**Special Relativity in Superposition**

**Abstract**

By deriving the Lorentz transformation from the absolute speed of light, Einstein demonstrated the relativistic variability of space and time, enabling him to explain length contraction and time dilation without recourse to a "luminiferous ether" or preferred frame of reference. He also showed that clocks synchronized at a distance via light signals are not synchronized in a frame of reference differing from that of the clocks. However, by mislabeling the relativity of synchrony the "relativity of simultaneity," Einstein implied that this effect concerns an actual difference in times from one frame to another rather than merely a failure of clock synchronization across frames. As a theory of length contraction and time dilation on the basis of relative motion in the context of the absolute speed of light, special relativity is the definitive interpretation of the Lorentz transformation and the correct explanation of relativistic phenomena. The relativity of simultaneity, as I demonstrate, plays no role in this explanation but instead provides apparent justification for a view of time in which the present moment is frame-dependent. In contrast to its legitimate application, special relativity fails as a theory of time on the basis of the relativity of simultaneity.

Keywords: Lorentz transformation; relativity of simultaneity; time dilation; space-time

**1 Introduction**

Einstein's special theory of relativity is generally understood as an explanation of length contraction, time dilation and mass increase as a result of extreme speed (Muller 2016, 43). A higher-speed object dilates in time relative to a lower-speed object because the speed of light is the same for both objects. If the speed of light cannot decrease in the frame of reference of the higher-speed object, the rate of *time* must decrease relative to that of the lower-speed object. Rather than the speed of light, what is variable is the flow of time.

Yet this is not at all how special relativity is typically presented in the scientific literature. Bohm (1958), Goldberg (1984) and Takeuchi (2010) present time dilation in terms of the relativity of simultaneity rather than relativity in the rate of time. "Time dilation," writes Takeuchi, "is a phenomenon caused by the relativity of simultaneity and has nothing to do with how fast time is flowing" (2010, 138). According to Bohm, "Once we admit that simultaneity is relative to the speed of the observer, it immediately follows that the measurement of length and time intervals must have a corresponding relativity" (1996, 58). As Einstein himself put it, when we "discard this assumption [of absolute simultaneity], then the conflict between the law of the propagation of light *in vacuo* and the principle of relativity… disappears" (1920, 27).

In this paper I demonstrate that special relativity conflates two distinct viewpoints, one concerning relativistic phenomena on the basis of motion in the context of the absolute speed of light and the other concerning the nature of time on the basis of the relativity of simultaneity. Following Mario Bacelar Valente (2012), I define the relativity of simultaneity as a fact about the readings of clocks which has no bearing on the nature of time, thereby expelling from special relativity the problematic metaphysics of time. Moreover, I demonstrate that time dilation in special relativity follows entirely from the uniformity of the speed of light in all frames of reference and that the *relativity of synchrony*, though a verifiable phenomenon, plays no causal role. Maintaining Lorentz invariance across frames of reference requires only the relative variability of the rate of time, not the variability of the present moment from one frame to another (relative simultaneity).

Limited to its proper role as an explanation of relativistic phenomena, special relativity cannot reasonably be invoked to justify the widespread belief among philosophers and physicists that time is merely a static dimension in a four-dimensional block universe.

**2 Background**

As we know from Galilean relativity, the Galilean-Newtonian laws of mechanics are wholly indifferent to the frame of reference of an observer. The lawfulness of the speed of light, however, calls into question the universality of relativity. Surely the speed of an electromagnetic ray varies depending on the observer's motion relative to the source of the light. To measure the speed of light at *c* the observer must occupy the correct or "privileged" frame of reference. The luminiferous ether was widely believed to provide the physical basis of this frame. Only when motionless with respect to the ether would an observer be truly or absolutely at rest, and only then would the speed of light come across as *c*. In all other frames the speed of light would differ.

