Information Relativity Theory Solves the Twin Paradox Symmetrically

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Abstract

The Twin Paradox is one of the most fascinating paradoxes in physics. In Special Relativity, the paradox arises due to the nonexistence of a preferred frame of reference, resulting in both twins observing that he or she is younger than the other twin. Nonetheless, it is commonly agreed that the "traveling" twin returns younger than the "staying" twin. The prevailing solution is obtained by deviating from the relativity principle and assuming that the "staying" twin's frame is preferred over the "traveling" twin's frame. Here I describe a newly proposed relativity theory, termed Information Relativity (IR) and show that it solves the twin paradox symmetrically, with the twins aging equally.

Keywords: Twin Paradox, Relativity, Information, Time Dilation, Ontic, Epistemic.

Introduction

The Twin Paradox is undoubtedly the most famous thought experiment in physics. The enormous literature about it renders any attempt to review it almost impossible. In the Twin Paradox, one of two twins stays on Earth while the other twin travels at near the speed of light to a distant star and returns to earth. According to Special Relativity, the twin who stayed on earth will measure a time dilation given by $\frac{t}{t'} = 1\Big/\sqrt{1-(\frac{v}{c})^2}$, where t and t' are the durations of the round trip from earth and back, measured in the internal frames of the remaining and the traveling twins, respectively; v is the spaceship velocity and c is the velocity of light. The paradox lies in the fact that from the point of view of the traveling twin, the "staying" twin is the one experienced as distancing away and then returning back with the same relative velocity v. Thus, the traveling twin will measure an equal time dilation of $\frac{t'}{t} = 1\Big/\sqrt{1-(\frac{v}{c})^2} = \frac{t}{t'}$. Hence the paradox, since upon their reunion, each of the twins will find the other one younger than him- or herself. It is worth noting that a similar argument was proposed more than half a century ago by the late Herbert Dingle, who served as president of the Royal Astronomical Society. In a paper published in 1962 in *Nature* [1], and in several subsequent writings [2-4], Dingle argued that the theory of Special Relativity leads to inconsistency. According to Dingle, "Einstein deduced, from the basic ideas of his theory that a moving clock works slower than a stationary one. By a similar line of reasoning I deduced from the same basic ideas that the same moving clock works faster than the same stationary one. Hence the theory, since it entails with equal validity two incompatible conclusions, must be false". ([2], p. 41). Dingle posited that the inconsistency of Special Relativity stems from Einstein's attempt to reconcile his theory with Lorentz's electrodynamics. In Dingle's words, "Einstein, in 1905, proposed an amendment of mechanics, the effects of which, however, would be perceptible only at velocities far beyond practical realization. If the amendment were justified it would succeed in making the electromagnetic equations, like those of mechanics, relativistic, and so remove the incompatibility; but, clearly, the only possible test of such a theory was a mechanical one. It was framed in order to justify electromagnetic theory, so that to use electromagnetic theory to justify it would be to argue in a circle" ([2], p. 49). Dingle concludes that "The alternative, that the laws of electromagnetism need reformulation, thus appears almost inescapable, and indeed, quantum phenomena have long been telling us this—though, in view of the apparent justification of the Maxwell-Lorentz theory by special relativity, attempts have naturally been concentrated (without success) on the attempt to reconcile it with such phenomena instead of on the formulation of fundamentally new laws" ([2], p. 59).

Dingle's critique was countered by many physicists and was eventually ignored. The prevailing solution of the paradox is one which prescribes that the "traveling" twin returns younger than the "staying" twin. This solution was proposed by Albert Einstein himself, first within the framework of Special Relativity, and later within the framework of General Relativity. In his famous 1905 paper [5], although calling SR's answer a ‘peculiar consequence’ (*eigent ümliche Konsequenz*), Einstein stated that the traveling brother is the one to become younger. According to Einstein, this solution is independent of whether the travel-path is comprised of straight lines or of a closed curve of any shape. In Einstein's words: ‘If there are two synchronous clocks at A, and one of them is moved along a closed curve with constant velocity [v] until it has returned to A, which takes, say t seconds, then this clock will lag on its arrival at A by $\frac{1}{2}\ t\ (\frac{v}{c})^2$ seconds behind the clock that has not been moved’ [5].

