, and perfect basis selection are mathematical idealizations. Real experiments involve finite sampling, detector noise, bounded resolution, incomplete environmental access, and limited intervention.

Geofinitist Reframing

Geofinitism begins from the premise that all knowledge claims must be finite, measured, and provenance-bearing. From this perspective, decoherence is not a cosmic event occurring in an inaccessible abstract space. It is an operational pattern observed through finite instruments.

A quantum state is therefore not treated as an exact object, but as a measured density operator:

$$\rho_t^{\mathbb{M}} = \big(\rho_t,\ \varepsilon_{\rho,t},\ P_{\text{tom}}\big),$$

where ρ_t is the reconstructed density matrix, $\varepsilon_{\rho,t}$ records tomographic, shot-noise, and systematic uncertainty, and P_{tom} records the measurement protocol and calibration.

Similarly, the dynamics over a finite interval Δt is represented as a measured channel:

$$\Lambda_{\Delta t}^{\mathbb{M}} = \big(\Lambda_{\Delta t},\ \varepsilon_{\Lambda},\ P_{\text{dyn}}\big),$$

where $\Lambda_{\Delta t}$ is the identified dynamical map and ε_{Λ} records process uncertainty.

Measured Coherence

Given a basis $B = \{b_i\}$, define measured coherence by:

$$C_B(t) = \left(\sum_{i\neq j} |\rho_t^{(ij)}|,\ \varepsilon_{C,t},\ P_C\right) \in \mathbb{M}.$$

This quantity measures how much off-diagonal structure remains observable in the selected basis.

A basis-sensitive entropy measure may also be used:

$$C_{\mathrm{rel}}(t) = \big(S(\rho_t^{\mathrm{diag}}) - S(\rho_t),\ \varepsilon_{S,t},\ P_S\big),$$

where S is the von Neumann entropy and ρ_t^{diag} is the state dephased in basis B.

The system is said to have decohered in B over a finite window $\mathcal{W} = [t_0, t_1]$ if:

$$\max_{t \in \mathcal{W}} C_B(t) \lesssim \tau_C$$

and

$$\max_{t \in \mathcal{W}} C_{\mathrm{rel}}(t) \lesssim \tau_S,$$

where comparisons are made within the uncertainty structure of $\mathbb{M}$.

Pointer Basis as Robust Measured Structure

The preferred-basis problem asks why some states become classical records rather than others. Geofinitism reframes this as an operational robustness problem.

For a candidate basis $B = \{b_i\}$, define:

$$\mathcal{R}(B) = \mathbb{E}_{t\in\mathcal{T}}\left[\sum_i \mathrm{Var}_t\big(b_i\rho_t b_i\big) - \lambda\sum_{i\neq j}|\rho_t^{(ij)}|^2\right],$$

where $\lambda \geq 0$ balances population stability against coherence suppression.

The measured pointer basis is:

$$B^\star = \arg\max_B \mathcal{R}(B),$$

within stated tolerances.

Thus, the pointer basis is not selected by metaphysical decree. It is the basis whose populations remain stable while coherences become operationally inaccessible under environmental interaction.

Environment Records and Classical Objectivity

Classicality requires more than loss of coherence. A record must become redundantly available. Let $\{E_k\}$ be disjoint environmental fragments. For an observable O, define redundancy:

$$\mathcal{R}_O(t) = \left|\{k \leq K : I_{\mathbb{M}}(O : E_k)_t \geq \iota\}\right|,$$

where $I_{\mathbb{M}}$ is measured mutual information and ι is a threshold.

Large $\mathcal{R}_O(t)$ indicates that information about O has become distributed through the environment. This provides an operational account of classical objectivity: a record is classical when it is stable, redundant, and accessible across multiple finite observational channels.

Recoverability and Irreversibility

Loss of visible coherence is not always irreversible. Spin echo, dynamical decoupling, and environmental control can sometimes restore coherence. Therefore, Geofinitism includes intervention tests.

Let $\mathcal{I}$ be a set of interventions. Define recoverability:

$$\mathsf{Rec}(\Delta) = \left(\max_t F(\rho_t, \rho_{t+\Delta}^{\text{echo}}),\ \varepsilon_{\text{rec}},\ P_{\text{echo}}\right),$$

where F is fidelity.

Low measured coherence together with high recoverability indicates reversible dephasing. Low coherence together with low recoverability supports operational irreversibility.

Classicality Band

A system enters a classical behavior band for observable O over window $\mathcal{W}$ when:

$$C_B(t) \lesssim \tau_C,$$

$$\mathrm{Var}_t(O) \text{ is stable within tolerance,}$$

$$\mathcal{R}_O(t) \geq R_{\min},$$

and

$$\mathsf{Rec}(\Delta) \text{ is low for tested interventions.}$$

If these criteria disagree within uncertainty, the correct Geofinitist outcome is:

INDETERMINATE.

This abstention is essential. It prevents the framework from claiming collapse, classicality, or irreversibility beyond what the finite measurements support.

The Geofinite Decoherence Thesis

> **Geofinite Decoherence Thesis.** Decoherence is not a metaphysical collapse of a quantum state into a classical reality, but a finite, measured transition in which coherence, recoverability, and basis ambiguity fall below operational thresholds while stable environmental records become redundantly available. The quantum–classical boundary is therefore not an absolute division, but a provenance-bearing measurement boundary determined by resolution, interaction, redundancy, and intervention.

Discussion

The Geofinite Decoherence Thesis preserves the predictive utility of decoherence theory while refusing to extend it into unsupported metaphysical territory. It accepts that off-diagonal terms become suppressed, that pointer bases emerge dynamically, and that environmental records stabilize classical appearances. But it insists that each of these claims must be stated with thresholds, uncertainty, and provenance.

This reframing also clarifies the relation between decoherence and interpretation. Copenhagen, Many-Worlds, objective collapse, and other interpretations may be viewed as additional narratives placed upon the measured structure. Geofinitism does not need to choose among them. It stops at the boundary of symbolic formation and asks only what is finite, measured, reproducible, and operationally distinguishable.

The apparent mystery of collapse is therefore transformed. The question is no longer, "When does the wavefunction truly collapse?" but rather, "Under what finite conditions do coherences become unrecoverable, records become redundant, and alternative descriptions lose operational distinction?"

This is a different question, and it is a better one for measurement.

Collapse to the Classical Account

In the idealized limit where measurement uncertainty vanishes, sampling becomes dense, and the dynamical model is exact, the Geofinitist account recovers standard decoherence theory:

$$C_B(t) \to 0$$

according to the fitted dynamical rates, and the pointer basis stabilizes.

But this limit is a fiction. It is useful as a mathematical approximation, not as a description of finite reality. Geofinitism keeps the finite guardrails in place.

Conclusion

Quantum decoherence becomes clearer when treated not as a metaphysical solution to measurement, but as a finite, measurable process. The Geofinite Decoherence Thesis reframes the quantum–classical transition as a threshold phenomenon involving suppression of coherence, stabilization of basis, redundancy of environmental records, and limited recoverability.

This does not diminish the depth of quantum theory. It strengthens it by grounding its claims in what can be measured, repeated, and audited. The quantum–classical divide is not a mysterious rupture in reality. It is a finite boundary in measurement space.

In this sense, decoherence is not the disappearance of quantum possibility. It is the loss of operational access to certain distinctions within a finite observational container.