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Lorentz vs Einstein: The Man Who Apparently Didn't Understand His Own Equations

Ion Vlad

Independent Researcher

contact@ionvlad.com

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ABSTRACT

Special relativity has survived a century of scrutiny, countless textbooks, and the occasional suspicion that its founder might have understood it correctly. This paper revisits Lorentz's transformations, simultaneity, the twin paradox, the ladder paradox, and the train-and-lightning thought experiment, arguing that the mathematics is considerably less controversial than its interpretation. By distinguishing physical events from their frame-dependent coordinate labels, we propose a Lorentz-consistent reinterpretation that challenges conventional readings without having the audacity to discard the equations themselves. The central question is deceptively simple: how did Lorentz's mathematics acquire an interpretation that apparently required Einstein to explain it better than Lorentz? The implications for spacetime diagrams and relativistic paradoxes are explored, in the hope that history itself may yet be transformed—and that Lorentz might finally receive the credit that Einstein's shadow has so long denied him.

Aim: *This paper aims to clarify aspects of special relativity by applying Lorentz-consistent coordinate assignments and distinguishing invariant events from frame-dependent spatial observations.*

MOtTo: "You can lead a horse to water, but you can't make it drink."

Disclaimer: Given that such a controversial paper stands virtually no chance of being published, I reserve the right to be as sarcastic as the circumstances demand. When the prospects of publication approach zero, one might as well maximise the entertainment value. The entire paper could be reduced to a single sentence: *Special relativity relies heavily on the Lorentz transformations, and Lorentz himself regarded simultaneity as absolute; how, then, did we arrive at the extraordinary conclusion that Einstein understood the Lorentz transformation equations better than the very man who formulated them?* Apparently, deriving the mathematical relationships is one thing; being credited with the definitive interpretation of their physical meaning is quite another. After all, we obviously know better what Leonardo da Vinci intended when he painted the Mona Lisa. Why should the interpretation of Lorentz's equations be any different?

This document is a snapshot of a more comprehensive paper, which is available in the repository linked in the references.

NikoUArxive_physic_20261018_983172

1 Introduction

It is crucial to clarify the scope of this inquiry: this paper does not seek to refute the mathematical formalism of special relativity, but only to revise certain interpretations. In particular, we focus on two related issues:

1. the distinction between coordinate time and measured temporal intervals (duration)
2. the interpretation of simultaneity and spacetime diagrams

We follow the mathematical formalism established by Lorentz Lorentz (1904), who first derived the transformation equations in 1904. However, we argue that the physical interpretation of these equations—particularly regarding simultaneity—should align with Lorentz's original framework rather than Einstein's 1905 reformulation. Einstein argued that establishing simultaneity requires synchronised clocks. In practice, however, we rarely rely on synchronised clocks directly. Instead, we use transformations and conventions, such as time-zone conversions in everyday life and Lorentz transformations in relativity. Conceptual difficulties in special relativity persist despite the theory's well-established mathematical structure. Among the most prominent are:

- the interpretation of spacetime diagrams
- the twin paradox
- the relativity of simultaneity
- the ladder paradox

These difficulties are often pedagogical rather than physical. As noted in standard treatments Taylor and Wheeler (1992), French (1968), relativistic effects arise from well-defined transformation laws, yet their interpretation is frequently obscured by implicit classical intuitions.

We argue that several apparent paradoxes arise from conflating invariant event structure with frame-dependent coordinate assignments.

2 Simultaneity – A Refined Framework

2.1 The ladder paradox

Classical Minkowski diagrams are often drawn in a simplified manner that distorts their proportions and obscures the geometric meaning of special relativity. In Figure 1 we represent the ladder paradox scenario in a Lorentz-consistent Minkowski diagram. It is necessary to clarify how this diagram is constructed and what distinguishes it from a conventional schematic representation. The spacing of the pink grid representing the frame S' is not uniform in Euclidean distance; instead, the correct Minkowski grid spacing must satisfy:

- Equal increments in ct' correspond to constant increments in $ct - vx$:

$$ct = vx + \frac{k}{\gamma}$$

- Equal increments in x' correspond to constant increments in $x - vct$:

$$x = vct + \frac{k}{\gamma}$$

The grid was rendered via a Python script. The source code is archived and accessible in the repository Vlad (2026). The coordinates are represented in unprimed units for frame S and primed units for frame S'. These units are grid divisions representing two different systems that are not interchangeable. Coordinates from different frames cannot be compared without

NikoUArxive_physic_20261018_983172

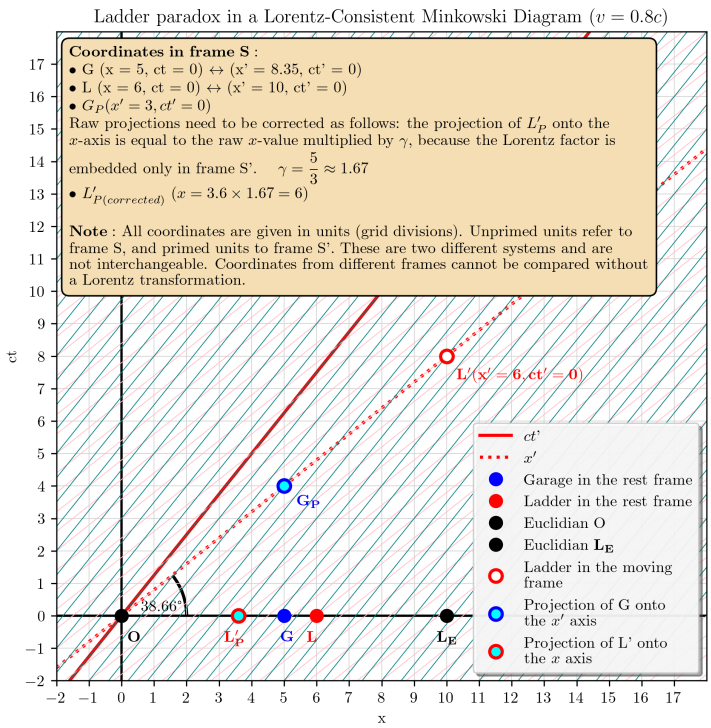

Figure 1: Ladder paradox in a Lorentz-consistent Minkowski diagram. Note that grid construction follows Lorentz's physical contraction model.

proper Lorentz transformation. Consider that the garage is 5 unprimed units long and the ladder 6 primed units long. The moment of measurement is irrelevant and we can consider it as $ct = ct' = 0$ since all measurements start from the origin. This establishes absolute simultaneity for the measurement events. In the rest frame, the garage has coordinates $G(x = 5, ct = 0)$ and the ladder $L(x = 6, ct = 0)$—both in unprimed units. In the S' frame at rest, the ladder has coordinates $L'(x' = 6, ct' = 0)$—these are primed units. In neither frame does the ladder fit into the garage. The observer at rest (garage frame) perceives the projection of L' onto the x-axis as $L'_P(x = 3.6, ct = 0)$ and may be tempted to conclude that the ladder will fit ($3.6 < 5$). However, the $L'_P(x = 3.6)$ coordinate is a "raw" (untransformed) projection. L' resides in a frame where the Lorentz transformation is embedded into the grid, but when projected onto the x-axis, this embedding is lost. Therefore, before any comparison, we must apply the correction factor to recover the invariant proper length: $L'_{P(corrected)} = 3.6 \times \gamma = 3.6 \times \frac{5}{3} \approx 6$. Since $6 > 5$, the ladder does not fit. The paradox arises only when we compare unprimed units with primed units without proper Lorentz transformation, or when we treat "raw" projections as already-transformed coordinates.

