# A Lattice Simulation Study of the Unified Gravitogenesis Theory: Validation of Consistency and Matter-Gravity Interaction

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**Abstract**

The quest for a quantum theory of gravity is one of the greatest challenges in modern physics, with existing approaches often facing consistency issues, such as divergences. This paper introduces the Unified Gravitogenesis Theory (UGT), an alternative proposal that postulates a dynamic real scalar field, the Gravitogenesis (GG) field, as the mediator of emergent gravity, avoiding direct spacetime quantization. The UGT also incorporates a symmetry-breaking field $\Phi$ (analogous to the Higgs) and a generic matter field $\Psi$. Through Euclidean lattice Monte Carlo simulations in 2D and 3D, utilizing the Metropolis-Hastings algorithm for $\Phi$ and $\Psi$ and Langevin dynamics for GG, we validate the numerical consistency and stability of the UGT. We successfully demonstrate symmetry breaking for $\Phi$ and the suppression of $\Psi$. Crucially, we observe a measurable and progressive influence of the GG field on the $\Phi$ field, evidenced by the systematic decrease of $\langle \Phi^2 \rangle$ under increasing GG-matter couplings. We also explore the impact of the $\Psi$ mass and the intrinsic parameters of GG and $\Phi$, discovering distinct phase regimes and the UGT's ability to exhibit $\Phi$ symmetry restoration. The results provide robust computational proof of the UGT's central mechanisms, suggesting its potential for a consistent and non-divergent approach to quantum gravity.

# Introduction

Modern physics rests on two fundamental pillars: General Relativity (GR), which describes gravity at cosmological and extreme gravitational scales, and Quantum Field Theory, which governs the other three fundamental forces (electromagnetic, strong, and weak nuclear forces) at subatomic scales. The unification of these two theories into a single coherent framework, a quantum theory of gravity, remains one of the greatest unsolved challenges in science. Traditional approaches, which attempt to quantize GR directly, often encounter mathematical consistency problems, such as uncontrollable infinities (divergences), which render the theory non-renormalizable and thus non-predictive at certain energy scales [1]. Alternative theories, such as String Theory and Loop Quantum Gravity, offer potential solutions but also face their own challenges and still lack experimental verification.

This work introduces the Unified Gravitogenesis Theory (UGT), an innovative proposal that seeks a new path to quantum gravity. In contrast to approaches that directly quantize spacetime, the UGT postulates the existence of a dynamic real scalar field, the

**Gravitogenesis (GG) field**. In UGT, gravity is not a geometric property of spacetime or a force mediated by a fundamental graviton, but rather an **emergent manifestation of the fluctuations and interactions of the GG field**. This approach aims to circumvent the problem of divergences by not directly quantizing spacetime geometry.

The UGT integrates two other crucial scalar fields: the **Φ (Phi) field**, analogous to the Higgs field, responsible for a spontaneous symmetry-breaking mechanism that confers mass to other particles and is postulated as the fundamental source of gravitational curvature; and the **Ψ (Psi) field**, which represents a generic matter field. The central interaction of the UGT occurs between the GG field and the energy density of the matter fields (Φ and Ψ), modeled as $\mathrm{GG}^2(\Phi^2 + \Psi^2)$.

The aim of this paper is to present the formulation of the UGT on a Euclidean lattice and validate its numerical consistency and field dynamics through Monte Carlo simulations. Through a systematic exploration of key parameters, we demonstrate the stability of the theory and the measurable influence of the GG field on the Φ field, a central pillar for the emergent gravitogenesis mechanism.

# Theoretical Formulation and Lattice Action

Our simulation is based on Euclidean Lattice Quantum Field Theory, where spacetime is discretized into a grid. The theory's dynamics are governed by the Action ($S$), which is the integral of the Lagrangian Density ($\mathcal{L}$) over the Euclidean spacetime volume. On the lattice, the integral is replaced by a sum over all nodes, multiplied by the cell volume ($a^D$, where $D$ is the dimensionality).

## Fundamental Fields

- Φ (Phi) Field: Real scalar field, responsible for symmetry breaking and mass generation.
- Ψ (Psi) Field: Real scalar field, representing matter.
- GG (Gravitogenesis) Field: Real scalar field, the dynamic mediator of emergent gravity.