Yet no experiment has demonstrated variation in the speed of light or an ether relative to which we might be in motion. In response to the failed Michelson-Morley interferometer experiments, Lorentz argued that the null results followed from changes in the observing instruments due to their motion with respect to the ether. If a charged particle is spherical at rest in the ether, in motion it ought to be shortened in the direction of its motion and therefore elliptical. This effect scales up from electrons to objects of perception. Where *l* is the length of an object moving at velocity *v* with respect to the ether, and *l0* is the length of the object at absolute rest, *l* = *l0*√1 - (*v*/*c*)2. The greater the velocity, the greater the contraction of the object in motion. Lorentz concluded that in each interferometer experiment the arm contracted in the direction of its motion through the ether, canceling out detection of the motion (Bohm 1996, 24-25).

In response to the Fizeau experiment, which involved a temporal component in the form of a turning wheel, Lorentz argued that the mass of an object in absolute motion – that is, in motion with respect to the ether – ought to increase, thereby slowing the operation of a clock. The basis of this effect, according to Lorentz, is that the electromagnetic portion of the mass of an electron causes it to resist acceleration. Where *m* is the mass of an electron moving at velocity *v* relative to the ether, and *m0* is the mass of an electron at absolute rest, *m* = *m0*/√1 - (*v*/*c*)2. The greater the velocity, the more the value of *m* exceeds that of *m0*. Since ordinary clocks are essentially harmonic oscillators, and heavier particles reduce the rate of oscillation, clocks in motion through the ether ought to run slow. Where *t* is the time of a clock moving at velocity *v* relative to the ether, and *t0* is a clock at rest, *t* = *t0*/√1 - (*v*/*c*)2. Together with length contraction, time dilation negates the Fizeau experiment as a way of calculating the speed of Earth through the ether (1996, 12, 26-30).

Lorentz generalized this result by incorporating the speed of light into the Galilean transformation, a set of equations for calculating the speed of an object from different frames of reference. According to Bohm, "the Lorentz theory implies that all uniformly moving observers will ascribe the same velocity *c* to light, independent of their speed of motion through the ether" (1996, 39).

Special relativity is Einstein's theory that the long-established principle of relativity does indeed apply in the case of electromagnetism (1996, 71). Rather than only *appear* the same in every inertial frame, the speed of light is in fact the same, and the frame-dependent variables are space and time. Rather than conceal variations in the speed of light depending on the motion of the observer, length contraction and time dilation facilitate its constancy.

Whereas Lorentz formulated the transformation equations on the ad hoc basis of maintaining an absolute frame of reference despite the failure to detect motion relative to it, Einstein derived them from first principles: 1) the invariance of physical law from one inertial frame to another, i.e. Galilean relativity, and 2) the lawfulness of the speed of light (Goldberg 1984, 109). Since speed amounts to distance over time, if the speed of light is invariable in relation to high-speed objects, space and time must be treated as variables rather than fixed absolutes.

**3 On the Electrodynamics of Moving Bodies**

Einstein's 1905 paper inaugurating relativity opens with an ingenious resolution to the problem of the "reciprocal electrodynamic action of a magnet and a conductor" (Lorentz, et al, 1923, 37). According to conventional wisdom at the time, the cause of an electric current in a conductor depends on whether the conductor or a magnet is in motion. If a magnet is in motion, the current is caused by an electric field. If the conductor is in motion, the current arises from an electromotive force. Yet either way the motion is defined against a theoretical state of absolute rest. Rejecting such a state, Einstein defines the motion of each *relative* to the other. "The observable phenomenon," he writes, "depends only on the relative motion of the magnet and the conductor." To say the magnet is in motion is to choose the conductor as our frame of reference. To say the conductor is in motion is to choose the magnet as our frame of reference. The objective basis of the current, meanwhile, has nothing to do with the reference frame chosen by a subjective observer.