If we were to perform the projection using Euclidean geometry, L' would be projected onto x axis as $L_E(x = 10)$. We could then calculate OL' as

$$OL' = \frac{OL_E}{\text{correction factor}} = \frac{10}{\cos(38.66°)} \approx \boxed{12.7} \qquad OL' > OL_E > OG$$

Unlike an ordinary Euclidean projection, in which the projected length is related to the original length by the cosine of the angle between the vector and the projection axis, the construction considered here relates the coordinate of an intersection on the x-axis to the corresponding coordinate on the x'-axis through the Lorentz factor. For the specific construction shown in the diagram, this relationship is $x = \frac{x'}{\gamma}$. We define $\frac{1}{\gamma}$ as the "Minkowski-grid projection factor" (or simply the "**projection factor**"), distinguishing it from the Euclidean projection factor,

NikoUArxive_physic_20261018_983172

$\cos\theta$. Its reciprocal, γ, is termed the "**correction factor**", as it recovers x' from x. The same terminology is used throughout this paper for the corresponding relationships between ct and ct'.

$$OL' = OL \times \gamma = 3.6 \times \frac{5}{3} \approx 6 \qquad OL' > OG$$

In conventional special relativity calculations, we assume that the projected length is the true length in that frame, overlooking the need to account for the *correction factor*, even though we account for it in Euclidean projections. Why does special relativity not require a correction when comparing the original length with its projection? L'_P is only a projection; therefore, we cannot use it untransformed when comparing it with unprojected values (G). We can use the raw values only when comparing one projection with another: L'_P compared with G_P (3.6 > 3).

$$L' \textbf{ versus } G \textbf{ versus } L'_P \times \gamma \textbf{ versus } G_P \times \gamma \rightleftarrows \textbf{6 versus 5 versus 6 versus 5}$$

Key Principle: Proper lengths are invariant under Lorentz transformation across all frames. The ladder's proper length (6 units) exceeds the garage's proper length (5 units) in every frame. Frame-dependent observations reflect measurement artefacts arising from grid geometry, not physical reality. The coordinate transformation follows Lorentz's equations (Lorentz, 1904), preserving absolute simultaneity while accounting for frame-dependent measurements through grid geometry embedding the γ factor.

2.2 Geometric analysis via spacetime diagrams

Consider the twin paradox scenario with a velocity of $v = 0.8c$ and a turnaround distance of 4 light-years. This configuration yields a coordinate time interval of $\Delta t_0 = 5$ years and a proper time interval of $\tau = 3$ years. The corresponding spacetime diagram is illustrated in Figure 2. In Figure 3, we have the same scenario, but this time the diagram is drawn consistently with

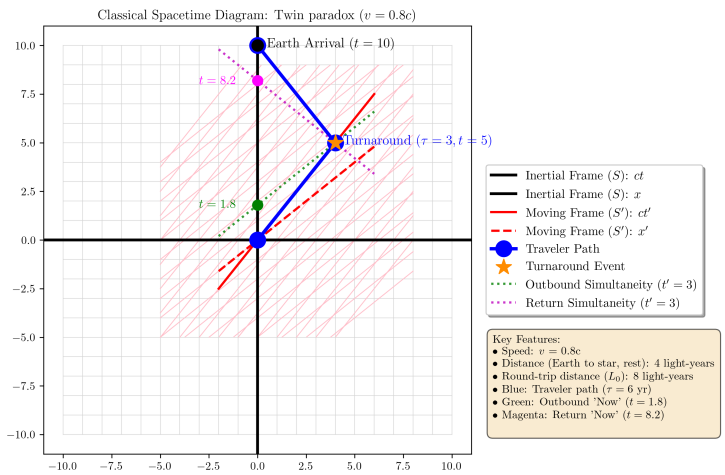

Figure 2: Conventional schematic Minkowski representation of the twin paradox for $v = 0.8c$

the Lorentz transformation. In S' and S'', the traveller's proper time along each inertial leg is 3 years, giving a total of 6 years for the entire journey. Since the proper time can be read directly from S' and S'', the lines of simultaneity become unnecessary; the diagram can be constructed without them.

The turnaround event is a single physical event but has been assigned three different coordinate labels—one for each frame. We can verify that by performing the transformations between frames (and back):

$$\gamma = \frac{5}{3} \approx 1.67 \quad \text{and} \quad \beta = \frac{v}{c}$$

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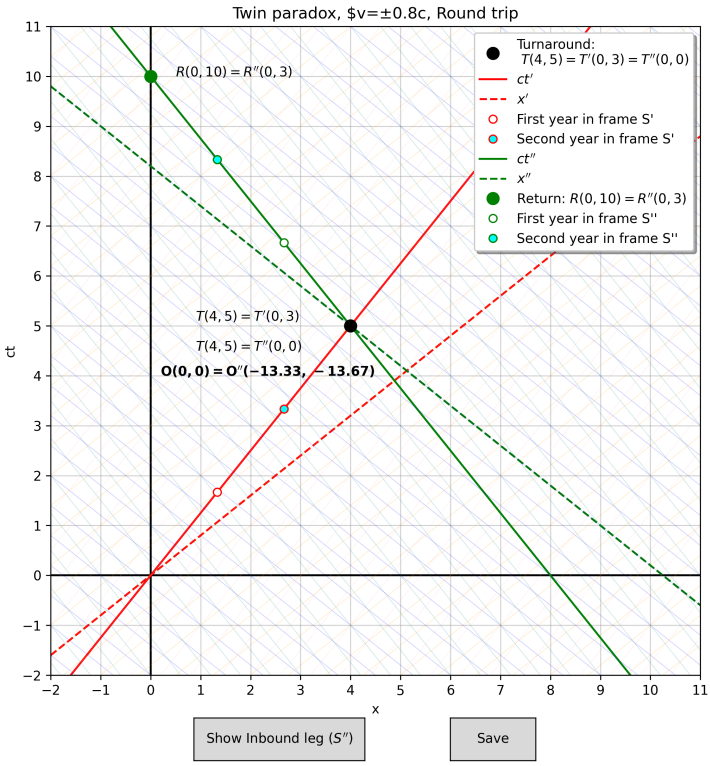

Figure 3: Twin paradox in Lorentz-consistent Minkowski diagram at $v = 0.8c$.

Origin:

$(S \to S')$:

$$x' = \gamma(x - \beta ct) = \frac{5}{3}(0 - 0.8 \times 0) = 0$$

$$ct' = \gamma(ct - \beta x) = \frac{5}{3}(0 - 0) = 0$$

Inverse $(S' \to S)$:

$$x = \gamma(x' + \beta ct') = \frac{5}{3}(0 + 0) = 0$$

$$ct = \gamma(ct' + \beta x') = \frac{5}{3}(0 + 0) = 0$$

Forward $T(4,5) \leftrightarrows T'(0,3)$:

$(S \to S')$:

$$x' = \gamma(x - \beta ct) = \frac{5}{3}(4 - 4) = 0$$

$$ct' = \gamma(ct - \beta x) = \frac{5}{3}(5 - 0.8 \times 4) = \frac{5}{3}(5 - 3.2) = 3$$

Inverse $(S' \to S)$:

$$x = \gamma(x' + \beta ct') = \frac{5}{3}(0 + 0.8 \times 3) = \frac{5}{3}(0 + 2.4) = 4$$

$$ct = \gamma(ct' + \beta x') = \frac{5}{3}(3 + 0.8 \times 0) = 5$$

Turnaround $T'(0,3) \leftrightarrows T''(0,0)$:

NikoUArxive_physic_20261018_983172

$(S' \to S'')$:

$$x'' = \gamma_{1\to 2}\left[x' + \frac{40}{41}(ct' - 3)\right] = 0, \qquad ct'' = \gamma_{1\to 2}\left[(ct' - 3) + \frac{40}{41}x'\right] = 0$$

where $\gamma_{1\to 2}$ represents the Lorentz factor between frame 1 (S') and frame 2 (S''). The $(ct' - 3)$ factor arises from setting T'' to zero as the new origin. Frames S' and S'' move relative to each other with a velocity (velocity addition):

$$u = \frac{(-0.8) - (0.8)}{1 - (-0.8)(0.8)} = \frac{-1.6}{1.64} = -\frac{40}{41} \approx -0.9756c$$

where velocities are in units of c.

$$\gamma_{1\to 2} = \frac{1}{\sqrt{1 - (40/41)^2}} = \frac{1}{\sqrt{(1681 - 1600)/1681}} = \sqrt{\frac{1681}{81}} = \frac{41}{9} \approx 4.556$$

In S'', the origin is now T'', but all frames must be compared using a common origin. Therefore, the origin of S transforms into the origin of S'' as follows:

$$O(0,0) \to x'' = \frac{41}{9}\left[0 + \frac{40}{41}(-3)\right] = -\frac{40}{3} = -13.33, \qquad ct'' = \frac{41}{9}(-3) = -\frac{41}{3} = -13.67$$

$$O(0,0) = O'(0,0) = O''(-13.33,\ -13.67)$$

Also, the origin T'' of S'' is offset from the origin O of S by $T(4,5)$ in S, and from the origin O' of S' by $T'(0,3)$ in S'. The 3-year interval is the proper time interval along the traveller's inbound world-line segment. To compare this interval with the Earth-frame coordinate time, the corresponding spacetime displacement must be Lorentz-transformed as a four-vector. This displacement causes $O''(-13.33,\ -13.67)$ to become $O''(-13.33,\ -16.67)$.

