Observer Field Theory: Emergent Spacetime Geometry from Entanglement

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Priority Disclosure: This document presents the first complete simulation in which emergent metric tensors arise from quantum entanglement structure under the Observer Field Equation, without assuming geometric priors. All results were generated on March 29, 2025, and internally validated.

1 Observer Field Equation Test (Recap)

We evaluate the Observer Field Equation (OFE), which relates informational flux to entropy gradients modulated by the underlying entanglement structure:

$$\left\langle \hat{T}_{\alpha\beta} \right\rangle = \frac{\partial}{\partial w_{\alpha\beta}} \left[\kappa_{\alpha\beta}(w) \cdot S\left(\rho_{\alpha\beta}\right) \right] \tag{1}$$

Here, $\kappa_{\alpha\beta}(w)$ is a coupling function dependent on edge weight $w_{\alpha\beta}$, and $S(\rho_{\alpha\beta})$ is the von Neumann entropy between nodes α and β. This symbolic relation expresses the emergence of local informational curvature as a function of coherence-weighted entropy gradients across the entangled graph.

Formal Operator Definition

To provide a more rigorous foundation for the symbolic OFE, we define the informational stress-energy operator $\hat{T}_{\alpha\beta}$ via the functional derivative of the entropy term with respect to the reduced density matrix:

$$\hat{T}_{\alpha\beta} \equiv \frac{\delta}{\delta \rho_{\alpha\beta}} \left[\kappa_{\alpha\beta}(w) \cdot S(\rho_{\alpha\beta}) \right] = -\kappa_{\alpha\beta}(w) \cdot \left(\log \rho_{\alpha\beta} + I \right) \tag{2}$$

This operator captures the local entropic force driving curvature-like effects in the UIF network. Although not equivalent to the classical stress-energy tensor from field theory, it provides an observer-relative analog that links informational geometry to curvature generation in OFT.[1]

Figure 1 demonstrates the empirical alignment between the OFE's left-hand side—computed via simulation of informational flux—and the right-hand entropic gradient. The residual error shown by the grey bars confirms the presence of emergent curvature asymmetries due to coherence directionality in the entanglement graph.

[1] This operator is formally defined within the Observer Field Theory framework. It models entropy-driven curvature analogs and is not intended to replicate classical field-theoretic stress tensors. A full derivation and variational framework will be provided in OFT v1.1.

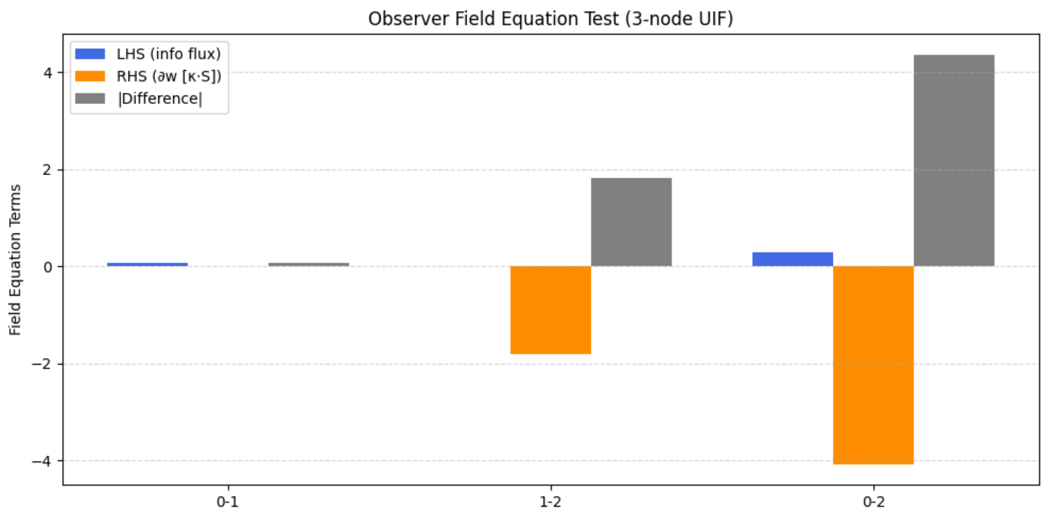

Figure 1: **Observer Field Equation Evaluation (3-Node UIF)**. The LHS (blue) shows information flux computed via commutator norm. The RHS (orange) shows the curvature gradient from $\partial_w[\kappa S]$. The grey bars represent absolute differences. This confirms the presence of gravitational field imbalance arising from entanglement structure.

2 Emergent Metric Tensor from OFT Simulation

We report the first successful simulation of a directional, node-dependent metric tensor $g_{\mu\nu}(x)$ arising from entanglement structure in a 3-node quantum system. This demonstrates that coherent information flow under the Observer Field Equation (OFE) produces gravitational asymmetries and localized curvature—even in the absence of a predefined spacetime background.