Several studies [e.g., 6, 7] has pointed that the essence of the Twin Paradox is the impossibility of simultaneity between the clocks of the two twins. But why should time dilation work in favor of the traveling twin, who becomes younger? This question could not be explained only by reference to the impossibility of simultaneity. Einstein justified his solution using an example in which one observer is located on the Earth's equator and the other is located at one of Earth's poles. According to Einstein, "a balance-wheel clock (*Unruhuhr*) that is located at the Earth’s equator must be very slightly slower than an absolutely identical clock, subjected to otherwise identical conditions, that is located at one of the Earth’s poles" [8]. This solution of the paradox assumes arbitrarily that the clock at the pole is "stationary", while the clock at the equator is the "moving" one. Such assumption is in complete contradiction with the principle of relativity, according to which an observer at the internal frame of the equator, will observe that the equator's clock is "stationary", while the pole's clock is "moving". In fact, the example brought by Einstein is irrelevant to the twin paradox, since in the paradox the two clocks should start from one location, from which the "traveling" clock moves in a closed curve and returns to the internal frame of the "staying" clock.

Einstein's confidence in his solution of the paradox, namely that the twin in the spaceship will return younger, has made him go as far as to speculate about the possibility of utilizing the time dilation on earth for a possible construction of a time-dilation machine. In a speech delivered in

1911 at the *Naturforschende Gesellschaft* in *Zurich*, Einstein is quoted to have said: "Were we, for example, to place a living organism in a box and make it perform the same to-and-fro motion as the clock discussed above, it would be possible to have this organism return to its original starting point after an arbitrarily long flight having undergone an arbitrarily small change, while identically constituted organisms that remained at rest at the point of origin have long since given way to new generations" [9].

The main point here is that the Twin Paradox is unsolvable within the framework of special Relativity, unless we make the assumption of a preferred frame of reference, which stands in diametrical opposition to the mere principle of relativity. In the Earth's pole-equator example, relativity implies that while an observer located at the pole will observe that the observer at the equator is rotating with an angular velocity w (or velocity $v = w R$, where R is the Earth radius at the equator), the observer located at the equator will observe that the one at the pole is rotating in an opposite direction with the same velocity.

Other attempts to solve the twin paradox evoke the relativity of accelerating frames. As mentioned before, Einstein himself, after developing General Relativity, resorted to this explanation in 1918, when he argued that since one of the clocks is in an accelerated frame of reference, the postulates of the Special Theory of Relativity do not apply to it and so ‘no contradictions in the foundations of the theory can be construed’ [6, 10]. More recent attempts which evoke General Relativity are aplenty [e.g., 11-14].

The acceleration argument, although reverted to by Einstein, could be easily dismissed by making the distance between Earth and the remote star long enough to render the acceleration effect arbitrarily small [15]. Moreover, any solution based on an acceleration effect could be dismissed on the bases of symmetry. In the absence of a preferred frame of reference, the reversal of the direction of movement is also relative, with no way to determine who turns around and who does not. This implies that any possible effect of acceleration should be canceled out.

Other solutions of the paradox in the framework of circular [e.g., 16] or another closed-curve motion will not be reviewed here. In fact, solution of the paradox in a linear motion seems sufficient, since its extension to the case of angular motion is quite straightforward.

Here I propose a solution to the paradox, based on a new theory of relativity for inertial systems, termed: *Information Relativity* (*IR*). The theory, detailed elsewhere [17-18] diverges from Einstein's view of relativity in a most fundamental way. Whereas, Einstein's view of relativity dictates, as a *force majeure*, an ontic view, according to which relativity is a true state of nature, IR adopts an epistemic approach, by viewing relativity as *difference in knowledge about Nature* between observers who are in motion relative to each other. Within this new framework of relativity, we ask what information an observer in a "stationary" reference frame will receive concerning some physical measurement taken by a second observer in the "moving frame," knowing the information carrier the observer transmitted from the "moving frame" to his/her frame travels with constant velocity V_0 , (V_0 > v).

