

A Unitary Analysis of Wigner's Friend with Decoherence and L2-Compatibility

Abstract

We present a fully unitary analysis of the Wigner's Friend scenario with environment-induced decoherence, using only standard quantum mechanics. Within a minimal qubit model, we derive exact closed-form expressions for coherence suppression and quantum mutual information between a measurement record and its environment. This allows us to (i) demonstrate the emergence of classical objectivity via redundancy in the environment (Quantum Darwinism), (ii) clarify the operational content of the Wigner's Friend paradox without invoking collapse or branching, and (iii) introduce a non-dynamical compatibility condition (L2) specifying when stable experience is possible without modifying the quantum state. The analysis is interpretational in scope: no new dynamics or empirical predictions are proposed.

1. Introduction and Scope

The Wigner's Friend thought experiment exposes a persistent tension in quantum foundations: how a globally unitary quantum description can coexist with the local experience of definite outcomes. While decoherence theory explains the suppression of interference and the emergence of classical records, it does not by itself explain why experience is restricted to a single, stable history.

2. Relation to Existing Work

This analysis builds on decoherence theory (Zeh; Zurek), Quantum Darwinism (Zurek), decoherent histories (Griffiths; Gell-Mann & Hartle), and modern Wigner's Friend extensions (Brukner; Frauchiger & Renner; Healey).

3. Unitary Pre-Measurement

A system qubit initially in superposition interacts unitarily with a Friend's memory qubit via a CNOT gate, producing a globally coherent but locally definite measurement record.

4. Environment-Induced Decoherence

Decoherence is modeled by coupling the Friend's record to N environment qubits via controlled rotations. Tracing out the environment yields exponential suppression of coherence.

5. Objectivity and Quantum Darwinism

Mutual information between the record and environment fragments quantifies objectivity and redundancy.

6. Operational Resolution of Wigner's Friend

Irreversibility is shown to be relative to environment accessibility, not fundamental.

7. L2-Compatibility

L2 is introduced as a non-dynamical condition restricting experience to record-stable states.

8. Dominant but Structurally Atypical Classicality

Decohered histories dominate probability mass while remaining structurally special.

9. Claims and Non-Claims

No Born rule derivation, no consciousness theory, and no new physics are claimed.

10. Conclusion

Standard quantum mechanics suffices to reconcile global unitarity with local definiteness.