Spacetime from Determinate Identity: A Logic-Realist Approach to General Relativity

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Abstract

We explore the consequences of Determinate Identity (Id) for spacetime structure, proposing that key features of general relativity emerge from logical constraints on physical instantiation. The derivation proceeds in stages: temporal ordering emerges from joint inadmissibility of configurations (Theorem 1); Lorentzian signature is forced by the asymmetry between jointly-inadmissible and jointly-admissible configuration pairs (Theorem 2); closed timelike curves are excluded by identity-preservation requirements (Theorem 3); and singularities are constrained by the requirement that identity cannot be destroyed (Theorem 4). These results are programmatic (rigorous formalization requires additional mathematical development), but they suggest that spacetime geometry, like Hilbert space structure, may be derivable from L_3 constraints rather than postulated independently.

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1. Introduction

1.1 The Problem

General relativity treats spacetime as a dynamical arena whose geometry is determined by matter-energy content via Einstein's field equations (Wald, 1984). But the framework assumes rather than derives several structural features:

- **Lorentzian signature**: Why (1,3) rather than (4,0) or (2,2)?
- **Temporal ordering**: Why is there a distinguished "timelike" direction?
- **Causal structure**: Why can't effects precede causes?
- **Singularity behavior**: What happens when geometry breaks down?

Standard GR takes these as inputs. We ask: can they be derived from more fundamental constraints?

1.2 The LRT Approach

Logic Realism Theory proposes that L_3 (Determinate Identity, Non-Contradiction, Excluded Middle) constrains physical instantiation. For quantum mechanics, this yields: - Complex Hilbert space (from local tomography) - Born rule (from vehicle-invariance) - Tsirelson bound (from Hilbert space structure)

Can similar reasoning constrain spacetime structure?

1.3 Strategy

We derive spacetime features from Id applied to configurations and their relations:

Spacetime Feature	Forced by
Temporal ordering	Joint inadmissibility (Theorem 1)
Lorentzian signature	Asymmetry in admissibility relations (Theorem 2)
CTC exclusion	Identity preservation (Theorem 3)
Singularity constraints	Information preservation (Theorem 4)

1.4 Caveats

This paper is more programmatic than the Hilbert space derivation. We sketch arguments rather than provide rigorous proofs. The goal is to show that LRT's constraint-based approach extends naturally to spacetime, not to claim complete derivations.

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2. Temporal Ordering from Joint Inadmissibility

2.1 Setup

Let A_Ω be the set of L_3-admissible configurations. Consider pairs of configurations $c_1, c_2 \in A_\Omega$.

Definition (Joint Admissibility): Configurations c_1, c_2 are *jointly admissible* if their conjunction is also admissible:

$$c_1 \wedge c_2 \in A_\Omega$$

Definition (Joint Inadmissibility): Configurations c_1, c_2 are *jointly inadmissible* if:

$$c_1 \wedge c_2 \notin A_\Omega$$

This occurs when the conjunction violates NC or EM, for instance "particle at position x_1" and "same particle at position $x_2 \neq x_1$" at the same time.

2.2 Theorem 1: Temporal Ordering Emerges

Theorem 1 (Temporal Ordering). If two L_3-admissible configurations are jointly inadmissible but both are instantiated, then they must be temporally ordered.

Proof sketch.

Suppose $c_1, c_2 \in A_\Omega$ but $c_1 \wedge c_2 \notin A_\Omega$.

If both c_1 and c_2 are instantiated, they cannot be co-instantiated (since their conjunction violates L_3).

Three options: 1. Only c_1 is instantiated (not c_2) 2. Only c_2 is instantiated (not c_1) 3. Both are instantiated, but at different "times"

Option 3 requires an ordering relation: "c_1 before c_2" or "c_2 before c_1".

Definition: The *temporal ordering* $<$ on instantiated configurations is the minimal ordering such that jointly-inadmissible but both-instantiated configurations are separated:

$$c_1 \wedge c_2 \notin A_\Omega \text{ and both instantiated} \Rightarrow c_1 < c_2 \text{ or } c_2 < c_1$$

Conclusion: Time emerges as the logical sequencing necessitated by joint inadmissibility. □

Remark: This does not yet give metric structure (duration, intervals). It gives only ordinal structure: before/after relations forced by L_3 constraints.

2.3 Physical Interpretation

Temporal ordering is not an additional postulate. It is the logical structure that permits individually-admissible configurations to both be instantiated despite being jointly inadmissible.

Consider: a particle cannot be at two locations simultaneously (NC violation). Yet both locations can be occupied at different times. Time is what makes this possible.

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3. Lorentzian Signature from Admissibility Asymmetry

3.1 The Signature Problem

A 4D spacetime metric has signature (p, q) with $p + q = 4$. Options: - $(4, 0)$: Euclidean (all positive) - $(3, 1)$: Lorentzian (one negative) - $(2, 2)$: Split signature (two negative)

Empirically, spacetime has Lorentzian signature $(3, 1)$. Why?

3.2 Theorem 2: Lorentzian Signature Forced

Theorem 2 (Lorentzian Signature). If temporal ordering arises from joint inadmissibility and spatial separation permits joint admissibility, then the metric signature must be Lorentzian.

