Is it necessary to reinterpret the Theory of Relativity ?

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As it is known, the Lorentz Transformation is the transformation of coordinates between reference systems in uniform relative motion that is at the basis of the Theory of Relativity. But what is its physical meaning? What do the variables obtained by applying this mathematical transformation represent, physically?

The interpretation that currently prevails in the context of contemporary physics is that these variables represent the physical space and time coordinates of a given event for a reference system in uniform and rectilinear motion with respect to another one. According to this interpretation, two events that are simultaneous for a given reference system are not simultaneous for another reference system that is in motion with respect to the first one, the so-called *"relativity of simultaneity"*, and therefore time and space are no longer absolute, invariant in the passage from one reference system to another, but become relative, resulting dependent from the state of motion of the system being considered.

However, as already observed by C. Somigliana in his paper presented to the Accademia dei Lincei over a century ago [1], this is not the only possible interpretation of the Lorentz Transformation. There is thus a need to establish a criterion to uniquely determine the correct physical interpretation of this mathematical transformation. To address this need, the manuscript [2], titled *"Preserving Absolute Simultaneity with the Lorentz Transformation"*, introduces a general clock synchronization criterion based on isotropic signals of any physical nature. Using this criterion and the mathematical properties of the Lorentz Transformation, it is demonstrated that the variables obtained by applying this transformation cannot be considered as real physical coordinates but must instead be interpreted as particular mathematical entities, which can be called *"generalized space-time coordinates"*, having specific invariance characteristics by virtue of the form of the Lorentz Transformation and of its properties.

In this alternative interpretation, the simultaneity of events, and with it also time and space, return to have an absolute character, invariant with respect to the state of motion of the observer and the corresponding reference system. This new interpretation of the Lorentz Transformation, which is not only more general and coherent, being valid for any value of the propagation speed of the synchronization signals, allows to remove all the paradoxes and contradictions that derive from the standard interpretation of Special Relativity. To illustrate its key features it may be useful to use the example of a simple physical system.

Let us consider a train moving with constant speed V on a straight track, and suppose that when the train arrives at the station platform, it activates the simultaneous lighting of a series of equidistant lampposts placed along the platform itself. Since all the posts are aligned with the rail track, we can take this direction as the x axis of a reference system K fixed to the station platform and having its origin O in correspondence of the first lamppost. For convenience, let us assume that in this reference system all the lamps light up at the instant $t = 0$.

With respect to this reference system K, the space and time coordinates of the events that represent the lighting of each lamppost are given by:

$$E_j \equiv (x_j, t_j) = (jL, 0) \qquad \textit{with} \qquad j = 0, 1, 2, ...N \tag{1}$$

where L is the distance that separates two consecutive posts.

Plotting the coordinates of these events in a two-dimensional graph, we obtain the diagram shown in Figure 1. As it can be noted from the graph, all the events corresponding to the lightning of the lampposts are aligned along a straight line, which is parallel to the x-axis and intercepts the y-axis at the value $t = 0$. This straight line divides the x-t plane into two non-intersecting regions: the region below it contains all the events characterized by having $t < 0$, i.e. all the events that occurred before the lamps were lit (region of the past), while the region above the straight line contains all the events having $t > 0$, i.e. all the events that occur after the lighting of the lamps (region of the future).

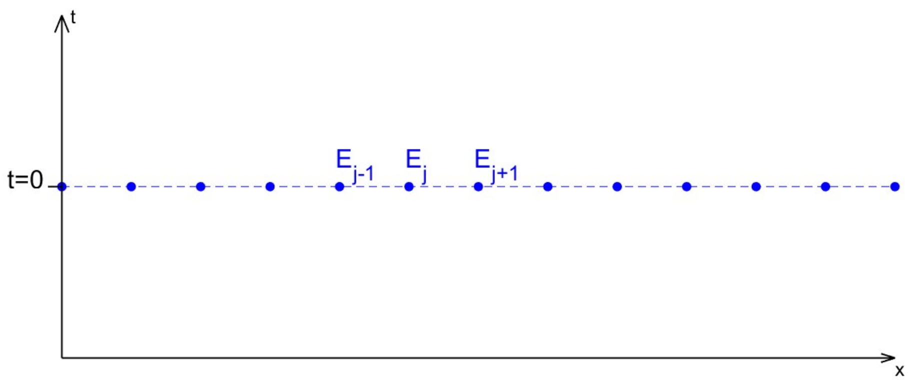

Figure 1: *The lamps lightning events in the reference system K fixed to the platform.*