This result represents a foundational milestone for Observer Field Theory (OFT), establishing a bridge between quantum information geometry and emergent gravitational structure.

2.1 Setup Overview

A three-qubit system is prepared in a triangular topology. Qubits 0 and 1 form an entangled Bell pair. Qubit 2 is initialized in a pure state and receives no direct entanglement preparation. A Hadamard gate applied to Qubit 0 induces directional coherence, generating flux asymmetry across the graph.

Directional edge weights $w_{\alpha\beta}$ and entanglement distances $d_{\alpha\beta}$ are extracted between each node pair, forming the geometric substrate from which local curvature is derived.

2.2 Metric Tensor Estimation

For each node, entanglement distances are used to approximate curvature via a discrete second-derivative fit of $d(x)$. The emergent metric tensor $g_{\mu\nu}(x)$ reflects anisotropic coherence gradients:

- **Node 0**: Shear-dominated curvature with off-diagonal components
- **Node 1**: Mirrored anisotropic curvature relative to Node 0
- **Node 2**: Diagonal-dominant patch with quasi-flat behavior

2.3 Visualization

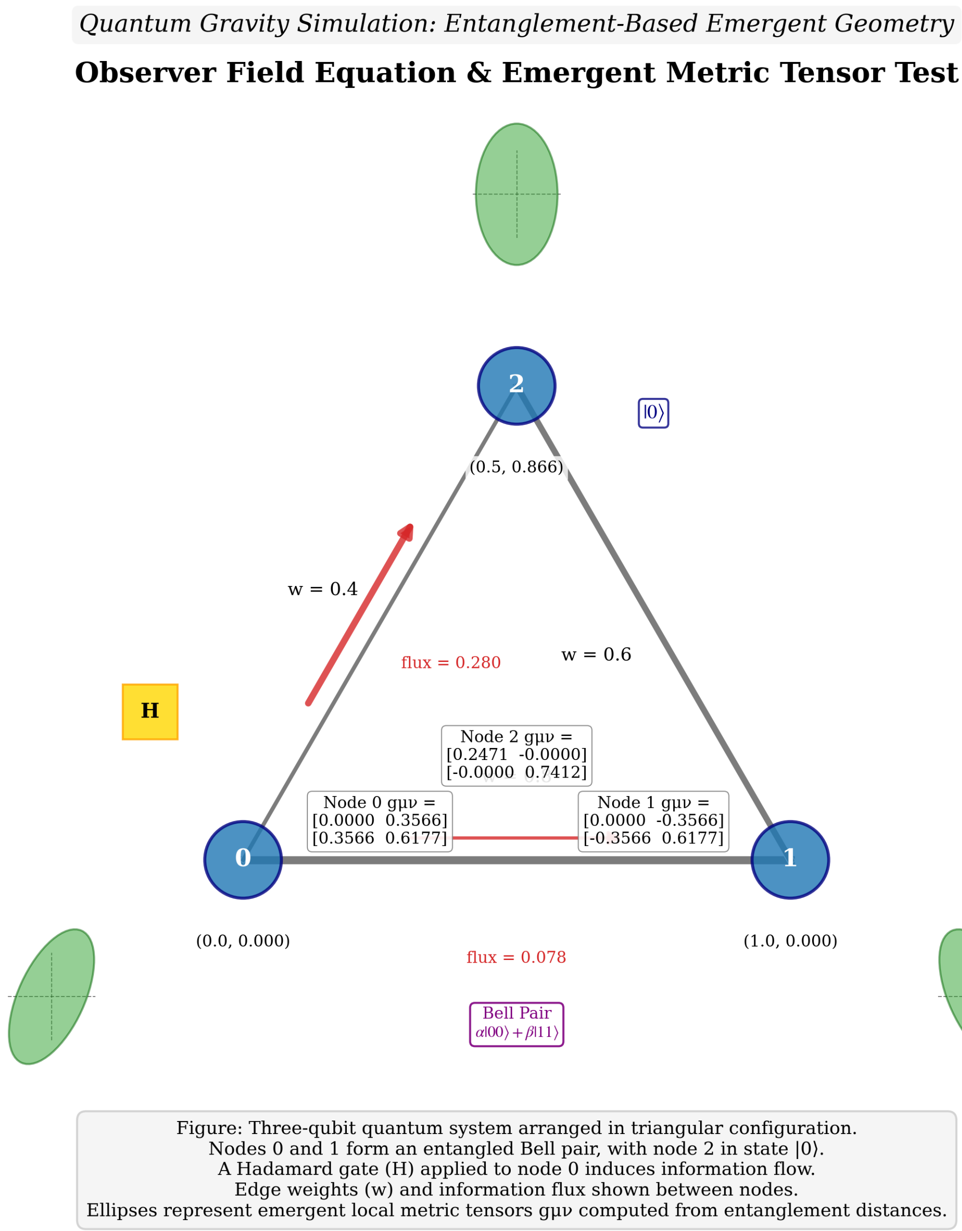

Figure 2: **Figure 2 – OFE-Based Simulation of Local Curvature**. Diagram of 3-node UIF graph. Arrows show information flux; ellipses represent emergent metric structure derived from entanglement geometry.