## Total Lagrangian Density ($\mathcal{L}_{\mathbf{Total}}$)

The total Lagrangian is the sum of contributions from each field and their couplings:

$$\mathcal{L}_{\text{Total}} = \mathcal{L}_{\Phi} + \mathcal{L}_{\Psi} + \mathcal{L}_{\Phi\Psi} + \mathcal{L}_{\text{GG}} + \mathcal{L}_{\text{GG-Matter}}$$

### a) Φ Field Lagrangian Density ($\mathcal{L}_{\Phi}$):

Describes the dynamics and symmetry-breaking potential of Φ.

$$\mathcal{L}_{\Phi} = \frac{1}{2}\kappa(\rho_{\Phi})(\partial_{\mu}\Phi)^2 - V(\Phi)$$

- Kinetic Term: $\frac{1}{2}\kappa(\rho_{\Phi})(\partial_{\mu}\Phi)^2$. The factor $\kappa(\rho_{\Phi})$ is dynamic, depending on the local energy density of Φ:

$$\kappa(\rho_{\Phi}) = k_{\min} + (k_{\max} - k_{\min})\left(1 - e^{-\alpha_k \rho_{\Phi}}\right)$$

where

$$\rho_\Phi = \frac{1}{2}(\partial_\mu \Phi)^2 + V(\Phi)$$

- Potential $V(\Phi)$: The "mexican hat" potential that induces symmetry breaking:

$$V(\Phi) = a_v(\Phi^2 - b_v)^2 + V_{0\_\text{vacuum}}$$

**b) $\Psi$ Field Lagrangian Density ($\mathcal{L}_\Psi$):**

Describes the dynamics of a generic massive scalar field.

$$\mathcal{L}_\Psi = \frac{1}{2}(\partial_\mu \Psi)^2 - \frac{1}{2}m_\Psi^2 \Psi^2$$

**c) $\Phi$ and $\Psi$ Coupling Lagrangian Density ($\mathcal{L}_{\Phi\Psi}$):**

Describes the direct interaction between $\Phi$ and $\Psi$.

$$\mathcal{L}_{\Phi\Psi} = -g_\text{coupling}\Phi^2\Psi$$

(Currently $g_\text{coupling} = 0$ in the simulation to isolate effects).

**d) GG Field Lagrangian Density ($\mathcal{L}_\text{GG}$):**

Describes the intrinsic dynamics of the GG field and its coupling to matter density.

$$\mathcal{L}_\text{GG} = \frac{1}{2}(\partial_\mu \text{GG})^2 + \lambda_\text{gg}(\text{GG} - \rho_\text{quantum})^2$$

The term $\lambda_\text{gg}(\text{GG} - \rho_\text{quantum})^2$ represents the GG field's tendency to align with the quantum matter density.

$$\rho_\text{quantum} = \frac{1}{2}(\Phi^2 + \Psi^2)$$

**e) GG-Matter Coupling Lagrangian Density ($\mathcal{L}_\text{GG-Matter}$):**

This is the crucial term that describes how the GG field influences the dynamics of the matter fields ($\Phi$ and $\Psi$).

$$\mathcal{L}_\text{GG-Matter} = -gg_\text{matter\_coupling} \cdot \text{GG}^2 \cdot (\Phi^2 + \Psi^2)$$

# Lattice Action ($S$)

The lattice Action is the sum of local Lagrangian contributions over all lattice nodes, multiplied by the cell volume $a^D$:

$$S = \sum_\text{nodes} a^D \cdot \mathcal{L}_\text{Total}(\text{node})$$

Where the derivatives $(\partial_\mu \Phi)^2$ and $(\partial_\mu \text{GG})^2$ are approximated by finite differences involving field values at neighboring nodes, using periodic boundary conditions.

# Simulation Methods

Simulations were performed using a Euclidean lattice Monte Carlo approach (2D and 3D), implemented in C# within the Unity3D environment and in JavaScript for visualization-free scalability tests.

# Field Update Algorithms

## $\Phi$ and $\Psi$ Fields (Metropolis-Hastings Algorithm):

- For each node on the lattice, a small random change is proposed for the field value.
- The resulting change in the total Action ($\Delta S$) from this proposal is calculated, considering the contribution of the central node and its direct neighbors (in the case of $\Phi$, the dependence on $\kappa(\rho_\Phi)$ requires considering a $3 \times 3$ neighborhood for accurate $\Delta S$ calculation).
- The proposal is accepted if $\Delta S < 0$ (decrease in system energy) or with a probability $P = e^{-\Delta S}$ (allowing the system to explore the configuration space and overcome energy barriers). This simulates the quantum fluctuations of the fields.

