The Harris Coherence Principle: A Variational Framework for Global Informational Consistency in Quantum Systems

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Abstract

We introduce the **Harris Coherence Principle (HCP)**, a variational framework for maintaining global informational consistency across quantum subsystems. By representing the universe as a distributed network of density matrices with mutual informational couplings, we formalize coherence as a functional that is extremized under dynamical evolution. This framework naturally accounts for classical emergence, contextual randomness, and decoherence, and provides a quantitative basis for interpreting quantum measurements as globally constrained informational updates. Connections to entropy, the Born rule, and multi-particle correlations are explored, highlighting the principle's explanatory and predictive potential.

1 Introduction

The measurement problem and the emergence of classicality remain central challenges in quantum mechanics. Existing interpretations address these issues in different ways, yet a unifying principle governing local outcomes in a globally coherent manner remains elusive.

The Harris Coherence Principle (HCP) posits that the universe maintains global informational coherence as a variational constraint, providing a mathematical framework for understanding quantum phenomena, classical emergence, and the apparent randomness observed by local observers.

2 Foundations of the Harris Coherence Principle

2.1 Global Coherence Functional

Consider a universe composed of N subsystems, each described by a density matrix ρ_i. Define a global coherence functional:

$$\mathcal{C}[\{\rho_i\}] = \sum_{i,j=1}^{N} w_{ij} \operatorname{Tr}(\rho_i \rho_j), \tag{1}$$

where w_{ij} are informational coupling weights quantifying mutual dependency between subsystems i and j. A higher $\mathcal{C}$ indicates stronger global coherence.

2.2 Variational Formulation

The HCP asserts that the evolution of the universe extremizes the coherence functional subject to constraints such as normalization:

$$\delta\mathcal{C} = 0, \quad \operatorname{Tr}(\rho_i) = 1 \quad \forall i. \tag{2}$$

Introducing Lagrange multipliers λ_i, we define the constrained Lagrangian:

$$\mathcal{L} = \mathcal{C} - \sum_{i=1}^{N} \lambda_i (\operatorname{Tr}(\rho_i) - 1), \tag{3}$$

from which Euler-Lagrange equations for the density matrices can be derived.

3 Dynamics of Coherence

3.1 Time Evolution

The local density matrices $\rho_i(t)$ evolve according to their Hamiltonians H_i while being constrained by global coherence:

$$i\hbar\frac{d\rho_i}{dt} = [H_i, \rho_i] + \sum_j w_{ij} f(\rho_i, \rho_j), \tag{4}$$

where $f(\rho_i, \rho_j)$ is a coherence flux term encoding information exchange between subsystems.

3.2 Relation to Decoherence and Classicality

We interpret the coherence flux term as the mechanism by which phase information is distributed, leading to effective decoherence and the emergence of stable, classical states at the macroscopic scale.

4 Probabilistic Interpretation

4.1 Coherence Potential and Outcome Probabilities

Define a coherence potential $\Phi_c(j)$ for each possible outcome j:

$$P(j) \propto \exp\Big(-\frac{\Phi_c(j)}{kT_c}\Big), \tag{5}$$

where T_c is an effective coherence temperature controlling permissible informational fluctuation. Outcomes minimizing Φ_c are most likely, providing an emergent derivation of the Born rule.

5 Entropy and Coherence

5.1 von Neumann Entropy and Trade-offs

Each subsystem has von Neumann entropy:

$$S_i = -\mathrm{Tr}(\rho_i \ln \rho_i). \tag{6}$$

Global coherence and entropy are linked through a trade-off:

$$\Delta \mathcal{C} + \alpha \Delta S_{\text{total}} = 0, \tag{7}$$

implying that increases in entropy correspond to adjustments in coherence to maintain global consistency.

6 Applications and Examples

6.1 Single-Photon Interference

Describe a Mach–Zehnder interferometer simulation within the HCP framework.

6.2 Entanglement and Multi-Particle Coherence

Show how Bell-state correlations emerge naturally from coherence constraints without invoking nonlocal signaling.

7 Discussion

- Emergence of classicality and apparent randomness. - Relation to other interpretations (Quantum Darwinism, Relational QM, etc.). - Conceptual and philosophical implications for determinism and observer-dependent perception.

8 Future Directions

- Numerical simulations of HCP dynamics. - Formal derivation of multi-particle coherence functions. - Potential experimental tests distinguishing HCP predictions.

9 Conclusion

The Harris Coherence Principle provides a variational, mathematically grounded framework for understanding global informational consistency in quantum systems. By formalizing coherence as a functional extremized under dynamical evolution, HCP accounts for classical emergence, decoherence, and probabilistic measurement outcomes, offering a unified perspective bridging quantum and classical domains.

References

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