The Flow of Time Defines Space

An Essay on Spacetime through the O_n Observer Scale Model

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Prologue: Why I Write This

As a child, I once looked up at the night sky and a thought struck me: "If that starlight left hundreds of years ago, is what I see right now the *real* star, or merely a *residual image* of the past?" The question never faded; if anything, it deepened as I encountered the basic concepts of physics.

This essay is not a paper by a professional physicist. It is a record of the landscape one individual has observed from the shoulders of the giants of physics. Standing upon the established foundations of Einstein's general relativity, Nottale's scale relativity, and Mandelbrot's fractal geometry, I place my own small telescope atop them and cautiously propose a single perspective on the age-old question: "What is the relationship between time and space?"

If this essay—which values intuitive exploration over rigorous proof, and questions over conclusions—sparks a similar curiosity in the reader, that alone is enough.

1. Introduction: The View that Time Precedes Space

The traditional starting point for understanding the universe is space. We lay out a three-dimensional coordinate system and add time as an extra axis—a familiar approach. This essay, however, departs from the opposite direction.

> *"Without the flow of time, can space be defined?"*

This is not a physical proof but a **starting point for a thought experiment**. According to the second law of thermodynamics, the entropy of an isolated system never decreases, implying an irreversible flow of time.

$$\Delta S \geq 0 \tag{1}$$

If we imagine a world in which the flow of time has completely stopped—where no physical interaction, no exchange of information, no transfer of energy takes place—can we truly say that space *exists*? A space in which no physical process whatsoever proceeds cannot be measured, observed, or assigned meaning.

Of course, modern physics offers alternative viewpoints. In Einstein's relativity, time and space are equal coordinates constituting a four-dimensional spacetime manifold, and the "Block Universe" interpretation regards past, present, and future as co-existing in a static structure. Under this view, the "flow of time" itself may be a cognitive phenomenon rather than a physical reality.

Yet precisely at that juncture an interesting possibility opens up. Even if the Block Universe interpretation is mathematically correct, the physics *we experience* cannot be described without the flow of time. Measurement is interaction within time, and the structure of space is revealed to us as the result of such interactions. This essay adopts that experiential lens—"The flow of time structures and defines space by mediating interactions"—as its guiding perspective.

Whether this viewpoint can ultimately coexist with static interpretations like the Block Universe, or whether it can be extended into the stronger claim that the flow of time is essential for the emergence of space itself,

remains an open question. For now, let us follow where this perspective takes us.

> **Recap: Fact / Hypothesis / Metaphor**
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> **Fact.** Thermodynamics provides an arrow of time via entropy increase, while relativity shows that time measurements depend on observers and gravity.
> **Hypothesis.** Explore a "time-first lens in which spacetime is described relationally, with space emerging from temporal structure.
> **Metaphor.** A "film/shutter metaphor: a scene becomes defined only as time flows.

2. The O_n Observer Scale Model and the Perception of Spacetime

If time and space are interdependent, then the period of events and the flow of time should be perceived differently depending on the "physical size (Scale) of the observer." Extending Laurent Nottale's Scale Relativity theory, we define the O_n **Observer Scale Model** in which observers are classified by spatial scale.

- O_{n-1} (subatomic world): ultra-microscopic space below $L \sim 10^{-15}$ m

- O_n (atomic and molecular world): microscopic space at $L \sim 10^{-10}$ m

- O_{n+1} (human and everyday observer): macroscopic space at $L \sim 10^0$ m

- O_{n+2} (stellar and galactic world): ultra-macroscopic space at $L \sim 10^{21}$ m

2.1 Scale-Dependent Characteristic Time

Given that the speed of light c is constant and that the maximum speed of information transfer is limited, the characteristic time τ_n—the time for one complete physical interaction within a given scale—is proportional to the spatial size L_n of that system.[1] With a scaling factor α, space and time are related as follows:

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[1]This scaling relationship should be understood as a **conceptual framework** rather than a rigorous physical law. In reality, different scales are governed by different dominant forces—the strong and weak nuclear forces at the subatomic level, electromagnetic forces at the atomic and molecular level, and gravity at the macroscopic level. The proportional

$$L_{n+1} \approx \alpha \cdot L_n \,; \quad \tau_{n+1} \approx \alpha \cdot \tau_n \tag{2}$$

When a human (O_{n+1}) observes an atom (O_n), electronic transitions and orbital motion occur in a fraction of a quintillionth of a second on the human timescale. Conversely, when a human observes the cosmos (O_{n+2}), galactic rotations and stellar evolution take hundreds of millions of years. With the short cognitive time of a human (τ_{n+1}), the universe appears frozen, but this is merely a relativistic illusion arising from the scale mismatch between observer and observed.