In order to demonstrate that the Galilean principle of relativity remains valid in the context of electromagnetism despite the absolute speed of light, Einstein begins with a discussion of simultaneity. In section 1 he defines simultaneity locally as the co-occurrence of an event and the reading of a clock. "If, for instance, I say, 'That train arrives here at 7 o'clock,' I mean something like this: 'The pointing of the small hand of my watch to 7 and the arrival of the train are simultaneous events'" (1923, 39). To establish a common time between distant clocks, he first stipulates that "by definition" light travels at the same speed whether from clock A to B or back again.

The next step is to find a means of synchronizing the clocks. "Let a ray of light start at the 'A time' *t*A from A towards B," he writes. "[L]et it at the 'B time' *t*B be reflected at B in the direction of A, and arrive again at A at the 'A time' *t'*A. In accord with definition the two clocks synchronize if *t*B − *t*A = *t'*A − *t*B" (1923, 40).

In section 2, after establishing that the length of a "rigid rod" varies in a different frame from its length in its own frame, Einstein introduces a thought experiment in which a rod is placed in motion at velocity *v* in the direction of its axis. He refers to the rod as the "moving system" in contrast to a "stationary system."

We imagine further that at the two ends A and B of the rod, clocks are placed which synchronize with the clocks of the stationary system, that is to say that their indications correspond at any instant to the “time of the stationary system” at the places where they happen to be. These clocks are therefore “synchronous in the stationary system” (1923, 42).

In other words, the clocks attached to the moving rod are set to tell time in the stationary frame rather than their own frame. He then demonstrates that the synchronization of the clocks depends on frame of reference.

We imagine further that with each clock there is a moving observer, and that these observers apply to both clocks the criterion established in section 1 for the synchronization of two clocks. Let a ray of light depart from A at the time *t*A, [and] let it be reflected at B at the time *t*B, and reach A again at the time *t'*A. Taking into consideration the principle of the constancy of the velocity of light we find that *t*B − *t*A = *r*AB/(*c* − *v*) and *t'*A − *t*B = *r*AB/(*c* + *v*) where *r*AB denotes the length of the moving rod – measured in the stationary system. Observers moving with the moving rod would thus find that the two clocks were not synchronous, while observers in the stationary system would declare the clocks to be synchronous (1923, 42).

Given that an object is always at rest with respect to itself, clocks attached to the "moving" rod ought to remain synchronized. By stipulating that these clocks are adjusted for the time of the stationary frame, Einstein arranges that the rod is effectively in motion relative to the clocks attached to it. Their timing thus reflects the fact that the velocity of the rod seems to reduce the velocity of the light ray (*c* - *v*) traveling in the same direction as the rod and, conversely, that the rod's motion seems to *increase* the velocity of the light ray (*c* + *v*) reflecting from B back to A. Yet we know from Lorentz that the velocity of the light ray must be measured exactly at *c* regardless of reference frame. Because the speed of light is simply *c* – neither *c* - *v* nor *c* + *v* – the time of the reflection of the light ray at B must vary from expectation in order to cancel out the apparent subtraction from *c*. Thus the clock at B displays an earlier time for the moving observers than the clock at A. Since the observers in the stationary frame did not move while the light ray passed from A to B and back again, from their standpoint the clocks remain synchronized. The synchrony of the clocks is relative to the frame of the observer.

According to Einstein, "we cannot attach any *absolute* signification to the concept of simultaneity, but that two events which, viewed from a system of coordinates, are simultaneous, can no longer be looked upon as simultaneous events when envisaged from a system which is in motion relatively to that system" (1923, 42). From the relativity of the synchrony of clocks, Einstein infers the relativity of the simultaneity of events and therefore the variability of time from one frame of reference to another.

