Causal Dimension Theory

A Visual Addendum

Christopher Troeger

March 2026

This addendum accompanies the main paper and provides visual and intuitive explanations of the core ideas in Causal Dimension Theory. It is written in two parts: first for general readers, then for those with a physics background.

PART ONE

For the Curious Reader

What Is Causal Dimension Theory Saying?

Most of us grow up thinking of the universe as a stage, a vast empty space where things happen. Particles, planets, and people move around on this stage, interacting according to physical laws. Space and time form the background that everything takes place in.

Causal Dimension Theory proposes something much more radical: **the stage doesn't come first**. What comes first is causality, the web of cause and effect that connects every event to every other event it can influence. Space and time, the familiar "stage," are patterns that emerge from that web. They are real, but they are not fundamental.

Think of it this way: imagine a story. The story has characters, settings, and a timeline. But none of those things exist before the story is told. They emerge from the narrative, from the web of "because this happened, then that happened." The setting is generated by the story, not the other way around. Causal Dimension Theory says the universe works exactly like this.

What Is Causal Potential (C)?

The central quantity in the theory is called **causal potential**, written as C. It is a number that describes, at any given location, how strongly events are causally bound to each other, how tightly the fabric of cause and effect is woven there.

C is not the number of events happening. It is not the speed of time. It is the *underlying structural capacity* for one event to influence another. Think of it like this:

- **C = 0**: No causal connection is possible. These two events are completely causally isolated, like two things happening on opposite sides of the universe at the same moment. Neither can influence the other. Because there is no causal connection, there is also no temporal ordering between them, you cannot say which happened "first."
- **C > 0**: Causal connection is possible. One event can influence the other. The larger C is, the stronger and more tightly bound that connection is.
- **C = C_max**: This is the maximum possible causal binding. It occurs at the event horizon of a black hole, where the gravitational grip on causality is so extreme that no event inside can influence anything outside. Every causal path leads inward. Time, as seen from the outside, stops completely.

Visualizing It: The Light Cone

The most important visual tool in physics for understanding causality is the light cone. Here is how to read it, and how it connects to C.

Imagine standing at a specific moment and place in the universe. Draw a cone opening upward (your future) and a cone opening downward (your past). The boundary of each cone is defined by the speed of light, events on that boundary could just barely reach you, traveling at exactly the speed of light.

Inside the cone: these are the events that can causally influence you (past cone) or be influenced by you (future cone). Causal connection is possible. **C > 0** here.

Outside the cone: these events are too far away for any signal, even light, to travel between you. They are causally disconnected. **C = 0** here. There is no fact of the matter about whether they happened "before" or "after" you, it depends on who is asking.

The light cone boundary *is* the C = 0 surface. It is not just a useful diagram, it is the precise geometric shape of zero causal potential.

