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Posted Date: 12 June 2025

doi: 10.20944/preprints202506.1083.v1

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Singularities as Entropy Resolution Boundaries: A Rigorous Result from TEQ

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Abstract: We demonstrate that within the Total Entropic Quantity (TEQ) framework, classical spacetime singularities correspond not to physical divergences, but to well-defined entropy resolution boundaries characterized by degeneracy of the entropy metric. Using the Schwarzschild singularity as an explicit example, we show that as classical curvature diverges, the entropy metric h_{ij} undergoes strict rank loss, signaling collapse of distinguishability rather than infinite physical content. The TEQ path integral formalism further ensures that singular configurations contribute zero weight to physical observables. This provides a rigorous structural resolution of the singularity problem in TEQ.

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A meta-abstract has been included to clarify which results are derived versus postulated, pre-empting misunderstandings by readers who skim the paper. No other changes or additions were made.

Meta-Abstract

This section provides a concise structural guide to the logic, assumptions, and derivational flow underpinning this work.

1. **Axioms and Principles:** The framework is based on two axioms: (1) entropy as a generative structural principle, and (2) the minimal principle of stable distinction. These are stated and developed in detail in [1].
2. **Derivation Pathway:** Section 2 shows how the entropy-weighted action S_{eff} and the entropy metric h_{ij}, which governs distinguishability, are derived from these principles, following [1].
3. **Technical Justification:** Section 3 applies these structural results to the Schwarzschild geometry, demonstrating that classical curvature divergence corresponds to strict rank loss of h_{ij}, not to physical divergence.
4. **Assumptions and Limitations:** The analysis assumes prior derivation of S_{eff} and h_{ij} within TEQ, as documented in [1]. The generalization to other singularities is discussed in Section 4 but not explicitly computed here.
5. **Section References:** The main structural principle is stated in Section 2; the explicit example is developed in Section 3; broader implications and generalization are discussed in Section 4.
6. **Supporting Material:** No appendices are included; the necessary supporting derivations for S_{eff}, h_{ij}, and their role in path suppression are provided in [1].
7. **Comparative Clarity:** Section 2 explicitly situates this result relative to other approaches to singularity resolution (e.g., [4–7]), highlighting that TEQ derives rank loss structurally from entropy geometry, rather than imposing it heuristically.

Precise references to equations and arguments are found in Sections 2–4. This meta-abstract serves as a map for the logical progression and structure of the paper.

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1. Introduction

Classical general relativity predicts singularities — regions where spacetime curvature diverges and the theory breaks down. Attempts to quantize gravity have struggled to resolve this issue, as singularities appear to represent both infinite curvature and physical pathologies.

The Total Entropic Quantity (TEQ) framework offers a fundamentally different perspective. In TEQ, spacetime geometry is not fundamental, but emergent from an underlying entropy geometry defined on configuration space. The core object is the entropy-weighted action:

$$S_{\text{eff}}[\phi] = \int dt(L(\phi, \dot{\phi}) - i\hbar\beta\, g(\phi, \dot{\phi})), \tag{1}$$

where $g(\phi, \dot{\phi})$ represents local entropy curvature. Path amplitudes are given by:

$$\mathcal{A}[\phi] = e^{iS_{\text{eff}}[\phi]/\hbar}. \tag{2}$$

This resolution is not a technical regularization of general relativity, nor an artifact of a particular quantization scheme. Rather, it arises from a fundamental shift of perspective: in the TEQ framework, spacetime is not fundamental, but emergent from an underlying entropy geometry. The apparent singularities of classical spacetime are structurally replaced by boundaries of distinguishability — points where the entropy metric loses rank. From this viewpoint, the singularity problem dissolves not because the infinities are "tamed," but because the very notion of spacetime divergence becomes inapplicable at resolution boundaries. This marks a profound correction to the inherited ontology of gravitational physics—not a technical adjustment, but a structural replacement.

In this paper, we prove that within TEQ:

- Singular configurations are exponentially suppressed in the path integral.
- Physical observables remain finite.
- Most importantly, the entropy metric h_{ij} exhibits *rank loss* at classical singularities, corresponding to collapse of distinguishability, not physical divergence.

We explicitly demonstrate this in the Schwarzschild singularity, providing the first rigorous example of singularity resolution in TEQ.

2. Singularities in TEQ: Structural Principles

In TEQ, the emergent spacetime metric arises from the entropy metric h_{ij}, defined on configuration space:

$$ds^2 = h_{ij}\, dx^i dx^j. \tag{3}$$

Entropy curvature $\delta^2 S_{\text{eff}}$ governs both the dynamics of resolution and the suppression of unstable configurations. The relation between entropy curvature and distinguishability is established explicitly in [1], where the form of h_{ij} and its role in defining resolution boundaries are rigorously derived. In regions where classical curvature diverges, entropy curvature likewise diverges, but this does not imply physical divergences.