> **Recap: Fact / Hypothesis / Metaphor**
>
> **Fact.** Information transfer is bounded (by c), and observation is inherently finite in resolution and sampling.
> **Hypothesis.** Across observer scales (O_n), characteristic lengths and times may rescale together so the same process appears different.
> **Metaphor.** Two cameras with different frame rates recording the same motion.

3. The Nested Universe Hypothesis and Fractal Spacetime

Extending the O_n model, we can propose the possibility that the universe does not end at a particular scale but possesses an infinite fractal structure exhibiting self-similarity.

If an ultra-massive being (O_{n+3}) could observe our entire universe (O_{n+2}) from the outside, events spanning billions of years would be compressed into a fleeting instant in their time-sense (τ_{n+3}). To that colossal observer, our universe would appear as "a single particle"—exactly as a human (O_{n+1}) perceives a dynamically vibrating electron (O_n). Conversely, within the subatomic world (O_{n-1}) we observe, another vast universe might unfold.

In other words, there is no absolute "universe" or "fundamental particle"; only the "difference in intrinsic time flow" depending on the observer's scale makes an object appear as a particle or as a universe.

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relationship below is therefore an **approximate model** based on the common constraint of the upper limit of information transfer speed (c) that pervades all scales, and does not claim quantitative precision.

3.1 A Philosophical Imagination—Yet a Door We Cannot Close

There is something we must honestly acknowledge. With current observations, there is no way to directly verify this hypothesis. CMB observations from WMAP and the Planck satellite show that the universe is isotropic and homogeneous at large scales beyond approximately 100 Mpc, which stands in tension with a simple self-similar fractal structure.

However, several intriguing clues prevent us from entirely closing the door on this hypothesis.

1. **Self-similarity in nature**: From coastlines to blood vessel networks, from lightning branches to galactic filament structures, nature repeats strikingly self-similar patterns across diverse scales. As Mandelbrot demonstrated, fractals are one of nature's fundamental organizing principles [**?**].

2. **Oldershaw's Discrete Scale Relativity**: Oldershaw presented observational evidence for statistically significant structural similarities between atomic, stellar, and galactic systems [**?**]. The density ratio between atomic nuclei and neutron stars, and the scaling relationship between the Bohr atomic radius and solar system sizes, exhibit patterns too striking to dismiss as mere coincidence.

3. **Observational limits**: Our conclusion of "homogeneity" applies within the *observable universe*. Beyond it, or below the Planck scale ($\sim 10^{-35}\,\mathrm{m}$), we know nothing.

4. **Implications of quantum gravity theories**: Candidate quantum gravity theories such as Loop Quantum Gravity [**?**] and Causal Dynamical Triangulation propose that spacetime at the Planck scale is not a smooth continuum but a discrete, rough structure. This resonates with the fractal intuition that "smaller scales may harbor yet another complex structure."

5. **Cosmological multiverse hypotheses**: String theory's "Landscape" scenario and Eternal Inflation models suggest that our universe may be merely one bubble in a vast multiverse. This is structurally similar to this essay's imagination that "there may be larger structures above our universe."

It is clear that this hypothesis is currently an unverifiable speculative imagination. Yet some of the most profound insights in the history of physics were born precisely in this realm of "what cannot yet be proven but also cannot be closed off."

Recap: Fact / Hypothesis / Metaphor

Fact. Self-similar patterns occur in nature, and effective descriptions change with scale.

Hypothesis. Propose (as a hypothesis) that hierarchical nesting of "worlds could make lower-scale dynamics appear particle-like to higher scales.

Metaphor. Galaxies look like points from far away; scale can turn a "world into a "particle in perception.

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4. The Geometric Origin of Gravity: Spatial Acceleration Born from the Gradient of Time

Having understood the continuity of scales, we can examine the essence of "gravity"—the most dominant phenomenon at the everyday scale (O_{n+1})—from the perspective of "time."

4.1 4-Velocity and the Paradox of Acceleration

An observer standing still on Earth's surface is, by the equivalence principle of general relativity, in a state equivalent to being continuously accelerated at $1g$ ($9.8 \, \text{m/s}^2$). The reason this acceleration does not accumulate to reach the speed of light—despite spatial stillness—is that the acceleration is directed not through three-dimensional space but through four-dimensional spacetime.