Let's now define a reference system K' fixed to the train and rigidly moving with it. Let's assume that the x' axis of this mobile reference system is parallel to the x axis of the stationary reference system K and let's set the origin O' of K' so that it is coincident with the origin O of K when the first lamppost of the station, the one located at $x = 0$, is switched on by the arrival of the train. With respect to the stationary system K, the mobile system K' is therefore in a state of uniform rectilinear motion with relative velocity V along the x axis. Denoting with t' the time coordinate in this mobile reference system, we can set $t' = 0$ when the origin of K' coincides with the origin of K. With these assumptions, when the train reaches the position corresponding to the position of the first post, it is $t' = t = 0$.

Let us now introduce, between the stationary reference system K and the moving one K', a coordinate transformation having the same mathematical form of the Lorentz Transformation:

$$x' = \frac{x - Vt}{\sqrt{1 - \frac{V^2}{v^2}}}; \qquad t' = \frac{t - \frac{V}{v^2}x}{\sqrt{1 - \frac{V^2}{v^2}}}; \tag{2}$$

where the parameter v is a positive constant representing the finite speed of isotropic propagation of the signals used to synchronize the clocks in the reference system K.[1]

Inserting the coordinates (1) into (2), it is immediate to calculate, in the moving reference frame, the transformed coordinates of the events E'_j which represent the lighting of the various lamps placed along the platform:

[1]Putting $v = c$ in this expression, where c is the speed of light in vacuum, we obtain the Lorentz Transformation. This transformation therefore represents a particular case of the transformation (2) which is obtained by choosing light signals propagating in vacuum as clock synchronization signals.

$$E'_j \equiv (x'_j, t'_j) = \left(\frac{jL}{\sqrt{1-\frac{V^2}{v^2}}}, \quad -\frac{\frac{V}{v^2} jL}{\sqrt{1-\frac{V^2}{v^2}}} \right) \qquad with \qquad j = 0, 1, 2, ...N \tag{3}$$

Similarly to what previously done, we can now plot the transformed coordinates of the lamp lighting events in a two-dimensional diagram. As it can be seen from Figure 2, also in this case in the x'-t' plane the coordinates of all these events are aligned along a straight line. However, while in the reference system K, stationary with respect to the platform, this straight line is parallel to the x axis, in the moving frame K' this straight line is tilted with respect to the x' axis and forms a non-zero angle with it. This corresponds to the fact that, while in the stationary system all events E_j have the same value of the time coordinate, i.e. it is $t_j = 0$ for every value of j, in the mobile reference frame K', instead, each event E'_j is characterized by a different value of the transformed time coordinate, i.e. it results $t'_i \neq t'_j$ for every $i \neq j$ and therefore $t'_j \neq 0$ for every $j \neq 0$.

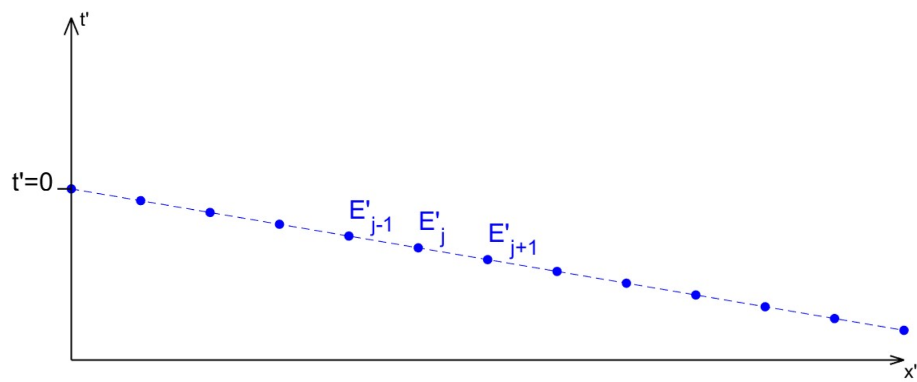

Figure 2: *Coordinates of the events of lamppost lighting in the moving reference system K'.*

We can now once again ask ourselves what is the physical meaning of these specific properties of the transformed coordinates x' and t', properties which derive directly from the mathematical form of the transformation (2).

In particular, for what concerns the transformed time coordinate, is it correct to say that t' represents physical time in the moving reference frame or is it necessary to assign a different physical meaning to this variable?