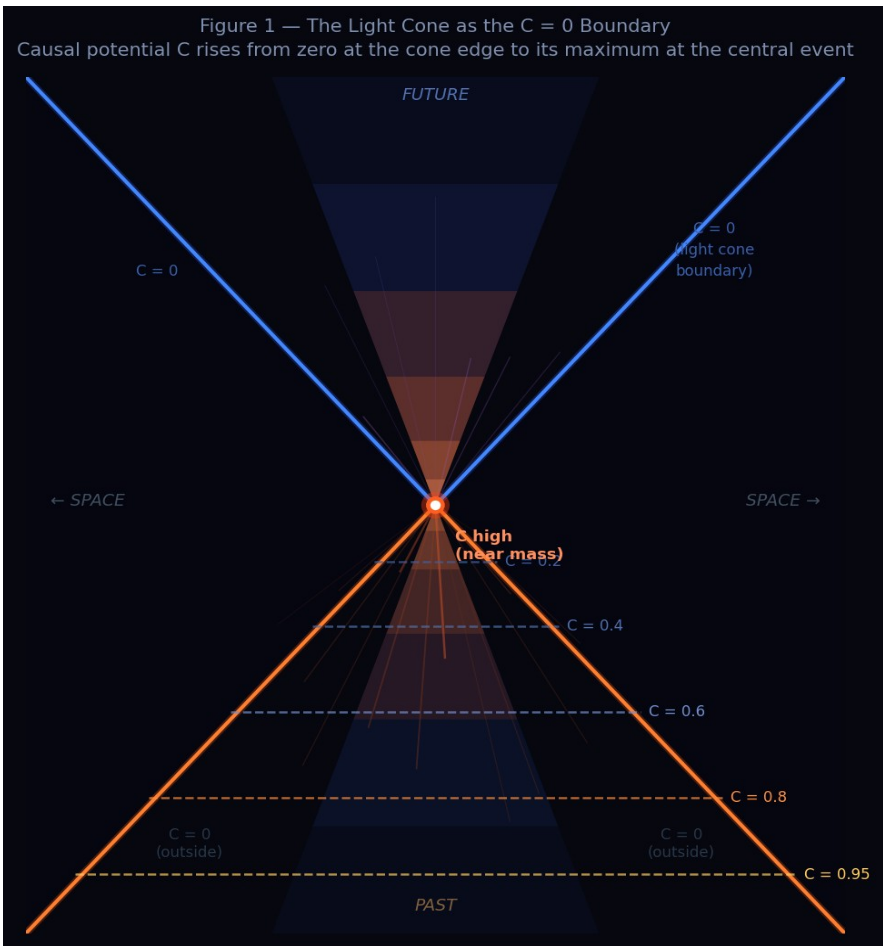

Figure 1. The Light Cone. The boundary lines mark C = 0, the limit of causal influence. Inside the cone, C > 0 and increases toward the center (the event). Outside the cone, C = 0 and there is no causal connection, no temporal ordering.

Why Does Time Run Slower Near Massive Objects?

One of the most surprising predictions of Einstein's theory of relativity, confirmed by countless experiments, is that time runs slower near massive objects. Clocks on the ground tick slightly slower than clocks on a satellite. Clocks near a black hole tick extremely slowly compared to clocks far away.

In Causal Dimension Theory, this is explained directly by C. Near a massive object, the web of causal connections is extremely dense and tightly bound. The causal potential C is high. And when C is high, each step in the causal chain takes longer, time is stretched.

The foundational equation expresses this simply:

$$\Delta t = k \times C$$

Here, **Δt** is the time interval between successive causal events (how slowly a clock ticks), **C** is the causal potential at that location, and **k** is a fundamental constant of nature. When C is high, Δt is large, the clock ticks slowly. When C is low, Δt is small, the clock ticks quickly.

This is exactly what we observe. Near the black hole Gargantua in the film *Interstellar*, the causal potential is enormous. One hour there corresponds to seven years farther away, a vast difference in Δt between the two locations, arising from the vast difference in C.

The Causal Web: What's Really There

The light cone diagram is drawn on a grid, with space on one axis and time on the other. That grid is useful, but it can be misleading. It suggests that space and time are the fundamental background, and that causality is something that happens on top of it.

Causal Dimension Theory inverts this. The following diagram removes the grid entirely and shows only what the theory says is truly fundamental: **events** (the glowing dots) and **causal threads** (the lines connecting them).

Near the center, near a massive object, the threads are dense and bright. Events are tightly bound to each other. C is high and time runs slowly. Far from the center, the threads are sparse and faint. Events are loosely connected. C is low and time runs quickly. Spacetime, the grid you normally imagine, is the pattern that emerges when you step back and look at all these threads from a distance. The grid is real, but it is a description of the pattern, not the pattern itself.

