Ontology of Causally Self-Consistent Regions

Abstract

We outline an ontological framework in which physical reality is identified with **causally self-consistent regions**, defined by horizon structure and causal accessibility rather than by volumetric extension within a pre-existing spacetime. Building explicitly on the causal–horizon perspective introduced in “A Causal–Horizon Perspective on the Early Universe”, the present work should be read as an ontological exploration of its implications rather than as an extension or modification of that framework.

Within this perspective, a physical domain is characterized by the degrees of freedom accessible to internal observers and by a causal boundary that constrains the system’s entropic content, without reference to an external, physically operative environment. Causal structure is treated as ontologically primary, while spatial geometry and temporal ordering emerge as effective descriptions associated with evolving accessibility and boundary conditions. Entropy is fundamentally associated with horizons, in line with established results from gravitational thermodynamics and quantum field theory in curved spacetime.

No new dynamical laws or specific cosmological models are introduced in this work. Instead, the conceptual fertility of the causal–horizon framework is illustrated through the notion of causally self-consistent regions and by examining the interior of a black-hole spacetime as an illustrative realization. This example is employed solely for conceptual clarity and should not be interpreted as a literal identification. By articulating an explicit ontological layer compatible with a horizon-centered causal framework, this work aims to strengthen its conceptual foundations while preserving its agnostic and minimal character.

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1. Introduction

Modern developments in gravitational physics and cosmology increasingly suggest that causal structure and horizon physics play a more fundamental role than volumetric descriptions of spacetime. Insights from black hole thermodynamics, quantum field theory in curved spacetime, and cosmological horizon studies consistently indicate that entropy, information, and physical accessibility are governed by causal boundaries rather than by the detailed microstate of spatial volumes.

This work builds explicitly on the causal–horizon perspective introduced in [Ref. X], and should be read as an ontological exploration of its implications rather than as an extension or modification of that framework. In particular, we adopt the horizon-centered viewpoint as a conceptual starting point and investigate what kind of ontological

structures are naturally compatible with it, without introducing additional assumptions or altering its foundational claims.

Within this context, we introduce the notion of *causally self-consistent regions* (CSCRs) as a minimal ontological realization of a horizon-based causal framework. The aim is not to advance a new dynamical theory or cosmological model, but to articulate an explicit ontological layer that clarifies how a physical domain can be consistently defined in terms of causal accessibility, horizon structure, and boundary-associated entropy.

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2. Causally Self-Consistent Regions: Definition and Axioms

2.1 Core Definition

A *causally self-consistent region* is a physical domain defined exclusively by the causal accessibility of internal observers, whose boundary is given by a horizon that fixes the physically relevant degrees of freedom. Such a region is not characterized by spatial extension or volumetric content, but by its causal structure and the entropic properties of its boundary. No reference to an external, physically operative region is required for its internal consistency.

2.2 Ontological Axioms

Causal Primacy. Causal relations are ontologically prior to spatial geometry; physical observables are defined relative to causal accessibility.

Causal Closure. A CSCR is causally closed: no physically observable influence crosses its horizon into the interior.

Fundamental Boundary. The horizon is a causal structure that defines the system itself, encoding information and constraining internal descriptions.

Boundary-Associated Entropy. Physically relevant entropy is primarily associated with the boundary and scales with its geometric properties.

Internal Self-Consistency. Effective interior dynamics must be compatible with the boundary's entropic and causal properties, without appeal to external initial conditions.

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3. What a CSCR Is Not

For clarity, a CSCR is not a region embedded within a larger physical space, not a bubble separated by a material wall, and not a claim about the totality of existence. It is an operationally complete physical domain defined from within by causal accessibility and horizon structure.

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4. Emergence of Space and Time

Within a CSCR, spatial geometry emerges as an effective description of relations among causally connected degrees of freedom, while time emerges as an ordering associated with changes in accessibility and available entropy. Temporal asymmetry is local and arises from evolving horizon conditions.

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5. Realizations of the Ontology

The CSCR ontology does not prescribe a unique geometry. Multiple spacetime constructions may realize the same causal structure, including cosmological models with effective horizons and horizon-dominated regimes. These realizations instantiate the ontology without defining it.

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6. Illustrative Case: Black-Hole Interior Geometry

The interior of a black-hole spacetime serves as a particularly instructive illustrative realization of a CSCR, as it displays a causal horizon, boundary-associated entropy, observer-dependent time, and constrained interior evolution. This example is used for conceptual clarity and is not a literal identification of the universe.

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7. Conceptual Fertility and Open Directions

Adopting a CSCR ontology reframes foundational questions concerning homogeneity, entropy growth, temporal asymmetry, and effective expansion, while remaining fully compatible with established phenomenology. The framework is offered as a conceptual scaffold rather than a completed theory.

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8. Conclusion

By identifying physical reality with causally self-consistent regions defined by horizon structure and information accessibility, this work articulates an ontological layer compatible with a horizon-centered causal framework. The approach strengthens conceptual foundations without introducing new dynamics and illustrates its potential through a black-hole interior analogy, inviting further formal and empirical investigation.