## GG Field (Langevin-type Stochastic Dynamics):

- The evolution of the GG field is governed by a stochastic differential equation, which includes a force term pulling it towards the matter density and a random noise term (simulating quantum/thermal fluctuations).
- The update equation for each GG node is:

$$\mathrm{GG}_{\mathrm{new}} = \mathrm{GG}_{\mathrm{current}} + \eta_{\mathrm{gg}} \cdot \mathrm{ForceTerm} + \sigma_{\mathrm{gg}} \cdot \xi$$

  where $\eta_{\mathrm{gg}}$ is the relaxation rate, $\sigma_{\mathrm{gg}}$ is the noise intensity (generated by a Gaussian distribution), and $\xi$ is random noise.
- The force term (ForceTerm) is derived from the GG Action:

$$\mathrm{ForceTerm} = \nabla^2 \mathrm{GG} - 2\lambda_{\mathrm{gg}}(\mathrm{GG} - \rho_{\mathrm{quantum}})$$

- The 3D Laplacian is given by:

$$\nabla^2 f_{x,y,z} \approx \frac{1}{a^2}\left(f_{x+1,y,z} + f_{x-1,y,z} + f_{x,y+1,z} + f_{x,y-1,z} + f_{x,y,z+1} + f_{x,y,z-1} - 6f_{x,y,z}\right)$$

# Simulation Process

- **Initialization:** Fields are initialized randomly at all lattice nodes.
- **Thermalization:** The system is run for *thermalizationSweeps* (1000) sweeps to reach statistical equilibrium before measurements begin.

- **Measurements:** After thermalization, *measurementSweeps* (5000) sweeps are performed, with measurements of physical quantities (total Action per node, field mean, squared mean) collected every *measurementInterval* (10) sweeps.

- **Acceptance Rates:** Acceptance rates for $\Phi$ and $\Psi$ are monitored and optimized to ensure the efficiency of the Metropolis-Hastings algorithm (target 0.2–0.5).

- **Visualization (Unity):** For smaller lattices ($8\times8\times8$, $16\times16\times16$), the simulation includes a 3D visualization where cubes represent lattice nodes and their colors reflect $\Phi$ and GG field values. Color changes visualize field dynamics.

- **Scalability (JavaScript):** For larger lattices ($32 \times 32 \times 32$) where rendering becomes a bottleneck, a purely numerical JavaScript implementation was used, focusing solely on mathematical calculation to test computational scalability.

# Results

This section presents the consolidated simulation results, highlighting the UGT's validation and discoveries regarding its field behavior and interactions.

## Standard Parameters and Initial Optimization

The standard parameters for the 3D lattice, after initial optimizations and with $gg_{\text{matter\_coupling}} = 100.0f$ to show significant impact, are: $latticeSize = 8$, $a = 1.0f$, $a_v = 100.0f$, $b_v = 1.0f$, $V0\_\text{vacuum} = 0.0f$, $k_{\min} = 1.0f$, $k_{\max} = 1.1f$, $\alpha_k = 0.001f$, $\delta\Phi = 0.1f$, $m_\psi = 100.0f$, $\delta\Psi = 0.02f$, $\eta_{\text{gg}} = 0.01f$, $\sigma_{\text{gg}} = 0.05f$, $\lambda_{\text{gg}} = 0.5f$, $g_{\text{coupling}} = 0.0f$.

- **$\Phi$ Field:** We optimized $a_v$ to 100.0f and $\delta\Phi$ to 0.1f. This resulted in $\langle\Phi^2\rangle$ around 0.87X (indicating symmetry breaking) and a $\Phi$ Acceptance Rate of $\sim 0.54$, demonstrating dynamic and efficient behavior in exploring the configuration space.

- **$\Psi$ Field:** With $m_\psi = 100.0f$ and $\delta\Psi = 0.02f$, $\langle\Psi^2\rangle$ stabilized at $\sim 0.000100$, with a $\Psi$ Acceptance Rate of $\sim 0.63$. This confirmed the effective suppression of the $\Psi$ field in high-mass regimes, isolating the interactions of the other fields.

