Gravity from Quantum Information and Entropic Gradients

A Thermodynamic Framework for Emergent Spacetime

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Abstract

We propose that gravitational dynamics emerge from gradients in operationally accessible entanglement entropy. This approach synthesizes thermodynamics, quantum information theory, and general relativity into a testable framework, where Newton's constant becomes an emergent quantity tied to information structure. The theory predicts inverse-square forces, cosmological acceleration, and decoherence-induced screening effects, with potential implications for both cosmology and engineered gravity.

1 1. Entropy as a Universal Constraint

Rigorous: From statistical mechanics,

$$S = k_B \ln \Omega,$$

where Ω is the number of accessible microstates. For a closed quantum system (the universe), the second law requires:

$$\frac{dS_{\text{universe}}}{dt} \geq 0.$$

Partitioning entropy into sectors:

$$S_{\text{universe}} = S_{\text{matter}} + S_{\text{vacuum}}, \tag{1}$$

where S_{vacuum} denotes vacuum entanglement entropy.

Physical: Entropy flows but cannot be destroyed; global information balance is preserved.

2 2. Entanglement Entropy and Information Density

Rigorous: Vacuum entanglement entropy follows area laws (e.g., Ryu–Takayanagi[1]). In lab systems, we define a scale-dependent entropy density:

$$S_{\text{ent}}^{(\text{op})} = \int \left(\frac{S_{\text{ent}}}{V} \right) dV. \tag{2}$$

This operational entropy reflects coarse-grained, decohered, and accessible information.

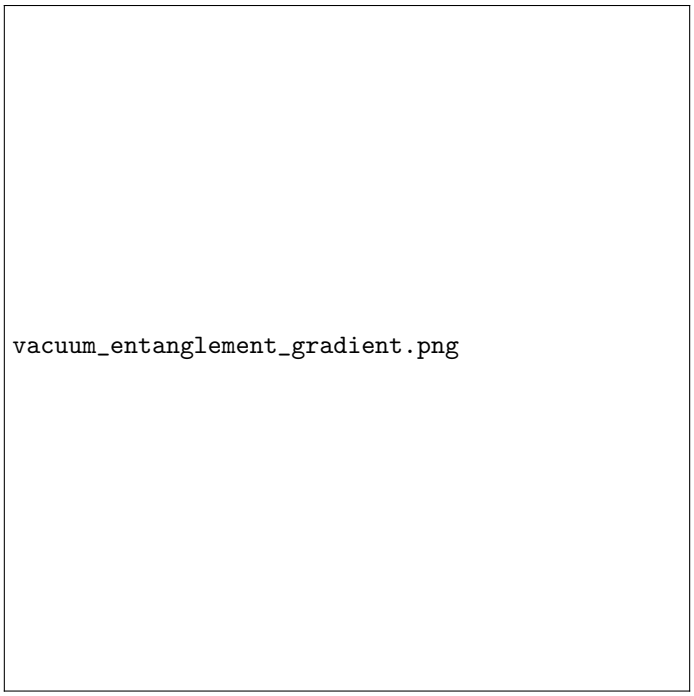

Figure 1: Schematic: Matter depletes vacuum entanglement, creating a gradient in entropy density.

Physical: Vacuum is maximally entangled at Planck scale, but macroscopic observers detect only finite coherent fractions.

3 3. Gravity as an Entropic Gradient Force

Rigorous: Mass disturbs local entanglement:

$$\partial_i \left(\frac{S_{\text{ent}}}{V} \right) \propto -\rho_{\text{mass}}. \tag{3}$$

Maximizing entropy over paths yields:

$$\vec{F} = -T_{\text{vac}} \nabla S_{\text{ent}}, \quad T_{\text{vac}} \sim \frac{\hbar c}{\ell_P}.$$

So,

$$\vec{F}_{\text{grav}} \propto +\nabla \rho_{\text{mass}}. \tag{4}$$

Physical: Gravity restores entanglement balance, analogous to pressure-driven thermal relaxation.

4 4. Information Density Determines Curvature

Rigorous: Dimensional analysis:

$$G_{\text{eff}} \sim \hbar c \left| \nabla \left(\frac{S_{\text{ent}}}{V} \right) \right|.$$

Physical: Newton's constant emerges from gradients of accessible quantum information.

5 5. Covariant Formulation and Energy Exchange

Rigorous: Modify Einstein's field equations:

$$G_{\mu\nu} = 8\pi G(T_{\mu\nu} + T^{\text{ent}}_{\mu\nu}), \tag{5}$$

with

$$T^{\text{ent}}_{\mu\nu} = \frac{\kappa}{8\pi G}\frac{c^4}{k_B \ln 2} S_{\text{ent}}(x) g_{\mu\nu}.$$

Conservation requires:

$$\nabla^\mu T_{\mu\nu} = -\nabla^\mu T^{\text{ent}}_{\mu\nu}. \tag{6}$$

Physical: Information-driven curvature mediates energy–momentum transfer between sectors.

6 6. Experimental Implications

- **Dark Energy:** Constant entanglement density mimics cosmological constant.
- **Artificial Gravity:** Highly entangled lab systems may generate detectable curvature.
- **Screening:** Decoherence attenuates gravitational contribution from small-scale entanglement.
- **Landauer Bound:** Information reset costs constrain local curvature[4].
- **Repulsive Gravity:** Negative pressure from entanglement creates expansion.

7 7. Predictions and Consistency

- Black hole entropy as horizon entanglement (Bekenstein–Hawking[2, 3])
- Inverse-square law from entropy dilution
- $m \sim k_B T \ln 2$ (mass-temperature link)
- $\Lambda \propto S^{(\text{vac})}_{\text{ent}}/V$
- Emergent G from entropy structure

8 Conclusion

This framework proposes that gravity is not fundamental, but an emergent force driven by entanglement entropy gradients. It connects thermodynamics, general relativity, and quantum information theory into a unified structure grounded in conservation laws and entropy dynamics. With theoretical consistency and testable implications, it opens a path toward engineered gravitational fields and new understandings of cosmology.

Source: `https://github.com/mssinternetmarketing-cyber/entropy-gravity-coupling`

References

[1] S. Ryu and T. Takayanagi, "Holographic Derivation of Entanglement Entropy from AdS/CFT," Phys. Rev. Lett. 96, 181602 (2006)

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