A Bundle-Theoretic Analysis of Minkowski Space: Geometric Arguments against the Block Universe

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Abstract

In the standard interpretation of special relativity, Minkowski space is viewed as an affine space. This paper argues that a *tangent bundle* ($\boldsymbol{T\mathcal{M}}$) is a more suitable mathematical structure. We show that the 4D "block universe" is a structural misinterpretation rather than a physical necessity. The standard eternalist view arises from an ontological reification error: the conflation of local tangent fibers ($\boldsymbol{T_p\mathcal{M}}$) with the global manifold ($\boldsymbol{\mathcal{M}}$). While there exists a "trivial isomorphism" between a fiber and the base manifold, which allows Minkowski tangent space at a given location to be treated as a global affine space, this paper demonstrates that it is only permissible in Euclidean geometry. In the pseudo-Euclidean structure of relativity—where time functions as an evolutionary parameter along a worldline—this globalization leads to inherent ontological instabilities. By analyzing the *Andromeda paradox* through the non-compactness of the Lorentz group, we identify the projected temporal jump of distant objects as a "coordinate shadow"—a mathematical artifact of an indefinite metric rather than a physical displacement in a 4D manifold. This geometric deconstruction resolves the paradox without resorting to a frozen ontology, thereby restoring the physical viability of a dynamic, 3D-first reality.

Keywords: Block Universe, Rietdijk-Putnam Argument, Andromeda Paradox, Minkowski Spacetime, Eternalism

1 Introduction

Since Hermann Minkowski's 1908 address[1], in which he proclaimed that "henceforth, space by itself and time by itself are doomed to fade away into mere shadows," the four-dimensional block universe has been treated not merely as a mathematical representation of space and time but as a definitive map of all events in reality.[2]

The transition from the mathematical success of the 4D Minkowski formalism to the philosophy of eternalism largely relies on the perceived logical necessity of the Rietdijk-Putnam argument[3, 4] (the Andromeda paradox[5]). This view was further popularized through Einstein's own expositions of the theory,[6] where the linear equation $x' = \gamma(x - vt)$ was presented as a global coordinate transformation rather than a local change of basis. However, this paper demonstrates that the Rietdijk-Putnam argument—and by extension, the block universe itself—rests upon a category error: the *reification of Minkowski space*. In the standard pedagogy, Minkowski space is treated as an affine space. We demonstrate, however, that the mathematical structure of the tangent bundle represents relativistic reality more accurately.[7] We contend that eternalism results from the conflation of a vector space ($T_p\mathcal{M}$) with the physical manifold ($\mathcal{M}$). This distinction is well-understood in the context of general relativity,[8] yet it is often overlooked in the ontological interpretation of special relativity.

The heart of the conflation lies in the "trivial isomorphism." In flat space, there exists a natural isomorphism between the affine manifold and the vector space of its tangent fibers. This has been used to mathematically project a *local hyperplane of simultaneity* in a global Minkowski space across the entire universe. In terms of local measurement, this projection is a useful tool. However, when treated ontologically, it creates an "infinite lever." Because the slope of the "now-slice" is determined by the observer's local velocity v, the projected time coordinate at a distance ℓ shifts by $\Delta t = v\ell/c^2$. At cosmic distances, a small change in local motion (e.g., a man walking on the street[4]) translates into a multi-day jump in what the observer identifies as the *present* in a distant galaxy—a phenomenon we term the "temporal rip." In the block universe, this *imaginary lever* is "a feature, not a bug." The rigid hyperplane of simultaneity of an observer represents physical reality: the observer's local state of motion dictates the reality of distant events.

This paper deconstructs the common misinterpretations in the literature by restoring the distinction between the map and the territory.[9] We proceed by identifying the *tangent bundle* as the correct geometric structure of Minkowski space, utilizing formalisms from fiber bundle theory.[10, 11] We demonstrate how the *trivial isomorphism* leads to the reification of coordinate projections. Through a series of *reductio ad absurdum* arguments, we show that the block universe leads to ontological paradoxes inherent in the eternalist framework. These paradoxes can be resolved by maintaining the distinction between the local tangent space and the global manifold and by recognizing the fundamental difference between the Euclidean and the Lorentz groups. By treating 4D Minkowski spacetime as a mathematical tool rather than a portrait of the physical world, we resolve the Andromeda paradox without resorting to the *frozen time* of eternalism. We thereby restore the physical viability of a dynamic world where the "flow of time" is not a mere afterthought but the primary driver of reality.

2 The Andromeda Paradox

The Andromeda paradox, popularized by Roger Penrose,[5] suggests that because two local observers in relative motion disagree on whether events in Andromeda have already occurred or not, based on their respective "now," those events must already exist in a static 4D geometric *block.*

There have been many rebuttal arguments against the Andromeda paradox and other attempts to support eternalism.[12, 13] The block universe ontology itself has been denounced by physicists and philosophers who prioritize the dynamical nature of time.[14–20] Yet, many still believe that eternalism is *mandated* by special relativity.[15, 21, 22] While many have argued that the eternalist interpretation of relativity is incompatible with the *relativity* (or "observer dependence") of simultaneity, these objections have often been ignored. We propose an alternative argument in this paper that provides a new insight into the Andromeda paradox. Our argument rests on two bedrock principles of (classical) physics: *locality* and the *relativity of simultaneity.*

2.1 A Four-Observer Variant of the Paradox

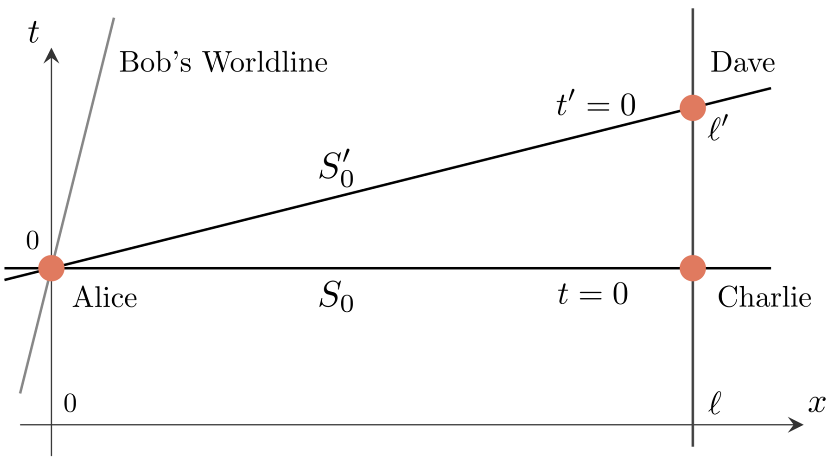

Figure 1 Two reference frames, K with coordinates (t, x) and K' with (t', x'). S_0 and S'_0 are Alice and Bob's respective simultaneity hyperplanes. Note that Alice and Bob coincide at the origin (of both K and K') at $t = t' = 0$, but their respective "now" projections at distance ℓ diverge significantly.

For concreteness, we define a precise variant of the Andromeda paradox involving four observers. Suppose Alice is at rest with respect to an inertial reference frame K at the spatial origin $x = 0$. At her local time $t = 0$ in K, a distant stationary observer, Charlie, is located at $x = \ell$. In the standard Minkowski description, Alice and Charlie are said to share a "hyperplane of simultaneity," denoted as S_0, in which every point $p = (t = 0, x)$ for $-\infty < x < \infty$ is considered equally "now," rendering all events in this hyperplane *simultaneous to both observers.*

Now, consider a second frame K' moving at uniform velocity v relative to K. Bob is stationary at the origin $x' = 0$ of K', such that at $t = t' = 0$, Alice and Bob are at the same spacetime event ("here and now"). *Simultaneously with Bob* (with respect to K'), Dave is at $x' = \ell'$. Dave is also at rest in K', meaning he is walking at the same pace and in the same direction as Bob relative to Alice and Charlie.

Figure 1 illustrates this setup.[1] While Alice and Bob are colocated at the origin, their respective definitions of simultaneity (S_0 for Alice and S'_0 for Bob) diverge significantly as they project across the distance ℓ.[2] To simplify the comparison, we choose Dave's rest position in K' to be $\ell' = \ell/\gamma$. As one can easily see, this choice ensures that Dave and Charlie are at the same spatial location at $t = 0$ in the reference frame K, allowing us to highlight the temporal discrepancy between them.