In section 3 Einstein takes a very different tack, establishing the variability of length and time directly from the frame-invariance of the speed of light. He begins by establishing that light propagates at the speed of light in a "stationary" system, that is, a system relative to which an observer is stationary. In the course of this discussion he invokes the procedure for synchronizing clocks via light signals but only to establish a well-defined time, much as he invokes measuring-rods to establish well-defined distance (1923, 43). To establish that the speed of light remains exactly at *c* in a "moving" system, he introduces a new thought experiment in which an expanding sphere of light is measured according to two systems of coordinates in relative motion along an axis. Because the systems overlap perfectly at the time of the flash, the sphere of light occupies the origin of each frame. Despite the divergence of the two systems due to their relative motion, they register the expanding sphere of light exactly the same way, that is, as "a spherical wave with velocity of propagation *c*" (1923, 46). For the *coup de grâce*, he models the scenario mathematically, step by step, until arriving at the Lorentz transformation (1923, 47-48).

In this way Einstein derives the Lorentz transformation from first principle, specifically the lawfulness, or frame-invariance, of the speed of light. The relativity of simultaneity plays no role.

In section 4 Einstein explains the physical meaning of his derivation of the Lorentz transformation, beginning with length contraction. Since the relative motion of the coordinate systems is only along the X axis, the Y and Z axes are unaffected.

Thus, whereas the Y and Z dimensions of the sphere… do not appear modified by the motion, the X dimension appears shortened in the ratio 1 : √1 - (*v*2/*c*2), i.e. the greater the value of v, the greater the shortening. For *v* = *c* all moving objects – viewed from the “stationary” system – shrivel up into plane figures (1923, 48).

Einstein then inquires into the rate of a clock in a system in motion with respect to an observer's frame of reference and concludes that it "is slow by 1 - √1 - (*v*2/*c*2) seconds per second."

From this there ensues the following peculiar consequence. If at the points A and B of [the system] K there are stationary clocks which, viewed in the stationary system, are synchronous; and if the clock at A is moved with the velocity *v* along the line AB to B, then on its arrival at B the two clocks no longer synchronize, but the clock moved from A to B lags behind the other which has remained at B by 1/2 *tv*2/*c*2… *t* being the time occupied in the journey from A to B (1923, 49).

This of course assumes the observer has chosen B as the frame of reference. If the observer switches to frame A, then B seems be in motion away from A and back again, in which case B undergoes time dilation, and therefore its clock "lags behind" the clock at A. This opens up the paradox that each clock is slow from the point of view of the other clock. Since it cannot be the case that the time of each frame is behind the time of the other, we must specify that the clock at A is moving objectively faster than the clock at B, that is, that the speed of A is closer than the speed of B to that of light.

The same problem appears when Einstein switches terrain from a straight line to a circular line:

If we assume that the result proved for a polygonal line is also valid for a continuously curved line, we arrive at this result: If one of two synchronous clocks at A is moved in a closed curve with constant velocity until it returns to A, the journey lasting *t* seconds, then by the clock which has remained at rest the travelled clock on its arrival at A will be 1/2 *tv*2/*c*2 second slow (1923, 49).

Only at this point does Einstein break the symmetry and establish the speed of one frame as definitively higher than the other frame:

Thence we conclude that a balance-clock at the equator must go more slowly, by a very small amount, than a precisely similar clock situated at one of the poles under otherwise identical conditions (1923, 49-50).

By placing his abstract scenario in a concrete setting, Einstein resolves the problem of symmetry between frames. Clearly the equator is revolving around the pole and therefore objectively moving faster. Only one frame dilates in time relative to the other.

**4 The Relativity of Simultaneity**

Since Einstein establishes time dilation from first principle in sections 3 and 4, what is the point of his discussion of simultaneity in sections 1 and 2? Does he also establish time dilation on this basis? Or does the relativity of simultaneity serve merely to insert a dubious metaphysics of time into an otherwise sound physical theory?