Let's start by examining the question for a specific case. Assuming no wind and homogeneity of the air characteristics along the railtrack, we can use acoustic signals to synchronize the clocks in the stationary reference frame K. In this scenario the constant v that appears in the transformation (2) represents the characteristic speed of sound propagation in the atmosphere. In this specific case we can state with certainty that the transformed variables x' and t' do not represent physical space and time in the mobile system K' since, if this were the case, it would result that the speed of sound represents a speed limit that cannot be exceeded, since for $V > v$ the transformed variables obtained from (2) become imaginary and therefore lose their physical meaning. In reality we know from experience that it is possible to travel at supersonic speed and that exceeding the speed of sound has no consequences on the passage of time. It can therefore be concluded that in the case of acoustic synchronization signals the variables x' and t' cannot be interpreted as true physical coordinates.

But if the transformed variables x' and t' do not represent the physical space and time in the moving reference frame K', how can they be interpreted? Without losing generality, these variables can be considered as *"generalized space-time coordinates"*, that is, as mathematical entities having specific properties that derive from the characteristics of the transformation (2). With this interpretation, in the mobile reference frame K' the condition of simultaneity of two events i and j is no longer given by the equality of the respective transformed time coordinates, that is, it is no longer given by the equality $t'_i = t'_j$, but rather by the belonging of the corresponding transformed point-events E'_i and E'_j to the inclined straight line of Figure 2 (or to a straight line parallel to it, for events that occur at times different from $t = 0$ in the stationary reference frame K). We can therefore state that in the moving frame K' this tilted straight line represents the line of simultaneity of events. Also in this case this straight line divides the x'-t' plane into two distinct and non-intersecting regions, the region below the straight line contains all the events that occurred before the lightning of the lampposts (region of past events), while the region above it contains all the subsequent events (region of future events).

Let us now consider the case, always assuming no wind and constant properties of the air along the railtrack, of using light signals to synchronize the clocks in the reference system K attached to the platform. In this case, the constant parameter v that appears in the transformation (2) takes the value of the speed of light in the air, that is, $v = c_o = c/n$, where n represents the refractive index of air ($n > 1$). Also in this case, in the x'-t' plane, the transformed events E'_j result aligned along a straight line tilted with respect to the x' axis. The amount of tilt of this straight line depends on the value of the ratio V/c_o and progressively reduces as this ratio decreases, but without ever becoming equal to zero (except in the trivial case of zero speed of the train). Since the speed of light in air varies with the physical conditions of the medium, if we were to interpret the transformed time variable t' as physical time, we would have to conclude that for an observer in motion with speed V, time depends on the characteristics of the medium in which the synchronization light signals propagate. But this interpretation, which is not considered valid even in the context of the Theory of Relativity, is not acceptable because it would imply that in the moving reference frame K' time depends on a physical characteristic that is completely unrelated to the system itself. In fact, this would mean to admit that for an observer moving with the train the flow of time varies as a function of the specific characteristics of the atmosphere in which the train is moving and that therefore, for example, time for an observer on the train varies as a function of the temperature of the external air. Therefore, also in the case of light signals propagating in the air with speed c_o lower than c we can conclude that the transformed variables obtained from (2) do not represent the physical coordinates for the moving reference frame, but must be considered, similarly to the previous case, as *"generalized coordinates"* and the simultaneity condition of the events in the x'-t' plane is given by the belonging of the transformed point-events to the inclined line of Figure 2.

Let us now consider the case of the Lorentz Transformation, that is, let us consider the particular case of the transformation (2) that is obtained by setting $v = c$. On the basis of the same considerations previously exposed, the interpretation of the transformed variables x' and t' as *"generalized coordinates"* is evidently valid and applicable also in this particular case, which from the physical point of view represents the limit that is obtained when the density of the propagation medium of the synchronization light signals tends to zero.

In the context of Special Relativity, however, this is not the commonly accepted interpretation and it is assumed instead that the transformed variables x' and t' actually represent physical space and time for the moving observer, with the related effects on length contraction and time dilation, and the corresponding implications on the simultaneity of events for moving observers, the so-called relativity of simultaneity. The relativistic interpretation therefore represents an exception to the general case, a *singularity of interpretation* applicable only to the case in which $v = c$ is set in the transformation (2), i.e. applicable only to the particular case of using light signals propagating in vacuum as synchronization signals, while in all other cases, characterized by having $v \neq c$, the variables x' and t' obtained from (2) are not considered as real physical coordinates of the transformed events.