2.2 The Temporal Rip

The relationship between the coordinates of frame K and K' is governed by the Lorentz-Einstein transformation:[3]

$$\begin{aligned} t' &= \gamma(t - vx/c^2) \\ x' &= \gamma(x - vt)\,, \end{aligned}$$

where $\gamma = (1 - v^2/c^2)^{-1/2}$. For Dave, who is *simultaneous with Bob* at $t' = 0$ and located at $x' = \ell' = \ell/\gamma$, his time coordinate in Alice's frame K is $t_D = \gamma(0 + v(\ell/\gamma)/c^2) = v\ell/c^2$. Meanwhile, Charlie is *simultaneous with Alice* at $t_C = 0$. Thus, although Charlie and Dave are at the same spatial location $x = \ell$ in frame K, they are separated by a temporal interval:

$$\Delta t = t_D - t_C = \frac{v\ell}{c^2}\,. \tag{1}$$

Suppose the Andromeda Galaxy is at a distance of $\ell \approx 2.5 \times 10^6$ light-years (2.36×10^{22} m). If Bob walks toward Andromeda at a casual pace of $v = 1.3$ m/s (roughly 3 mph) relative to Alice, his local frame K' is *hyperbolically* rotated relative to K. While this rotation is negligible for local measurements, the projection of Bob's "now-slice" across the distance ℓ results in a temporal jump of $\Delta t \approx 3.9$ days. In the eternalist framework, Bob has effectively "shifted" the temporal reality of the entire galaxy simply by changing his local state of motion ("temporal rip"). Events that reside in the *undecided future* for Alice (relative to the "Alice-Charlie present") are already in the *fixed past* for Bob (relative to the "Bob-Dave present").[4]

[1] While light cones are essential, and the most important *invariant,* elements of spacetime diagrams, we omit them here to reduce visual clutter. They can be visualized as two diagonal lines passing through the origin. We do not assume $c = 1$; thus, scales are arbitrary.

[2] As we demonstrate throughout this paper, the misinterpretation of 4D Minkowski diagrams reinforces a cognitive bias toward the block universe. Cf. Appendix A.

[3] We adopt this terminology in this paper, which we believe is more appropriate than the more conventional designation: the Lorentz transformation.[6]

[4] Statements like this will be clarified/corrected in the following sections in view of our new mathematical model for Minkowski space (Section 3).

2.3 The Euclidization Fallacy and the Indefinite Metric

The perceived "paradox" stems from the *Euclidization fallacy*: the intuitive, yet misplaced, application of Euclidean geometric stability to Minkowski spacetime. In a Euclidean space with a positive-definite metric (++++), a rotation of coordinates is an ontologically stable operation. A "slice" through a Euclidean block is a solid, localized (or "compact") section of that block (Section 4). However, the Minkowski metric has an indefinite signature, e.g., (−+++). This minus sign ensures that the "spacelike" hyperplane is not an extension of the manifold's physical substance, but a mathematical projection across a region causally disconnected from the observer.

The Rietdijk-Putnam argument elevates this coordinate projection to an ontological status, claiming that because Bob can define a coordinate system where Dave's event ("existence") is *simultaneous* with his own, Dave must be "as real" as Bob at *Bob's now.* This confuses the mathematical map (the tangent space projection) with the physical territory (the events on the manifold). In the remainder of this paper, we will demonstrate that this *infinite lever*—where local motion dictates distant reality—is a *reductio ad absurdum* that exposes the flaws in the block universe logic, and the global Minkowski space. To resolve this, we must adopt a more rigorous geometric structure: the *tangent bundle.*

3 The Tangent Bundle Structure of Minkowski Spacetime

The ontological error of the block universe is ultimately rooted in the failure to distinguish between the base manifold ($\mathcal{M}$) and the tangent space ($T_p\mathcal{M}$). We formalize Minkowski space as a fiber bundle ($T\mathcal{M}$) where $\mathcal{M}$ is the set of events and each fiber is the local tangent vector space $T_p\mathcal{M}$,[10, 23] and not as a rigid, globally extended Euclidean-like manifold. This distinction is critical for a more rigorous physical interpretation of the mathematical structure of special relativity, as it allows us to decouple the relational properties of the manifold of events from the algebraic properties of the vectors used to describe physical interactions.

3.1 The Formal Definition of 4D Minkowski Space

We define the base manifold $\mathcal{M}$ as a 4D differentiable manifold. It represents the set of all possible events $p \in \mathcal{M}$. $\mathcal{M}$ itself does not possess an intrinsic metric or vector space structure.[8] One cannot "add" two events $p + q$ on the manifold any more than one can add two cities on Earth.

We attach to each event p a fiber: a tangent space $T_p\mathcal{M}$. This fiber is a four-dimensional vector space $\mathbb{M}^4$ equipped with the Minkowski metric $\eta_{\mu\nu}$ and is invariant under the Lorentz group $O(3, 1)$. All the "local physics"—velocities, 4-momentum, and the hyperplane of simultaneity—resides strictly in the tangent space.

The tangent bundle $T\mathcal{M}$ is the disjoint union of all tangent spaces:

$$T\mathcal{M} = \bigsqcup_{p \in \mathcal{M}} T_p\mathcal{M} \, .$$

We define the canonical projection map $\pi : T\mathcal{M} \to \mathcal{M}$ which maps every vector $v \in T_p\mathcal{M}$ back to its base point p. In this formalism, the "now-slice" S_p (the hyperplane of simultaneity) is a three-dimensional vector subspace of the fiber $T_p\mathcal{M}$:

$$S_p \subset \pi^{-1}(p) ,$$

that are orthogonal to the observer's 4-velocity along their worldline, and it is not a "slice" of the physical universe $\mathcal{M}$. Standard formulations of special relativity often tacitly assume that the bundle $T\mathcal{M}$ is globally trivial (i.e., $T\mathcal{M} \cong \mathcal{M} \times \mathbb{M}^4$). This assumption facilitates the *trivial isomorphism* between the vector space $T_p\mathcal{M}$ and the affine manifold $\mathcal{M}$ at every event p. The block universe assumes that because we can map $T_p\mathcal{M}$ to $\mathcal{M}$ globally, the properties of the fiber, e.g., rotations and Lorentz boosts, apply directly to the manifold's existence. Although this "local trivialization" can be used to label the manifold using the fiber, the label (the coordinates) is not the event itself.

3.2 Formal Definition of the Lorentz-Einstein Transformation

The Lorentz group $SO(3, 1)$ does not act on the points $p \in \mathcal{M}$. Instead, it acts on the vectors $v \in T_p\mathcal{M}$ (the fiber) at a specific point p. A Lorentz boost is a local frame rotation—a change of basis in $T_p\mathcal{M}$.[24] The *now-slice* at a given point is a set of vectors in the tangent space; its "extension" to distant events is a mathematical extrapolation, not a physical mapping of the manifold.

Let $\{e_\mu\}$ be a basis for $T_p\mathcal{M}$ and $\{\theta^\mu\}$ be the dual basis in the cotangent space $T^*_p\mathcal{M}$. A Lorentz-Einstein transformation Λ is a change of basis in the tangent space:

$$e_{\mu'} = \Lambda^{\mu}{}_{\mu'} e_\mu .$$

This transformation preserves the flat metric tensor $\eta \in T^*_p\mathcal{M} \otimes T^*_p\mathcal{M}$ (Minkowski metric) such that:

$$\eta_{\mu\nu} = \Lambda^{\alpha}{}_{\mu}\Lambda^{\beta}{}_{\nu}\eta_{\alpha\beta} .$$

3.3 The Fallacy of "Transforming Positions"

In standard pedagogy, the Lorentz-Einstein transformation is often written as:

$$x'^{\mu} = \Lambda^{\mu}{}_{\nu}\, x^{\nu} ,$$

which is formally ill-defined in a general (curved) manifold because x^μ are coordinates of a point, not components of a vector. The block universe assumes that because we can label events with numbers (t, x, y, z) and treat those numbers as components of a vector, the events themselves inherit the properties of a vector space (such as global linearity and rigid rotation). This shorthand is only possible, however, in an affine space in which one can define a displacement vector Δx^μ from an arbitrarily chosen origin O.[5] By treating event x^μ as a vector, the eternalist implicitly "glues" the tangent space to the manifold, extending the local rotation of the observer's frame of reference across the entire universe.