Hawking and Mlodinow illustrate the relativity of simultaneity with a streamlined thought experiment involving an airplane in flight and a ground observer (2010, 96-97). Suppose a passenger on the airplane drops a ball that bounces off the floor and back into the passenger's hand. Rather than traveling straight down and back up, for the ground observer the ball's trajectory is slanted forward both as it drops and returns. Thus the ground observer disagrees with the passenger on the distance traveled by the ball, though they agree on the interval. The problem is easily resolved in accord with the Galilean transformation, as the ground observer simply adds the speed of the ball to that of the airplane to account for the greater distance traveled in the same amount of time. Hawking then introduces a wrinkle by emitting a pulse of light from the tail of the airplane to the nose. As in the case of the bouncing ball, the pulse travels farther in the frame of the ground observer than for the passenger. "Since speed is distance traveled divided by the time taken, this means that if they agree on the speed at which the pulse travels – the speed of light – they will not agree on the time interval between the emission and the reception." Lorentz's addition of a time-variability component to the Galilean transformation clears up the problem.

To bring Hawking and Mlodinow's thought experiment in line with Einstein's, we add clocks to the nose and tail of the airplane. In contrast to Einstein's cumbersome approach, we allow the clocks on the airplane to measure the time proper to the airplane. Because the speed of light is frame-invariant, the greater distance traveled by the pulse in the ground observer's frame must be matched by a greater time interval, preserving the speed of the pulse at *c*. The result is that the nose clock, when illuminated by the pulse, reads a later time for the ground observer than for the passenger, indicating that the airplane is dilating in time relative to the ground. However, if the pulse of light reflects off the nose and returns to the tail to illuminate the other clock, the relative motion of the airplane *reduces* the distance traveled by the pulse. When the tail clock is illuminated, it therefore displays an *earlier* time for the ground observer than for the passenger. This indicates that the ground is dilating in time relative to the airplane.

Now we have a problem that not even the Lorentz transformation can clear up.

Whichever direction the pulse is traveling, the clocks on the aircraft are synchronized in the frame of the passenger but not in the frame of the ground observer. Einstein's condition for the relativity of simultaneity has been satisfied. But do we have time dilation?

In 1971 Hafele and Keating (1972b, 168-70) carried out an actual experiment that demonstrated time dilation for an airplane flying east and time *gain* for an airplane flying west. Due to Earth's rapid eastward rotation, an eastbound airplane outpaces the surface from which it took flight, whereas an airplane flying west only subtracts from the greater speed of the surface below (1972a, 166). Whereas in the Hafele-Keating experiment the speed of the eastbound airplane – compared to the Earth's surface directly below – was closer to *c*, the speed of the westward airplane relative to the ground was farther from *c*. In each case we see clearly which frame dilated in time relative to the other frame, which by necessity gained in time.

As measured in a laboratory frame, a muon traveling at very high speed dilates in time relative to the laboratory (Bailey, et al, 1977, 301-05). As a result it decays more slowly than a particle at rest with respect to the laboratory frame. Hence time dilates only for the high-speed muon, relative to which the laboratory undergoes time gain. To invoke the relativity of simultaneity, however, would result in the absurdity that the front of the muon dilates in time while the back of the muon gains in time. Obviously these effects would cancel each other out, leaving the muon with the same temporal status as the laboratory. As long as we understand the relativity of simultaneity as nothing more than the earlier or later than expected readings of clocks, it presents no problem. Only when we try to affiliate it with time dilation do we arrive at an absurd outcome.

According to Valente, the relativity of simultaneity is better understood as the relativity of synchronized clocks (2012, 8). As Einstein demonstrates, clocks that are synchronized in one frame display successive readings in another frame. In a universe where the fixed value of *c* is both the signal speed and the speed of light, the relativity of synchrony is a simple fact. Rather than *exemplify* time dilation, however, the relativity of synchrony merely *signifies* that it will occur under proper conditions. Time dilation requires not simply an observer viewing images carried on light but an objectively higher speed – that is, a higher speed relative to *c* – of one frame compared to another, as Einstein states in section 4 of his paper. It is because of this analysis, on the basis of the derivation of the Lorentz transformation from first principles, that Einstein is credited with correctly interpreting it.