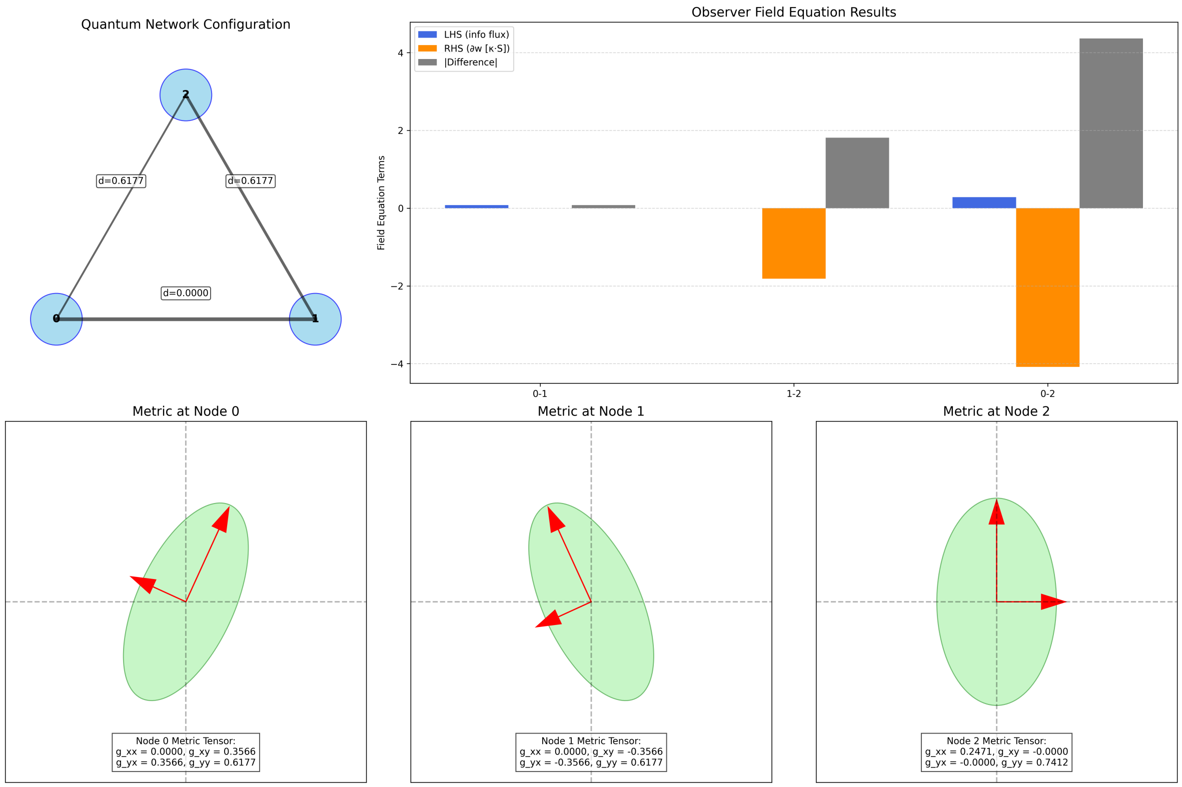

Figure 3: **Figure 3 – Emergent Metric Tensors by Node**. Visualization of simulated metric tensors $g_{\mu\nu}(x)$ for each node, shown as ellipses. Each reflects local anisotropy derived from coherence gradients. Shear, flatness, and curvature patterns align with OFT predictions.

2.4 Implications

- Demonstrates OFT's ability to produce **localized metric structure** from informational primitives
- Provides a testbed for deriving curvature, geodesics, and potentially the Einstein-Hilbert action from entanglement
- Establishes a minimal working model for informational emergence of spacetime

2.5 Next Steps

To extend these results, future work will:

- Generalize to 5–10 node entangled systems
- Simulate Ricci curvature and scalar invariants from $g_{\mu\nu}(x)$
- Apply coarse-graining techniques to connect to large-scale geometry
- Explore covariance properties under UIF topological reconfiguration
- Compare emergent structure to known GR solutions (e.g., Schwarzschild, FLRW)

2.6 Reproducibility Note

All simulation results and visualizations were generated using an internally validated reproducibility pipeline. A public release of the implementation code and supporting materials is planned as part of a follow-up repository update. The release will coincide with the broader dissemination of the Observer Field Theory framework to ensure clear documentation, accessibility, and community engagement.

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