3.4 The Role of the Connection

To relate vectors at different points (i.e., on different fibers), a connection must be introduced. The eternalist interpretation implicitly relies on the choice of a global flat connection:

$$\nabla_{\dot{\gamma}} X = 0\,,$$

which serves as the "ontological glue" binding independent fibers into a singular, rigid block. To claim that *Alice's now* on Earth and *Charlie's now* in Andromeda are part of the same "slice of reality," one has to parallel transport the concept of *simultaneity* from Alice to Charlie.[6] In the bundle view, the fibers $\pi^{-1}(p)$ and $\pi^{-1}(q)$ are distinct spaces. By prioritizing the tangent bundle, the "global Minkowski space" is revealed not as a physical necessity, but as a specific mathematical limit where the connection is trivialized to force a global isomorphism across the manifold.

3.5 The Fallacy of Global Extension (The Exponential Map)

The exponential map allows the tangent space at a given point to be extended to a finite neighborhood around that point:

$$\exp_p : T_p\mathcal{M} \to \mathcal{M}\,.$$

The Andromeda paradox can be viewed as relying on the use of the exponential map to project the local vector subspace S_p across the entire base manifold to create a global hyperplane Σ:

$$\Sigma = \{\exp_p(v) \mid v \in S_p\}\,.$$

In a general manifold, the exponential map is only a "good" local approximation up to a certain range. In flat Minkowski space, the exponential map is an identity, and hence, mathematically, the "injectivity radius" is infinite. The block universe blindly treats Σ as a physical "global slice of existence" beyond its domain of ontological validity (Section 5.2). The "ontological validity" of the projection decays as ℓ increases because of the $v\ell/c^2$ divergence.

By distinguishing the fiber (the linear space of measurement) from the base (the arena of spatiotemporal events), we show that a Lorentz boost is merely a change of basis within the tangent space $\pi^{-1}(p)$. It has no *rigid lever* to alter or define the existence of distant events on $\mathcal{M}$. The "isomorphism illusion" occurs when we forget that π is a many-to-one mapping, and that the *now-slice* belongs to the observer's map, not the universe's territory.

[5] We were all taught "position vectors," but a position has neither magnitude nor direction and is thus ontologically distinct from a vector. While this mapping is "less harmful" in Euclidean space, it leads to severe category errors in the hyperbolic geometry of Minkowski space.

[6] This is instantaneous in static geometry, but this "transport" should be done over the distance of 2.5 million light years in reality.

3.6 Summary of Geometric Type Errors

The transition from special relativity to the block universe relies on several fundamental "type errors" that conflate distinct geometric categories:

- **Point → Vector:** Treating a location on the manifold ($p \in \mathcal{M}$) as a direction or magnitude in the tangent space ($v \in T_p\mathcal{M}$).
- **Fiber → Base:** Mistaking a local rotation of the coordinate basis (a Lorentz boost in the fiber) for a physical rotation of the underlying territory (the manifold).
- **Map → Territory:** Elevating a coordinate-dependent projection (the hyperplane of simultaneity) to the status of a global, invariant ontological state.

In flat space, the *trivial isomorphism* masks these errors. When Bob walks, he rotates his local sense of "now" within his tangent space. The eternalist, blinded by the natural isomorphism, believes the manifold itself has rotated, leading to the Andromeda paradox. This dynamical perspective aligns with the "Lorentzian pedagogy" advocated by Brown,[25] who suggests that Minkowski structure is a property of field dynamics rather than a pre-existing container.

A Lorentz boost is a local frame rotation (Section 3.2). It describes how an observer at point p decomposes their local tangent space $T_p\mathcal{M}$ into *timelike* and *spacelike directions:* (a) The *now-slice* hyperplane is the set of all vectors $v \in T_p\mathcal{M}$ orthogonal to the observer's 4-velocity $u \in T_p\mathcal{M}$. (b) Since v is a vector in the tangent space, its "extension" to distant events (like Dave and Charlie in Andromeda) is a mathematical extrapolation and not a physical mapping.

4 The Isotropy Fallacy — SO(4) vs SO(3,1)

We identify another block universe reification error: the failure to distinguish between a positive-definite Euclidean metric and the indefinite Minkowski metric.

The reification of the block universe stems from projecting "Euclidean intuition" onto an indefinite Minkowski metric ($-$$+$$+$$+$). In Euclidean geometry ($+$$+$$+$$+$), all dimensions are spatial, and a "slice" is ontologically stable. In Minkowski space, the minus sign partitions the manifold into causally distinct regions.[26, 27] The *spacelike hyperplane of simultaneity* consists entirely of events that are causally disconnected from the observer's time and location. In Minkowski space, the light cone essentially prevents the "block" from being a single, unified "object" in the Euclidean sense.

4.1 The Euclidean Illusion

In a 4D Euclidean manifold ($\mathbb{E}^4$), the Euclidean metric:

$$ds^2 = dw^2 + dx^2 + dy^2 + dz^2 \,,$$

is positive-definite. Under the rotation group $SO(4)$, which is *compact*, any coordinate can be transformed into any other without changing the nature of the interval. Because all dimensions are spatial, you can rotate any axis into any other axis (in the four-dimensional space). This implies isotropy: all dimensions are ontologically identical. A *slice* through the block is as solid and *as real* as a slice through a "loaf of bread."

This is the origin of the *Euclidean intuition* that eternalists inadvertently project onto 3+1D spacetime. The Lorentz group $O(3,1)$ is, however, non-compact and this projection leads to an ontologically invalid conclusion. Unlike the compact rotation group $SO(4)$, where any axis can be continuously rotated into another, the non-compactness of $SO(3,1)$ reflects the fundamental asymmetry between timelike and spacelike directions. One cannot "rotate" a spatial axis into a temporal one in the four-dimensional Euclidean sense; time is not merely a direction of extension but a direction of causal evolution.[7]

In Euclidean geometry, a rotation $x' = x\cos\theta + w\sin\theta$ is "stable." The coordinates stay bounded. On the other hand, in Minkowski space, a boost $x' = \gamma(x - vt)$ is *hyperbolic.* As $v \to c$, the transformation "stretches" coordinates toward infinity. This "hyperbolic stretching" is what causes the Andromeda paradox. The *now-slice* isn't just tilted; it is mathematically divergent. At cosmic distances, the "lever arm" of the boost becomes so long that it *rips* the coordinate system (Section 5).

4.2 The Indefinite Metric and Causal Partitioning

Minkowski space ($\mathbb{M}^4$) is governed by an indefinite metric signature ($-$+++ or +$---$), in which a spacetime interval is defined, for instance, as:

$$ds^2 = -c^2 dt^2 + dx^2 + dy^2 + dz^2 \,.$$

The indefinite metric signature partitions the manifold into three ontologically distinct causal domains: null, spacelike, and timelike. Euclidean metric only measures distance ("how far"). The Minkowski metric signature ($- + ++$) acts as a causal classifier of existence. Crucially, the *now-slice* is composed entirely of spacelike intervals ($ds^2 > 0$), which are regions of fundamental causal disconnection. Events with a spacelike separation ($ds^2 > 0$) are not just "far away"; they are causally unreachable. To reify this slice as a "shared global reality" is to assert a physical unity among events that can neither communicate nor interact in any dynamical sense, rendering the concept of a global simultaneity-state ontologically vacuous and strictly frame-dependent. Following the principle of interactive realism, the "shared global reality" of the block universe is a physical non-sequitur. It's merely a mathematical set of points, not a physically bound "state of the universe."

The Andromeda paradox relies on the *globalization* of a spacelike hyperplane. In Euclidean geometry, a plane is a solid *slice* of reality. However, in a manifold with an indefinite metric, a spacelike hyperplane ($T_p\mathcal{M}$) consists of events that are causally unreachable from the observer's "here and now" (p). While the *trivial isomorphism* allows us to mathematically treat the t-axis as a fourth dimension for the purpose of calculation, the metric reveals its true nature: Time is a parameter of evolutionary change along a worldline, not an axis of static extension.

[7] $O(3,1)$ does not support a 4D rotation. It only supports Lorentz boosts. On the other hand, Lorentz boost is not part of the $O(4)$ symmetry. This is an obvious but critical distinction.