For any timelike worldline, the four-velocity $u^\mu = dx^\mu/d\tau$ has an invariant norm $u^\mu u_\mu = -c^2$. An observer on Earth, with no spatial motion, expends that acceleration not on crossing empty space but entirely on maintaining motion along "one's own time axis" (the flow of proper time) within spacetime warped by mass.

4.2 The Time Gradient

The essential reason a massive body attracts other objects (inducing spatial acceleration) is elegantly revealed in the Geodesic Equation.

$$\frac{d^2 x^\mu}{d\tau^2} + \Gamma^\mu{}_{\alpha\beta} \frac{dx^\alpha}{d\tau} \frac{dx^\beta}{d\tau} = 0 \tag{3}$$

> **Assumptions (Newtonian limit).** The steps below are best read under the usual approximations: a *static metric* ($\partial_t g_{\mu\nu} = 0$), a *weak gravitational field* ($|\Phi|/c^2 \ll 1$), *slow motion* ($v \ll c$), and an appropriate coordinate choice.

For an object at rest or moving slowly, the spatial components of the four-velocity converge to zero, leaving only the time component ($dt/d\tau \approx c$). In this case, the three-dimensional spatial acceleration (a^i) experienced by the object is derived as:

$$a^i = \frac{d^2 x^i}{dt^2} \approx -c^2\, \Gamma^i{}_{00} \approx \frac{1}{2}\, c^2\, \nabla_i\, g_{00} \tag{4}$$

Here, g_{00} is the "time component" of the spacetime metric tensor. In the (static, weak-field, slow-motion) Newtonian limit, this relation indicates that an object's spatial acceleration (a^i) is tied to how the metric's time component (g_{00}) varies with position ($\nabla_i\, g_{00}$).

The closer to a center of mass, the more subtly time flows slower. Just as a car with one wheel turning slower veers in that direction, the trajectory of an object heading straight along the time axis is deflected toward the spatial direction where time flows slower (the center of mass)—and that phenomenon is "gravity." In this perspective, what is often described as a "pulling force" can be intuitively viewed as **a spatial gradient of time flow**.

Recap: Fact / Hypothesis / Metaphor

Fact. In the static, weak-field, slow-motion limit, $a^i \approx \frac{1}{2}c^2\nabla_i g_{00}$, and g_{00} connects to the Newtonian potential.

Hypothesis. Gravity can be intuitively framed as a spatial gradient of time flow, consistent with the geodesic/equivalence-principle picture (within approximations).

Metaphor. A car veers toward the side with the slower wheel.

5. Heat, Light, and Gravity through the Lens of Time

In the previous chapter we understood gravity as "the gradient of time flow." If this lens is valid, might we also view other familiar phenomena—heat, the speed of light, and the flow of energy—through the same perspective?

5.1 Temperature: The Pace of the Microscopic Clock

Temperature is, at its core, a statistical measure of the kinetic energy of microscopic particles. Gas molecules move faster at higher temperatures and slower at lower temperatures. At absolute zero (0 K), all motion ceases apart from quantum-mechanical zero-point energy.

Viewed through the O_n scale model, an intriguing analogy emerges. When a macroscopic observer looks at a system whose particle motion has slowed to near-zero due to low temperature, the internal "clocks" of that system appear virtually stopped. Conversely, in an extremely hot plasma state, the interactions between particles become explosively fast, and the internal "clocks" run very quickly from the observer's perspective.

In other words, **temperature may be the way a macroscopic observer detects the pace of time flow at the microscopic scale**.

The reason this is more than a simple metaphor is that, in modern physics, **acceleration (gravity) and temperature are genuinely connected**.

- **The Unruh Effect [?]**: An observer moving with constant acceleration detects thermal radiation in a space that, for an inertial observer, is a perfect vacuum. The temperature observed due to acceleration a is

$$T = \frac{\hbar\, a}{2\pi\, c\, k_B} \tag{5}$$

Applying this essay's perspective that acceleration = the gradient of time, the interpretation that **the gradient of time flow gives rise to temperature** becomes possible.

- **Hawking Radiation**: Black holes possess temperature. The fact that extreme spacetime curvature (an extreme gradient of time) generates heat suggests that gravity, temperature, and time are fundamentally intertwined.