Crucially, we show that the entropy metric undergoes strict *rank loss* in such regions. The apparent singularity is thus reinterpreted as a boundary of distinguishability — an entropy resolution boundary.

While the idea of interpreting singularities as loss of degrees of freedom has appeared in various forms (e.g., quantum geometry approaches [4–7]), TEQ provides a systematic and quantitative mechanism: rank loss arises from entropy curvature divergence within an explicitly weighted path integral. The entropy metric h_{ij}, derived from the effective action, is not imposed but computed from first principles. This structural derivation is unique to the TEQ framework as formulated here.

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3. Explicit Example: Schwarzschild Singularity

Consider the Schwarzschild metric:

$$ds^2 = -\left(1 - \frac{2GM}{r}\right)dt^2 + \left(1 - \frac{2GM}{r}\right)^{-1} dr^2 + r^2 d\Omega^2, \tag{4}$$

with $d\Omega^2 = d\theta^2 + \sin^2\theta\, d\phi^2$. The classical singularity occurs at $r \to 0$, where curvature scalars diverge.

In TEQ, configuration variables are $x^i = (r, \theta, \phi, t)$, and the entropy metric h_{ij} determines local resolution. Near $r \to 0$, we analyze the scaling of $h_{ij}(r)$:

$$h_{ij}(r) \sim \begin{pmatrix} h_{rr}(r) & 0 & 0 & 0 \\ 0 & h_{\theta\theta}(r) & 0 & 0 \\ 0 & 0 & h_{\phi\phi}(r) & 0 \\ 0 & 0 & 0 & h_{tt}(r) \end{pmatrix}. \tag{5}$$

Scaling behavior:

$$h_{\theta\theta}(r) \sim r^2 \to 0, \tag{6}$$
$$h_{\phi\phi}(r) \sim r^2 \to 0, \tag{7}$$
$$h_{tt}(r) \sim \left(1 - \frac{2GM}{r}\right) \to 0, \tag{8}$$
$$h_{rr}(r) \sim \left(1 - \frac{2GM}{r}\right)^{-1} \sim r \quad \text{(finite)}. \tag{9}$$

Eigenvalue behavior:

$$\lambda_\theta(r),\ \lambda_\phi(r),\ \lambda_t(r) \to 0, \tag{10}$$
$$\lambda_r(r) \sim \text{finite}. \tag{11}$$

Therefore, as $r \to 0$:

$$\text{rank}(h_{ij}) \to 1. \tag{12}$$

4. Suppression of Singular Paths

Entropy curvature diverges as $R \sim 1/r^6 \to \infty$, leading to:

$$\Im(S_{\text{eff}}) = \hbar\beta \int dt\, g(\phi, \dot{\phi}) \to \infty. \tag{13}$$

Thus:

$$|\mathcal{A}[\phi]| \to 0. \tag{14}$$

Singular configurations contribute zero weight to the path integral. Physical observables:

$$\langle O \rangle = \frac{\int \mathcal{D}\phi\, O[\phi]\, e^{iS_{\text{eff}}[\phi]/\hbar}}{\int \mathcal{D}\phi\, e^{iS_{\text{eff}}[\phi]/\hbar}}, \tag{15}$$

remain finite.

5. Conclusion

We have explicitly demonstrated that in TEQ:

- Classical singularities correspond to strict *rank loss* in the entropy metric.
- No physical divergence occurs.

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- The apparent singularity becomes a well-defined *entropy resolution boundary* — a collapse of distinguishability.
- The TEQ formalism remains fully consistent and well-defined.

The result presented here exemplifies how a shift to an entropy-based structural framework, rather than an attempt to quantize a flawed spacetime ontology, can naturally resolve longstanding conceptual paradoxes. In TEQ, the singularity problem does not require a technical solution because it does not arise: resolution boundaries replace unphysical divergences.

While we explicitly demonstrated the mechanism for the Schwarzschild singularity, the result is not tied to this specific example. The entropy metric h_{ij} reflects local distinguishability, and the process of rank loss under divergent entropy curvature is generic. In cosmological singularities (e.g., big bang models), the proper volume elements collapse, producing the same degeneration of h_{ij}. For rotating black holes (Kerr), the angular momentum introduces additional off-diagonal structure, but again, the distinguishability structure in collapsing regions reduces to lower-dimensional forms, leading to rank loss. A systematic treatment of these cases is underway.

Beyond this structural resolution, the operational implications of entropy rank loss merit further exploration. In particular, the suppression of entropy-weighted path contributions near gravitational boundaries may lead to testable signatures in high-curvature regimes, or in deviations from classical predictions for quantum-gravitational modes. Investigating such measurable effects represents an important direction for future work.

In this precise sense, we may say: the universe has no singularities—only limits of distinguishability.

Acknowledgments: This work was carried out independently during a period of cognitive and physical rehabilitation following a brain hemorrhage. It reflects part of a personal recovery process rather than a formal research program. ChatGPT was used for language refinement and structural organization; all theoretical content is the author's own.

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