4.3 Metric Instability as an Ontological Limit

The *temporal rip* effect demonstrated in Section 2 is a direct consequence of the hyperbolic nature of Lorentz boosts. Unlike the stable, compact rotations of Euclidean geometry, a Lorentz boost involves a hyperbolic parameter ($\beta = \tanh\phi$) that mathematically "stretches" the simultaneity projection as distance increases. We contend that a structure exhibiting such discontinuous instability under infinitesimal local changes cannot be a fundamental ontological feature of the universe. It is, instead, a "coordinate shadow" cast by the observer's local motion across the indefinite metric of the tangent bundle.

Although the globalization of a tangent space has unrealistic ontological consequences, that does not mean, however, that we have to settle with the "point solipsism" (Section 3.5) as we will further discuss in the rest of this paper. Clearly, there are other possibilities as well.[19, 28]

5 The Rigid Hyperplane Paradox

If we treat the hyperplane of simultaneity as a rigid, physical extension of the observer's reality according to the block universe view, then we encounter discontinuities that violate the most basic requirements of physical persistence (Section 2.2). This exposes the ontological fragility of the block universe.

5.1 The Oscillating Observer and the Temporal Rip

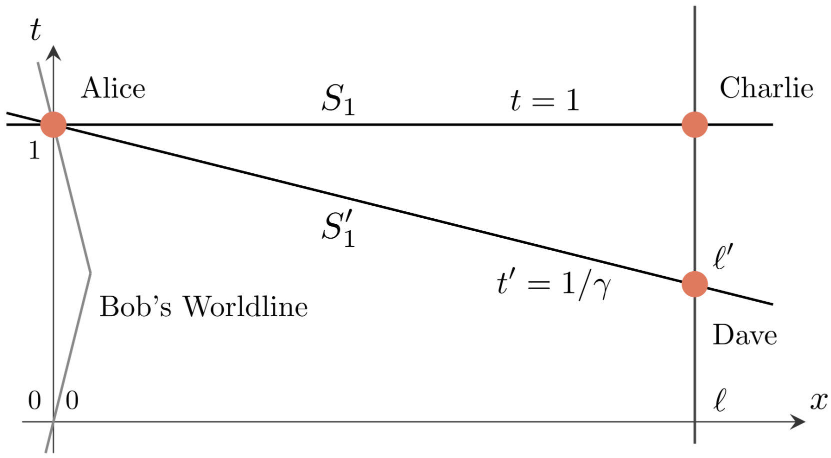

Figure 2 The Oscillating Observer: Bob paces back and forth on Earth. His projected "now-slice" in Andromeda swings wildly across a range of several days, while he himself has barely moved.

Let's consider again the 1+1D universe of Section 2, inhabited by four observers. Suppose Bob on Earth is initially at rest relative to Alice ($t = t' = 0$). He projects his *now-slice* across the distance ℓ to Andromeda. Now, Bob begins to walk toward Andromeda with velocity $v = 1.3$ m/s, and his "now" in Andromeda jumps forward by 3.9 days, as shown earlier in Figure 1. When he stops and turns around to walk away from Andromeda, his "now" jumps backward by 7.8 days relative to his previous state. This is shown in Figure 2. For illustration purposes, Bob is assumed to be back, at $t = 1$, to exactly where Alice is with respect to K.

In the eternalist framework, where the simultaneity plane *defines* existence, Bob would be effectively "rewriting" the reality of a distant galaxy with every footstep. As Bob paces back and forth, his "now" in Andromeda instantly jumps several days forward and backward. This creates a *temporal rip*—a massive ontological instability triggered by a negligible local motion. This is due to the hyperbolic divergence in Minkowski space, i.e., the $\Delta t = v\ell/c^2$ effect. While each segment of Bob's motion is treated as inertial (within a valid ontological radius), the transitions involve acceleration. In the tangent bundle formalism, acceleration is a connection issue involving parallel transport between distinct fibers. The eternalist assumption of a singular, rigid, global flat connection is what causes the "rip" when the observer's local state changes. This instability demonstrates that the *now-slice* is a gauge-dependent coordinate projection—akin to a laser dot moving across the Moon—rather than a substantive physical cross-section of reality. This *rigid hyperplane paradox* poses a critical challenge to eternalist ontologies.[29]

5.2 Ontological Radius and Persistence of Reality

The Rietdijk-Putnam argument falters by assuming the hyperplane of simultaneity is a diffeomorphism-invariant mapping of the manifold. In truth, it is an ephemeral projection rather than a substantive slice of matter. The *temporal rip* phenomenon demonstrates that this projection has a finite "ontological radius"—a distance beyond which the mathematical map loses its physical coherence for the local observer. As indicated earlier, the divergence of the infinite lever, or the temporal jump (Δt), is proportional to the product of the distance between the relevant observers (ℓ) and the variation of the velocities of relevant motions (δv), that is:

$$\Delta t = \frac{\ell \delta v}{c^2} \,.$$

Hence, as soon as this product $\ell\delta v/c^2$ becomes big compared to the relevant time scale, the trivial isomorphism ceases to be a valid approximation ("hyperbolic divergence"). In other words, in terms of distance, as long as ℓ remains much smaller than $c^2\Delta t/\delta v$, the local exponential map retains its ontological coherence. On Earth, the fastest speed is that of jet airplanes, on the order of 1000 m/s. This translates to the ontological radius R_o, using one millisecond tolerance:

$$R_o = \frac{c\Delta t}{v/c} \approx 0.6 \text{ AU} \,.$$

That is, as long as we consider a region whose linear dimension is much smaller than 0.6 AU, we "share" the "common now," just as all of us do on Earth. Or, if we consider the speed of Earth around the Sun, the ontological radius is roughly 20 AU with one second tolerance.[8] This is a short distance in the cosmic scale.[9] In the limit $\ell \to 0$ (the tangent point), the error indeed vanishes. This explains why many accept the hypothesis that the world is a block in our daily lives—the "lever" is too short for us to see the rip. The *ontological radius* can be viewed as the point where the "gauge-dependent noise" (the $v\ell/c^2$ shift) overwhelms the "physical signal" (the persistent state of the object).

If we accept the block universe, walking on Earth becomes a "superpower" capable of shifting the temporal reality of distant galaxies. Since this is physically untenable, the premise that simultaneity is reality, or even existence, must be false. Just as a map of a city cannot be projected onto the surface of a sphere without eventually tearing or distorting, the linear "now" of a local observer cannot be projected across a manifold with an indefinite metric without creating ontological or logical inconsistencies. By recognizing the hyperplane of simultaneity as a section of the tangent bundle rather than a rigid slice of the manifold, we resolve the paradox: Bob's walk rotates his local map, but the distant territory remains undisturbed in its own persistent present.

As Craig Callender notes in *What Makes Time Special?*,[2] there is a profound "explanatory gap" between the time of our experience and the time of our equations. However, this gap only exists if we accept the global 4D Minkowski manifold as the foundation of our reality. By distinguishing between the tangent space and its local projection (the map) and the manifold (the territory), we find that the "manifest" present is not a psychological illusion, but a geometric necessity of local existence.

6 The Multiple Hyperplane Paradox

The most glaring absurdity of the eternalist position is revealed when we examine the physical status of a distant object from the perspective of a local observer. If you look at the relative 4D locations of Dave in Figures 1 and 2, he is at the same 3D location as Charlie, but "his time" is 3.9 days earlier or later than Charlie. As Bob walks back and forth, Dave "goes through" Charlie *through time* like a ghost. Will Charlie see Dave *coming from the future* and *disappearing to the past* when Bob changes his direction of walking? This conceptual difficulty arises because eternalism treats time as a dimension, not unlike extended spatial dimensions, and because it views mathematical hyperplanes of simultaneity as reflections of reality.

6.1 Colocation Invariance in Three-Dimensional Space

Figure 3 shows Dave's worldline that goes through the hyperplanes S_0 (for $t = 0$) and S'_0 (for $t' = 0$).[10] From the perspective of Alice K, Dave is at ℓ_D at $t = 0$ (Dave$_A$) and at ℓ at $t = t_D$ (Dave$_B$). That is, Dave walks distance $d = \ell - \ell_D$ in time t_D. On the other hand, Bob, who is now supposed to be at rest relative to Alice at $t = 0$, can

[8] Considering the high speed of light, 299,792,458 m/s, the inner solar system more or less belongs to the same "time zone."

