Time for Another Paradox

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Abstract

We consider the detection of a superluminal signal. We show that there exists a particular inertial frame in which the superluminal signal is not uniquely localizable and that it is detected everywhere at the same instant within the inertial frame. This leads to a novel paradox to which we attribute the relativity of simultaneity.

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Introduction

Special relativity (SR) is well known for its puzzling predictions. Paradoxes such as the barn-pole paradox[1] or the twin-clock paradox[2] are still greatly debated subjects. With the advent of superluminal signals (SLS), scientists sought to explain the phenomenon with SR. It was concluded that superluminal signals can travel not only forward in time but also "backward" in time, leading to the grandfather type paradoxes[3]. Although unintuitive, SR's prediction on such matters is unequivocal: a non-causal SLS can travel backwards in time and this is supported by recent experiments[4-8].

In this text, we show that there is another unintuitive relativistic prediction, augmenting the collection of SR "paradoxes". Like many relativistic effects, its root lies in the interpretation of relativity of simultaneity. We consider the propagation of a localizable SLS. What is meant by *localizable* is that the passage of the signal can unambiguously be attributed a spatial location, namely, the location of the detector detecting it. For example, a detector detecting the passage of a hypothesized tachyon, or the passage of the peak of a signal, occurs there where it is detected.

We show that the spatial location of such a signal is well defined for all inertial frames except for a particular inertial frame S_p in which its location is ambiguous. Although the algebraic development presented is not new, the paradoxical nature of the effect remains little known. We therefore expose this enigmatic effect and offer a simple explanation.

The Paradox

Consider two inertial frames S and S' with relative speed v in the standard configuration. Let there be a localizable signal traveling with constant speed along the x axis of frame S. Two detectors D_o and D_1 are fixed at locations $x = 0$ and $x = D$ respectively. Each detector is triggered as the signal coincides with it. We ask: at what location and at what time will these two detectors be triggered relative to S'?

The triggering of the detectors can be attributed space-time coordinates. Relative to S, these coordinates are (0, 0) for D_o and (D, T) for D_1. From the Lorentz equations, relative to S', these two events have space-time coordinates (0, 0) and $((D - vT)\gamma, (T - Dv/c^2)\gamma)$ respectively, where γ is the usual gamma factor.

Consider the particular inertial frame S_p such that $v = c^2T/D$. The space-time coordinates of the triggering of D_1 becomes $((D - vT)\gamma, 0)$. Hence, the two detectors D_o and D_1 are triggered at the same time ($T' = 0$) relative to S_p. The same is concluded for any array of detectors lying within S; according to observers in S_p, all the detectors will be triggered simultaneously and at different spatial locations. This occurs only in S_p. In other inertial frames such that $v \neq c^2T/D$, the space-time coordinates of the events all differ and no two occur simultaneously. In other words, all those events (the coincidences between the signal and S's detectors) are recorded by S_p's clocks to all occur simultaneously throughout S_p. Observers in S_p may interpret this as a localizable signal existing everywhere at the same instant, a highly unintuitive and paradoxical idea. To

aggravate matters, if one attributes a particulate nature to the signal (as often attributed to the tachyon), then this would imply that *the* particle is located everywhere throughout S_p's universe.

Note that if the signal is subluminal ($D/T < c$), this implies that S_p has a speed of $v > c$ relative to S, and is thus an unrealistic reference frame; we would not be able to observe our paradoxical effect. However, if the signal is superluminal ($D/T > c$) then $v < c$. Such a frame is a realistic frame within the context of SR and we could, in principle, observe the paradoxical effect.

The above paradox may be better understood and "resolved" in the following manner. The particular frame S_p has a speed v such that the speed of the SLS relative to S_p is infinite. Since the signal has an infinite speed, it can be detected everywhere at the same time. However, this explanation leads yet to another paradoxical feature: a finite speed SLS traveling in the x direction of S will be observed to have a greater speed (an infinite speed) by observers in S_p, even though these observers are also traveling in the same direction as the signal.

Be it experimentally confirmed or in principle, there are numerous ways to produce a "real" localizable SLS[4-10]. Can these localizable effects still be considered "real" for observers in S_p – a question to be contemplated by the reader[11,12].

Although there are no logical inconsistencies in the foregoing analysis, a paradox arises in the sense that the result is unintuitive and does not adhere to the common view of everyday physics. This paradox, like many other paradoxes in SR, originates from the unintuitive concept of "relativity of simultaneity": two events simultaneous in one frame are not simultaneous in another frame. In our discussion, we have a pair of events which are not simultaneous in the frame S and have found a reference frame S_p in which the pair of events are simultaneous and spatially disjoint. The definition of time in SR, i.e. the clock coordination procedure, makes it such that the two disjoint clocks of S_p indicate the same value on detection of their respective event. Since we have the tendency to give a particulate nature to the SLS, we have the tendency to say that *it* is detected at two different locations but at the same time, a rather unintuitive idea indeed. Our paradox is simply a variant of the relativity of simultaneity, compounded with a pair of non-causal events.

Conclusion

Due to the nature of simultaneity, special relativity incorporates many paradoxical results. We have presented a variant of these paradoxes, namely that a signal with finite speed in one frame may have an infinite speed in another frame. As a consequence of its infinite speed, the signal may be said to be located everywhere at the same instant throughout the latter frame, a rather unintuitive result from the standpoint of everyday physics.

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