Argument (sketch, not rigorous proof):

(Step 1: Two types of separation)

Consider two configurations localized in spacetime. They can be: - **Timelike separated**: One is in the causal past/future of the other - **Spacelike separated**: Neither is in the causal past/future of the other

(Step 2: Admissibility asymmetry)

For jointly-inadmissible configurations (e.g., same particle at two locations): - Timelike separation permits sequential instantiation - Spacelike separation does not apply (they must be separated in time)

For jointly-admissible configurations (e.g., different particles at different locations): - Both timelike and spacelike separation permit co-instantiation - Spacelike separation is "cheaper," requiring no ordering constraint

(Step 3: Metric signature encodes this asymmetry)

A metric with signature $(3, 1)$ treats one dimension (time) differently from the other three (space): - Timelike intervals: $ds^2 < 0$ (ordering constrained) - Spacelike intervals: $ds^2 > 0$ (no ordering constraint) - Null intervals: $ds^2 = 0$ (boundary case)

The Lorentzian signature is the unique signature that: 1. Distinguishes one dimension (time) from the others (space) 2. Permits joint admissibility for spacelike-separated configurations 3. Forces ordering for timelike-separated jointly-inadmissible configurations

(Step 4: Other signatures fail)

- $(4, 0)$: No distinguished temporal direction; all directions equivalent. Cannot represent the asymmetry between jointly-admissible and jointly-inadmissible pairs.
- $(2, 2)$: Two "timelike" directions. Would permit multiple independent temporal orderings, violating the requirement that jointly-inadmissible configurations have a *unique* ordering relation.

Conclusion: Lorentzian signature is forced by the structure of L_3 admissibility. □

Caveat: This argument is heuristic. A rigorous derivation would require formalizing the relationship between joint admissibility and metric signature.

3.3 Relation to Causality

The Lorentzian signature encodes causal structure: - Timelike curves connect causally-related events - Spacelike surfaces connect causally-independent events - Null curves are the boundary (light cones)

LRT interprets this as: - Timelike = sequential instantiation of jointly-inadmissible configurations - Spacelike = possible co-instantiation of jointly-admissible configurations - Null = limiting case where ordering is just barely required

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4. CTC Exclusion from Identity Preservation

4.1 The CTC Problem

Closed timelike curves (CTCs) are worldlines that loop back on themselves, allowing an observer to return to their own past. General relativity permits CTC solutions (Gödel universe, Kerr black holes, wormholes).

Are CTCs compatible with L_3?

4.2 Theorem 3: CTCs Violate Id

Theorem 3 (CTC Exclusion). Closed timelike curves violate Determinate Identity and are therefore excluded from A_Ω.

Proof.

Suppose a worldline γ is a CTC. Then there exists an event e on γ such that e is in its own causal past.

Let c_e be the configuration at event e. On a CTC: - c_e causes some later configuration $c_{e'}$ - $c_{e'}$ eventually causes c_e again (the loop closes)

Apply Determinate Identity (Id-3: Persistence Principle): identity persists through transformation unless the transformation constitutes a change of identity.

On a CTC: - The "first" occurrence of c_e has identity i_1 - The "second" occurrence of c_e (after the loop) has identity i_2 - But they are the same event: $i_1 = i_2$

The problem: Is i_1 causally prior to i_2, or is i_2 causally prior to i_1? On a CTC, both. But this violates the antisymmetry of causal ordering:

$$i_1 < i_2 \text{ and } i_2 < i_1 \Rightarrow i_1 \neq i_2$$

Yet $i_1 = i_2$ by assumption (same event). Contradiction.

Conclusion: CTCs violate Id. Spacetimes containing CTCs are not in A_Ω. □

Physical interpretation: You cannot be your own ancestor. Identity requires a consistent causal history. CTCs create loops where an entity is both cause and effect of itself, destroying determinate identity.

4.3 Chronology Protection

Hawking conjectured that physics conspires to prevent CTC formation ("chronology protection"). LRT provides a *logical* version: CTCs are excluded not by dynamical mechanisms but by the requirement that instantiated configurations have determinate identity.

This doesn't explain *how* CTC formation is prevented, only *why* it must be.

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5. Singularity Constraints from Information Preservation

5.1 The Singularity Problem

General relativity predicts singularities: points where curvature diverges and the metric is undefined. Examples: - Black hole singularities - Big Bang singularity - Potential future Big Crunch

At singularities, geodesics terminate. What happens to the identity of configurations that reach a singularity?

5.2 Theorem 4: Identity Cannot Be Destroyed

Theorem 4 (Identity Preservation). If Determinate Identity holds, then no physical process can destroy identity-constituting information.

Proof.

Let c be a configuration with determinate identity i. By Id-3, identity persists through transformation unless the transformation constitutes a change of identity.

Suppose c evolves to a singularity where it "ceases to exist." Two options:

(Option A): Identity i is destroyed (no successor configuration).

This violates Id-3: identity cannot simply vanish. If i was determinate, it must either persist or transform into a new identity i', but not disappear.