[9] For reference, the distance to Alpha Centauri, our Sun's closest neighbor, is about 3×10^5 AU, and the distance to Andromeda is 1.5×10^{11} AU.

[10] As we will further discuss in Appendix A, this is not a correct way to draw a spacetime diagram. Spacetime diagrams are strictly local with respect to the observer's "here and now."

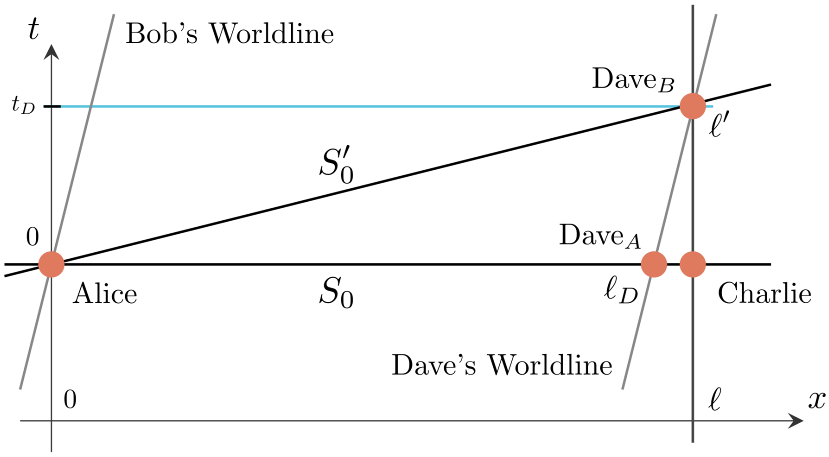

Figure 3 This illustration shows Dave's worldline that goes through ℓ_D in K and ℓ' in K'. Note that the worldlines of Bob and Dave are "parallel" to each other in this illustration.

"instantly move" Dave just by walking toward Andromeda. When he is at rest, his hyperplane of simultaneity S'_0 coincides with that of Alice S_0. When he gradually starts to walk, according to the eternalist interpretation, his rigid plane of simultaneity S'_0 starts to lift from S_0, and it settles at a certain angle as his walking pace stabilizes ($\phi = \operatorname{arctanh}(v/c)$). During that short amount of time, Dave has traveled 3.9 days *through time*, which does not reflect reality of any kind for any observers.

In the original illustration (e.g., Figure 1), we assumed that Bob and Dave were walking at the same speed in the same direction.[11] And, we assumed that *Bob's notion of simultaneity and that of Dave were the same.* What happens now if Dave stops walking at $t' = 0$? What happens to Dave's simultaneity hyperplane? Does it collapse into S_0 of Alice and Charlie? Or, does it become a separate hyperplane which is parallel to S_0 but which goes through Dave$_B$ (at $t = t_D$)? Where is Dave right after he stops walking in this four-dimensional diagram?

Another interesting question follows: Are Dave$_A$ and Dave$_B$, shown in Figure 3, the same person, or are they two different people? Four-dimensionalists claim that they are two different cross sections of a "four dimensional worm" (perdurantism). If *Alice's now* contains Dave$_A$ and *Bob's now* contains Dave$_B$ (who is Dave$_A$-minus-3.9-days), and both are "equally real," then there are literally two Daves (or more!) inhabiting the same 3D spatial region of Andromeda. The 4D block universe transforms a difference in perspective into a multiplication of entities. Based on our examples above, however, that cannot be true. Even from Bob's perspective, Dave$_B$ is a continuation of Dave$_A$ (endurantism). From Alice's perspective, Dave$_A$ and Dave$_B$ are also the same person, just viewed at two different times, separated by 3.9 days.

[11] This was a clearly nonsensical assumption to begin with, which was, however, consistent with the block universe paradigm. The very next sentence shows why we end up with such a counterintuitive view of the world. *The reality is local,* according to special relativity.

Now, from Charlie's perspective, the situation becomes conceptually transparent. The vertical line that passes through $(t = 0, x = \ell)$ is Charlie's worldline. Charlie is at rest at $x = \ell$ in K. At $t = 0$, Dave is on his left at $x = \ell_D$. As time passes, Dave is walking toward him. After 3.9 days, their worldlines cross, that is, Dave reaches where Charlie is. In the block universe, Dave$_B$ is already at $x = \ell$, and he "waits" for Charlie. But, "where in time," exactly? The 4D view thus leads to a profound ontological inconsistency. Dave$_A$ and Dave$_B$ are one and the same person—a principle of *numerical identity* that the block universe framework violates through its commitment to *perdurantism* (the view that objects are four-dimensional 'worms'). This "ontological doubling" is a *reductio ad absurdum* demonstrating that the 4D worldline is a mathematical record of history, not a substantive physical structure extending through a pre-existing manifold. It is a *reductio ad absurdum* that proves the block universe, and perdurance, are a mathematical artifact of the misapplication of the trivial isomorphism and the misinterpretation of the 4D Minkowski diagram.

We propose a "more correct" way of reading Minkowski spacetime diagrams in Appendix A. In this new recipe, Dave and Charlie always exist in the same 3D spatial world (e.g., on a particular star in Andromeda), and there are no separate worlds for different times, as the block universe would have us believe. According to special relativity, the clocks of Dave and Charlie may run differently depending on their relative motion and depending on which observer looks at them, but that in no way implies that they live in two different "temporal worlds."

6.2 The Same-Location-Different-Moments Absurdity

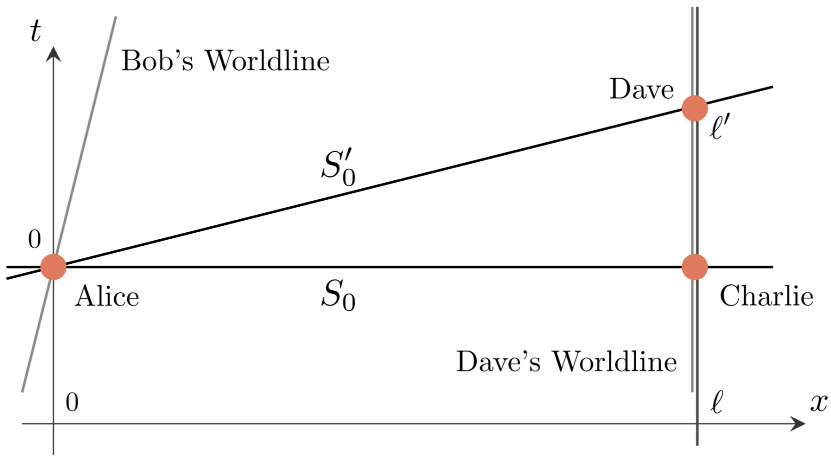

Figure 4 Dave and Charlie are located in the same 3D location. But, can they be at two different moments in time?

Let's examine this from a slightly different angle. Suppose now Dave is at rest relative to Charlie. Since Dave "exists" to Bob regardless of his motion relative to K', according to 4D eternalism, Bob perceives his presence at $x' = \ell'$ in K' (although actual "seeing" might take 2.5 million years). Figure 4 shows Dave's worldline as a vertical line with the same spatial coordinate with Charlie in K. From Alice's perspective, Dave and Charlie are at the same location, but they are *at different times.* This result is conceptually problematic within a dynamical framework.

The eternalist claim that distinct cross-sections of a worldtube represent equally real, physically distinct states is ontologically unsustainable. Dave and Charlie are at the same 3D location—an invariant fact of the manifold. There is no "Bob's Dave" or "Alice's Dave" inhabiting different temporal layers. Charlie and Dave are colocated in the same spatial region; no arbitrary "slicing" or coordinate "foliation" of a 4D block can alter this physical coincidence. To suggest otherwise is to posit a form of "ghostly coexistence" where objects share a location but inhabit separate, isolated realities.

The same can be said from Bob's perspective. Charlie is neither *in his past* nor *in the past of Dave.* Charlie and Dave are colocated in the same 3D location, and again this fact is invariant. No arbitrary *slicing of the 4D loaf of bread* will change this fact. Bob cannot "teleport" Dave from the future of Charlie to his past simply by walking in particular directions on Earth.

