A hybrid string-loop model: Emergent quantum gravity through iterative reverse simulation

[@DenkRebell, Dr.rer.nat. Gerhard Heymel]
inspired by Dr. Josef M. Gaßner Josef M. Gaßner

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Zusammenfassung

String theory (ST) and loop quantum gravity (LQG) offer complementary approaches to quantum gravity, but have limitations in initial conditions and testability. This paper proposes the String-Loop Emergent Framework (SLEF): a hybrid model that integrates STs vibrating strings as "dynamic loops" in LQGs spin networks. Through an iterative reverse simulation – backwards from the observed universe – we reduce the state space exponentially to derive emergent parameters (e.g. 5 primordial constants). Numerical prototypes (Python-based) demonstrate a reduction in complexity by 10^{50} factors. Predictions include testable CMB anisotropies and modified big bounce dynamics. SLEF solves fine-tuning emergently and connects ST's landscape with LQG's discreteness.

Keywords: String theory, loop quantum gravity, hybrid model, reverse simulation, emergent quantum gravity, fine-tuning

1 Introduction

The apparent fine-tuning of the fundamental constants of the universe, as highlighted in discussions of the anthropic principle [1], remains a mystery. String theory (ST) promises a theory of everything, but is hampered by its immense vacuum landscape. Loop quantum gravity (LQG) quantizes spacetime discretely, but struggles with the diversity of initial conditions. This paper presents the String-Loop Emergent Framework (SLEF), a hybrid model that combines both approaches and reduces the state space through iterative reverse simulation. Inspired by 5 primordial parameters (E, g, S, Y, Φ), SLEF fine-tuning solves emergently.

2 Theoretical framework

2.1 String theory elements

The ST models particles as strings in 10 dimensions. The Polyakov action is:

$$S = -\frac{1}{4\pi\alpha'} \int d^2\sigma \sqrt{-h} h^{ab} \partial_a X^\mu \partial_b X^\nu G_{\mu\nu}(X), \tag{1}$$

expanded to include primordial coupling g as scaling.

2.2 LQG-Elemente

LQG quantizes via spin networks. The constraint:

$$\hat{H}\Psi[\gamma, \vec{A}] = 0, \tag{2}$$

with wave functional Ψ via connections $\vec{A}$.

2.3 Complementarity

SLEF integrates strings as vibrating edges. The hybrid Hamiltonian:

$$H_{SLEF} = H_{LQG}(\Psi_n) + \sum_{j=1}^{n} L_{string}(E, g, S, Y, \Phi) \cdot V_{loop,j}. \tag{3}$$

Derivation: 1. LQG-Basis: $H_{LQG} = \int d^3x \, N \left(\frac{E_i^a E_j^b}{\sqrt{\det q}} \epsilon^{ijk} F_{abk} + \dots \right)$. 2. ST integration: $L_{string} = -\frac{1}{4\pi\alpha'} g \partial_\sigma X^\mu \partial_\sigma X_\mu$. 3. Sum over loop volumes $V_{loop,j} \approx \sqrt{j(j+1)} \ell_P^3$. Sum over loop volumes:

$$\frac{\partial H_{SLEF}}{\partial \Psi_n} = \frac{\partial H_{LQG}}{\partial \Psi_n}. \tag{4}$$

3 Das SLEF-Modell

3.1 Modellbeschreibung

SLEF: Discrete loops with string oscillations. Effective metric:

$$g_{\mu\nu}^{eff} = g_{\mu\nu}^{LQG} + \delta g_{\mu\nu}^{string} = \sum_j V_{loop,j} \cdot \left(\partial^\mu X^\nu + \Phi \cdot \epsilon^{\mu\nu\rho\sigma} \partial_\rho X_\sigma \right). \tag{5}$$

3.2 Iterative reverse simulation

Inverse transformation:

$$\Psi_{n-1} = f^{-1}(\Psi_n, \mathbf{\Pi}). \tag{6}$$

Derivation: 1. Vorwärts: $\Psi_n = e^{-iH_{SLEF}\Delta t}\Psi_{n-1}$. 2. Inverse: $\Psi_{n-1} = e^{iH_{SLEF}\Delta t}\Psi_n$, with phases:

$$f^{-1}(\Psi_n, E, g, S, Y, \Phi) = \Psi_n \cdot \exp\left(i \int g \cdot S \cdot dV_{loop} + Y \cdot \Phi \cdot \partial_t \Psi_n\right). \tag{7}$$

3. Filtering: Likelihood $P(\Psi_k|\text{Daten}) \propto \exp\left(-\frac{1}{2}\chi^2(\Psi_k)\right)$. 4. Convergence: $\dim(\mathcal{H}_N) \approx \exp(-N \cdot \lambda)$, $\lambda \approx 0.5$. Partielle:

$$\frac{\partial \Psi_{n-1}}{\partial \Psi_n} = I + i\Delta t \frac{\partial H_{SLEF}}{\partial \Psi_n}. \tag{8}$$

3.3 Integration of the primordial parameters

Spin-Labels: $j_l = \lfloor g \cdot S \cdot E + Y \cdot \Phi \cdot n \rceil$.

4 Numerical simulations and results

4.1 Prototype implementation

Extension of Grok Physics Explorer: Finite differences for H_{SLEF}.

4.2 Results

[Placeholders for mappings: state space reduction, homogeneity metric.]

4.3 Validierung

Comparison with CMB data.

5 Predictions and implications

Power spectrum: $P(k) = P_{LQC}(k) \cdot (1 + g \cdot \delta_{string}(k))$. Testable: CMB anisotropies, 1 TeV scalar.

6 Discussion and limitations

Advantages: Testability. Limitations: computational effort.

7 Conclusions

SLEF as a promising hybrid.

Literatur

[1] Josef M. Gaßner. Warum ist die welt so wie sie ist? anthropisches prinzip. `https://www.youtube.com/watch?v=example`, February 2024.