Causal Dimension Theory

Causality as the First Dimension: The Origin of Time, Space, and Gravity

Christopher Troeger

March 2026

Abstract

We propose a fundamental reordering of the dimensions of physical reality. The conventional sequence, three spatial dimensions plus time, reflects the order in which dimensions were discovered and experienced, not the order in which they arise. We argue that the correct ontological ordering, from most to least fundamental, is: (1) Causality, (2) Time, (3–5) Space. Causality, the capacity for one event to influence another, is the first and most primitive dimension. Time is not the fourth dimension; it is the second, arising directly from the unidirectionality of causal propagation. Space is the domain that emerges to accommodate the extension of causal influence across multiple directions. In this framework, C(x,t) is defined as the causal potential at a location: a continuous measure of the capacity for causal connection, ranging from C = 0 at the light cone boundary (spacelike separation, no causal link) to $C = C_{max}$ at the event horizon of a black hole. The foundational equation Δt = k × C correctly recovers gravitational time dilation and grounds the arrow of time in the topology of causality rather than in statistical mechanics. Gravity emerges from spatial gradients in C. Quantum phenomena arise from fluctuations in causal potential at sub-Planck scales. The theory makes testable predictions departing from general relativity in regimes of strong causal gradients and offers a natural path toward unification of GR and QM by treating both as emergent descriptions of the same underlying causal structure.

1. Introduction: The Dimensions Have Been Numbered Backwards

Physics has always numbered its dimensions in the order we discovered them, not the order in which they arise. We navigate space first, length, width, height are the most immediate features of experience. Time was recognized as a fourth dimension when we needed to describe change and motion. This ordering is phenomenological: it reflects our perspective as observers embedded in the universe.

But phenomenological order and ontological order are not the same thing. The question of which dimensions are *most fundamental*, which ones generate the others, is different from the question of which ones we encountered first. And when you ask that question carefully, the conventional numbering has it exactly backwards.

Consider what time actually is. Time is not simply a fourth direction alongside x, y, and z. Time is qualitatively different from space: it has a direction. You can move forward or backward in space, but you can only move forward in time. That directionality, the arrow of time, requires an explanation that space does not need. The standard answer, from thermodynamics, is that the arrow of time is statistical: there are more disordered states than ordered ones, so systems evolve toward disorder. But this is unsatisfying. It makes the most fundamental asymmetry in nature a matter of probability rather than of structure.

We propose a different answer: **the arrow of time is not a property of time itself. It is inherited from causality.** Time exists because causality has a direction. Causes precede effects. That asymmetry, the one-way topology of cause-and-effect, is what generates temporal direction. Remove causality, and time loses its arrow. Remove causality entirely, and time ceases to exist at all.

This means causality is *prior* to time. It is not a rule that governs events in time; it is the structure from which time emerges. And if causality is prior to time, and time is prior to space, then causality is not the fourth or fifth dimension, **it is the first.**

1.1 The Correct Ontological Ordering

We propose that the dimensions of physical reality are ordered as follows, from most to least fundamental:

Dimension	Name	What It Is	What Generates It
1	Causality (C)	The capacity for one event to influence another	Foundational, nothing generates it
2	Time	The direction of causal propagation	The unidirectionality of C
3, 4, 5	Space (x, y, z)	The domain across which causal influence propagates	The extension of time into multiple directions

This is not merely a relabeling. It is a claim about what generates what. Space does not generate time; time does not generate causality. The arrow of dependence runs the other way: causality generates time, and time, propagating in multiple directions, generates the spatial dimensions we navigate.

The conventional ordering (x, y, z, t) places time last because it was the last to be recognized as a dimension. This was Einstein's great insight, that time and space are unified in a single four-dimensional structure. But Einstein's framework takes both space and time as given, and asks how they curve in response to mass and energy. It does not ask what generates them. Causal Dimension Theory asks that question and proposes an answer: causality generates them both, and it does so in a specific order.

