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Rohit Dhormare *

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A Quantum Geometric Extension of Gravity-Probabilistic Correspondence

Rohit Dhormare

Independent researcher; India; rohitgravity4@gmail.com

Abstract: We develop a novel framework connecting quantum mechanics with gravitational geometry through a deformation of probability amplitudes. Inspired by Rohit Dhormare's geometric formulation of probability under gravitational fields, we reinterpret the influence of curvature on probability not within classical settings, but in the domain of quantum amplitudes. We propose a quantum probabilistic manifold where space-time curvature induces topological and metric deformations on Hilbert space projections, affecting interference, measurement outcomes, and entropy. This formulation offers new pathways for understanding quantum gravity, decoherence, and information localization.

1. Introduction

Classical and quantum physics both rely fundamentally on probability, albeit differently: classical probability is based on ignorance, while quantum probability is intrinsic and rooted in wave function amplitudes. While general relativity has successfully described gravity as a manifestation of space-time curvature, quantum mechanics lacks such a geometric interpretation of probability that includes gravitational effects.

Inspired by Dhormare's framework that models gravity-induced distortion of classical probabilities via a geometric manifold, this work seeks to extend the concept to quantum systems, where probability is governed by the Born rule and amplitudes in Hilbert space. We propose a geometric formulation where gravity acts as a deformation field on the underlying quantum probability amplitudes, fundamentally modifying their structure and evolution.

2. Quantum Probability and Geometry

2.1. Standard Framework

In quantum mechanics, a system is described by a state vector $|\psi\rangle \in H$, and observables are Hermitian operators on H. The probability P_i of obtaining outcome i is:

$$P_i = |\langle\varphi_i|\,\psi\rangle|^2,$$

where $\{|\varphi_i\rangle\}$ is a complete measurement basis.

2.2. Probability Manifold of Quantum States

We define a quantum probability manifold M_Q, a submanifold of the projective Hilbert space $CP^{\{n-1\}}$, equipped with the Fubini–Study metric:

$$ds^2 = 4(\langle d\psi \mid d\psi\rangle - |\langle\psi \mid d\psi\rangle|^2).$$

Quantum Fisher information and Bures distance also provide alternative metrics on M_Q, each capturing different aspects of distinguishability between states.

3. Gravitational Deformation of Amplitudes

3.1. Gravity as a Deforming Field

In this model, gravity induces a deformation on the geometry of M_Q through a curvature tensor $R^i_{\{jkl\}}$. The effect on the quantum transition amplitude $\langle\varphi \mid \psi\rangle$ is given by:

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$\delta\langle\psi \mid \varphi\rangle \propto R_{\{ijkl\}} \xi^j \eta^k \chi^l$,
where ξ^j, η^k, χ^l represent directions in the tangent space of M_Q.

3.2. Amplitude Modulation

We propose that gravitational curvature modifies transition amplitudes through an exponential damping factor:
$\langle\varphi \mid \psi\rangle \rightarrow \langle\varphi \mid \psi\rangle \cdot e^{\{-\alpha R\}}$,
where R is the scalar curvature and α is a coupling parameter encoding gravitational strength at the quantum scale.

This deformation implies that quantum interference and transition probabilities are measurably altered in regions of high curvature (e.g., near black hole horizons).

4. Quantum Entropy and Curvature

4.1. Entanglement Entropy

Consider a bipartite pure state $|\Psi\rangle_{\{AB\}}$. The von Neumann entropy of the reduced density matrix ρ_A is:

$$S_A = -Tr(\rho_A \log \rho_A).$$

Gravitational curvature affects the Schmidt coefficients λ_i of the decomposition:

$$\lambda_i \rightarrow \lambda_{i(R)} = \lambda_i e^{\{-\beta R\}}.$$

Thus,

$$S_A^{\{(R)\}} = -\Sigma\, \lambda_i(R) \log\,[\lambda_i(R)].$$

4.2. Curvature-Entropy Conjecture

Positive scalar curvature increases quantum entanglement entropy in a quantum probability manifold, while negative curvature reduces it.

This is consistent with the holographic entanglement entropy predictions of AdS/CFT correspondence.

5. Quantum Evolution on Curved Manifolds

5.1. Modified Schrödinger Equation

The standard Schrödinger equation is:

$$i\hbar\, \partial/\partial t\, |\psi(t)\rangle = \hat{H}\, |\psi(t)\rangle.$$

On M_Q We generalize this using a covariant derivative ∇_t accounting for curvature:

$$i\hbar\, \nabla_t |\psi(t)\rangle = \hat{H}\, |\psi(t)\rangle.$$

5.2. Geometric Quantum Phases

Gravitational curvature contributes to the geometric phase γ acquired by a quantum system under adiabatic evolution:

$$\gamma = \oint A_i dx^i + \iint F^i_{\{ij\}dx} \wedge dx^j.$$

6. Implications for Quantum Gravity

This framework has implications for reconciling quantum mechanics with gravity:

- Quantum fields in curved space-time.
- Gravity-induced decoherence.
- Quantum information localization.

These insights may inform efforts in loop quantum gravity, string theory, and emergent space-time models.

7. Conclusions and Outlook

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We have proposed a novel framework for quantum probability deformation under the influence of gravitational curvature, extending Rohit Dhormare's classical geometric probability concepts to the quantum domain. This theory opens doors to new interpretations of quantum measurements, entropy, and coherence in curved space time and may contribute toward a unifying perspective of quantum gravity.

Future directions include the explicit construction of curved quantum manifolds, numerical simulation of amplitude deformation, and experimental tests via interferometry.

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