

Einstein's train scenario revised

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(Preprint — September 2026)

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Disclaimer: *This is only a revised chapter from a more complex work Time vs. Duration : A Reinterpretation of Special Relativity, that can be found on NikoUArXive server: <https://www.nikouarxive.com/article.php?id=34>*
(Preprint ID: NikoUArXive_physic_20260828_844919)

Abstract

This paper revisits Einstein's classic train thought experiment to address persistent conceptual difficulties in interpreting simultaneity within Special Relativity. While affirming the mathematical formalism remains experimentally valid, we argue that apparent paradoxes stem from conflating frame-dependent coordinate assignments with invariant event structures. By introducing verification conditions requiring marks on both train and tracks, and emphasising proper Lorentz transformations when transferring measurements between frames, we demonstrate that observers in both inertial and non-inertial reference frames can consistently identify the same physical events. The distinction between observational slices through spacetime and true simultaneity planes resolves lingering pedagogical confusions without modifying the theory's structure.

Aim: To clarify the interpretation of simultaneity in Einstein's train scenario by distinguishing frame-dependent observations from invariant event structures.

Keywords: Time, Duration, Simultaneity, Paradox, Train, Scenario

1. Introduction

It is crucial to clarify the scope of this inquiry: this paper does not seek to refute the mathematical formalism or empirical predictions of Special Relativity, which remain robust and experimentally verified. In particular, we focus on two related issues:

- the distinction between what we see and reality
- the interpretation of simultaneity choosing reference points from both frames: inertial and accelerated one

This interpretation does not modify the formal structure of Special Relativity, but concerns only the ontological interpretation of reference points and event identity. 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

These difficulties are often pedagogical rather than physical. As noted in standard treatments (e.g. [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. The standard presentation and its limitations

The classic thought experiment involving a moving train struck by lightning, first derived 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.

2.1. The misinterpretation

In Einstein's example, the belief is that the observer on the platform sees the two strikes simultaneous while the observer on the train can argue about that since it is moving at a high velocity.

In reality things are a bit different: the platform observer is at rest while the train is moving. For that reason, he sees the train contracted as $L' = \frac{L_0}{\gamma}$. On the other hand, the observer on the train is at rest regarding the train, so for him the train has the same length as the train at rest. Since the observer is located in the middle of the train and is at rest regarding the train, the distances between him and the two ends of the train remain the same (equal) for the entire experiment. Since the light travels with the same speed in inertial and in accelerated frames, the light signal from the flash in front of the train will travel the same distance and will arrive in the same moment with the light signal from the end of the train flash. Because he is in an inertial frame regarding the train, he will

definitely see the light flashes as simultaneous while the platform observer can disagree. That's opposite than what the textbooks teach us.

2.2. 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 1).

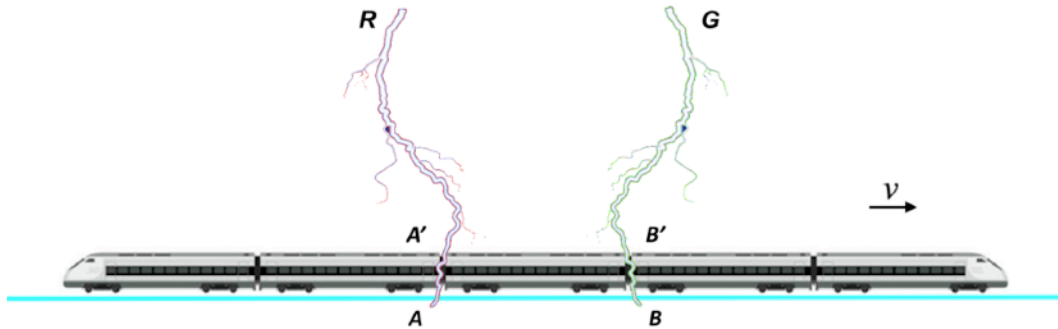


Figure 1. A train is struck by two lightning bolts in the order RA'A-GB'B

Verification conditions:

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

- Both strikes leave marks on both the train and the tracks.
- The order of marks is consistent: Red aligns with A' and A, and Green aligns with B' and B.
- The transformed length A'B' must relate to the original length AB via Lorentz transformation.