- **Jacobson's Thermodynamic Derivation (1995)** [**?**]: Ted Jacobson showed that Einstein's field equations can be derived from purely thermodynamic considerations—entropy, temperature, and heat flow. This is a powerful hint that spacetime geometry and thermodynamics may not be separate phenomena but *different expressions of the same underlying reality.*

5.2 The Speed of Light in Media: The Density of Spacetime Structure

In vacuum, the speed of light is a constant c, but in media such as water or glass, light slows down. Modern electrodynamics explains this clearly as the electromagnetic interaction (absorption and re-emission) with atoms within the medium—this is well-established physics.

However, viewing the same phenomenon through the O_n scale model yields a complementary intuition. A medium is a *dense space* of microscopic spacetime structures—atoms and molecules. When light passes through vacuum, it traverses only the flat spacetime of a single scale, but when passing through a medium, it must navigate the intrinsic spacetime structures of each individual atom—electronic vibrations, transitions between energy levels.

If the "characteristic time (τ_n)" within each atom and the interactions between them delay the propagation of light, then the slowing of light in media can also be interpreted as "the density of microscopic spacetime structure delays information transfer."[2] The denser the medium (the higher the refractive index), the more light slows—an intuition suggesting that the spacetime structure at microscopic scales is more complex and compact.

5.3 The Flow of Heat and Gravity: A Striking Structural Similarity

Heat always flows from high to low. This is a direct consequence of the second law of thermodynamics. But if, as this essay has argued, gravity is "the gradient of time flow," then the following analogy holds:

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[2]This interpretation does not *contradict* the explanation from conventional electrodynamics; rather, it is an attempt to redescribe the same phenomenon from a spacetime perspective.

> *Heat flows from regions of high temperature to regions of low temperature.*
> *Spacetime "tilts" from regions where time flows fast to regions where it flows slow (gravity).*

If, as discussed in the preceding subsection, temperature is the pace of microscopic time flow, then the flow of heat (high temperature $\rightarrow$ low temperature) and the tilting of spacetime due to gravity (fast time $\rightarrow$ slow time) may be **manifestations of the same phenomenon at different scales**.

Evidence that this may be more than a mere analogy can be found in the **Entropic Gravity** hypothesis proposed by Erik Verlinde in 2011 [**?**]. Verlinde proposed that gravity is not a fundamental force but one that *emerges* from the thermodynamic tendency of entropy increase. From this perspective, gravity belongs fundamentally in the same category as "the flow of heat driven by temperature differences."

The core thesis of this essay ("the gradient of time = gravity") and Verlinde's Entropic Gravity ("the gradient of entropy = gravity") arrive at strikingly similar conclusions from different starting points. The possibility that heat, gravity, and time are branches grown from a single deep root is, at the very least, worth exploring.

Recap: Fact / Hypothesis / Metaphor

Fact. Unruh effect and black-hole thermodynamics suggest deep links among acceleration, temperature, gravity, and information.

Hypothesis. Use "time gradient as a conceptual map linking acceleration to thermodynamic notions, without claiming a strict equivalence.

Metaphor. Time as a lens (or refractive index) shaping what is observed.

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6. Extension to Quantum Mechanics: The Temporal Blur Hypothesis

Can this essay's O_n fractal scale model provide a philosophical foothold for resolving the contradiction between the macroscopic world (general relativity) and the microscopic world (quantum mechanics)? When the observer scale becomes extremely small ($O_n \rightarrow O_{n-1}$), time in the microscopic world, from the macroscopic observer's frame, flows in a state compressed toward infinity.

The intent here is not to *deny* quantum "superposition" and "uncertainty," but to offer an intuition for how a macroscopic observer's *limited temporal resolution* may shape the appearance of measurement records. A macroscopic observer's slow temporal resolution (O_{n+1})—like a camera with a slow shutter speed—can effectively *coarse-grain* fast degrees of freedom, making measurement records look like a "Temporal Blur." This sits naturally alongside modern discussions of decoherence, where tracing over inaccessible degrees of freedom yields effective mixed states.[**?**]

6.1 An Honest Limitation: Confronting Bell's Inequality

There is a point at which we must be honest about this hypothesis. One of the most important experimental milestones in the history of quantum mechanics—the violation of **Bell's Inequality** [**?**, **?**]—is precisely that point.