Which are the consequences of adopting the relativistic interpretation to the case of the lightning of the lampposts at the arrival of the train to the station?

Let's start by observing that from the expression (3) of the transformed coordinates of the events of switching on of the lamps, it results $t'_j < 0$ for each value of $j > 0$, that is, it results that in the mobile reference frame K' the switching on of each lamp, apart the one placed at the beginning of the station platform, occurs in correspondence of a negative value of the transformed time variable t'. Since in its movement with uniform speed along the positive direction of the x axis the train reaches the station platform only at time $t' = 0$, this means that the event E'_j, that is, the event of switching on of the j-th lamp in the reference frame K', occurs when the train has not yet reached the station platform. But, on the basis of how the system under consideration has been defined, when the train has not yet reached the station platform all the lamps are still off. Therefore, interpreting the transformed variable t' as the physical time of the moving system leads to an unsolvable contradiction, as it would force us to admit that each lamppost placed along the platform (except the first one) is at the same time both on and off, but this is impossible. Therefore, the relativistic interpretation of the variables obtained from the Lorentz Transformation must be discarded being in contradiction with the physical reality of the system under consideration.

This is not the only contradiction associated with the relativistic interpretation of the Lorentz Transformation. In fact, as shown in the manuscript [2], if we consider two parallel light beams propagating in vacuum, it is possible to demonstrate that the speed of light propagation of one of the two beams with respect to a reference system linked to the other beam, calculated using the relativistic rule of composition of the velocities, turns out to be zero, that is, it results that the speed of light with respect to a luminal observer is equal to zero. This result therefore contradicts the postulate of invariance of the speed of light, which is one of the two cardinal postulates on which the theory itself is based and represents therefore an internal contradiction of the Theory of Special Relativity .

On the basis of what stated above, it can therefore be observed that the new interpretation of the Lorentz Transformation, discussed here by applying it to the example of the lampposts turned on by the passage of the train, according to which the variables obtained from this transformation must not be considered as true physical coordinates but as *"generalized coordinates"*, is the only possibility free from contradictions and paradoxes from a logical, mathematical and physical point of view, and that is valid for any value of the parameter v.

The difficulties of interpretation do not regard just the theoretical and conceptual elements but are applicable also to the experimental aspects as well. In fact, although it is widespread belief that there is a vast basis of experimental evidence that confirms the validity of the Theory of Special Relativity, it should be noted that also such experimental evidences can be susceptible to different possibilities of interpretation and can be compatible with alternative physical models that do not use the deformation of space-time to explain the obtained experimental results . A remarkable example from this point of view is represented by the Michelson-Morley interferometric experiment. The null result of this experiment can in fact be explained not only by invoking the effects predicted by the Theory of Relativity, but also by making use of the Ritz emission theory [3], or by adopting the hypothesis of the dragging of the aether. A similar situation occurs also for many other experiments, whose results can be prone to different possibilities of interpretation and therefore not conclusive [4].

It could therefore be worth to identify further experimental elements that could allow to unambiguously establish which is the correct physical interpretation. In order to achieve this result, the experimental test should be as simple and direct as possible. Ideally, since the Lorentz Transformation involves only kinematic elements, its experimental verification should investigate only these elements, excluding other factors or physical effects that could complicate or make the interpretation of the results non-unambiguous. A possible test of this type, based on the use of time series of accurate astrometric observations and aimed at experimentally verifying the invariance of the speed of light with respect to the motion of the observer, is described in the last section of the aforementioned manuscript [2].

The new elements presented here could somehow contribute to initiate a thorough process of revision of the theoretical and experimental foundations of the Theory of Relativity, aimed in particular at re-evaluating the validity of the current standard interpretation of the Lorentz Transformation. Such a critical review would in any case have positive outcomes for Physics. In fact, if solid and motivated arguments were to emerge from it, capable of refuting the objections raised with respect to the standard interpretation of the Lorentz Transformation, then the Theory of Relativity would result even stronger, having demonstrated of being able of passing new tests, both at theoretical and experimental level. Conversely, if the alternative interpretation of the Lorentz Transformation proposed here were to be confirmed as valid, the resulting paradigm shift could open the doors to new developments in Physics, developments that could allow to overcome the current situation of incompatibility between relativistic theories on the one hand and quantum theories on the other and to improve our understanding of the laws that govern the evolution of physical processes.

References

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