$(S'' \to S)$:

$$\Delta x = \gamma\left[x'' - v(ct'' - ct''_R)\right] = \frac{5}{3}\left[(-13.33) - 0.8(-16.67)\right] = \frac{5}{3}\left[-13.33 + 13.33\right] = 0$$

$$\Delta ct = \gamma\left[(ct'' - ct''_R) - vx''\right] = \frac{5}{3}\left[(-16.67) - 0.8(-13.33)\right] = \frac{5}{3}\left[-16.67 + 10.67\right] = -10$$

Reversing a displacement reverses its transformed vector. So both of these are perfectly consistent, contradicting nothing:

$$\underbrace{(13.33,\ 16.67)}_{\Delta(O\to R)} \to (0,\ 10) \qquad\qquad \underbrace{(-13.33,\ -16.67)}_{\Delta(R\to O)} \to (0,\ -10)$$

Inverse of the return boost, plus T offset $(S'' \to S)$:

$$R''(0,3): \quad x = 4 + \gamma\left[x'' - \beta ct''\right] = 4 + \frac{5}{3}(0 - 2.4) = 0$$

$$ct = 5 + \gamma\left[ct'' - \beta x''\right] = 5 + \frac{5}{3}(3 - 0) = 10$$

Trivially $x = 4$, $ct = 5$ — the translation does all the work.

The "3" that belongs to the inbound leg's proper time (R'' at $ct'' = 3$) combines with O'' to reconstruct the 10-year gap in S. Notably, the boost transforms the mixed components (13.33, 16.67) into a purely temporal (0, 10), because O and R both sit at $x = 0$ — the spatial parts cancel exactly, the same cancellation mechanism as in the O'' event check, now acting on

NikoUArxive_physic_20261018_983172

differences instead of absolute coordinates. The vector $\Delta(R \to O)$ expressed in S'' instructs us: "starting from R, walk to O". In S, that is (0, -10): ten units downward along the ct-axis. Re-anchored:

$$R(0,10) + (0,-10) = O(0,0) \qquad \Longleftrightarrow \qquad O(0,0) + (0,+10) = R(0,10)$$

This concludes that the **coordinates assigned** to an event are frame-dependent and **do not** change the physical properties of the event, regardless of how it is interpreted in that frame. Changing an event's coordinates in accordance with a Lorentz transformation is like changing a person's name: it does not change the person's personality, appearance, address, or wealth. A nickname only makes it easier to identify an individual within a group without affecting the person's physical identity.

In Figure 4, we have two groups of simultaneous events: A appears to be simultaneous with B and E in frame S, and C' is simultaneous with D' and E' in frame S'. The events (A, B, C, D, E) and their primed counterparts (A', B', C', D', E') are the same physical events described in two different inertial frames. They are related by the Lorentz transformation:

$$X \to X' = \big(\gamma(x - \beta ct),\ \gamma(ct - \beta x)\big)$$

and

$$X' \to X = \big(\gamma(x' + \beta ct'),\ \gamma(ct' + \beta x')\big)$$

Nevertheless, different observers may disagree about whether events are simultaneous in different

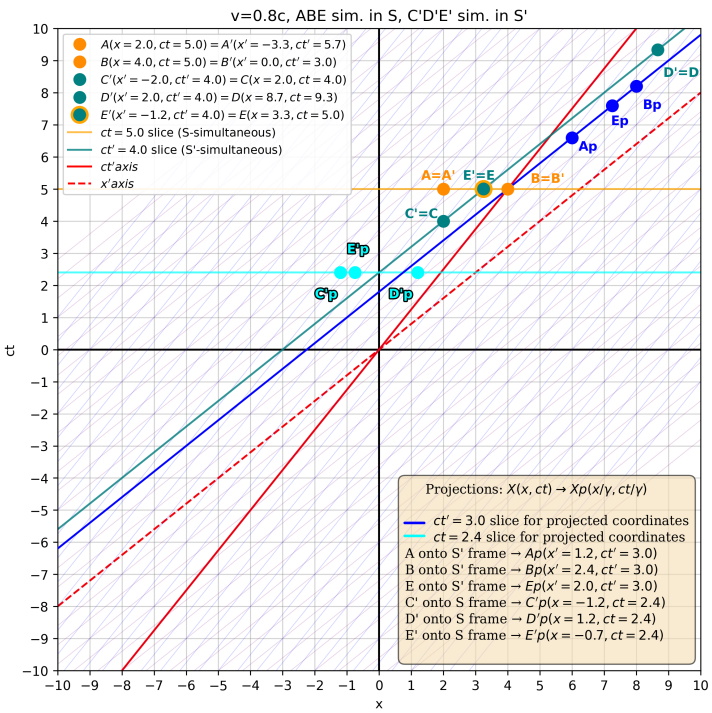

Figure 4: Two pairs of events, each simultaneous in a different frame.

frames, even though the physical events themselves do not change. This is because the observers analyse the information only within their own frame and do not apply the proper Lorentz corrections. In other words, those coordinates are only **"raw", frame-dependent observational labels read directly from the grid.** Since frame S' has the Lorentz factor embedded in the grid whereas frame S does not, comparing directly the temporal coordinate of A with that of A' is meaningless. We therefore have to apply the *projection factor* to the temporal coordinate of A and construct its projection onto the ct' axis, such that $ct'_{Ap} = \dfrac{ct_A}{\gamma}$. If we apply the same

NikoUArxive_physic_20261018_983172

projection factor to x_A, $\left(x'_{Ap} = \frac{x_A}{\gamma}\right)$, we obtain the corresponding projection of event A onto frame S'. Importantly, Ap **is not a new event**, but rather a geometrical representation of the same event A obtained by consistently relating its coordinates to frame S'. We always apply the *projection factor* to the coordinates in the frame at rest, (S) since Lorentz factor is already embedded into the S' grid. Now it is obvious that $ct'_{Ap} = ct'_{Bp}$, and $ct_{Cp} = ct_{Dp} = ct_{Ep}$ which means that the events are simultaneous in both frames after the correct Lorentz coordinate transformations have been applied (Figure 3). We can now establish an order of occurrence for the events:

- From the perspective of frame S: $ct_C = 4$, $ct_A = 5$, so C, D, E occur first, followed by A and B.
- From the perspective of frame S': $ct'_C = 4$, $ct'_A = 5.7$, so C, D, E occur first, followed by A and B.

A natural question remains: how can event E appear to be simultaneous with A and B, and with C and D at the same time, without causing events A and B to be simultaneous with C and D? This is because event E is a wild card: the S' grid is not a Euclidean grid, and the relations between the events do not follow Euclidean mathematical rules. In fact, upon closer examination, we realise that E is only simultaneous with C and D, and that the apparent perception of simultaneity with A and B is only a **frame-dependent observation, an artefact caused by forcing a complex four-dimensional representation onto a simplified two-dimensional image.** This wild card occurs because the S' grid construction mixes the x and ct coordinates. It is not a flaw; rather, it reveals how **relative motion perturbs the observer's description.** This is described in more detail in Section 4.

If observers transform the two events into **all** the other relevant frames and find that they are not simultaneous in **any** of them, then they can say with certainty that the events are **not** simultaneous in any of those frames. If observers describe the same two events in **all** the other relevant frames and, using consistent Lorentz transformations, **all** observers find that the events are simultaneous in the same inertial frame, then they can say with certainty that the events **are simultaneous** in that frame. Their agreement does not arise from a preferred frame or majority voting, but from the consistency of the transformations relating their descriptions. This can be written as follows: Let $R = F_0, F_1, \ldots$ denote the relevant inertial frames connected by consistent Lorentz transformations $\Lambda_i \to {}_j$, let Δt_F denote the temporal coordinate difference between events A and B in frame F, and write $A \sim_F B$ when $\Delta t_F = 0$.

$$\boxed{\begin{array}{c} \forall F_i \in R,\ \Delta t_{F_i} \neq 0 \implies \neg\exists F \in R : A \sim_F B \\ \exists F_0 \in R : \Delta t_{F_0} = 0 \implies \forall F_i \in R : \Lambda_{i\to 0}(\Delta t_{F_i}) = 0 \end{array}}$$

In words, the criterion is neither a preferred observer nor majority agreement. The criterion is covariance: all observers using consistent transformations must obtain the same set of physical relations between the events. This means that coordinate labels are frame-dependent and, by themselves, cannot determine whether events are simultaneous without considering the relevant transformations between frames. **Claiming that two events are not simultaneous in one particular frame does not mean that they are not simultaneous in every frame.** It is only a frame-dependent observation. Therefore, "simultaneity lines" are frame-dependent observational constructs that, by themselves, cannot definitively determine simultaneity across frames.

