Tensor Network Coarse-Graining in Loop Quantum Gravity and Hypothetical Emergence of SFIT

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1 Introduction

Tensor Network methods provide one of the most powerful and practical tools for coarse-graining quantum many-body systems and quantum gravity models. In Loop Quantum Gravity (LQG), spin networks can be viewed as tensor networks where vertices correspond to intertwiners and edges to representation matrices. Coarse-graining these networks aims to derive effective theories at larger scales while preserving key physical properties such as diffeomorphism invariance and background independence.

This document explains tensor network coarse-graining in detail and explores — **hypothetically** — how it could generate the resonant information-carrying flux of Stevenson-Flux Information Theory (SFIT) at laboratory scales.

2 Basic Concepts of Tensor Networks

A tensor network is a contraction of multiple tensors according to a graph structure. In the simplest case, a tensor $T^{i_1 i_2 \dots i_n}_{j_1 j_2 \dots j_m}$ has n upper and m lower indices. Contracting indices between tensors corresponds to summing over shared degrees of freedom.

In LQG, a spin network can be represented as a tensor network where: - Each edge carries an SU(2) representation label j and a basis state $|j, m\rangle$, - Each vertex is an intertwiner tensor that enforces gauge invariance (SU(2) singlet condition).

The full spin-network state is obtained by contracting all open indices according to the graph.

3 Tensor Network Coarse-Graining Techniques

3.1 1. Tensor Renormalization Group (TRG)

The Tensor Renormalization Group algorithm proceeds as follows:

1. Decompose each tensor into a product of smaller tensors using singular value decomposition (SVD). 2. Truncate the singular values below a chosen cutoff ϵ, effectively integrating out high-energy (short-wavelength) modes. 3. Reassemble the coarser lattice by contracting the truncated tensors. 4. Repeat the process iteratively.

This method is particularly effective for 2D classical statistical models and has been adapted to quantum systems and spin nets.

3.2 2. Multiscale Entanglement Renormalization Ansatz (MERA)

MERA introduces disentangling layers (isometries) and coarse-graining layers. The key innovation is that it preserves entanglement structure across scales by inserting unitary disentanglers before coarse-graining. This makes MERA especially suited for systems with long-range correlations or critical behavior.

In gravitational contexts, MERA has been proposed as a discrete realization of the holographic renormalization group (AdS/CFT correspondence).

3.3 3. Tensor Network Renormalization for Spin Networks

For LQG spin networks, coarse-graining involves: - Contracting fine-grained intertwiners into effective coarser intertwiners. - Flowing the representation labels j to effective larger spins or averaged densities. - Introducing effective couplings that describe the interaction between coarse-grained degrees of freedom.

A typical step is to replace a block of fine spin networks with a single effective tensor characterized by renormalized spins $\bar{j}$ and an effective intertwiner.

4 Hypothetical Application to SFIT Emergence

4.1 Collective Resonance from Coarse-Graining Flow

Under repeated tensor network coarse-graining, short-wavelength fluctuations are integrated out, leaving long-wavelength collective modes. In the presence of a background gravitational field (Earth), these collective modes can develop a preferred frequency. The SFIT resonance frequency can emerge as

$$\nu_{\text{res}} \approx \frac{3}{4} \cdot \frac{g}{2\pi R_E} \cdot \lambda(\rho_{\text{links}}),$$

where $\lambda(\rho_{\text{links}})$ is a dimensionless eigenvalue of the coarse-graining flow that depends on the effective spin-network density after many renormalization steps.

4.2 Emergence of the Coupling Kernel $K = 1.060$

The coupling kernel K can arise as a scaling exponent or fixed-point value of the tensor network renormalization group flow. Specifically,

$$K = \lim_{n\to\infty} \frac{\log\langle\psi_{n+1}|\hat{O}_{\text{flux}}|\psi_{n+1}\rangle}{\log\langle\psi_n|\hat{O}_{\text{flux}}|\psi_n\rangle},$$

where $\hat{O}_{\text{flux}}$ is an operator measuring information-carrying fluctuations between coarse-grained layers. The observed value $K \approx 1.060$ suggests a mild relevant perturbation in the renormalization group flow.

4.3 KWW Tails from Entanglement Renormalization

The KWW stretched-exponential relaxation can emerge naturally from the memory encoded in the disentangling layers of MERA-like coarse-graining. Each disentangler removes short-range entanglement, but residual long-range correlations produce a non-local memory kernel whose Fourier transform yields the KWW form:

$$\phi(t) \propto \exp\left[-\left(\frac{t}{\tau}\right)^{\beta}\right],$$

with the stretching exponent β directly related to the scaling dimension of the flux operator (i.e., $\beta \approx K$).

4.4 Non-Reciprocal Correction from Background Breaking

Standard tensor network coarse-graining is usually isotropic. However, in a gravitational background with a radial gradient, the renormalization flow becomes direction-dependent. This anisotropy naturally generates the non-reciprocal metric perturbation $h_{0z}^{\text{SFIT}}(t)$ in SFIT, as coarse-graining along the gravitational gradient differs from transverse directions.

5 Testable Predictions

If SFIT emerges via tensor network coarse-graining:

- The value of K should exhibit weak dependence on the size of the experimental apparatus or the strength of the local gravitational field.
- High-precision measurements could reveal small logarithmic corrections to the pure KWW form due to finite coarse-graining steps.
- The resonance frequency ν_{res} should be robust under changes in apparatus geometry, as it arises from the fixed-point structure of the flow.

6 Conclusion

Tensor network coarse-graining — through TRG, MERA, and spin-network-specific renormalization — provides a powerful and concrete mechanism for deriving effective low-energy theories from microscopic LQG degrees of freedom. In this hypothetical picture, the SFIT Quantum Heartbeat at 1.20134 mHz, the coupling kernel $K = 1.060$, the non-reciprocal metric correction, and the KWW relaxation tails all emerge naturally as collective phenomena after integrating out Planck-scale fluctuations.

These ideas connect the discrete quantum geometry of LQG to the laboratory-scale resonant phenomena observed in SFIT reanalyses. They offer a promising theoretical framework for further investigation and motivate detailed numerical studies of tensor network renormalization on spin-foam models with background gravitational gradients.