Note the above-described setup is universal. It supposes two reference frames moving with respect to each other while communicating information about observables measured in one reference frame to the other. Except for the specific measurements taken by an observer in his or her rest frame, and the two velocities, v and V_0, no additional information is known to us. We also do not make any pre-assumption.

We ask what the value an observer in reference-frame F will infer from the information he or she receives from an observer in reference frame F' regarding a physical measurement conducted in reference-frame F'. For the above described framework the theory yields a system of transformations that differs completely from those of SR (for details see [17-18]). Since we are interested here in the time transformation, we detail its derivation hereafter.

Derivation of the Time Transformation

We consider a simple preparation in which the time duration of an event, as measured by an observer A who is stationary with respect to the point of occurrence of the event in space, is transmitted by an information carrier which has a constant and known velocity v_c, to an observer B who is moving with constant velocity v with respect to observer A. We make no assumptions about nature of the information carrier, which can be either a wave of some form or a small or big body of mass. Aside of the preparation describes above and the measurements taken by each observer, throughout the entire analysis to follow, no further assumptions are made. This also means that we do not undertake any logical steps or mathematical calculations unless measurements of the variables involved in such steps or calculations are experimentally measurable.

We ask: what is the event duration time to be concluded by each observer, based on his or her own measurements of time? And what could be said about the relationship between the two concluded durations?

In a more formal presentation, we consider two observers in two reference frames F and F'. For the sake of simplicity, but without loss of generality, assume that the observers in F and F' synchronize their clocks, just when they start distancing from each other with constant velocity v, such that $t_1 = t_1{}' =0$, and that at time zero in the two frames, origin points of were F and F' were coincided (i.e., x_1=$x_1{}'$ = 0).

Suppose that at time zero in the two frames, an event started occurring in F'at the point of origin, lasting for exactly $\Delta\text{t}'$ seconds according to the clock stationed in F', and that promptly with the termination of the event, a signal is sent by the observer in F' to the observer in F.

After $\Delta\text{t}'$ seconds, the point at which the event took place stays stationary with respect F' (i.e., $x_2{}'$ =$x_1{}'$= 0), while relative to frame F this point would have departed by x_2 equaling:

$x_2 = v\,\Delta t'$ ……. (1)

The validity of eq. 1 could be checked and verified by more than one operational, i.e., experimentally feasible methods: For example, if the two observers meet any time after the event has terminated, then the observer in F will be able to read the time of the event as registered by the clock stationed in F' and learned what the duration of the event in F', for which the event was stationary. Another operational way by which the observer in F can infer about the actual time of travel until the event terminated and the signal was sent is by mimicking the even in F by having an identical event with the same duration (in its inertial frame), start promptly with the even in F'. It is important to note that the above two operational suggestions presume the rule stating that the laws of nature are the same in the two frames. In the first example, the above restriction leaves no possibility for the observer in F to suspect that the reading of the clock stationed F' in e time duration of the event in reading of the clock at F' (in the first example), or to suspect that a time registered by a clock at his/her own frame F will differ by the time that will be registered for an identical event, by an identical clock placed in F'.

If the information carrier sent from the observer in F' to the observer in F travel with constant velocity V_F relative to F, then it will be received by the observer in F after a delay of:

$$t_d = \frac{x_2}{V_F} = \frac{v\,\Delta t'}{V_F} = \frac{v}{V_F}\,\Delta t' \qquad \text{……. (2)}$$

Since F' is distancing from F with velocity v, we can write:

$V_F = V_0 - v$ …… (3)

Where V_0 denotes the information carrier's velocity in the rest-frame F'. Substituting the value of V_F from eq. 3 in eq. 2, we obtain:

$$t_d = \frac{v\,\Delta t'}{V_0 - v} = \frac{1}{\frac{V_0}{v} - 1}\,\Delta t' \qquad \text{...... (4)}$$