Consider drawing a shape on a piece of paper. There is a chance that, when viewed from the left, it will look like the number 9, while when viewed from the right, it will look like the number 6. Both observers are correct within their respective reference frames, and neither can claim that the other is simply wrong. But that distinction is ultimately irrelevant to what was actually

NikoUArxive_physic_20261018_983172

drawn. When we created the shape, we did not have either 6 or 9 in mind. The shape itself existed independently of how different observers happened to interpret it. It is much like a painting in a museum: a million visitors may have a million different interpretations of what they see, but those interpretations do not determine what the artist actually intended at the moment of creation.

The same distinction should be made when discussing simultaneity. **If two events are simultaneous in the physical frame in which they occur, then their simultaneity is a fact about the events themselves, not something created by an observer's choice of reference frame.** A Lorentz transformation may cause an observer in another frame to assign different time coordinates to those events, but that does not change the events themselves or the relationship they had when they occurred. In other words, the transformation changes the observer's description of the events, not the underlying physical reality that the description is attempting to represent.

Simultaneity is an intrinsic property of two events alone; it is a relation that specifies whether those events occur at the same time in a given reference frame. Once that frame is specified, the **simultaneity relation can be consistently determined in all other reference frames through the Lorentz transformation.** Although observers may assign different time coordinates to the events, they must all agree on the simultaneity relation when the transformation is applied consistently. Thus, while observations are frame-relative, simultaneity itself is not frame-dependent.

A coordinate label is a description assigned within a particular frame; it does not change the physical construction of the event. Just as a name does not say anything about someone's personality, a coordinate label does not determine the physical nature of an event. We can express numbers in hexadecimal using letters only (0xB = 11, 0xD = 13). That does not make the numbers "less" prime. A city occupies the same physical location on both a 2D (distorted) map and a 3D map (a globe). More importantly, its latitude and longitude always remain the same, despite the fact that the two maps may show the city in different locations. For this reason, it can be easier to use a common "language" in which all observers agree on the labelling convention. This does not mean that one frame is preferred. Rather, it is a common convention that allows all observers to describe and compare the same physical events consistently.

2.3 Preserving the coordinates across frames

For readability, **we can adopt the convention** of preserving the coordinates across frames, to avoid the tedious calculations that would otherwise be necessary. In the following example, we can easily visualise "time dilation" in the twin paradox scenario. This convention of preserving the coordinates between frames allows us to establish a clearer relationship between an event's label and its position on the grid while keeping everything Lorentz-consistent.

Note: In reality, we cannot preserve the coordinates across frames when constructing a Lorentz-consistent Minkowski diagram, since events are mapped onto both frames using the appropriate Lorentz transformation. **This convention is used solely to facilitate the visualisation of "time dilation".**

In Figure 2, the green dotted line of "simultaneity" passing through the turnaround point intersects the ct axis at 1.8 years, not 3 years. This is because spacetime diagrams are typically not drawn to scale in order to simplify the representation, and the event's coordinates have been mapped incorrectly. A Lorentz-consistent Minkowski diagram would appear as shown in Figure 3 or Figure 5. It is essential to assign coordinates in a consistent manner:

- The event labelled $T(x = 4, ct = 5)$ represents the turnaround point in frame S (which does not exist in frame S')

NikoUArxive_physic_20261018_983172

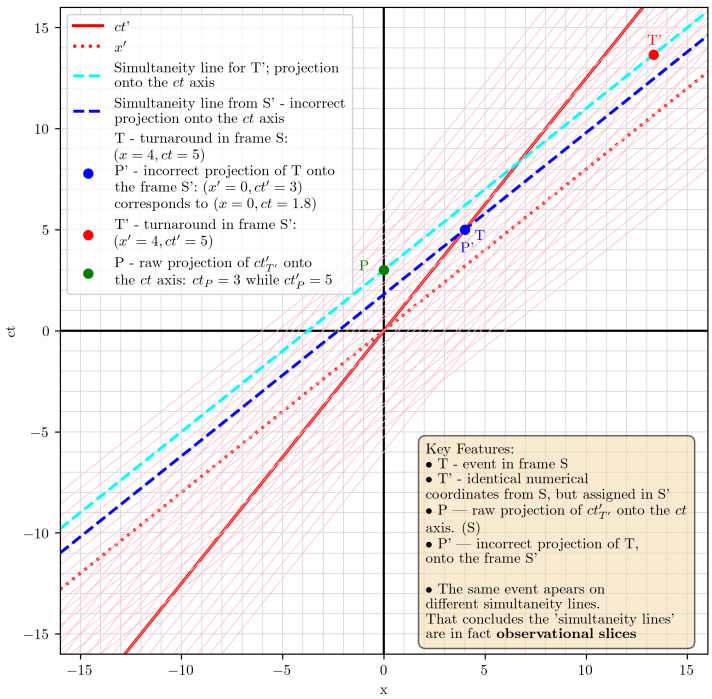

Figure 5: Lorentz-consistent Minkowski diagram illustrating the assignment of preserved turnaround coordinates and simultaneity structure for $v = 0.8c$.

- The event labelled $T'(x' = 4, ct' = 5)$ represents the turnaround point in frame S'. It is crucial to distinguish this from the event at $(x' = 2.4, ct' = 3)$ to avoid conflation in the analysis. **We preserve those coordinates across the frames so that they are identical to those of T.**
- The point labelled P represents the projection of $ct'_{T'}$ onto the ct axis.
- The point labelled P' represents an incorrect projection of T onto frame S'

The points under consideration refer to the same physical event, expressed in different frames. **Once the Lorentz transformation has been applied to construct the S' grid (pink), the coordinates of the event in S must be preserved; applying the transformation again at the level of coordinates would amount to double-counting.**

This potential error is illustrated by the "simultaneity line" of S' passing through T. Read incorrectly, it may suggest that the event has coordinates $P'(x' = 0, ct' = 3)$ in S', which, when projected onto the ct axis, would appear as $(x = 0, ct = 1.8)$ (cf. the corresponding dotted green line in Figure 2 or the corresponding dotted blue line in Figure 4). That is because $ct'_{P'} = 3$ would already have the Lorentz factor applied (from the grid) and, when projected onto ct axis (with no Lorentz factor incorporated), would not be $ct = 1.8$, but rather $ct = 1.8 \times \gamma = 3$.

A "simultaneity line" in S' cannot be drawn through T, since T is not defined in that frame. However, T already represents the event in the S frame, with coordinates $(x = 4, ct = 5)$, and cannot be reinterpreted within the same frame. The correct procedure is to retain the original S-coordinates and assign these values within the S' grid, yielding $T'(x' = 4, ct' = 5)$—the turnaround in S'. This accounts for why T' does not possess the coordinates $(x' = 2.4, ct' = 3)$. Projecting $ct'_{T'}$ onto the ct axis then gives "raw" $ct_P = 3$, corresponding to the proper time recorded by the traveller during the outbound leg (3 years), in agreement with the predictions of special relativity.

<u>Important note:</u> If T' were in the S frame, its coordinates would be $(13.33, 13.67)$. These coordinates are exactly the same as those of $O = O' = O''$ from Section 2.2. Even when the coordinates are preserved between frames, the event's physical

NikoUArxive_physic_20261018_983172

properties remain preserved by the S' grid. This construction clarifies the interpretation of simultaneity and the operational meaning of invariant quantities in special relativity. While no inertial frame is physically preferred, comparisons between observers require the adoption of a **common reference frame** in which all quantities are expressed. In practice, this entails transforming all measurements into a chosen frame, analogous to expressing physical quantities in a common system of units. The selected frame thus serves as a shared reference for comparison, without acquiring any fundamental status, consistent with special relativity. In Figure 4, this common reference frame shows all the equivalent projections C'_P, D'_P, and E'_P, as well as A_P and B_P, with the same (already corrected) temporal coordinates, making them ready for comparison.

Simultaneity should not be conflated with visual appearance. In Figure 5, a single event has the same numerical coordinates in both frames, $T(x = 4, ct = 5)$ and $T'(x' = 4, ct' = 5)$; its physical identity remains unchanged, while it is represented at different positions on the diagram because the S' coordinate grid is tilted relative to the S grid.