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 merely the contracted spatial projection of the segment A'B' on the train. However, P regards A'B' itself as uncontracted. Therefore, from his perspective, A'B' has the proper length L_0 , whereas AB is its contracted projection ($AB = L'$), so *this is where we make a mistake: we forgot to apply the Lorentz transformation. Without this transformation, we end up assigning two different values to the same distance*, 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 thus appears contracted. Consequently, T measures

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

Conclusion: The third condition is perceived differently in each frame, but the length of AB stays the same in both frames:

- For P: $AB = \frac{A'B'}{\gamma} = \frac{L_0}{\gamma} = L'$

- For T: $AB = \frac{A'B'}{\gamma} = \frac{L_0}{\gamma} = L'$

Since $AB = L'$ in both frames, this is the first indication that simultaneity is not frame-dependent and that the two frames should agree.

2.3. Observer perspectives

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

- Both strikes hit the train and the tracks $\rightarrow$ simultaneity
- The order of marks is RA'A—GB'B $\rightarrow$ simultaneity
- $AB = \frac{A'B'}{\gamma} = L' \rightarrow$ simultaneity

Train observer (T): The observer on the train perceive the strikes as simultaneous as well:

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

2.4. Illustrative examples:

Example 1: 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 2).

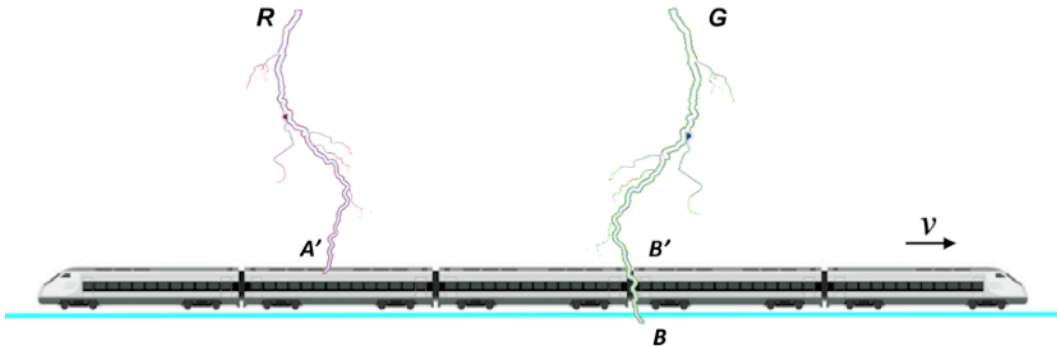


Figure 2. A train is struck by two lightning bolts in the order $RA'–GB'B$.

- Both strikes hit the train, not the tracks $\rightarrow$ non-simultaneity
- Order: $RA' - GB'B \rightarrow$ non-simultaneity
- For both observers $AB \neq \frac{A'B'}{\gamma} = L' \rightarrow$ non-simultaneity

Example 2: 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) (Figure 3)

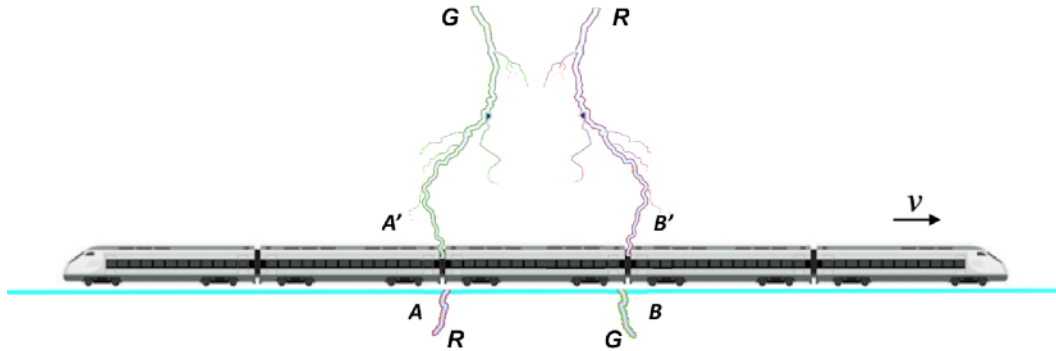


Figure 3. A train is struck by two lightning bolts in the order $RB'A - GA'B$.