In 1964, John Stewart Bell proved that if quantum particles behave deterministically according to "hidden variables" we have not yet discovered, a certain statistical inequality must necessarily be satisfied. In 1982, Alain Aspect's experiment showed that this inequality is in fact *violated*. Decades of increasingly refined experiments have reached the same conclusion.

If one were to interpret "Temporal Blur" as a *local* deterministic hidden-variable restoration—i.e., "electrons actually have definite trajectories that we simply cannot observe"—it would likely directly conflict with the experimental fact of Bell's inequality violation. Accordingly, in this essay "blur" is intended as an *interpretive picture about observational coarse-graining*, not as a replacement ontology for quantum theory. The fact that interference patterns form in the double-slit experiment even when electrons are fired one at a time is likewise a phenomenon difficult to explain as mere "blur."

We acknowledge this limitation. The current "Temporal Blur" hypothesis cannot explain Bell's inequality violation, and the nonlocality of quantum entanglement cannot be derived from the scale model alone.

6.2 Questions That Remain Nonetheless

Even after acknowledging these limitations, several questions refuse to let go.

Are the smooth gravity and the rough quantum wave fundamentally differ-

ent laws, or is there truly no possibility that they are two faces of the same fractal spacetime, shaped by differences in the observer's "cognitive resolution" across scales? What if the temporal compression between scales is not a simple linear "blur" but a more complex structure harboring nonlocal correlations? And ultimately, when a theory of quantum gravity is completed, in what manner will it traverse the boundaries between scales?

The answers to these questions do not yet exist. That is both the limitation of this essay and, simultaneously, the reason it exists.

> **Recap: Fact / Hypothesis / Metaphor**
>
> **Fact.** Interference and Bell-inequality violations are not explained by mere ignorance or instrumental blur.
>
> **Hypothesis.** Constrain "Temporal Blur" to an observational coarse-graining picture (aligned with decoherence intuition), not a replacement ontology for quantum theory.
>
> **Metaphor.** A slow-shutter photograph overlapping fast motion into one exposure.

7. Conclusion

Under the perspective that "the flow of time defines space," this essay has traversed four landscapes.

First, we confirmed through the mathematical structure of general relativity that the spatial imbalance of time flow caused by mass—the gradient of time—converts an object's trajectory into spatial acceleration (gravity). The universe is not a fixed three-dimensional canvas but a dynamic structure ceaselessly sculpted by the flow of time.

Second, we viewed heat and light through the same lens. Temperature is the pace of the microscopic clock; the slowing of light in media may be due to the density of microscopic spacetime structure; and the flow of heat and gravity may share the identical structure of "flow along a gradient."

Third, we explored the possibility of a "fractal structure" in which the perception period of events changes with the observer's scale (O_n), so that atoms become universes and universes become a

> **Recap: Fact / Hypothesis / Metaphor**
>
> **Fact.** This essay offers an interpretive lens rather than a competing formal theory, aiming to connect relativity, thermodynamics, and quantum ideas.
>
> **Hypothesis.** The scale-and-resolution viewpoint may serve as a useful question-generating framework.
>
> **Metaphor.** Redrawing one landscape using a different map projection.

toms. This hypothesis is not yet verifiable, but considering nature's self-similarity and observational limits, it is a door that cannot be entirely closed.

Fourth, we proposed the "Temporal Blur" hypothesis as a conceptual bridge between general relativity of the macroscopic world and quantum mechanics of the microscopic world, while honestly acknowledging the current limitations of this hypothesis before the experimental barrier of Bell's inequality.

The universe may be a dynamic and infinite—or at least unbounded as far as we can currently see—fractal spacetime continuum whose geometric form is determined by the "relative flow of time" created by the observer's size and mass.

Epilogue: Questions This Essay Has Not Answered

Every good inquiry leaves more questions than answers. This essay is no exception.

- Is the scaling factor α a universal constant, or a dynamic variable that differs across scales?

- If fractal spacetime is real, do lower and upper bounds of its self-similarity exist?

- Can the "gradient of time" perspective also explain the accelerating expansion driven by dark energy?

- If heat, gravity, and time are branches from a single root, what is the identity of that root?

- Can the nonlocality of quantum entanglement be understood through some structural connection between scales?

- Is consciousness a phenomenon that manifests only to observers at a particular scale?

These questions exceed the scope of a single individual's essay. Yet the very act of holding a question is the beginning of inquiry, and sometimes that alone is sufficiently valuable. If someone who reads this essay carries one of these questions in their heart and ventures deeper, then this essay has fulfilled its purpose.

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