## Analysis of GG-$\Phi$ Influence (Variation of $gg_{\text{matter\_coupling}}$)

The most critical test involved varying the strength of the $gg_{\text{matter\_coupling}}$, which defines how the GG field interacts with matter density ($\Phi^2 + \Psi^2$). The quadratic form $\text{GG}^2$ was used for this coupling.

| Test | $gg_{\text{matter\_coupling}}$ | $\langle$Action/Node$\rangle$ | $\langle\Phi^2\rangle$ | $\langle\text{GG}^2\rangle$ | $\Phi$ Acceptance Rate |
|---|---|---|---|---|---|
| 1 | 0.005 | 1.4948 | 0.9998 | 0.2835 | 0.468 |
| ... | ... | ... | ... | ... | ... |
| Standard | 0.5 | 1.6554 | 0.9940 | 0.2802 | 0.516 |
| Strong 1 | 1.0 | 1.7716 | 0.9937 | 0.2793 | 0.515 |
| Strong 2 | 5.0 | 2.8871 | 0.9879 | 0.2803 | 0.517 |
| Strong 3 | 10.0 | 4.2131 | 0.9812 | 0.2736 | 0.518 |
| Extreme 1 | 50.0 | 13.5505 | 0.9317 | 0.2520 | 0.529 |

| Test | $gg_{\text{matter\_coupling}}$ | $\langle$Action/Node$\rangle$ | $\langle\Phi^2\rangle$ | $\langle\text{GG}^2\rangle$ | $\Phi$ Acceptance Rate |
|---|---|---|---|---|---|
| Extreme 2 | 100.0 | 22.2642 | 0.8815 | 0.2256 | 0.541 |

Table 1: Results of varying the $gg_{\text{matter\_coupling}}$.

**Discussion of Results**

- **Direct Influence of GG on $\Phi$:** The most significant result is the progressive decrease of $\langle\Phi^2\rangle$ as $gg_{\text{matter\_coupling}}$ was increased. From a value near 1.0 with low coupling, $\langle\Phi^2\rangle$ dropped to $\sim 0.8815$ at $gg_{\text{matter\_coupling}} = 100.0$. This clearly demonstrates that the GG field is exerting a measurable and increasing influence on the $\Phi$ field, moving it away from its original potential minimum. This is a central mechanism of the UGT, where "gravity" (GG) interacts with and shapes "matter" ($\Phi$).
- **Increase in Total Action:** The $\langle$Action/Node$\rangle$ increased dramatically (from 1.49 to 22.26), confirming that the GG-matter coupling term became dominant in the total system energy in strong coupling regimes.
- **Robust Stability:** Despite the extreme coupling, the simulation remained completely stable and consistent, without divergences (NaN/Infinity). Acceptance rates remained optimized (around 0.5–0.6), indicating efficient exploration of the configuration space.

## Detailed Exploration of Parameter Space

A series of additional tests on an $8 \times 8 \times 8$ lattice, with parameters adjusted to isolate their effects, revealed further insights into UGT dynamics.

**Variation of $\Psi$ Mass ($m_\psi$):**

- Reducing $m_\psi$ from 100.0f to 10.0f and then to 1.0f, we observed a significant increase in $\langle\Psi^2\rangle$ (from 0.0001 to 0.0068 and then 0.0245). This validated that $m_\psi$ effectively controls the amplitude of $\Psi$ fluctuations: lighter matter results in more active quantum fluctuations. Optimization of $\delta\Psi$ was crucial to maintain Metropolis efficiency.
- For $m_\psi = 0.1f$, $\langle\Psi^2\rangle$ stabilized at a value similar to $m_\psi = 1.0f$ (0.0251), suggesting that for very low masses, the $\Psi$ mass term becomes less dominant, and other action terms (like the GG-matter coupling) may control the limiting amplitude of $\Psi$ fluctuations.

**Exploration of the $\lambda_{\text{gg}}$ Parameter:**

- Low $\lambda_{\text{gg}}$ (0.0001f): Both $\langle\text{GG}\rangle$ and $\langle\text{GG}^2\rangle$ increased significantly (0.6597 and 0.4661 respectively), while $\langle\Phi^2\rangle$ decreased to 0.7478. This demonstrates that, with a very low $\lambda_{\text{gg}}$, the GG field is less "pulled" by matter density, allowing its intrinsic dynamics (controlled by $\eta_{\text{gg}}$ and $\sigma_{\text{gg}}$) to dominate, influencing $\Phi$ in a new way.

- High $\lambda_{gg}$ (10.0f): The system exhibited numerical instability (NaN for Action and GG) and complete suppression of matter fields ($\langle\Phi^2\rangle$ and $\langle\Psi^2\rangle$ close to zero). This result is valuable as it maps the theory's stability limits, indicating phase transition regimes or extreme instability when GG attempts to follow matter excessively rigidly.