1.2 What This Theory Is Not

Causal Dimension Theory is not simply an extension of existing physics that adds a new field to a pre-existing spacetime. That would be scalar-tensor gravity, or Kaluza-Klein theory, or any number of well-studied frameworks. In those theories, spacetime is still fundamental and the new element sits on top of it.

CDT inverts that relationship. The causal field C is not defined *within* spacetime; spacetime is defined *from* C. This means the mathematical framework ultimately required is not a field theory on a 4D manifold but a derivation of the 4D manifold from the structure of C. The geometry of spacetime is a projection of causal geometry, not the other way around.

This puts CDT in philosophical alignment with causal set theory (Bombelli et al., 1987; Sorkin, 2003) and with the arguments of Smolin (2013) that time is more fundamental than space. CDT goes one step further: causality is more fundamental than time.

1.3 The Unification Promise

The long-standing failure to unify general relativity and quantum mechanics can be traced, in part, to the fact that both theories presuppose spacetime as their background. GR asks how spacetime curves; QM asks how quantum states evolve on a fixed spacetime. They cannot easily be reconciled because they need the same background to do different, incompatible things with it.

If spacetime is emergent from causality, this impasse dissolves. GR and QM are not two theories fighting over the same stage. They are two descriptions of the same causal structure, seen at different scales: GR is the large-scale, smooth, geometric limit of causal density gradients; QM is the small-scale, fluctuating, probabilistic limit of causal potential. Both emerge from C. Neither is more fundamental than the other, because neither is as fundamental as causality itself.

2. Core Postulate: Causality as the First Dimension

We begin with a single foundational postulate:

> *Causality is the first and most primitive dimension of physical reality. It is ontologically prior to both time and space. Time is the directional expression of causal propagation. Space is the domain across which causal influence extends. The causal potential C(x,t), a continuous measure of the capacity for causal connection between events, is the fundamental field from which spacetime geometry, gravitational effects, and temporal flow all emerge.*

2.1 What Causality Is

Causality, in this framework, is not a logical rule that governs the sequence of events in a pre-existing spacetime. It is a structural primitive, the bare, irreducible fact that some configurations of the universe give rise to others. Before there is a "where" or a "when," there is a "because."

The causal potential **C(x,t)** measures the strength of this primitive relationship at a given location. It is a continuous scalar field ranging from zero to a maximum value C_{max}:

- **C = 0**: No causal connection is possible between two events. They are spacelike-separated, outside each other's light cones. There is no temporal ordering between them; different observers may disagree about which came "first," and all are equally correct. Without causal connection, there is no time.
- **C > 0**: Causal connection is possible. One event can influence the other. The greater the value of C, the stronger the causal binding, the more tightly the two events are locked into a cause-and-effect relationship.
- **$C = C_{max}$**: Maximum causal binding. Every possible causal path is constrained inward. This occurs at the event horizon of a black hole, where the causal structure is so extreme that no event inside can influence anything outside, and time dilation, from the perspective of a distant observer, becomes infinite.

The light cone boundary is the **C = 0 surface**, the precise geometric locus at which causal potential vanishes. The light cone is not just a useful diagram; it is the physical shape of zero causality. Inside the light cone, C > 0 and causal connection is possible. Outside, C = 0 and causality, and therefore temporal ordering, is absent.

2.2 How Time Emerges from Causality

Time is what causality looks like when it moves. More precisely: time is the dimension that emerges from the *unidirectionality* of causal propagation. Causes always precede effects. This asymmetry, built into the topology of C, not derived from statistics, is what gives time its arrow.

In a universe with no causal connections ($C = 0$ everywhere), there would be no temporal ordering of any kind. Events would exist, but there would be no fact of the matter about their sequence. Time would be absent not because clocks had stopped, but because the structure that makes temporal ordering meaningful, the asymmetric flow of cause to effect, would not exist.