The differing "simultaneity lines" therefore reflect the frame-dependent manner in which events are described, and may be interpreted as observational slices through spacetime. To illustrate the

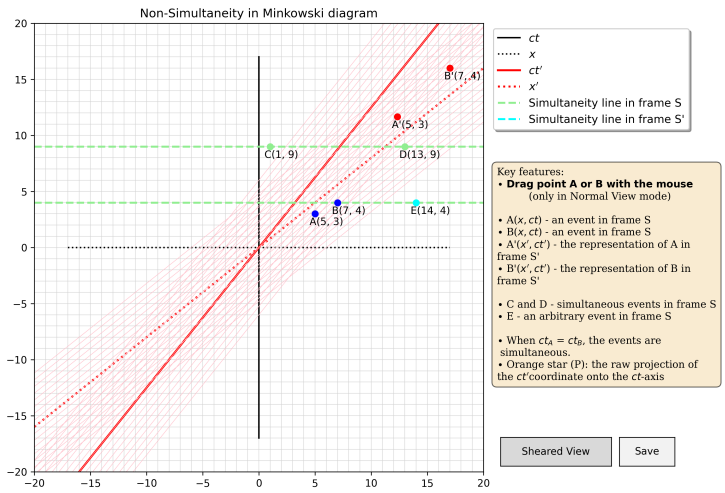

Figure 6: Lorentz-consistent Minkowski diagram illustrating two distinct events with frame-dependent coordinate assignments

distinction more clearly, consider two events, shown in Figure 6. Events A and B are specified in S, while A' and B' denote their corresponding representations in S', obtained via mapping between frames. These pairs correspond to the same physical events (same coordinates) but differ in their position on the diagram. In this configuration, the events are not simultaneous in either frame. If the coordinates of one event in S are adjusted so that it lies on the same simultaneity line as the other, its counterpart in S' acquires different coordinates and becomes simultaneous with the corresponding event in that frame, as illustrated in Figure 7. An interactive Python implementation was developed to facilitate visualisation of these coordinate transformations and simultaneity relations. The code used to generate the figures is available in the archived repository (`src/v2.0/Interactive_Simultaneity_Shear.py`) Vlad (2026).

However, since the Lorentz transformation factor is effectively embedded in the structure of the moving inertial frame, the coordinate relationships are preserved, and the physical identity of the spacetime event remains invariant, even though the local units of measurement may differ in scale between frames while the number of units (grid divisions) remains the same.

Figure 5 is drawn from the perspective of S (the rest frame); therefore, to interpret it from the perspective of S' as the rest frame, the diagram must be sheared so that the ct' axis is rendered vertical, thereby preserving internal consistency. Applying the corresponding transformation

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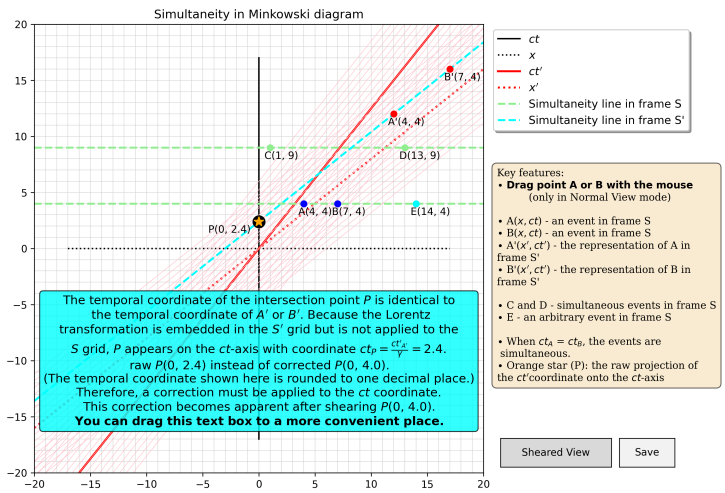

Figure 7: Lorentz-consistent Minkowski diagram illustrating how coordinate reassignment changes simultaneity relations between events

yields Figure 8. Since simultaneity is fundamentally a temporal concept, any line perpendicular

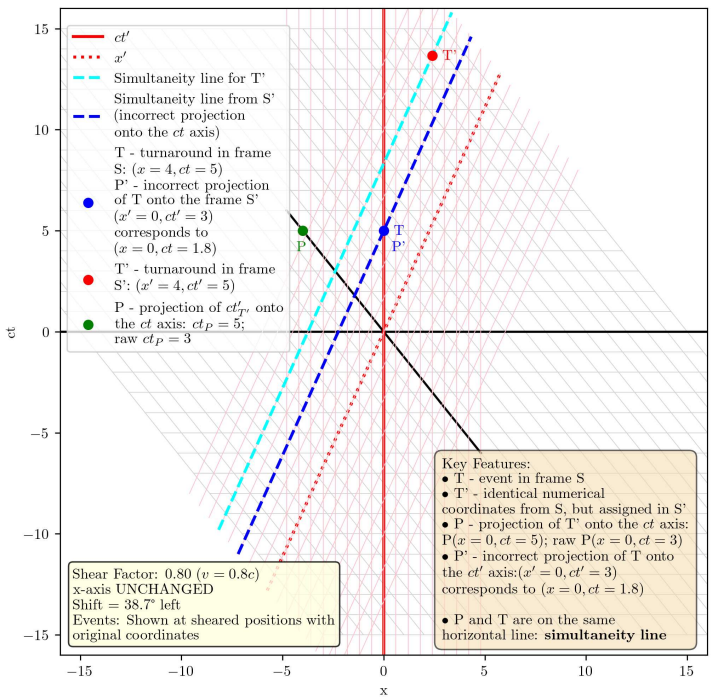

Figure 8: Lorentz-consistent Minkowski diagram illustrating the transformed simultaneity structure for $v = 0.8c$.

to the vertical time axis defines a simultaneity plane. In this representation, points P and T lie on the same horizontal line, indicating that they are related to the same event, with P representing the temporal projection of T'. The temporal coordinate of P is identical to the temporal coordinate of T' ($ct' = 5$). Because the Lorentz transformation is embedded in the S' grid but is not applied to the S grid, "raw" P appears on the ct-axis with coordinate $ct_P = \dfrac{ct'_{T'}}{\gamma} = 3$. Therefore, the *correction factor* must be applied to the ct coordinate. Consequently, the projection of T' onto the S grid initially appears at $(x = 2.4, ct = 3)$. It is important to recognise that the coordinates of $P(x = 0, ct = 3)$ do not correspond to a single event in S. Rather, they arise from a separate projection onto the ct axis under the assumption that $x = 0$, and

NikoUArxive_physic_20261018_983172

therefore cannot be combined into a unique spacetime point. A consistent event representation is recovered only after the appropriate Lorentz transformation is applied. Once the *correction factor* is applied, the coordinates of "raw" $P(x = 0, ct = 3)$ become $P(x = 0, ct = 5)$, and the projection of T' is correspondingly located at $T(x = 4, ct = 5)$, thereby preserving the coordinate relationships between the two frames.

Since there is no preferred frame when mapping events between frames, we must apply the Lorentz transformation correctly. Moreover, the coordinate time associated with the ct axis appears dilated when viewed from the S' frame, with $ct'_5 < ct_5$, while the spatial units in S' are contracted compared with those in S, in agreement with the predictions of special relativity. This difference reflects the distinction between coordinate time and elapsed proper time, which underlies the standard interpretation of "time dilation".

Consider 1 kg of water at 4°C, which occupies approximately 1 L. When the same quantity of water is cooled to 0°C or below, its volume changes, even though its mass remains constant. The underlying physical entity is unchanged, while its measured properties depend on the conditions of observation. Importantly, the quantity of water itself has not changed; only the conditions under which it is observed have been altered. When the temperature is restored, the volume returns to its original value while the mass remains unchanged throughout. The analogy is not exact, but it illustrates a general principle: changes in observational or measurement conditions can modify the numerical values assigned to certain properties without altering the underlying physical entity. Similarly, in relativity, changes in relative motion affect the measured duration associated with an event, while the event itself remains the same physical occurrence across all reference frames.

2.4 The standard presentation and its limitations

The classic thought experiment involving a moving train struck by lightning, first described by Einstein (1905), is frequently employed to illustrate the relativity of simultaneity. While this scenario successfully demonstrates how observers in different reference frames may perceive events differently, it may obscure the underlying physical reality.

This paper argues that part of the apparent disagreement between observers arises from inconsistent identification of reference points in addition to the standard relativity of simultaneity. When reference points are chosen carefully across both inertial and non-inertial frames (and when physical verification conditions are met), all observers can consistently compare the same physical events once the reference frame and transformation procedure are clearly specified. After all, simultaneity is not what we perceive or see, **but what we measure.** Two events are simultaneous when they have the same temporal coordinate in a given reference frame. If the events are initially described in different frames, their coordinates **must first be transformed consistently into each frame** before their temporal coordinates can be compared, without privileging any particular frame. If they are found to be simultaneous in one frame, then one may conclude that they are simultaneous, as described in Section 2.2 above.

