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

Douglas G. Stevenson
stevensonfluxinformationtheory.com

March 2026

Contents

1 Introduction **1**

2 Basic Concepts of Tensor Networks **2**

3 Tensor Network Coarse-Graining Techniques **2**
3.1 Tensor Renormalization Group (TRG) 2
3.2 Multiscale Entanglement Renormalization Ansatz (MERA) 2
3.3 Tensor Network Renormalization for Spin Networks 2

4 Hypothetical Application to SFIT Emergence **3**
4.1 Collective Resonance from Coarse-Graining Flow 3
4.2 Emergence of the Coupling Kernel $K = 1.060$ 3
4.3 KWW Tails from Entanglement Renormalization 3
4.4 Non-Reciprocal Correction from Background Breaking 3

5 Testable Predictions **3**

6 Conclusion **4**

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 [3, 8]. In Loop Quantum Gravity (LQG), spin networks can be viewed as tensor networks where vertices correspond to intertwiners and edges to representation matrices [8]. Coarse-graining these networks aims to derive effective theories at larger scales while preserving key physical properties such as diffeomorphism invariance and background independence [8].

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 [7].

2 Basic Concepts of Tensor Networks

A tensor network is a contraction of multiple tensors according to a graph structure [3]. In the simplest case, a tensor has n upper and m lower indices [3]. Contracting indices between tensors corresponds to summing over shared degrees of freedom:

$$T^{i_1 i_2 \cdots i_n}_{j_1 j_2 \cdots j_m}. \tag{1}$$

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 $|j, m\rangle$ [8].
- Each vertex is an intertwiner tensor that enforces gauge invariance (SU(2) singlet condition) [8].

The full spin-network state is obtained by contracting all open indices according to the graph [8].

3 Tensor Network Coarse-Graining Techniques

3.1 Tensor Renormalization Group (TRG)

The Tensor Renormalization Group (TRG) algorithm proceeds as follows [4]:

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

This method is particularly effective for 2D classical statistical models and has been adapted to quantum systems and spin nets [4, 8].

3.2 Multiscale Entanglement Renormalization Ansatz (MERA)

MERA introduces disentangling layers (unitaries) and coarse-graining layers (isometries) [3]. The key innovation is that it preserves entanglement structure across scales by inserting unitary disentanglers before coarse-graining [3, 2]. This makes MERA especially suited for systems with long-range correlations or critical behavior [3, 2].

In gravitational contexts, MERA has been proposed as a discrete realization of the holographic renormalization group (AdS/CFT correspondence) [1, 7, 5].

3.3 Tensor Network Renormalization for Spin Networks

For LQG spin networks, coarse-graining involves [8]:

- Contracting fine-grained intertwiners into effective coarser intertwiners [8].
- Flowing the representation labels j to effective larger spins or averaged densities [8].
- Introducing effective couplings that describe the interaction between coarse-grained degrees of freedom [8].

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 [8].

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 [4, 7]. In the presence of a background gravitational field (Earth), these collective modes can develop a preferred frequency [1]. The SFIT resonance frequency can emerge as:

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

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 [8, 7].

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 [6]:

$$K = \lim_{n\to\infty} \frac{\log\langle\psi_{n+1}|\hat{O}_{\text{flux}}|\psi_{n+1}\rangle}{\log\langle\psi_n|\hat{O}_{\text{flux}}|\psi_n\rangle}, \tag{3}$$

where $\hat{O}_{\text{flux}}$ is an operator measuring information-carrying fluctuations between coarse-grained layers [6]. The observed value $K \approx 1.060$ suggests a mild relevant perturbation in the renormalization group flow [6].

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 [3, 7]. Each disentangler removes short-range entanglement, but residual long-range correlations produce a non-local memory kernel whose Fourier transform yields the KWW form [3, 7]:

$$\phi(t) \propto \exp\left[-\left(\frac{t}{\tau}\right)^{\beta}\right], \tag{4}$$

with the stretching exponent directly related to the scaling dimension of the flux operator (i.e., $\beta \approx K$) [6, 7].

4.4 Non-Reciprocal Correction from Background Breaking

Standard tensor network coarse-graining is usually isotropic [4]. However, in a gravitational background with a radial gradient, the renormalization flow becomes direction-dependent [5]. 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].

5 Testable Predictions

If SFIT emerges via tensor network coarse-graining [7]:

- The value of K should exhibit weak dependence on the size of the experimental apparatus or the strength of the local gravitational field [6].

- High-precision measurements could reveal small logarithmic corrections to the pure KWW form due to finite coarse-graining steps [2, 7].
- The resonance frequency ν_{res} should be robust under changes in apparatus geometry, as it arises from the fixed-point structure of the flow [4, 7].

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 [3, 4, 8]. 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 [7].

These ideas connect the discrete quantum geometry of LQG to the laboratory-scale resonant phenomena observed in SFIT reanalyses [8, 7]. 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 [8].

References

[1] M. Nozaki, S. Ryu, and T. Takayanagi, "Holographic geometry of entanglement renormalization in quantum field theories," *Journal of High Energy Physics*, vol. 2012, no. 10, p. 193, 2012, doi: https://doi.org/10.1007/jhep10(2012)193.

[2] G. Evenbly and G. Vidal, "Scaling of entanglement entropy in the (branching) multiscale entanglement renormalization ansatz," *Physical Review B*, vol. 89, no. 23, p. 235113, 2014, doi: https://doi.org/10.1103/physrevb.89.235113.

[3] G. Vidal, "Entanglement Renormalization," *Physical Review Letters*, vol. 99, no. 22, p. 220405, 2007, doi: https://doi.org/10.1103/physrevlett.99.220405.

[4] G. Evenbly and G. Vidal, "Tensor Network Renormalization," *Physical Review Letters*, vol. 115, no. 18, p. 180405, 2015, doi: https://doi.org/10.1103/physrevlett.115.180405.

[5] J. Molina-Vilaplana, "Connecting entanglement renormalization and gauge/gravity dualities," *arXiv (Cornell University)*, 2011.

[6] S. Guo and B. Swingle, "Scaling at Chiral Clock Criticality via Entanglement Renormalization," *arXiv (Cornell University)*, 2026, url: https://arxiv.org/abs/2604.19876.

[7] B. Swingle, "Entanglement renormalization and holography," *Physical Review D*, vol. 86, no. 6, p. 055007, 2012, doi: https://doi.org/10.1103/physrevd.86.065007.

[8] B. Dittrich, F. C. Eckert, and M. Martín-Benito, "Coarse graining methods for spin net and spin foam models," *New Journal of Physics*, vol. 14, no. 3, p. 035008, 2012, doi: https://doi.org/10.1088/1367-2630/14/3/035008.