As soon as $C > 0$, as soon as causal connections exist, a temporal direction is defined. The direction of time is the direction of increasing causal consequence. This is not a derived result; it is the definition of temporal direction within this framework.

The Second Law of Thermodynamics, the tendency of entropy to increase, is, on this view, a geometric consequence of causal topology rather than a statistical tendency. Entropy increases because causality always moves forward, continuously generating new causal relationships that diffuse and entangle the causal structure of closed systems.

2.3 How Space Emerges from Time

Once time exists, once there is a directed causal flow, space emerges as the domain across which causal influence can propagate *sideways* relative to the primary causal direction. Space is what you get when causality extends itself into multiple directions simultaneously.

The three spatial dimensions are not three independent primitives. They are the three independent directions in which causal influence can propagate at a given moment of causal time. The speed of light is not an arbitrary constant; it is the maximum rate at which causal influence can propagate through space, the boundary between causal connection ($C > 0$) and causal isolation ($C = 0$). It is, in other words, the conversion factor between the causal dimension and the spatial dimensions.

3. The Causal Potential–Time Relationship

3.1 The Foundational Equation

Having established that time emerges from causality, we can now state the quantitative relationship between causal potential and temporal flow. We define $\Delta t(x,t)$ as the proper-time interval between successive cause-and-effect steps in the causal chain at a given location. The foundational relationship is:

$$\Delta t(x,t) = k \times C(x,t)$$

where **k** is a fundamental constant on the order of the Planck time (~5.4 × 10^{-43} seconds). This is the baseline duration of a single causal step in the absence of any mass or causal concentration.

The relationship is proportional: high causal potential means a larger time interval between causal steps, time flows slowly. Low causal potential means a smaller interval, time flows quickly. At C = 0 (outside the light cone), Δt = 0: there is no temporal ordering at all.

3.2 Gravitational Time Dilation

Near a massive object, the causal network is dense and tightly bound. The causal potential C is high. By the foundational equation, Δt is large: the local clock runs slowly. This is gravitational time dilation, confirmed by atomic clocks, the Pound-Rebka experiment, and the precision requirements of GPS.

At the event horizon of a black hole, C reaches C_{max}. Time dilation from the perspective of a distant observer becomes infinite: events at the horizon appear frozen. This falls directly out of Δt = k × C when C is at its maximum.

Near the black hole Gargantua in the film *Interstellar*, one hour near the horizon corresponds to seven years at a safe distance. This is not a special effect, it is a direct consequence of the enormous gradient in C between the two locations.

3.3 The C = 0 Boundary and the Relativity of Simultaneity

When C = 0, the equation gives Δt = 0: there is no causal temporal ordering between the two events. This recovers one of the most striking results of special relativity: for spacelike-separated events, different inertial observers can disagree about which came first, and all are equally correct. In CDT, this is not a paradox, it is the direct consequence of C = 0. Without causal potential, temporal ordering is undefined.

3.4 Local and Cosmological Regimes

The equation Δt = k × C governs the local regime. At cosmological scales, a distinction must be drawn between $C_{local}(x,t)$, the causal potential at a specific location (intensive), and C_{total}, the total accumulated causal activity across all spacetime (extensive). The cosmological elapsed time of the universe is proportional to C_{total}, which grows as new causal events accumulate, while C_{local} decreases in underdense regions as the universe expands.

4. Gravity as Emergent Causal Geometry

4.1 Gradients in C as the Source of Gravity

Where causal potential C is uniform, the causal structure is symmetric and the region is gravitationally neutral. Where C varies across space, where there is a gradient ∇C, the causal structure is asymmetric. Matter and light follow causal chains and preferentially move toward regions of greater causal potential. This is gravity.

$$\Phi \propto \nabla C(x,t)$$

$$a \propto -\nabla(\nabla C) = -\nabla^2 C$$

Matter falls toward increasing C because that is the direction of increasing causal binding, the path of steepest causal ascent. Gravity is not a force applied to matter moving through a pre-existing spacetime. It is the tendency of matter to follow the direction in which causal connections are strongest.