2.5 A refined scenario

Consider a modified version of the train scenario: A train moves along a track at constant velocity. Two lightning strikes occur: a red strike on the left-hand side (points A' on the train, A on the tracks) and a green strike on the right-hand side (points B' on the train, B on the tracks). For simplicity, we assume the lightning passes through gaps between carriages, leaving marks on both the train and the tracks (Figure 9).

Verification conditions: For simultaneity to be established, three conditions must be satisfied

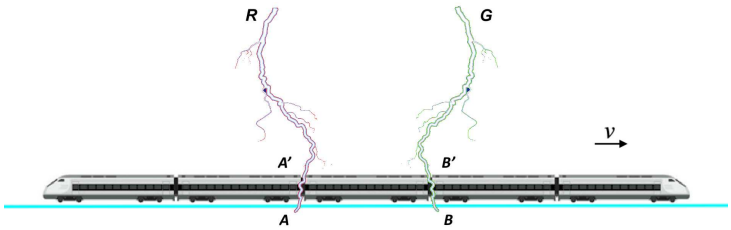

Figure 9: A train is struck by two lightning bolts in the order RA'A–GB'B

NikoUArxive_physic_20261018_983172

simultaneously:

1. Both strikes leave marks on both the train and the tracks.
2. The order of marks is consistent: Red aligns with A' and A, and Green aligns with B' and B.
3. The lengths AB, $A'B'$, L_0, and L' should be related to one another through Lorentz transformations.

Taken together, these three conditions establish a unique simultaneity relationship between frames S and S', preserved under the Lorentz transformation by ensuring that the temporal coordinates of events A and B to be equal under Lorentz transformation in both frames: $ct_A = ct'_{A'} = ct_B = ct'_{B'}$. This highlights the importance of selecting corresponding reference points both frames simultaneously. Accordingly, in Figure 3, projections are necessary to link the two frames within a common reference perspective. If A and B were located ahead of and behind the train, respectively, the comparison between the two frames would be incomplete, and the unique simultaneity frame could not be established due to incomplete data analysis. We believe this was what Einstein had in mind when he proposed the train thought experiment, but that he missed the point by focusing on clock synchronisation, which, as we demonstrate, is not mandatory.

Note: It is crucial to understand how each observer perceives these lengths:

a) From the platform observer's (P) rest frame: The train is moving at constant velocity. Consequently, the length of a carriage at rest (L_0) appears contracted to

$$L' = \frac{L_0}{\gamma}$$

For P, the distance AB on the tracks is only the spatial projection of the segment $A'B'$ on the train. However, P measures $A'B'$ as having the contracted length L'. Therefore, from P's perspective, $AB = L'$, so:

$$AB = \frac{A'B'}{\gamma} = \frac{L_0}{\gamma} = L'$$

b) From the train observer's (T') rest frame: The observer is at rest relative to the carriage, so the carriage retains its proper length, L_0. Thus, T' measures $A'B' = L_0$. However, for T', the track segment AB is moving and therefore appears contracted to a length L', ($AB = L'$). Consequently, T' measures

$$AB = \frac{A'B'}{\gamma} = \frac{L_0}{\gamma} = L'$$

Conclusion: The third condition is perceived differently in each frame, but both observers measure the same length AB:

$$AB = \frac{A'B'}{\gamma} = \frac{L_0}{\gamma} = L'$$

<u>This is where the mistake occurs: we forgot to apply the Lorentz transformation. Without this transformation, we end up assigning two different values to the same distance.</u>

NikoUArxive_physic_20261018_983172

Since $AB = L'$ in both frames, this is the first indication that simultaneity is not frame-dependent and that the observers should analyse points of reference from both frames simultaneously.

2.6 Observer perspectives

Platform observer (P): The observer on the platform perceives the strikes as simultaneous. This can be verified because:

1. Both strikes hit the train and the tracks
2. The order of marks is RA'A—GB'B
3. $$AB = \frac{A'B'}{\gamma} = L'$$

All conditions are met → simultaneity.

Train observer (T'): The observer on the train perceives the strikes as simultaneous as well:

1. Both strikes hit the train and the tracks
2. The order of marks is RA'A—GB'B
3. $$AB = \frac{A'B'}{\gamma} = L'$$

All conditions are met → simultaneity.

As long as these conditions are satisfied, both observers can consistently identify the same physical events and compare them without contradiction, even though their coordinate descriptions may differ.

2.7 Illustrative examples

Example 1: The green lightning hits first at points B' and B; then red lightning hits the train at point A'. Because the strike does not pass through the gap between carriages, the mark appears only on the train, not on the tracks (Figure 10).

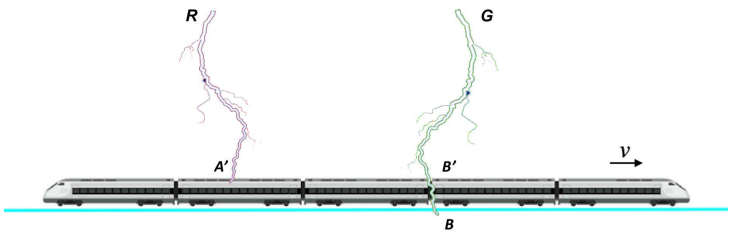

Figure 10: A train is struck by two lightning bolts in the order RA'–GB'B.

1. Both strikes hit the train, not the tracks → non-simultaneity
2. Order: RA'—GB'B → non-simultaneity
3. No complete comparison between the two reference frames is possible

Rule: Any combination of RA', RB, RB', GA, GA' or GB', will lead to non-simultaneity. However, RA or GB indicate whether the strikes occurred before or after the train; therefore, no complete comparison between the two reference frames is possible. **This does not mean that there is no simultaneity.**

Example 2: The red lightning strikes first at points B' (on the train) and A (on the track); the train moves, and then green lightning hits points A' (on the train) and B (on the track)

NikoUArxive_physic_20261018_983172

(Figure 11).

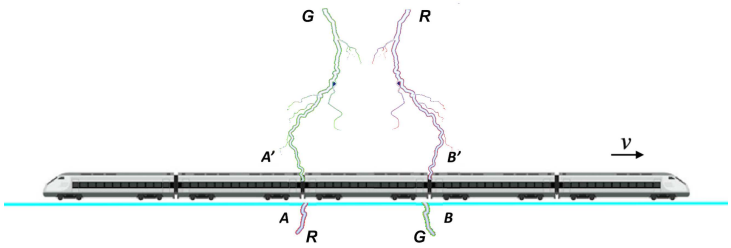

Figure 11: A train is struck by two lightning bolts in the order RB'A–GA'B.

1. Both strikes hit the train and the tracks, but their temporal-coordinate difference in the specified frame is non-zero → non-simultaneity
2. Order: RB'A–GA'B → non-simultaneity
3. For both observers:

$$AB = \frac{A'B'}{\gamma} = L'$$

Example 3: First, green lightning strikes points B' (on the train) and B (on the tracks) simultaneously in the ground frame, occurring just after carriage #1. As the train moves, red lightning strikes A' (on the train) and A (on the tracks, just after carriage #3). Consequently, the distance $A'B'$—measured within the moving train frame—has expanded from one carriage to two (Figure 12).