Due to the information time delay, the event's time duration $\boldsymbol{\Delta t}$ that will be registered by the observer in F is given by:

$$\Delta t = \Delta t' + t_d = \Delta t' + \frac{1}{\frac{V_0}{v} - 1}\,\Delta t' = \left(1 + \frac{1}{\frac{V_0}{v} - 1}\right)\Delta t' = \left(\frac{\frac{V_0}{v}}{\frac{V_0}{v} - 1}\right) = \left(\frac{1}{1 - \frac{v}{V_0}}\right)\Delta t' \qquad \text{...(5)}$$

Or:

$$\frac{\Delta t}{\Delta t'} = \frac{1}{1 - \frac{v}{V_0}} \qquad \text{... (6)}$$

Or: $$\frac{\Delta t}{\Delta t'} = \frac{1}{1 - \beta} \qquad \text{....(7)}$$

Where $\beta = \frac{v}{V_0}$, and V_0 is the velocity of the information carrier as measured in the rest-frame. For $v \ll V_0$ the time transformation in eq.7 reduces to the classical Newtonian equation $\Delta t = \Delta t'$, while for $v \rightarrow V_0$, $\Delta t \rightarrow \infty$ for all positive $\Delta t'$.

Quite interestingly, eq. 7 derived for the time travel of moving bodies with constant velocity is quite similar to the Doppler's Formula [19-20] derived for the frequency modulation of waves emitted from traveling bodies. Importantly, in both cases **the direction of motion matters**. In the Doppler Effect a wave emitted from a distancing body will be red-shifted (longer wavelength), whereas a wave emitted from an approaching body with be blues-shifted (shorter wavelength). In both cases the degree of red or blue shift will be positively correlated with the body's velocity. The same applies to the time duration of an event occurring at a stationary point of a moving frame. If the frame is distancing from the observer, time will be dilated, whereas if the frame is approaching the observer will contract.

It is especially important to note further that the above derived transformation applies to *all* carriers of information, including the commonly employed *acoustic* and *optical* communication media. For the case in which information is carried by light or by electromagnetic waves with equal velocity, equation (6) becomes:

$$\frac{\Delta t}{\Delta t'} = \frac{1}{1-\frac{v}{c}} \qquad \text{..... (8)}$$

Since an objection might be raised for the cases of information translation by means of light or other waves with equal velocity, such objection could be avoided by restricting the theoretical model derived above to wave propagation in mediums that are not a vacuum, which in fact the case in almost all physical situations of interest.

Information Relativity Solution of the Twin Paradox

To apply *IR* to the twin paradox, consider the example in Fig.1, in which one twin (Joe) stays at Earth (the "staying twin), and the other twin (Jane, the "traveling" twin) travels at high velocity to a very distant star and returns back to Earth at the same velocity. For convenience, in the two frames of reference F and F', I denote the times of flight away from Earth by t_i, with an arrow above pointing rightward, and the times of flight towards Earth by t_j', with an arrow above pointing leftward. Now assume that the travel start times, relative to Earth (F) and to the spaceship (F'), are synchronized such that $\overrightarrow{t_1} = \overrightarrow{t_1}'$. Furthermore assume that upon the arrival of Jane at the distant star, a signal is sent from the star to Joe's station at Earth, indicating the arrival of Jane to the star. To solve the paradox I treat the paths Earth → Star and Star → Earth, each in turn.

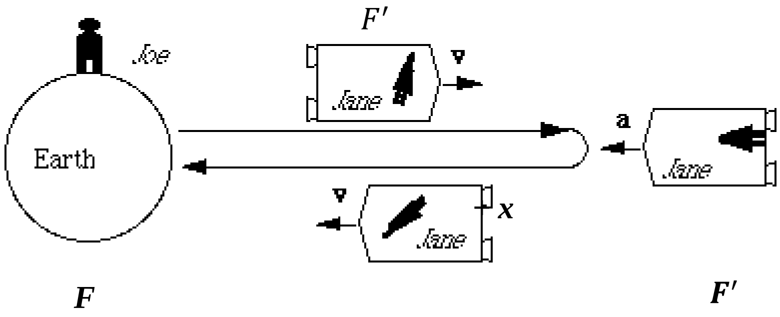

Figure 1: Twin Paradox

1. Earth → Star

The signal indicating the arrival of Jane at the star will arrive at Earth with a delay of $\frac{d}{c}$ s., where d is the distance between Earth and the star, and c is the velocity of light (both measured at the Earth's frame).