- Both strikes hit the train and the tracks
- Order: $RB'A - GA'B \rightarrow$ non-simultaneity
- For both observers $AB = \frac{A'B'}{\gamma} = L'$

Rule: Any combination of RB' , RB , GA' , or GA will lead to non-simultaneity (where RB and GA means the strikes were before or after the train).

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 4).

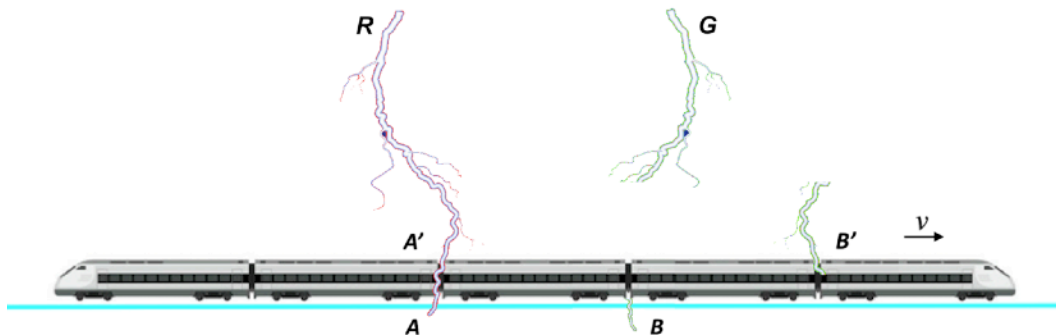


Figure 4. A train is struck by two lightning bolts in the order $RA'A - GB'B$ (non-simultaneous)

- Both strikes hit the train and the tracks
- Order: RA'A—GB'B
- For both observers $AB \neq \frac{A'B'}{\gamma} = L' \rightarrow$ non-simultaneity

Note: in a particular scenario, AB can be equal to $\frac{A'B'}{\gamma}$, while still not being equal to L'

$$\left(AB = \frac{A'B'}{\gamma} \neq L' \right).$$

2.5. 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: they initially analyse only points of reference from their own moving frame—A', B'. To reach the same conclusion, they must either apply appropriate corrections when transferring measurements to the inertial frame or select reference points from both frames.

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.

3. Conclusion on interpretation:

- We should not conflate simultaneity with observing (simultaneity plane with observational slices through spacetime).

- 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, not by “simultaneity line” which is in fact an **observational** line. Observational lines are frame dependent while simultaneity is not.

- 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.

- Special Relativity remains fully valid during motion; however, attempting to retain untransformed measurements after the motion has ceased leads to apparent paradoxes, incorrect results, and conceptual confusion.

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

4. References and Bibliography:

- Einstein, A. (1905). "On the Electrodynamics of Moving Bodies." Annalen der Physik, 17, 891-921.

← [Return to Section 2](#)

- Taylor, E. F., & Wheeler, J. A. (1992). Spacetime Physics (2nd ed.). W.H. Freeman.

← [Return to Section 1](#)

- French, A. P. (1968). Special Relativity. W.W. Norton & Company.

← [Return to Section 1](#)

- Ion Vlad, "Time vs Duration: Lorentz-Consistent Minkowski Diagrams", (2026), DOI = 10.5281/zenodo.20506983, Zenodo, url = <https://doi.org/10.5281/zenodo.20506983>, note = Preprint. Available at: <https://zenodo.org/record/20506983>