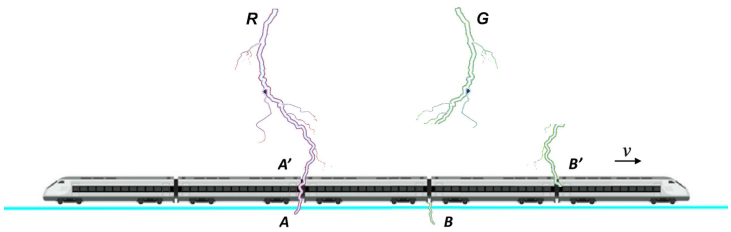

Figure 12: A train is struck by two lightning bolts in the order RA'A–GB'B (non-simultaneous)

1. Both strikes hit the train and the tracks, but their temporal-coordinate difference in the specified frame is non-zero → non-simultaneity
2. Order: RA'A—GB'B
3. For both observers:

$$AB = L' \neq \frac{A'B'}{\gamma} \rightarrow \text{non-simultaneity}$$

Note: In a particular scenario, AB can be equal to:

$$\frac{A'B'}{\gamma}$$

while still not being equal to L',

$$AB = \frac{A'B'}{\gamma} \neq L'.$$

2.8 The role of reference points

The platform observer analyses reference points from both frames ($A'B'$ from the moving frame and AB from the inertial frame) and therefore reaches a consistent conclusion about simultaneity. For the train observer, the situation differs: in Einstein's scenario, the train observer

NikoUArxive_physic_20261018_983172

analyses only reference points within their own moving frame (A' and B'), whereas in this framework, reference points are selected from both frames, making the conclusion more robust. **Since the Lorentz transformation is involved, analysing reference points from only a single frame can lead to incorrect conclusions if the transformation is not taken into account. By contrast, analysing reference points from both frames requires the transformation to be applied. Again, what we see is not necessarily what we measure.** This process is analogous to unit conversion: just as one must convert centimetres to inches to compare lengths accurately, one must apply Lorentz transformations to compare temporal measurements across frames. While special relativity remains valid within non-inertial frames, proper transformations are required when transferring measurements to an inertial reference frame.

2.9 The distinction between "now" and "observation"

A critical distinction must be made between the ontological present (the actual state of events occurring "now") and the epistemological delay (the time it takes for information to reach an observer).

Consider two events separated by a vast distance. While they may occur simultaneously in the common comparison frame, an observer will only become aware of the distant event after a delay determined by the speed of light. This delay creates the illusion that the distant event belongs to the "past", even though it is occurring in the frame-defined present.

Analogy: Imagine calling a friend and asking them to mail an original document. Your friend states, "I am sending it to you now.", while standing at the post office. However, you will not be "updated" about this event until the physical mail arrives days later. The act of sending the information and the later receipt of that information are distinct physical events. The delay between them is determined by the finite propagation speed of the signal. This observational delay should not be confused with the coordinate-time relation between distant physical events in a specified reference frame.

This illustrates that the plane of simultaneity (the set of events assigned the same coordinate time within a chosen reference frame) is fundamentally distinct from the observational slices (the set of events we have received information about). **The delay in receiving information does not negate the simultaneity of the events; it only reflects the finite speed of signal transmission.**

This distinction provides a direct resolution to the Andromeda Paradox Rietdijk (1966); Putnam (1967); Penrose (1989)—as originally formulated by Rietdijk (1966) and Putnam (1967). In that thought experiment, two observers walking in opposite directions are said to have different "nows" regarding an event in the Andromeda galaxy (millions of light-years away). Under the standard interpretation, this implies that reality itself is fragmented.

However, under the Time vs. Duration framework, the now in Andromeda is a single event. The difference between the two observers is not in the existence of the event, but in their observational slice. One observer's now slice intersects the light signal from Andromeda that left millions of years ago, while the other's intersects the same signal but slightly later.

The "paradox" arises only when we confuse the arrival of the signal (observation) with the occurrence of the event (reality). Once we separate the two, causal coincidence is preserved, and the paradox dissolves.

NikoUArxive_physic_20261018_983172

3 The Twin Paradox – Time vs. Duration

3.1 Distinguishing time from duration

A primary source of confusion surrounding the twin paradox lies in the conflation of two distinct concepts: time (coordinate time) and duration (proper time). In spacetime, coordinate time functions as a spacetime coordinate analogous to the spatial coordinates x, y, and z, while remaining physically distinguished by the metric signature.

Just as we do not directly measure x, y, or z but instead measure intervals Δx, Δy, and Δz, we do not directly measure time itself; rather, we measure Δt the duration between two events. A crucial distinction emerges:

- While there is no preferred frame, time itself, expressed as coordinate time, provides a common temporal reference for all observers (all observers perform their calculations with respect to the spatial coordinate x and the temporal coordinate ct).
- Duration—proper time—depends on the geometry of the world-line and therefore differs for observers following different inertial or accelerated trajectories.

Einstein implicitly distinguished between two notions of time: the time coordinate of a system and the time measured along an observer's world-line; distinctions later formalised as coordinate time and proper time. Over the past century, translation nuances and interpretive drift have rendered these terms a source of ongoing confusion. When Einstein stated that time is relative, he likely referred to "proper time". This terminology is somewhat misleading, as "proper" suggests something to be taken for granted. More precise alternatives might include "relative time", "observer's time", or "proper duration". Coordinate time serves as the universal reference for all observers; all calculations reference it. From this perspective, coordinate time functions as the temporal axis itself and should be considered a common comparison frame. Proper duration, by contrast, depends on the observer's world-line and can be affected by both relative velocity and acceleration. This is why duration is not continuous in the same way as coordinate time, and why Einstein described proper duration as relative.

Special relativity asserts that no reference frame is preferred—all observers are equally valid within their own frames. However, meaningful comparison of events or measurements between frames requires agreement on a common reference frame for performing transformations. Without such consensus—for instance, without agreeing on which train is under discussion—comparisons become impossible. In this operational sense, the agreed-upon frame assumes the role of a common comparison frame with frame-defined simultaneity values and coordinates.

This distinction parallels the relationship between mass and weight: mass remains constant regardless of gravitational environment, while weight varies with local conditions. The distinction between coordinate time and duration can clarify pedagogical misunderstandings of special relativity without challenging the theory's mathematical framework.

3.2 Mathematical framework

Consider the following parameters for analysis:

- Speed: $v = 0.8c$
- Distance (Earth to star, rest): 4 light-years
- Round-trip distance (L_0): 8 light-years

In the inertial frame (Earth):

$$\Delta t_0 = \frac{L_0}{v} = \frac{8}{0.8} = 10 \text{ years}$$

NikoUArxive_physic_20261018_983172

Lorentz factor:

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{1}{\sqrt{1 - 0.64}} \approx 1.67$$

Length contraction (moving inertial frame):

$$L' = \frac{L_0}{\gamma} = \frac{8}{1.67} = 4.8 \text{ light-years}$$

Proper duration (traveller):

$$\tau = \frac{\Delta t_0}{\gamma} = \frac{10}{1.67} \approx 6 \text{ years}$$

Difference in durations:

$$D_{difference} = \Delta t_0 - \tau = 10 - 6 = 4 \text{ years}$$

3.3 Velocity consistency check

From the traveller's perspective, the velocity calculation must remain consistent:

$$v = \frac{L'}{\tau} = \frac{4.8}{6} = 0.8c$$

3.4 The return to the rest frame

The situation becomes more complex when the spaceship returns to Earth and comes to rest again. At that point, the distance between Earth and the star returns to its original value—4 light-years (8 light-years round-trip). The traveller's clock records only 6 years of proper duration, but this does not imply that "time itself" has been permanently altered. The traveller's clock cannot be "reset" to the elapsed coordinate time. Once motion ceases and both twins are again in rest frames, physical quantities such as distance and time are consistently defined—there is no paradox.

3.5 Addressing common misconceptions

Common error: After the journey ends, some incorrectly compute the traveller's velocity using untransformed quantities.

$$v = \frac{L_0}{\tau} = \frac{8}{6} = 1.33c \quad \text{(Yields superluminal speed} \rightarrow \text{physically invalid)}$$

This calculation incorrectly transfers untransformed measurements (τ) from one frame to another, yielding a superluminal velocity ($v > c$) that contradicts the fundamental postulates of special relativity. Years measured in a non-inertial frame are not directly equivalent to inertial frame years: each frame possesses its own consistent system of measurement. Upon the restoration of the length to its rest value in the inertial frame, the measured duration must likewise revert to its corresponding inertial-frame value; the two quantities are inextricably linked by the Lorentz transformation. **We must not conflate a physical clock with a mathematical clock (a calculated duration):** a physical clock never reverses its readings, whereas the mathematical calculation must remain consistent. In reality, the two clocks will never show the same duration, since the physical clock cannot account for velocity and acceleration effects.

