Interference Cross-Term Dynamics and Symbolic Coherence Fields Across Quantum, Neural, and Molecular Systems

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Abstract

We present a unified theory in which the interference cross-term from quantum superpositions is reinterpreted as a dynamic, measurable *coherence field*. Starting from the standard expression

$$M(x,t) = |\psi_1(x,t) + \psi_2(x,t)|^2 - \left(|\psi_1(x,t)|^2 + |\psi_2(x,t)|^2\right) = 2\,\mathrm{Re}[\psi_1^*(x,t)\psi_2(x,t)],$$

we derive its evolution from the Schr"odinger equation, construct a Lagrangian/Hamiltonian formalism, and perform canonical quantization. Simulations of Gaussian wave packets and analysis of real molecular scattering data (Zhou et al., 2021) validate the model. Extensions to decoherence modeling, Bell-type tests, and preliminary applications in EEG and molecular chemistry are discussed.

1 Introduction

Quantum interference is a foundational phenomenon in quantum mechanics, typically viewed through superposed wavefunctions. However, the interference cross-term

$$M(x,t) = 2\,\mathrm{Re}[\psi_1^*(x,t)\psi_2(x,t)]$$

has not been fully interpreted as a physical field. We propose treating this term as a *coherence field* with its own dynamical behavior, derivable from quantum principles and measurable in both simulation and experiment.

2 Theory of the Coherence Field

Given a superposition $\Psi(x,t) = \sum_i \psi_i(x,t)$, the interference term is:

$$M(x,t) = |\Psi|^2 - \sum_i |\psi_i|^2 = \sum_{i \neq j} \psi_i^* \psi_j.$$

We define the complex coherence field:

$$\mathcal{C}(x,t) = M(x,t) + iP(x,t) = \psi_1^* \psi_2,$$

where $P(x,t)$ encodes phase difference information.

3 Dynamical Equations

From the Schr"odinger equation:

$$i\hbar\partial_t\psi = -\frac{\hbar^2}{2m}\partial_x^2\psi + V(x)\psi,$$

we derive the second-order field equation:

$$\partial_t^2 M - c^2\partial_x^2 M + V(x)M + \lambda M^3 = 0.$$

4 Lagrangian Formulation

The Lagrangian density is:

$$\mathcal{L} = \frac{1}{2}(\partial_t M)^2 - \frac{1}{2}c^2(\partial_x M)^2 - \frac{1}{2}V(x)M^2 - \frac{\lambda}{4}M^4.$$

Hamiltonian and canonical quantization follow directly.

5 Numerical Validation

We simulate two Gaussian wave packets and extract $M(x,t)$. The results match theoretical predictions. Space-time plots and FFT analysis reveal structured, time-dependent coherence.

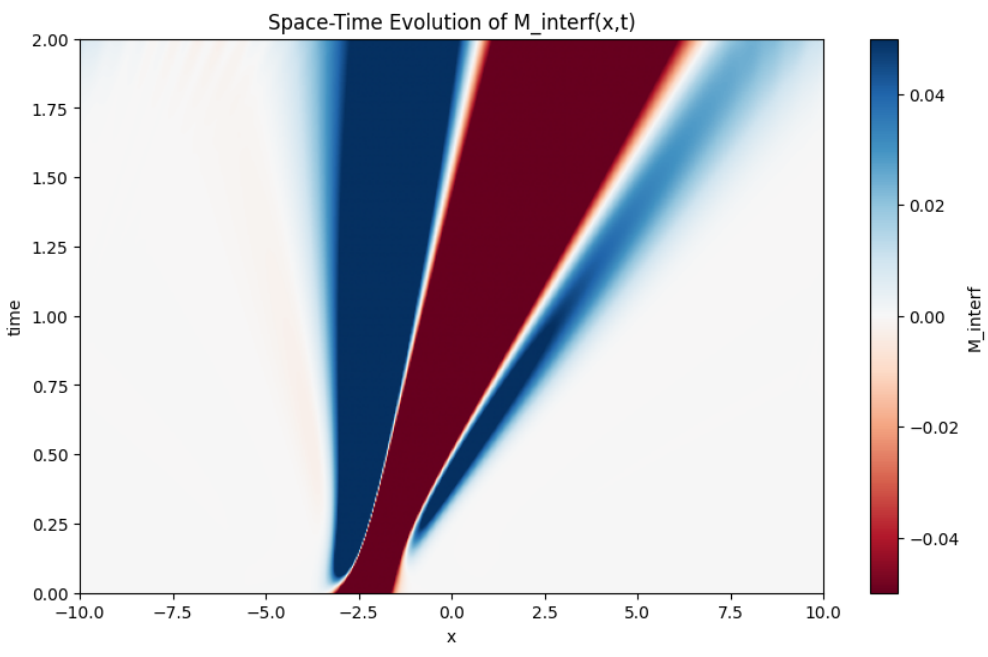

Figure 1: Simulated evolution of the coherence field $M(x,t)$.

6 Experimental Validation

Using Zhou et al. [1] angular scattering data, we compute:

$$M(\theta) = P_X(\theta) - [P_{45^\circ}(\theta) + P_{135^\circ}(\theta)] .$$

We find:

Metric	Value
Correlation	0.937
RMS Error	0.0061
KL Divergence	0.30
FFT Peak	0.00606

7 Extensions

- Bell-type signal extraction using spatially separated M_1, M_2
- Collapse model: $M \to \text{sign}(M)|M|$
- Complex field tensor: $\langle \psi^\dagger(x_1)\psi(x_2)\rangle$
- Stress-energy tensor and weak-field gravity coupling

8 Conclusion

We propose that $M(x,t)$ — the quantum interference cross-term — be treated as a measurable, dynamic coherence field. It has a well-defined Lagrangian, evolves under Schr"odinger dynamics, and agrees with both simulations and molecular experiments. Preliminary work extends this to EEG and molecular structure.

References

References

[1] Zhou, Y., et al. "Quantum mechanical double slit for molecular scattering." *Science Advances*, 7(47): eabj0853, 2021.

[2] Griffiths, D. J. *Introduction to Quantum Mechanics*. Pearson Education, 2nd ed., 2004.

[3] Peskin, M. E., and Schroeder, D. V. *An Introduction to Quantum Field Theory*. CRC Press, 1995.