6.3 The Violation of Coincidence Invariance

This *ontological doubling* suggests that, in the 4D block universe, the existence of a distant galaxy is a fragmented, multi-valued function of local terrestrial motion—a state of "ontological fragmentation." In a 3D-first (presentist) view, a star in Andromeda exists as a single, persistent entity that evolves over time. At any given moment, there is only one star at that location (although the *star's now* may be "hidden" to the local observer at *his now*). If an observer on Earth walks past a friend, are they interacting with a different "version" of that friend than someone standing still would be? If simultaneity dictates reality, then a simple difference in local motion would imply we are interacting with "temporal ghosts" of our acquaintances. The fact that we never witness such doubling in our local environment strongly suggests that the $v\ell/c^2$ effect is a mathematical artifact of distance and coordinate choice, not a physical property of matter. The eternalist, however, is forced to claim that the star exists as a four-dimensional "world-filament" and that *Alice's star* and *Bob's star* are just different "cross-sections" of this filament. But this reification fails to account for the fact that these cross-sections are not physically distinct entities. If Charlie and Dave are the same object, then "where" in time is that object? Does it inhabit two moments of its own history (or more!) at once? This absurdity arises from the erroneous projection of a local tangent space basis onto the global manifold.[5] By treating the t-coordinate as a spatialized dimension of extension, the eternalist transforms a simple difference in *perspective* (how we measure time) into a duplication of *existence* (where the object is in time).

The alternative view of reality is far simpler: there is only one friend, and there is only one of the same star. When Alice and Bob are passing each other on the street, they are not going away to two separate *temporal worlds.* They live in the same 3D universe, and they will likely meet again, at some different location and at some different moment in time. The temporal discrepancy $\Delta t = v\ell/c^2$ is a mathematical artifact of how we sync our clocks over a distance, not a physical displacement of the friend in a 4D block. By recognizing that t is an evolutionary parameter (or, the observer's proper time) rather than a space-like dimension, we dissolve the *multiple hyperplane paradox* and restore the possibility of the singular, objective reality of the "common present," which might be momentarily *hidden,* or *delayed,* to a particular observer due to the finite speed of causal propagation (Appendix A).

7 The Fallacy of the Global Minkowski Space

The ontological weight of the block universe rests entirely on the *trivial isomorphism,* which is a mathematical convenience as we stated earlier. Because the 4D Minkowski space $\mathbb{M}^4$ used in special relativity is an affine space, there exists a natural, one-to-one mapping between each event p in the manifold $\mathcal{M}$ and a displacement vector v in its tangent space $T_p\mathcal{M}$ with respect to an arbitrary origin O in $\mathcal{M}$.

7.1 The Position Vector Category Error

This isomorphism allows physicists to speak of the "position vector" x^μ, as we briefly alluded to in Section 3.3. In Euclidean geometry, this conflation is benign although conceptually shaky. However, in relativistic spacetime, it facilitates a fundamental category error. A vector in $T_p\mathcal{M}$ is a local linearized description—a "velocity" or a "direction" at a point. A point in $\mathcal{M}$ is an event. By treating x^μ as a vector, the eternalist implicitly assumes that the linear structure of the observer's local coordinate system is a global property of the universe itself.

When we transform x^μ via a Lorentz boost, we are rotating a coordinate basis in $T_p\mathcal{M}$ (Section 3.2). The eternalist, blinded by the trivial isomorphism, believes they are rotating the physical manifold $\mathcal{M}$. This is the root of the Andromeda paradox: the observers rotate their local coordinate systems in the tangent space, and because the map is trivially identified with the territory, they conclude that the distant territory has physically shifted its state of existence, and reality, in time and space.

7.2 Globalization and the Failure of Shared Reality

Einstein originally developed special relativity based on an observer-dependent concept of simultaneity. However, in his transition to general relativity, he recognized that coordinate systems are "mere numbers" and that global simultaneity has no invariant meaning on a curved manifold.[12] While simultaneity remains a useful tool for local synchrony in flat-space approximations, it is effectively a gauge choice—a mathematical convention rather than a physical substance. This projection is only valid within the "ontological radius" of the local observer. Beyond this domain, the reification of simultaneity leads to the inherent ontological instabilities of the *block universe.*

7.3 Reality is Local

The absurdity of *ontological doubling* (Section 6) occurs precisely because we attempt to "globalize" these local tangent space projections. As shown in Figures 5 and 6,

[12] This is known as Einstein's "point coincidence" argument (*Punktkoinzidenz*).

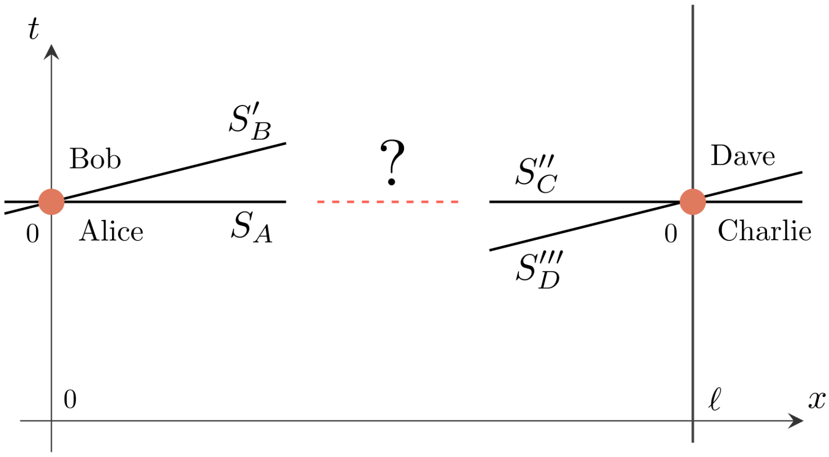

Figure 5 Hyperplanes of simultaneity for different observers defined in their respective tangent spaces; S_A, S'_B, S_C, and S'_D for Alice, Bob, Charlie, and Dave, respectively.

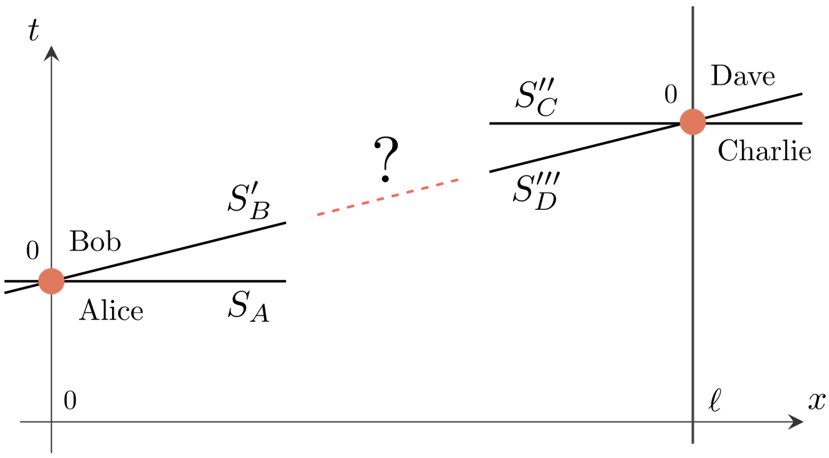

Figure 6 The same diagram as Figure 5, drawn slightly differently. Note that Alice/Bob and Charlie/Dave are spacelike separated (at $t = t' = 0$), and their respective "here and now" events have no inherent relationship to each other.

Alice and Charlie each possess their own local hyperplane of simultaneity in different tangent spaces. Likewise, Bob and Dave occupy separate tangent spaces at different locations with their own hyperplanes of simultaneity. These hyperplanes are not shared global Minkowski space. In a 3D-first ontology, these fibers are only linked by their shared presence on the manifold (Section 3.4). The eternalist, however, attempts to bridge the distance ℓ by extending Alice's $t = 0$ hyperplane as if it were a rigid physical structure. When Bob walks, his *now-slice* intersects the world-filament of Dave at a different point than Alice's. If both slices are "equally real," then Dave is *duplicated.* This duplication is not a confirmation of 4D geometry; it is a "warning light" that the trivial isomorphism has been pushed beyond its mathematical domain of validity.