Correct approach: Apply the Lorentz factor to recover inertial-frame consistency.

$$v = \frac{L_0}{\tau \times \gamma} = \frac{8}{6 \times 1.67} = \frac{8}{10} = 0.8c$$

NikoUArxive_physic_20261018_983172

$$\Delta t_{Spaceship} = \frac{\gamma \times L'}{v} = \frac{L_0}{v} = \frac{8}{0.8} = 10 \text{ years}$$

3.6 The limit as v approaches c

As velocity approaches the speed of light:

$$\lim_{v \to c^-} \gamma = \infty$$

$$\lim_{v \to c^-} \tau = \lim_{v \to c^-} \frac{\Delta t_0}{\gamma} = 0$$

$$\lim_{v \to c^-} L' = \lim_{v \to c^-} \frac{L_0}{\gamma} = 0$$

The limit $\lim_{v \to c^-} \tau = 0$ should not be interpreted as light "stopping" or having no duration. Photons do not possess a rest frame in special relativity. We are simply evaluating the mathematical limit of the proper duration expression using the Lorentz transformation, without requiring a physical rest frame for the photon.

$$v = \frac{L_0}{\tau \times \gamma} = \frac{L_0}{\Delta t_0}$$

$$\lim_{v \to c^-} v = \lim_{v \to c^-} \frac{L_0}{\Delta t_0} = \frac{L_0}{\frac{L_0}{c}} = \frac{L_0}{L_0} \times c = c$$

The vanishing of proper duration ($\tau \to 0$) and contracted length ($L' \to 0$) does not imply a breakdown of physics, but rather that the "relative" measurements collapse to zero while the "absolute" coordinate relationship $L_0 = \Delta t_0 \times c$ remains intact. This supports the paper's thesis that coordinate time and simultaneity serve as the stable, common comparison frame, while duration and length are relative measurements subject to transformation. Attempting to substitute numerical values directly into expressions involving infinity leads to meaningless results. Instead, algebraic simplification reveals the correct behaviour: To find the coordinate time in the limit as $v \to c^-$, we first simplify the algebraic expression before applying the limit:

$$\Delta t_{\text{Light}} = \frac{\gamma \times L'}{c} = \frac{\gamma \times \frac{L_0}{\gamma}}{c} = \frac{L_0}{c}$$

Now, taking the limit as $v \to c^-$:

$$\lim_{v \to c^-} \Delta t_{\text{Light}} = \frac{L_0}{c} = \frac{8 \text{ ly}}{c} = 8 \text{ years}$$

This demonstrates that while $\gamma \to \infty$ and $L' \to 0$ individually, their product remains finite and equal to the rest distance L_0, preserving the consistency of the speed of light.

If a mirror were placed on the star and a laser beam bounced back to Earth, the light would take 8 years to complete the journey. The travelling twin could not make the round trip in only 6 years while travelling at $v = 0.8c$.

3.7 Photons and proper duration

The claim that "photons don't experience time" requires careful interpretation. Along a null world-line, the proper duration interval between emission and absorption is zero. After absorption, the energy and momentum of the photon contribute to the state of the absorbing system,

whose subsequent world-line may have a non-zero proper duration. However, when compared with other reference frames, corrections must be applied. If proper duration were absolute, no corrections would be necessary. The fact that corrections are required indicates that proper duration is relative to the observer's state of motion.

4 An analogy for simultaneity

Consider a book where two words, A and B, appear on the same page (page 9). Their creation timestamp is identical—simultaneity frame. This establishes their simultaneity within the book's structure—spacetime. If a reader browses the book randomly or backwards (observer-frame-dependent), they may encounter a word B on page 35 and a word A on page 20. This creates the illusion that the words appeared at different times t_{35} and t_{20}. However, these timestamps represent the moment of observation, not the moment of creation. By returning to the correct reference point—the first page—and verifying that both words share the original timestamp t_9, we confirm their simultaneity. It is logically impossible for two distinct events to share an identical creation timestamp unless they are, by definition, simultaneous—the same simultaneity frame. Even if the words reappear later on the same page (t_{30}), this does not alter the simultaneity frame established at the moment of their creation (t_9). **This acts like the $E = E' = Ep$ wild card shown in Figure 4.**

Thus, the simultaneity frame is preserved, even when compared against itself across different instances of observation, while the observation of events is frame-dependent.

Simultaneity and observation **must not be conflated.**

NikoUArxive_physic_20261018_983172

5 Conclusion

5.1 Conclusion regarding simultaneity

- Our analysis suggests that Lorentz's original physical interpretation from his earlier work Lorentz (1895) provides a more consistent account of invariant proper lengths than the standard relativity of simultaneity framework.
- We should not conflate simultaneity with observation; a simultaneity frame is distinct from an observational slice through spacetime.
- An incomplete analysis within a given reference frame does not imply that simultaneity does not exist.
- When two events occur simultaneously, they possess their own reference frame—a simultaneity frame—which is preserved when transferred across different reference frames.
- Since the coordinates of an event are observer-dependent, the events remain simultaneous even if, in one frame, their coordinates do not indicate this. If an observer has not been informed about an event and therefore cannot assign coordinates to it in the simultaneity frame, the events still retain the same physical properties: they remain simultaneous.
- The framework presented above indicates that while observational slices through spacetime are frame-dependent, simultaneity is determined by the temporal coordinate (t), which maintains its value across different frames, **when the Lorentz transformation is applied correctly.**
- When reference points are chosen carefully and proper transformations are applied, all observers should agree on whether events are simultaneous. Apparent paradoxes arise not from the physics itself, but from inconsistent application of reference points or failure to apply necessary corrections when transferring measurements between frames.

NikoUArxive_physic_20261018_983172

- The spacetime diagram analysis assumes that the "vertical" axis represents the common temporal dimension, and the tilt represents the relative measurement of duration.
- By treating coordinate time as the common reference frame and proper duration as the relative measurement, we preserve the mathematical rigour of special relativity while eliminating the semantic ambiguities that lead to paradoxes. This approach does not replace Einstein's theory but rather refines the language used to describe it, making the transition from Newtonian intuition to relativistic reality more seamless.
- Although no reference frame is preferred, the rest frame often provides a more stable and reliable basis for interpretation, since relative motion can affect how observations are interpreted. Nevertheless, Lorentz corrections may still be necessary in certain cases.

5.2 Conclusion regarding the twin paradox

In many textbook treatments, the scenario is idealised by assuming that the travelling twin remains inertial over most of the trajectory, thereby simplifying the analysis. However, this approximation obscures the essential role of acceleration in enabling the return segment of the journey. The resulting asymmetry is often discussed in terms of a discontinuous "jump" in simultaneity Rindler (2006); however, such a feature arises from the construction of piecewise inertial frames and does not represent a physical effect.

- As noted above, the formalism admits a more direct and transparent treatment without invoking this artefact ("the jump"). Moreover, in the limiting case of purely inertial motion, the proper duration of the traveller coincides with that of the Earth-bound twin within a single inertial frame. These considerations underscore the importance of employing a physically consistent, rather than overly idealised description of the scenario.
- As illustrated in Figure 8, the traveller's proper duration is consistently shorter than the coordinate time (Δt_0) from the outset. This demonstrates that the observed "time dilation" is not a consequence of changing symmetries or reference frame transitions (such as turning around), but is an inherent effect of motion itself. **Even if the traveller never returns to Earth and continues indefinitely in a straight line, their proper duration remains shorter relative to Δt_0.** Consequently, the coordinate time in the rest frame appears dilated from the perspective of the traveller's frame. It is this perceived expansion of the rest frame's coordinate time that gives rise to the term "time dilation", while in reality the proper duration along the world-line is shorter.
- More importantly, for both twins, the journey's duration and distance are divided into the **same number of grid divisions**—five units of time and four units of length per leg—despite their differing perceptions of those units. They employ different measurement systems, yet the coordinate values describing the events remain the same. Crucially, these two time intervals can still be compared and reconciled, provided we select reference points from both the inertial and moving inertial frames simultaneously, or perform the correct Lorentz transformation.
- As we can see in Section 2.2 and Section 2.3, the labels are not mandatory, as they are observer-dependent, provided that the Lorentz transformation is applied consistently. Even if we have not been informed about an event and therefore cannot assign any labels to it, the event retains its physical properties.
- The traveller twin appears to have aged less **only** while moving. **Once motion ends and both twins are again in rest frames, physical quantities are consistently defined.** The apparent age difference reflects the accumulated duration measured by the traveller's clock during the moving portions of the journey, not a fundamental alteration of time itself.
- The main reason we struggle with the twin paradox is that we transfer "raw" measurements from a moving reference frame to an inertial frame without applying the *correction*

factor. Similarly, neglecting frame-to-frame corrections in relativistic scenarios leads to apparent paradoxes that dissolve under proper analysis. Moreover, drawing an incorrect or oversimplified grid for the moving inertial frame further amplifies the confusion.

The mathematics of special relativity are robust; only the way we interpret the conclusions after analysing the events needs to be readjusted.

Ultimately, **no paradox remains once the data are complete and have been fully and consistently analysed.**

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Note: This may not be the latest version of the paper. Please refer to the Zenodo link in the references for the latest version of full repository (including Python scripts).

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