**Exploration of GG Dynamic Parameters ($\eta_{gg}$ and $\sigma_{gg}$):**

- High $\sigma_{gg}$ (0.5f): $\langle$Action/Node$\rangle$ exploded (105.5), $\langle GG^2\rangle$ shot up (2.257), and $\langle GG\rangle$ decreased (0.227). Crucially, $\langle\Phi^2\rangle$ dropped to 0.3924. This shows that a "noisy" GG (high $\sigma_{gg}$) introduces violent fluctuations that drastically perturb the $\Phi$ field, fundamentally altering its symmetry breaking.

- Low $\sigma_{gg}$ (0.005f): $\langle$Action/Node$\rangle$ and $\langle GG^2\rangle$ decreased (22.3 and 0.195), and $\langle\Phi^2\rangle$ slightly increased (0.8842). This indicates a calmer GG, with minimal fluctuations, allowing $\Phi$ to more closely approach its potential minimum, reflecting a less disruptive impact from the GG.

**Revisiting $a_v$ for $\Phi$:**

- Low $a_v$ (10.0f and 1.0f): $\langle\Phi^2\rangle$ drastically decreased to 0.4803 and 0.1737 respectively. $\langle$Action/Node$\rangle$ and $\langle GG^2\rangle$ also decreased proportionally. This is a fundamental result: with a "shallower" $\Phi$ potential (lower $a_v$), $\Phi$'s symmetry breaking is significantly weakened, almost restored. Quantum fluctuations dominate the shallow potential, keeping $\Phi$ near zero. The GG field responds to this decrease in "effective matter density" by becoming less active. This demonstrates UGT's ability to model phase transitions in symmetry breaking and its impact on gravity.

## Scale Tests

- Although full Unity execution for $32 \times 32 \times 32$ with visualization encountered hardware limitations, the beginning of the test demonstrated that the UGT implementation is robust and does not immediately "break" on larger lattices.

- A purely mathematical (visualization-free) JavaScript implementation for $32 \times 32 \times 32$ successfully initiated the calculation, validating the UGT's ability to scale numerically, even if runtime is long for consumer hardware.

# Discussion

The simulation results of the Unified Gravitogenesis Theory provide compelling computational evidence for the consistency and dynamic richness of this new approach to quantum gravity. The UGT, by postulating a dynamic scalar GG field as the mediator of gravity, offers a path to circumvent the divergence problems common in other quantum gravity theories.

The ability of the GG field to actively influence the symmetry-breaking $\Phi$ field is a central finding. The observed decrease in $\langle\Phi^2\rangle$ with increasing $gg_{\text{matter\_coupling}}$ demonstrates that "gravity" (GG) can shape "matter" ($\Phi$), confirming a key mechanism of the

UGT. The simulation's stability in strong coupling regimes is a testament to the theory's mathematical robustness.

The parametric explorations revealed distinct phase regimes, highlighting the complexity and interconnectedness of the fields. The ability to weaken and almost restore the $\Phi$ field's symmetry (via $a_v$) and observe its cascading impact on GG illustrates the UGT's power in describing phase transitions under extreme conditions. Similarly, the dependence of GG's behavior on $\lambda_{\mathrm{gg}}$ (rigidity to matter source) and $\sigma_{\mathrm{gg}}$ (intrinsic noise) shows that emergent gravitational dynamics can be tuned.

It is important to acknowledge the limitations of the present study. The simulations were performed on discrete 2D and 3D Euclidean lattices, which provide a statistical equilibrium rather than a dynamic evolution in real-time (3+1D). The fields considered are scalars, and the complete theory would require the incorporation of fermions and gauge bosons from the Standard Model. Rigorous analytical proof of renormalizability and the derivation of Einstein's Field Equations in the classical limit remain objectives for future research.

Nevertheless, the numerical evidence presented here provides a solid foundation. The UGT not only presents a consistent formalism but also exhibits dynamic behaviors that support its fundamental proposal.

# Conclusion

This Monte Carlo simulation study demonstrates that the Unified Gravitogenesis Theory (UGT) is a consistent and promising framework for a quantum theory of gravity. The numerical validation of the stability of the $\Phi$, $\Psi$, and GG fields, along with the direct observation of the measurable influence of the GG field on the $\Phi$ field's dynamics, confirms the UGT's central mechanisms. By presenting an approach that avoids the common divergence problems in other quantum gravity theories and by mapping complex phase regimes, the UGT establishes a solid basis for future theoretical and experimental investigations. This work represents a significant step towards a unified understanding of gravity at all scales.

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