Figure 5 shows the hyperplanes of simultaneity, S_A, S'_B, S_C, and S'_D for Alice, Bob, Charlie, and Dave, respectively. Note that all four observers are ultimately spacelike-separated (except when they coincide at the same "here and now") and these tangent spaces are only related to each other via the speed of light c. In particular, it takes two and a half million years to establish any temporal relationship between Alice's now and Charlie's now, and at any given time there is no inherent relationship between them. This is illustrated as broken hyperplanes between Alice and Charlie, and between Bob and Dave. The connected lines S_0 and S'_0 in Figure 1, for example, are illusions. Note that in this particular "snapshot" at $t = t' = 0$, Alice and Bob, and Charlie and Dave, reside on the same tangent spaces, and they are related to each other through the local ("intra-fiber") Lorentz-Einstein transformations.

Figure 6 is essentially the same diagram as Figure 5, but it is drawn slightly differently. Again, there is no inherent temporal relationship between Alice and Charlie (or Dave), and between Bob and Dave (or Charlie), until 2.5 million years have passed. Aligning their now-slices as in this figure, and connecting them as in Figure 1, for example, are simply invalid and they do not have any ontological significance. To re-emphasize, all these observers are spacelike separated if we broaden its definition to include the coincidence in spacetime as a special case of spacelike separations.[13]

In fact, one can easily see that there is no way to *simultaneously* satisfy the dotted line connections in these two diagrams. This clearly demonstrates that our casual use of 4D minkowski diagrams can lead to unrealistic picture of the real world. The diagrams included earlier, Figures 1 through 4, are indeed incorrect uses of the Minkowski diagram. It can only be legitimately viewed as a reflection of the tangent space at a single point in the physical manifold, and possibly extrapolation to its immediate neighborhood in the manifold through the exponential map, i.e., within the ontologically valid region. Notice that all these earlier diagrams include multiple tangent spaces at different points (e.g., one on Earth and another in Andromeda).[14]

Finally, the Andromeda paradox which we started with is based on the incorrect interpretation of the 4D Minkowskian world. The questions like whether the Andromeda fleet has already launched or not may make sense to the local observers like Charlie and Dave, but they are meaningless questions to distant observers like Alice and Bob on Earth. It's not that it's just "unknowable" but it's that temporal orders have *no ontological meaning* between distant spacelike-separated events, e.g., beyond a certain ontological radius, to the non-local observers. We have shown that the violation of this fundamental result of special relativity in the block universe leads to a paradoxical conclusion, from a novel geometrical viewpoint in this paper. Furthermore, the causal structure of 4D Minkowski space is not incompatible with 3D-first world views.

[13]Strictly speaking, no two atoms can occupy the same 3D location at the same time. Our observers are treated as *points* that occupy no space.

[14]To be clear, however, this in no way invalidates our main arguments in this paper. We were pointing out the invalidity of the eternalists' arguments relying on the (mis-)uses of Minkowski diagram. There is one tangent space at every point in the hyperplane of simultaneity, and the block universe *amalgamates* all these disparate tangent spaces at different locations into *one giant block*.

8 Conclusion

The transition from Minkowski's geometric formalism to the block universe represents one of the most significant ontological leaps in the history of science. For over a century, 4D Minkowski space has been used as definitive proof that the flow of time is a "persistent illusion" and that the future is as *fixed* as the past. Many physicists and philosophers have accepted this *counterintuitive conclusion,*[2, 14, 15, 17, 30] believing it to be mandated by the mathematical rigor of special relativity.[22]

As J.R. Lucas poignantly observed, the block universe is "a fatalist's dream, but a scientist's nightmare."[15] He argued that if time is truly just another spatial dimension, then our experience of the "flow" of time—the transition from the potentiality of the future to the actuality of the past—is rendered meaningless. In a static 4D block, nothing ever *happens*; everything simply *is*. This view not only contradicts our deepest intuitive grasp of reality but also strips physical processes of their dynamic, evolutionary character.

This paper has argued that the eternalist conclusion is not a physical or even mathematical necessity but simply a *reification error*. By formulating 4D Minkowski space as a tangent bundle $T\mathcal{M}$, rather than a global affine space, and by distinguishing between the base manifold $\mathcal{M}$ and its tangent fibers $T_p\mathcal{M}$, we have shown that the *rigid hyperplane of simultaneity* is a local coordinate projection within the observer's tangent space, rather than an invariant sub-manifold of reality. While general relativity mandates a bundle-theoretic view due to global curvature, the block universe has persisted in the *flat world* of special relativity by exploiting the "unreasonable effectiveness" of the trivial isomorphism.

The *Andromeda paradox* is not a discovery of distant 4D reality; it is a fundamental breakdown of the assumption that the 3+1D space and time coordinate system can be pushed beyond its geometric and ontological limits. Just as extending a small-scale city map to cover the entire globe would eventually lead to distortions and rips, extending the local *now-slice* across cosmic distances reveals the instability of the trivial isomorphism in pseudo-Euclidean space.

Relativity does not forbid a dynamic present; it merely forbids a global coordinate present common to all observers.[28, 31] By restoring the distinction between the map and the territory, we restore the viability of *the present* and *the flow of time*. The *frozen time* of eternalism is a shadow cast by our own coordinate systems; beyond that shadow, the universe continues to *become*.[32, 33]

Declarations

- **Conflict of interest:** The author declares no competing interests.
- **Author contribution:** The author confirms being the sole contributor of this work and has approved it for publication.
- **Disclosure:** During the preparation of this manuscript, the author used Gemini for conceptual clarification, background research, and to assist in drafting the initial manuscript. Following this process, the author personally reviewed, critically revised, and edited the content to ensure accuracy and scientific integrity. The author takes full responsibility for the final version of the manuscript and its conclusions.

Appendix A Deconstruction of the Minkowski Diagram

The perdurantist block view is often reinforced by the visual habit of looking at the Minkowski diagram as a 4D map.[34] The four-dimensional block universe is not just a mathematical theory; it is a visual doctrine. The standard Minkowski diagram, by spatializing time as a "vertical dimension," subtly encodes a cognitive bias toward eternalism. In this appendix, we deconstruct the *visual rhetoric* of these diagrams and demonstrate that the kinematics of special relativity can be understood from a dynamic, 3D-first point of view without any loss of rigor.

A.1 The Illusion of Static Geometry

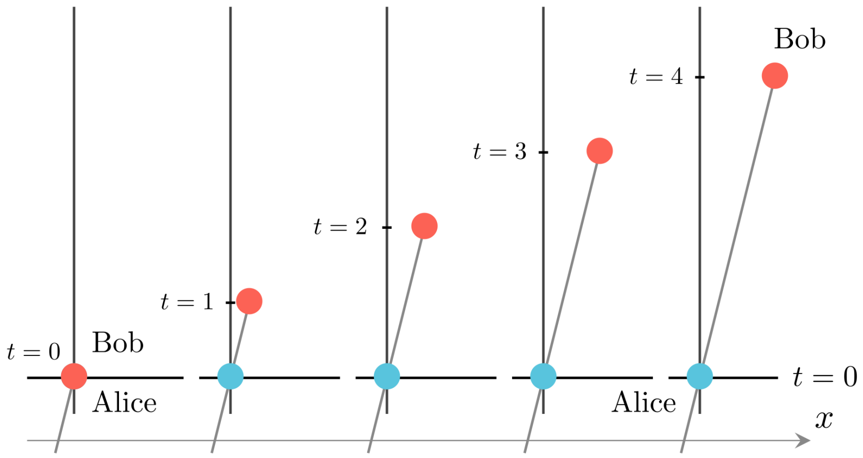

Figure A1 The spatialization error: Stacking temporal states horizontally creates the illusion of a static, slanted worldline existing in a pre-determined 4D block.

The eternalist arguments are often tautological. For example, the Andromeda paradox (Section 2) relies on the existing 4D world, as shown in Figure 1. Alice, Bob, Charlie, and Dave and their worldlines already exist in this static world. Clearly, it is an error to interpret this visual representation as an ontological proof. Figure A1 shows the "growing worldline" of Bob in time, in Alice's reference frame K. It includes five diagrams at five distinct times, stacked horizontally. At $t = 1$, for instance, Bob only exists at $t = 1$. But, the Minkowski diagram combines all snapshots at different moments, essentially from $t = -\infty$ to $t = \infty$, and presents them as a static, eternal map, obscuring the dynamical nature of motion. This is a visual artifact. This figure debunks this static fallacy by showing only a few temporal snapshots.