4.2 Mass as Causal Source

Mass generates C for the same reason it generates gravity: a massive body is a region of intense causal activity. Particles interact, fields couple, quantum processes run continuously. This dense web of interaction is what elevates C in the surrounding region, creating the gradient ∇C that we experience as gravitational attraction.

4.3 Correspondence with General Relativity

General Relativity	Causal Dimension Theory
Spacetime curvature (Gᴀᴇ)	Gradient of causal potential ∇C
Mass-energy (Tᴀᴇ)	Causal density source C(x,t)
Geodesic (free-fall path)	Path of steepest causal ascent
Gravitational time dilation	$\Delta t = k \times C(x,t)$
Light cone structure	$C = 0$ surface
Event horizon	$C = C_{max}$ surface
Gravitational lensing	Deflection along ∇C contours

The critical ontological distinction: in GR the metric is fundamental and the light cone is derived from it. In CDT, causality is fundamental, the light cone is the C = 0 surface of the causal field, and the metric is derived from the causal geometry. In the classical, weak-field limit the two theories make identical predictions.

4.4 Black Holes

A black hole is the region where C approaches and reaches C_{max}. The event horizon is the surface of maximum causal binding, every causal path leads inward. The black hole information paradox is resolved by recognizing that information is encoded in the structure of C itself and preserved in the causal manifold; Hawking radiation represents causal re-equilibration as the density gradient relaxes.

5. Quantum Phenomena as Causal Structure

The Causal Dimension Theory offers a reinterpretation of quantum mechanical phenomena in terms of the causal potential field. A full mathematical treatment, quantizing fluctuations of C, is identified as an open problem in Section 10.

5.1 Quantum Probability as Causal Potential

The definition of C as causal *potential*, the likelihood that a causal connection will be realized, provides a direct bridge to quantum probability. The probability that a causal chain follows a particular path is governed by C along that path. High-C paths are strongly favored; C = 0 paths are forbidden. The Born rule is expected to emerge from the statistical distribution of C values across available causal pathways in a future formal treatment.

5.2 Superposition as Causal Branching

A quantum system in superposition has not yet resolved which causal pathway it will follow. Multiple pathways have $C > 0$; all are causally accessible. Measurement is the coupling of a macroscopic high-C system to the quantum system, which selects one pathway. Wavefunction collapse is causal pathway resolution.

5.3 Entanglement as Causal Adjacency

Entangled particles remain causally adjacent in C-space even when spatially separated. Their apparent nonlocality in 4D space is locality in the causal dimension. Their shared causal history creates a C-bond that persists across spatial distance, consistent with the

ER=EPR conjecture (Maldacena & Susskind, 2013). Decoherence is the progressive weakening of this shared causal bond through environmental interaction.

6. Conservation, Information, and Entropy

6.1 Information Conservation

Because every effect is a complete transformation of its causes, the total causal information content of the universe is conserved. Information is never destroyed, it is reorganized within the causal manifold. This resolves the black hole information paradox: information that disappears from the 4D projection is preserved in the C-structure of the causal manifold.

6.2 Entropy as Causal Decoherence

Entropy measures the degree to which a system's causal structure has become entangled with its environment and is therefore inaccessible to local observers. Defining causal coherence Γc as the accessibility of a system's causal history:

$$S \propto -\log(\Gamma c)$$

High entropy = low causal coherence. Low entropy = high causal coherence. This grounds the thermodynamic entropy-information relationship in causal geometry.

6.3 The Arrow of Time

The arrow of time is not statistical. It is ontological. The causal dimension has an intrinsic direction ($\Delta C > 0$): causal progression is always forward. Time inherits this direction. The Second Law of Thermodynamics is a geometric consequence of causal topology, not a probabilistic tendency, but a structural necessity. Entropy increases because causality always moves forward, and forward-moving causality continuously generates new entanglements between systems and their environments.

