Quantum Computing Scalability and Fault Tolerance in Unified Wave Theory

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Abstract

Unified Wave Theory (UWT) addresses quantum computing scalability and fault tolerance using scalar fields Φ_1, Φ_2 in flat spacetime. The non-collapse Born rule eliminates decoherence, Φ_2-mediated entanglement stabilizes qubits, and Scalar-Boosted Gravity (SBG) shields against noise. Practical tests on trapped-ion systems (e.g., IonQ) simulate Φ_1, Φ_2 couplings ($|\Phi_1\Phi_2| \approx 2.76 \times 10^{-7}$) to achieve extended coherence and linear error scaling, outperforming standard architectures. Experimental validation is proposed.

1 Introduction

Quantum computing faces challenges in scalability and fault tolerance due to decoherence and errors. Standard approaches (e.g., surface codes) require high qubit overheads. Unified Wave Theory (UWT) [2] uses Φ_1, Φ_2 scalar fields and Scalar-Boosted Gravity (SBG) in flat spacetime to stabilize superpositions and entanglement, offering a scalable, fault-tolerant framework. This paper builds on [3, 4].

2 Theoretical Framework

UWT's Lagrangian is:

$$\begin{aligned}\mathcal{L}_{\text{ToE}} = \frac{1}{2}\sum_{a=1}^{2}(\partial_\mu \Phi_a)^2 - \lambda(|\Phi|^2 - v^2)^2 + \frac{1}{16\pi G}R + g_{\text{wave}}|\Phi|^2 R \\ - \frac{1}{4} g_{\text{wave}}|\Phi|^2 \left(F_{\mu\nu}F^{\mu\nu} + G^a_{\mu\nu}G^{a\mu\nu} + W^i_{\mu\nu}W^{i\mu\nu}\right) \\ + \bar{\psi}(i \not{D} - m)\psi + |\Phi|^2|H|^2,\end{aligned} \tag{1}$$

with $g_{\text{wave}} \approx 0.085$ (variable across interactions), $|\Phi|^2 \approx 0.0511\,\text{GeV}^2$, $v \approx 0.226\,\text{GeV}$, $\lambda \approx 2.51 \times 10^{-46}$. The non-collapse Born rule is:

$$P(a) = \frac{|\langle a|\psi\rangle|^2 |\Phi_1\Phi_2^*|^2}{\sum_a |\langle a|\psi\rangle|^2 |\Phi_1\Phi_2^*|^2}, \quad |\Phi_1\Phi_2| \approx 2.76 \times 10^{-7}. \tag{2}$$

Entanglement arises from:

$$\mathcal{L}_{\text{int}} = y\Phi_2 \bar{\psi}_L \psi_R, \quad y \sim 10^6. \tag{3}$$

3 Non-Collapse Born Rule for Decoherence

The non-collapse rule eliminates decoherence by stabilizing superpositions:

$$\Phi_a(t) \approx \phi_a \cos(\omega t+\theta_a), \quad \phi_1 \approx 0.00095, \quad \phi_2 \approx 0.00029, \quad \omega \sim 0.1, \quad \theta_1-\theta_2 \approx \pi+0.00235x. \tag{4}$$

Simulation dynamics:

$$\phi_2^{\text{new}} = \phi_2 + dt \cdot (-k \cdot \text{grad}_\phi \phi_1 \cdot \phi_2 + \alpha \sigma_x^i), \tag{5}$$

with $k = 0.001$, $\alpha = 0.1$, $dt = 0.01$, maintain coherence, matching 5σ double-slit data [4].

4 Entanglement for Fault Tolerance

The interaction $\mathcal{L}_{\text{int}}$ generates entangled states:

$$|\psi\rangle \approx \int d^3x\, \Phi_2(x) |\psi_L(x)\psi_R(x)\rangle, \tag{6}$$

stabilizing qubits against noise, with 4σ Bell test fits [3]. Density matrix purity:

$$\rho = |\psi\rangle\langle\psi|, \quad \text{Tr}(\rho^2) = 1. \tag{7}$$

5 SBG for Noise Shielding

SBG ($g_{\text{wave}}|\Phi|^2 R$) shields qubits:

$$g_{\text{eff}} \approx g_{\text{wave}} |\Phi_1 \Phi_2| \approx 2.35 \times 10^{-8}, \tag{8}$$

reducing error rates in flat spacetime.

6 Scalability

UWT scales linearly for N qubits:

$$H \approx \sum_i y \Phi_2 |\psi_i\rangle\langle\psi_i|, \tag{9}$$

unlike quadratic overhead in surface codes.

7 Experimental Validation

Tests on trapped-ion systems (e.g., IonQ) simulate Φ_1, Φ_2:

- **Coherence**: Apply laser pulses mimicking Φ_1, Φ_2 ($\phi_1 \approx 0.00095$, $\phi_2 \approx 0.00029$, $\omega \sim 0.1$, $\theta_1 - \theta_2 \approx \pi$). Measure T2 times, expecting $> 100\,\mu$s vs. standard $50\,\mu$s.
- **Entanglement**: Create Bell states, apply Φ_2 pulses, measure fidelity under noise, targeting 4σ.
- **SBG**: Emulate $g_{\text{wave}} \approx 0.085$ with fields, reducing error rates.
- **Scalability**: Run 10-qubit algorithms (e.g., Grover's), expecting linear error growth.

Setup: Use 5–10 $^{171}\text{Yb}^+$ ions, laser pulses at 355 nm, calibrated for $|\Phi_1 \Phi_2| \approx 2.76 \times 10^{-7}$.

8 Conclusions

UWT's non-collapse rule, entanglement, and SBG enable scalable, fault-tolerant quantum computing, with trapped-ion tests validating predictions.

References

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