The visual result is a "slanted worldline" that appears to exist as a pre-constructed geometric object, reinforcing the eternalist intuition that the future is a pre-existing destination. By drawing spatial axes at each temporal step, the diagram visually fragments reality into isolated slices, suggesting that observers in relative motion inhabit separate worlds. We contend that this *slanted worldline* is a visual artifact—a mathematical record of spatial displacement over time rather than a physical filament extending through a manifold.

Figure A1 also highlights a subtle conceptual error: as time passes, the observer (Alice) must also "ascend" through the temporal states, yet standard interpretations often subconsciously fix the observer at the origin. A spacetime diagram is ontologically valid only for the observer's "here and now"; as the present advances, even infinitesimally, the diagram must be updated to reflect the new state of the manifold.

A.2 The Kinematic Filmstrip: Time as a Sequence of States

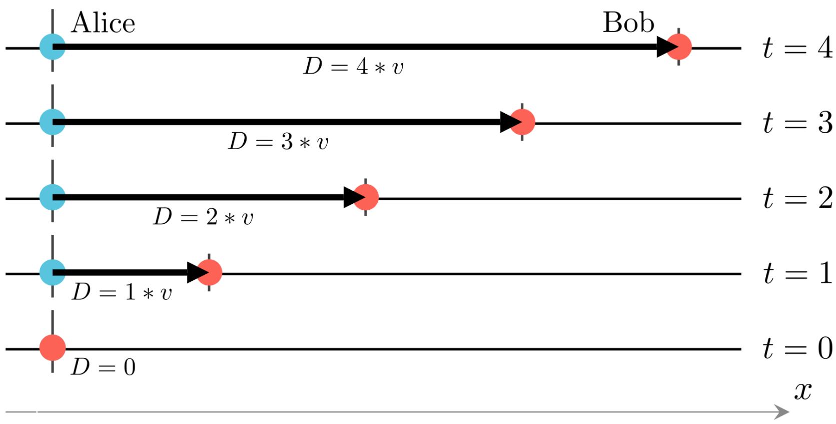

Figure A2 The Kinematic Foliation: Five snapshots of motion stacked vertically. Time is represented as an index of state-change, from $t = 0$ to $t = 4$ (in an arbitrary unit), preserving the reality of Alice's present while accurately mapping inertial motion.

To remove these geometrical biases, Figure A2 employs what we term a "kinematic foliation." In this representation, time is treated not as a dimension of extension, but as an external parameter indexing the evolution of a spatial arena.

The horizontal lines in this model represent the *same* spatial universe at successive moments. Bob's motion is depicted as a purely spatial displacement ($x = vt$) within a shared, advancing present. By placing both Alice and Bob on the same horizontal slice for every increment of t, the diagram recovers all the kinematic predictions of special relativity while stripping away the *block* ontology. In this view, Bob moves strictly *laterally* relative to Alice, and his *slanted worldline* is revealed to be a mathematical record of past locations, not a physical trajectory through a frozen future.

Figures A1 and A2 demonstrate that relativity can be represented in a dynamic, 3D-first framework. By treating time as an indexing parameter for state-change, we recover the formalisms of the Lorentz-Einstein transformation without committing to a 4D ontology.[35] The past worldline is recognized as a *historical locus*—a trace of where objects were—rather than a physical structure extending through a manifold.

A.3 Worldlines as Historical Loci

Finally, Figure A3 provides an ontological correction that restores the status of the present. In this model, physical entities exist exclusively upon the horizontal axis labeled "Now." The space above this axis remains unmapped, as the future has not yet occurred.

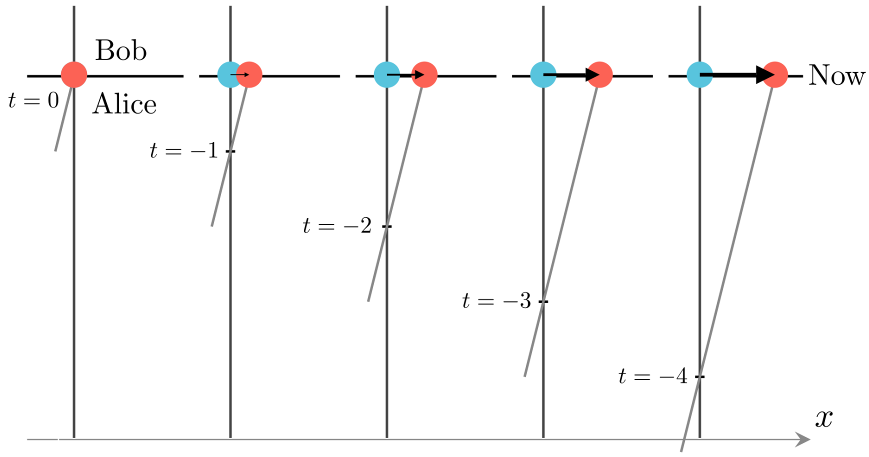

Figure A3 The Historical Locus Model: Physical objects exist only in the "Now." Worldlines (gray lines) are relegated to the past ($t < 0$) and treated as historical records, not physical structures. For Alice, the future segment of Bob's trajectory is non-existent. Bob moves simply "to the right" in this interpretation; his local notion of "now" carries no ontological weight beyond Alice's past light cone.

By visually severing present entities from their past trajectories and denying a geometric future, we demonstrate that the mathematical formalism of relativity describes how we coordinate perspectives, not how we inhabit a static block. The ontological status of the past—whether it "still exists" or has faded away—is outside the scope of this paper. For Alice, reality is centered on her *perspectival present.*[15]

Even this refined diagram contains an unrealistic extrapolation due to the finite speed of light. Strictly speaking, Bob remains an "illusion" to Alice except during their local coincidence at $t = 0$. Until a causal signal arrives, Alice's reality is effectively constrained by her past light cone. As we have discussed, while the extrapolation of the "here and now" point is valid within a finite neighborhood (the ontological radius), events in Alice's global "now" are nonetheless primarily mathematical abstractions.

[15] One can view a Minkowski diagram not as a static graph, but rather as a series of dynamic snapshots, which "flow downward" relative to the coordinate system and the *static* observer at the origin. That is, in this visualization, time does not flow from the past to the future. Instead, time flows from the (non-existent) future to the (frozen) past like a river.

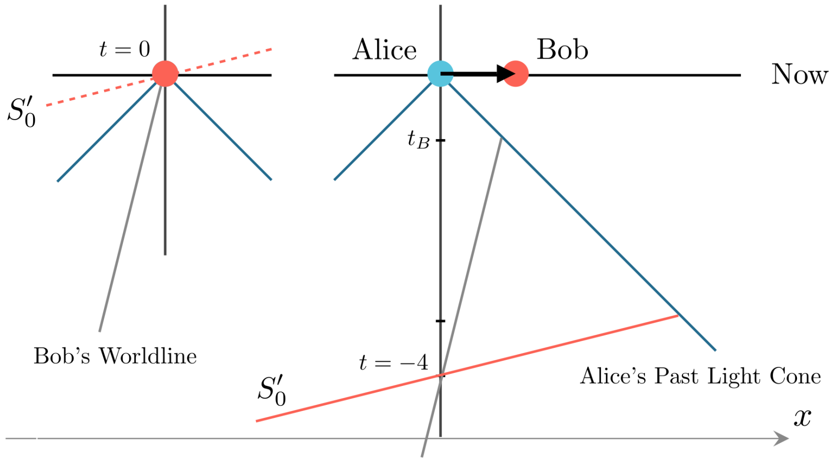

Figure A4 The Observer's "Now" as an Extrapolation: Events identified as "now" (beyond the "here and now"), and in fact, all spacelike separated events, are mathematical predictions or extrapolations, which may turn out incorrect as signals arrive.

Figure A4 illustrates this point: Bob's position at $t = 0$ has no direct ontological significance to Alice until her worldline advances and his past enters her light cone. Everything outside her past light cone, including every event at *her now*, is an extrapolation to her (albeit a very good one in the relevant scale of everyday life).[16]

By recognizing the Minkowski diagram as a local reflection of the tangent space of an observer rather than a global map of simultaneous existence, we resolve the *Andromeda paradox* and restore the possibility of a more dynamical, 3D-first structure of the physical world that we live in.

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