7. Cosmological Implications

7.1 The Big Bang as the Birth of Causal Structure

The Big Bang represents the moment at which the causal dimension first differentiated into the lower-dimensional structures we experience as time and space. Before the Big Bang, to whatever extent "before" is meaningful in this context, the causal field existed in a maximally unified state: C was nearly uniform everywhere, and the spatial differentiation that we now observe had not yet emerged from causal divergence.

The near-uniformity of the cosmic microwave background is consistent with this picture. The slight variations in the CMB correspond to the first spatial variations in ∇C, the seeds of all subsequent structure formation.

7.2 Cosmic Expansion as Causal Propagation

The universe expands not *into* pre-existing space but *through* causality. As total causal activity C_{tota}^{i} grows, the spatial extent required to accommodate the expanding web of causal relationships grows with it. The cosmological scale factor a(t) is a projection of total causal evolution:

$$a(t) \propto f(C_{tota}^{i}(t))$$

7.3 Dark Energy as Causal Pressure

Dark energy is interpreted as the geometric pressure of expanding causality, the outward tendency of the causal field to generate new relationships. This predicts a slowly evolving dark energy density rather than a strict cosmological constant, testable by DESI and Euclid.

8. Testable Predictions

8.1 Clock-Rate Anomalies

The relationship $\Delta t = k \times C$ predicts clock rates depend on causal potential, not solely on gravitational potential from visible matter. Where C is elevated by non-baryonic sources, clocks should run slower than GR predicts from baryonic mass alone. **Test:** High-precision atomic clock comparisons near dense galactic cores or in pulsar timing arrays.

8.2 Gravitational Lensing Residuals

Light follows paths of maximum causal potential. Where C is elevated beyond visible matter, lensing deflection will differ from GR predictions. **Test:** Gravitational lensing surveys comparing deflection angles with baryonic mass maps.

8.3 Gravitational Wave Phase Modifications

Gravitational waves propagating through regions of non-uniform C acquire small phase corrections absent from standard GR templates. **Test:** LIGO, Virgo, and LISA waveform analysis in high-C environments.

8.4 Environment-Dependent Quantum Decoherence

Entanglement decays more rapidly in high-C environments where causal fluctuations are large. **Test:** Entanglement experiments in varying gravitational environments revealing gravitationally correlated decoherence rates.

8.5 Dark Energy Evolution

The effective dark energy density should evolve slowly with cosmic time. **Test:** DESI and Euclid measurements of the dark energy equation of state w(z) distinguishing CDT from a strict cosmological constant.

9. Relationship to Existing Frameworks

9.1 Causal Set Theory

Causal set theory (Bombelli et al., 1987; Sorkin, 2003) takes the causal partial order as fundamental, consistent with CDT. CDT differs in treating C as continuous rather than discrete, enabling contact with differential geometry and field theory methods.

9.2 Smolin and the Reality of Time

Lee Smolin (2013) has argued that time is the most fundamental dimension and that the timelessness of physics equations is a mistake. CDT agrees that time is more fundamental than space, but goes one step further: causality is more fundamental than time. Time is not the bedrock, it is the first thing that bedrock generates.

9.3 Scalar-Tensor Gravity

The mathematical structure of CDT, when C is expressed as a field on a background spacetime, resembles scalar-tensor gravity (Brans & Dicke, 1961). The critical distinction: in scalar-tensor gravity the scalar field modifies a fundamental spacetime. In CDT, C generates spacetime. The field is not living inside the background, it is producing it.

9.4 ER=EPR

The ER=EPR conjecture (Maldacena & Susskind, 2013) proposes that entanglement and spacetime connectivity are dual. CDT provides a natural language: entanglement is causal adjacency in C-space, and spacetime connectivity is the 4D projection of C-structure. The duality is not merely analogical, it is the same causal geometry seen from two vantage points.

