Discreteness of Spacetime from Two Minimal Axioms

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Abstract

We explore whether two axioms—(1) that no physical identity remains unchanged, and (2) that division and recombination of identities entail a non-zero cost—are sufficient to enforce discreteness in the structure of spacetime. We argue that, under these assumptions, continuous models of spacetime are untenable, and a discrete substrate emerges naturally as the only self-consistent alternative.

1. Introduction

Modern physics treats spacetime as a continuum, whether in the smooth manifold of general relativity or the Hilbert-space formalisms of quantum theory. Yet attempts to reconcile these frameworks at the Planck scale routinely encounter divergences tied to the assumption of infinite divisibility. Here we examine whether discreteness follows directly from two minimal axioms, without introducing additional postulates.

2. The Axioms

Axiom 1 (Non-identity persistence): No physical system or identity remains static; all structures evolve under time or entropic flux.
Axiom 2 (Transformational cost): Division or recombination of any unity entails a non-zero cost. Division generates new interfaces and destroys coherence; recombination requires reconciliation of histories, phases, or boundaries.

3. Implications of Axiom 1

If no entity remains unchanged, then no globally smooth, static substrate can exist. A continuum background implies the possibility of subregions that persist identically under arbitrary refinement, which violates the axiom. Instead, all physical entities—including spacetime intervals—must be subject to change. This undermines the notion of infinite smooth divisibility.

4. Implications of Axiom 2

Division is not neutral. Cutting a system generates additional boundary conditions, entropy, or energetic burden. For example, halving a physical body increases surface area and alters thermodynamics. At atomic and nuclear scales, subdivision

transforms identity (e.g., splitting a nucleus requires energy and alters binding properties). Thus infinite subdivision, which presumes arbitrarily cost-free partition, is physically incoherent.

Similarly, recombination is non-trivial: restoring two halves to a whole cannot recover the exact original state without additional cost. This rules out the linear arithmetic of parts and wholes underpinning continuum reasoning.

5. Synthesis: Emergence of Discreteness

Taken together, these axioms forbid:

- **Arbitrary refinement of intervals (contradicts Axiom 2).**
- **Static persistence of subdivided states (contradicts Axiom 1).**

Therefore, subdivision must terminate at some finite scale where further division ceases to produce coherent identities. This scale defines the elementary units of spacetime, not as imposed quanta but as stable survivors of the cost–flux balance implied by the axioms.

6. Discussion

The discreteness that follows here is not postulated but enforced. Continuous spacetime implies both zero-cost subdivision and static persistence—precisely what the axioms exclude. Discreteness thus appears as the only viable resolution. This aligns with independent motivations for quantization in physics: renormalization, black hole entropy, and holography all suggest a finite density of degrees of freedom. The present argument shows such finiteness can be derived from two elementary axioms alone.

7. Conclusion

If (1) nothing remains unchanged and (2) division and recombination incur cost, then spacetime cannot be continuous. Infinite subdivision violates the cost principle, and infinite persistence violates the flux principle. Discreteness follows as the necessary structure of physical reality.