Denote by $\overrightarrow{t_2}$ and $\overrightarrow{t_2'}$ Jane's arrival times at the star, as measured by the "staying" and the "travelling" twins, respectively. We can write $\overrightarrow{t_2} = \overrightarrow{t_2'} + \frac{d}{c}$, or:

$$\overrightarrow{t_2'} = \overrightarrow{t_2} - \frac{d}{c} \qquad \text{..... (9)}$$

We also have

$$\overrightarrow{t_1} = \overrightarrow{t_1'} \qquad \text{..... (10)}$$

2. Star → Earth

The "staying" twin receives the signal indicating that the "travelling" twin **has departed** from the distant star with delay of $\frac{d}{c}$. This makes him conclude that his "travelling" twin has departed from the star later by $\frac{d}{c}$ s. than the time measured by the travelling twin. Denote the return-trip's start time as measured by the "staying" and the "travelling" twins by $\overleftarrow{t_3}$ and $\overleftarrow{t_3'}$, respectively, and the respective arrival times to Earth by $\overleftarrow{t_4}$ and $\overleftarrow{t_4'}$. We can write $\overleftarrow{t_3} = \overleftarrow{t_3'} + \frac{d}{c}$, or:

$$\overleftarrow{t_3'} = \overleftarrow{t_3} - \frac{d}{c} \qquad \text{..... (11)}$$

We also have:

$$\overleftarrow{t_4} = \overleftarrow{t_4'} \qquad \text{..... (12)}$$

3. Earth → Star → Earth

The total time measured by the "staying" brother is:

$$(\overrightarrow{t_2} - \overrightarrow{t_1}) + (\overleftarrow{t_4} - \overleftarrow{t_3}) \qquad \text{..... (13)}$$

While the total time measured by the "travelling" brother is:

$$(\overrightarrow{t_2'} - \overrightarrow{t_1}') + (\overleftarrow{t_4'} - \overleftarrow{t_3'}) \qquad \text{.... (14)}$$

Substituting the values of $\overrightarrow{t_1'}$, $\overrightarrow{t_2}'$, $\overleftarrow{t_3'}$ and $\overleftarrow{t_4'}$ from Eq. 9-12 in 14 we get:

$$(\overrightarrow{t_2'} - \overrightarrow{t_1}') + (\overleftarrow{t_4'} - \overleftarrow{t_3'}) = ((\overrightarrow{t_2} - \frac{d}{c}) - \overrightarrow{t_1}) + (\overleftarrow{t_4} - (\overleftarrow{t_3} - \frac{d}{c}))$$

$$= (\overrightarrow{t_2} - \overrightarrow{t_1}) + (\overleftarrow{t_4} - \overleftarrow{t_3}) - \frac{d}{c} + \frac{d}{c} = (\overrightarrow{t_2} - \overrightarrow{t_1}) + (\overleftarrow{t_4} - \overleftarrow{t_3}) \qquad \text{....(15)}$$

Thus, the twins age equally.

Obviously, the solution presented here contradicts the widely accepted solution, according to which the "traveling" twin returns younger than the "staying" twin. The reader is left to decide between two options: (a) that the "staying" twin, together with all the inhabitants of Earth, including distant organisms who could not be possibly aware of that the "traveling" twin has left Earth, should grow in age more than the "traveling" twin, implying that she in fact will return to the future. (b) That, in accordance with the relativity principle, the two twins undergo similar physical occurrences, and as result, similar biological processes, resulting in them growing equally. The first option has two obvious advantages: (1) It was advocated by Albert Einstein (2) It continues to spark the imagination of science-fiction writers and cinematographers. Its huge drawback is that it doesn't make sense!

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