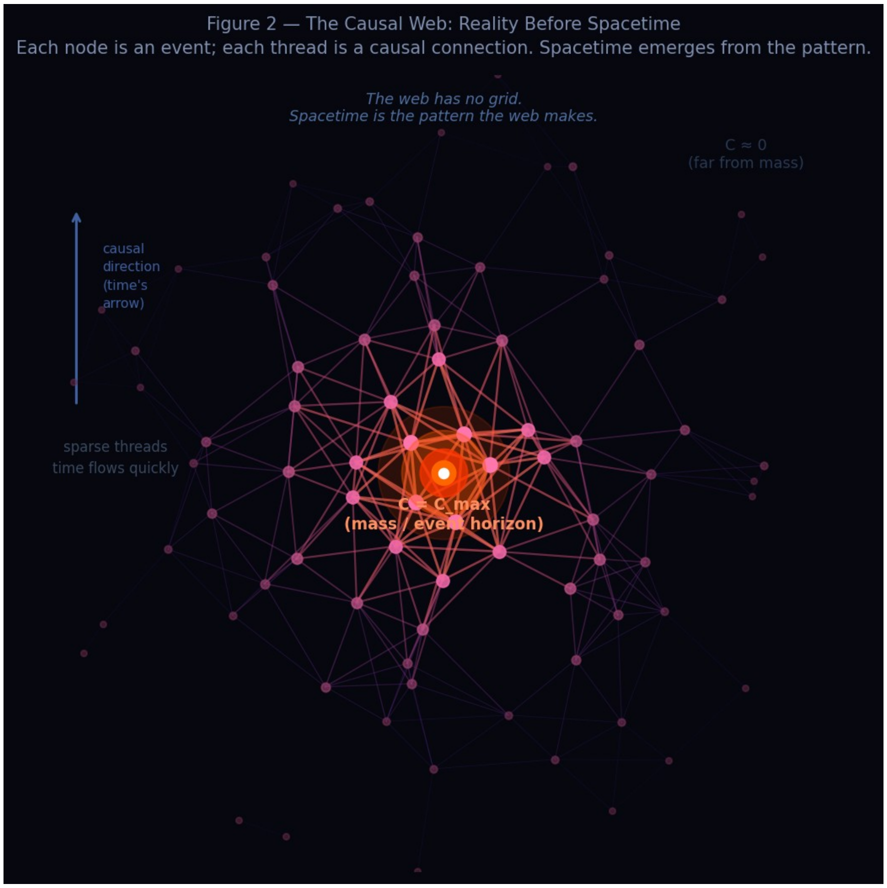

Figure 2. The Causal Web. No spacetime grid is drawn, because in Causal Dimension Theory the grid is not fundamental, it is emergent. Only events (dots) and their causal connections (threads) exist at the most basic level. Dense, bright threads near the center indicate high C; sparse, dim threads at the edges indicate C approaching zero.

What a Black Hole Looks Like in C

A black hole is the most extreme concentration of causal potential in the universe. Moving from empty space toward a black hole, C rises continuously, from nearly zero in the void between galaxies, through moderate values in ordinary space near stars, to very high values in the immediate vicinity of the black hole, to its absolute maximum at the event horizon.

The event horizon is not a physical surface you could touch. It is a causal boundary: the surface at which $C = C_{max}$, where causal binding is total and no causal chain can escape. From the outside, an observer would see clocks near the horizon running infinitely slowly, time approaching a complete stop. From the perspective of something falling through the horizon, nothing special happens locally, you cross it without feeling anything. But from that point on, every causal path leads toward the singularity.

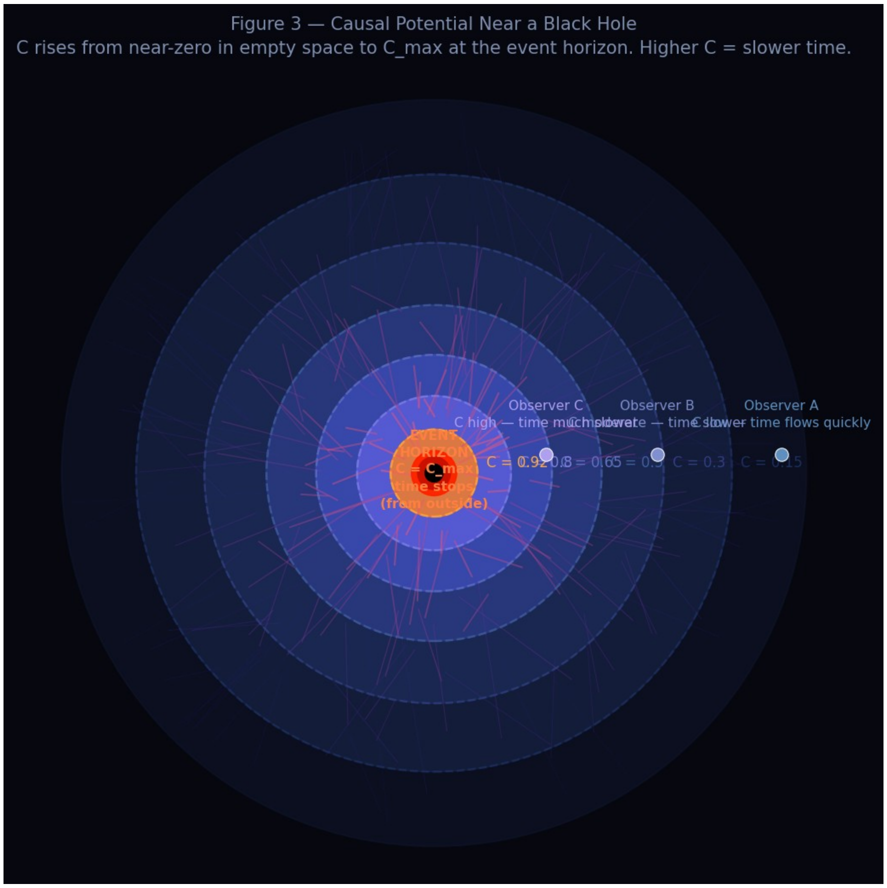

Figure 3. Causal Potential Near a Black Hole. C rises from near-zero in empty space (outer rings, blue) to C_max at the event horizon (center, orange/red). The three observers experience dramatically different rates of time: Observer A (far away) has low C and a fast clock; Observer C (near the horizon) has high C and a very slow clock.