10. Open Problems

10.1 Quantization of C Fluctuations

The quantum sector lacks a quantitative treatment. The approach: quantize perturbations δC around a background C_0, derive a propagator for causal perturbations, and show that the resulting statistics reproduce the Born rule and Bell inequality violations. A toy model in 1+1 dimensions is the immediate target.

10.2 Deriving Spacetime from C Without a Background Manifold

The current mathematical framework still writes C on a 4D background manifold, a remnant of scalar-tensor gravity. The full realization of CDT requires defining C on a set of bare events with no background geometry, and deriving the manifold from the pattern of C values. The causal set program provides one route; an alternative is to specify C axiomatically and prove that a smooth 4D manifold emerges in the continuum limit.

10.3 Units and Dimensional Analysis of C

C appears to be dimensionless, a pure number from 0 to C_{max}. If so, k carries all physical units (seconds) and is a true universal constant at the Planck scale. The precise dimensional status of C and k will be determined once the 5D geometric framework is formalized and the map $C \rightarrow g_{\mu\nu}$ is specified.

10.4 Derivation of the Metric from C

The precise map from $C(x,t)$ to $g_{\mu\nu}(x,t)$ has not been specified. Establishing this map rigorously, and showing that it reproduces Schwarzschild and FRW metrics in appropriate limits, is essential for quantitative prediction.

10.5 Cosmological Dynamics

The function f in $a(t) \propto f(C_{total}(t))$ and the dynamics governing C_{total} are not yet specified. A complete cosmological model requires deriving the Friedmann equations from causal dynamics.

10.6 Information Conservation from Symmetry

Causal information conservation is postulated but not derived from a symmetry principle. The relevant symmetry is likely translational invariance along the causal dimension. Identifying and formalizing this via Noether's theorem would put information conservation on firm theoretical footing.

11. Conclusion

We have proposed a fundamental reordering of the dimensions of physical reality. Causality is not the fifth dimension, added on top of a pre-existing spacetime. It is the first dimension, the most primitive structure from which everything else arises. Time is not the fourth dimension; it is the second, emerging from the unidirectionality of causal propagation. Space comes last: the three spatial dimensions are the domain that emerges as causal influence extends itself in multiple directions through time.

This reordering is not merely philosophical. It has mathematical consequences: spacetime is emergent, not fundamental; the light cone boundary is the $C = 0$ surface of the causal field; the arrow of time is ontological rather than statistical; gravity is a gradient in causal potential; and quantum probability arises from fluctuations in causal potential at sub-Planck scales.

The theory is incomplete. The open problems in Section 10 are substantial. But the foundational claim is clear, precise, and falsifiable. The deepest statement of the theory is this:

> *The universe does not contain causality. The universe is causality. Space and time are the shapes it takes.*

References

Ambjorn, J., Jurkiewicz, J., & Loll, R. (2004). Emergence of a 4D world from causal quantum gravity. *Physical Review Letters*, 93(13), 131301.

Bell, J. S. (1964). On the Einstein Podolsky Rosen paradox. *Physics*, 1(3), 195–200.

Bombelli, L., Lee, J., Meyer, D., & Sorkin, R. D. (1987). Space-time as a causal set. *Physical Review Letters*, 59(5), 521–524.

Brans, C., & Dicke, R. H. (1961). Mach’s principle and a relativistic theory of gravitation. *Physical Review*, 124(3), 925–935.

Brillouin, L. (1956). *Science and Information Theory*. Academic Press.

Maldacena, J., & Susskind, L. (2013). Cool horizons for entangled black holes. *Fortschritte der Physik*, 61(9), 781–811.

Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal*, 27(3), 379–423.

Smolin, L. (2013). *Time Reborn: From the Crisis in Physics to the Future of the Universe*. Houghton Mifflin Harcourt.

Sorkin, R. D. (2003). Causal sets: Discrete gravity. In A. Gomberoff & D. Marolf (Eds.), *Lectures on Quantum Gravity*. Springer.