(Option B): Identity i transforms into a new configuration c' with identity i'.

This is compatible with Id, but requires the singularity to be a transformation, not an endpoint.

Conclusion: Physical singularities cannot destroy identity. Either: 1. Singularities are not genuine endpoints (information escapes) 2. Singularities involve identity transformation (not destruction) 3. Classical singularities are artifacts of incomplete physics □

5.3 Black Hole Information

This has implications for the black hole information paradox:

Standard problem: Hawking radiation is thermal (carries no information) (Hawking, 1975). If black holes evaporate completely, the information about what fell in is destroyed, violating unitarity.

LRT prediction: Information (identity-constituting structure) cannot be destroyed. Therefore: - Black hole evaporation must be unitary - Information must escape, either in Hawking radiation correlations or through other mechanisms - Singularities inside black holes cannot be genuine information-destroying endpoints

This aligns with modern views from AdS/CFT, but LRT provides a *logical* reason: Id forbids information destruction.

5.4 Big Bang and Cosmological Singularities

The Big Bang singularity poses similar questions: - Was there a "before" the Big Bang? - Where did the universe's initial information come from?

LRT perspective: - The Big Bang cannot be a genuine creation ex nihilo of identity-bearing configurations - Either: the Big Bang is a transformation from a prior state, or "before" is not applicable - Initial conditions carry determinate identity; they are not arbitrary

This is speculative but suggests that LRT may constrain cosmological models.

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6. Metric Structure and Einstein's Equations

6.1 What We Have Not Derived

The arguments above derive: - Temporal ordering (from joint inadmissibility) - Lorentzian signature (from admissibility asymmetry) - CTC exclusion (from Id) - Information preservation at singularities (from Id)

We have *not* derived: - The specific form of the metric (curvature, geodesics) - Einstein's field equations $G_{\mu\nu} = 8\pi T_{\mu\nu}$ - The equivalence principle - The specific value of constants (Newton's G, speed of light)

6.2 Programmatic Suggestions

Einstein's equations from vehicle-invariance?

In QM, vehicle-invariance (probability assignments independent of decomposition choice) forces the Born rule. Could an analogous principle apply to spacetime?

Conjecture: The metric must be determined by a *vehicle-invariant* procedure from matter-energy content. Einstein's equations might be the unique such procedure satisfying: 1. Lorentzian signature 2. Diffeomorphism invariance (coordinate independence = descriptive invariance) 3. Local determination (metric at a point depends only on local matter-energy)

This is speculative and requires substantial development.

Equivalence principle from Id?

The equivalence principle states that gravitational and inertial mass are identical. Could this follow from Id?

Conjecture: If the identity of a massive configuration is determinate, then there is a unique mass associated with it, not separate "gravitational" and "inertial" masses. The equivalence principle is forced by the requirement that identity is unitary.

Again, speculative.

7. Discussion

7.1 What This Paper Achieves

We have shown that L_3 constraints, specifically Determinate Identity, have natural implications for spacetime structure:

Result	Status
Temporal ordering emerges	Argued (Theorem 1)
Lorentzian signature forced	Sketched (Theorem 2)
CTCs excluded	Argued (Theorem 3)
Singularities constrained	Argued (Theorem 4)

These are not complete derivations but programmatic proposals showing that LRT's logic-first approach extends beyond quantum mechanics.

7.2 Comparison with Other Approaches

Causal set theory (Sorkin, 2003): Spacetime emerges from discrete causal relations. LRT's "joint inadmissibility → ordering" is compatible but grounded differently (logic, not discrete structure postulate). Malament (1977) established that causal structure determines spacetime topology, supporting the primacy of causal ordering that LRT derives from L_3.

Loop quantum gravity (Rovelli, 2004): Quantizes spacetime geometry directly. LRT would ask: does LQG's structure satisfy L_3 constraints? Are its predictions L_3-admissible?

String theory: Requires specific dimensions and structure. LRT might constrain which string vacua are L_3-admissible.

7.3 Open Questions

1. **Metric derivation**: Can Einstein's equations be derived from L_3 + vehicle-invariance?
2. **Quantum gravity**: How does L_3 constrain the interface between quantum and gravitational structure?
3. **Cosmology**: What does L_3 imply for initial conditions and cosmic evolution?
4. **Constants**: Can G, c, or other constants be derived from L_3?

8. Conclusion

Determinate Identity has implications for spacetime structure. Temporal ordering emerges from joint inadmissibility; Lorentzian signature encodes the asymmetry between timelike (ordering-required) and spacelike (ordering-optional) separations; CTCs are excluded by identity preservation; singularities cannot destroy information.

These results are programmatic. Full derivations require: - Rigorous formalization of the admissibility → signature argument - Connection to Einstein's field equations - Treatment of quantum gravity

But the direction is clear: if L_3 constrains instantiation, that constraint applies to spacetime itself, not just to configurations within spacetime. The arena of physics is not a neutral backdrop but a structure that must itself satisfy logical admissibility.

This is the ultimate extension of logic realism: not just "physics is logical" but "spacetime is logical."

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