The One Big Idea

> *Spacetime is not the stage on which causality operates. Spacetime IS causality, seen from the inside. The web of cause and effect is the fundamental fabric of reality. Everything else, space, time, gravity, quantum chance, is the shape that fabric takes.*

PART TWO

Technical Notes for the Physicist

On the Definition of C

The causal potential $C(x,t)$ is defined operationally via the light cone structure of the spacetime manifold. For a given event p, C characterizes the degree of timelike separability between p and neighboring events: $C = 0$ on the null surface ($\partial J^+(p) \cup \partial J^-(p)$), and $C > 0$ in the interior of the causal future and past ($I^+(p) \cup I^-(p)$).

Crucially, C is not defined as an event rate or interaction frequency. It is a measure of causal binding strength, the structural weight of a causal connection, independent of how many interactions actually occur per unit proper time. This distinguishes CDT from frameworks that identify causality with information-theoretic quantities like mutual information or transfer entropy.

The boundary condition $C = C_{max}$ at the event horizon of a Schwarzschild black hole ($r = r_s = 2GM/c^2$) is defined by the requirement that $\Delta t \to \infty$ as $r \to r_s$ from the coordinate perspective of a static observer at infinity, consistent with the divergence of the Schwarzschild time component $g_{tt} \to 0$ at the horizon.

The Foundational Equation and GR Recovery

The central relation is:

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

where $k \sim t_P$ (Planck time). In the weak-field, static limit with $C = C_\infty + \delta C(x)$, $||\delta C|| \ll C_\infty$, this recovers the standard gravitational redshift:

$$\Delta t / \Delta t_\infty \approx 1 + \Phi_C / c^2, \quad \Phi_C \propto \nabla C$$

and in the Newtonian limit, Φ_C reduces to the Newtonian gravitational potential when the source of ∇C is identified with baryonic mass density. The full general relativistic correspondence requires the mapping $C \to g_{\mu\nu}$ to be specified (see Open Problem 10.3 in the main paper).

C as Pre-Geometric vs. Scalar-Tensor

A natural question for the physicist is: how does CDT differ from scalar-tensor gravity (Brans-Dicke, f(R), or Horndeski theories), in which a scalar field φ modifies the effective gravitational constant?

The formal distinction is ontological. In scalar-tensor theories, the scalar field lives on a manifold whose metric is taken as fundamental. The action is written on a 4D background: $S = \int d^4x \sqrt{-g}\, [\varphi R/2\kappa + \ldots]$. The light cone structure is derived from $g_{\mu\nu}$, and the scalar field modifies dynamics within that structure.

In CDT, C is prior to the metric. The light cone structure is the C = 0 surface of C, not derived from a pre-existing metric. The metric $g_{\mu\nu}$ is a derived quantity, an effective description of the large-scale pattern of C. This inversion means that in CDT, the scalar field generates the background rather than living within it. The formal mathematical realization of this requires a 5D framework with dimensional reduction (Open Problem 10.2), which has not yet been specified.

Connection to Causal Set Theory

Causal set theory (Bombelli et al., 1987) takes the causal partial order as fundamental and imposes the additional condition of discrete counting (the "number-volume correspondence"). CDT agrees on the primacy of causal structure but differs in treating C as a continuous field rather than a discrete partial order. This allows CDT to make contact with differential geometry and existing field theory methods at the cost of not automatically reproducing the discreteness scale at the Planck length.

A productive research direction would be to derive CDT as the continuum limit of a causal set, with C playing the role of the coarse-grained causal density variable. The relationship $C(x) \sim n(J^+(x) \cap J^-(y)) / V$, where n counts causal links and V is a coarse-graining volume, is a natural starting point.

Quantum Correspondence

The most significant open question is the relationship between C and quantum probability. The proposal is that the Born rule amplitudes $||\psi||^2$ arise from the distribution of causal potential values across available pathways in a path-integral sense:

$$P(\gamma) \propto C(\gamma) \quad \Leftrightarrow \quad |\langle\varphi|\psi\rangle|^2$$

where γ is a causal path and C(γ) is the integrated causal potential along it. This is a conjecture, not a derivation. Establishing it formally requires quantizing perturbations δC around a background C_0, computing the path integral over C configurations, and demonstrating convergence to standard QFT amplitudes in the flat-space limit.

The entanglement proposal, that entangled particles are causally adjacent in C-space despite spatial separation, is consistent with the ER=EPR framework and would follow naturally from a 5D formulation in which the C-distance between events is independent of their 4D spatial distance.

This visual addendum is intended as a companion to the full theoretical paper. Readers wishing to engage with the complete mathematical framework, field equations, testable predictions, and open problems are directed to the main text: *Causal Dimension Theory: Causality as the Origin of Spacetime, Gravity, and Quantum Phenomena* (Troeger, 2026).