Yet the relativity of simultaneity plays no part in that interpretation. Whereas the relativity of *synchrony* is a fact of observation, the relativity of simultaneity is a false inference that the earlier or later than expected time displayed on a clock entails an actual temporal discrepancy. Clearly no such effect takes place, for only in the mind of the observer is the tail clock, for instance, thrown back into a past moment. That the clock displays an earlier than expected time does not mean the clock itself occupies that time. Rather than an objective effect such as time dilation, which requires the propulsion of a rigid coordinate system to give it a higher speed than a comparison system, the relativity of simultaneity is a subjective inference resulting from differing *perspectives* on the same events. Because Einstein equated time with the readings of clocks, as indicated in section 1 of the 1905 paper, he failed to discern the merely symbolic meaning of a clock's earlier or later than expected reading.

As Hawking and Mlodinow point out, "all observers have their own measures of time, and the times measured by two observers who are moving relative to each other will not agree" (2010, 98). This is indeed the basis of the relativity of simultaneity, but it has no bearing on time dilation, which follows from acceleration of one of the frames to a greater speed relative to *c* (also known as lightspeed or simply $β$). The basis of the apparent "twin paradox" is symmetry between frames. Whereas the stay-at-home twin judges the astronaut twin to be in motion and therefore dilating in time, from the astronaut's perspective the Earth is receding at high speed and therefore undergoing time dilation. The result is that each twin dilates in time relative to the other, meaning that each twin is now younger than the other. The contradiction dissolves in light of the asymmetry between frames introduced by the acceleration of one of the twins but not the other. When the twins come back together, only one of them – the astronaut – is younger, a difference anyone can see regardless of reference frame. In stark contrast to the relativity of simultaneity, time dilation is objective, that is, frame-independent.

In the opening of his 1905 paper on relativity, Einstein explains that the cause of an electric current cannot be the choice of reference frame on the part of an observer. Like electromagnetism as the objective basis of the electric current, the difference in lightspeed between two bodies provides the basis of time dilation. Since this difference can be established from any arbitrary frame of reference, what counts is not the frame from which the two bodies are viewed but the objectively differing lightspeeds of the bodies themselves. Yet Einstein reverses course in section 2, establishing relative simultaneity on the basis of the reference frame of an observer, echoing perfectly the conventional wisdom that attributed the electric current to either an electric field or an electromotive force depending on what a subjective observer defined as stationary. Only with his derivation of the Lorentz transformation from first principle in the following section does Einstein establish an objective basis of time dilation in keeping with the opening of the paper.

Bohr credited Einstein with helping inspire the quantum-mechanical principle of complementarity by exposing the "subjective character of all the concepts of classical physics" (Jammer 1974, 131). But the idea that one measurement yields a "particle" with a precise position and another yields a "wave" with precise momentum – and neither of these opposed classical concepts captures the underlying quantum reality – is far removed from the proposition that the subjective choice of reference frame causes the objective phenomenon of time dilation.

Though Einstein called the relativity of simultaneity "the most important… theorem of the new theory of relativity" (1997, 4), his principle is irrelevant to objective relativistic phenomena and serves only to justify a metaphysical concept of time in which the present moment, because it varies from one frame to another, has no universal applicability.

**5 Absolute Simultaneity**

Unlike the Hafele-Keating experiment, which conclusively demonstrated a variation in time between different frames, Einstein's thought experiment illustrates only an apparent variation of time between frames. To demonstrate an actual temporal discrepancy, a thought experiment would have to compare the clocks of different frames from the perspective of a third frame.

Richard Muller proposed just such a thought experiment in order to illustrate a ramification of the relativity of simultaneity. If simultaneity is actually relative to frame of reference – that is, for instance, if events that are simultaneous in the frame defined by an airplane in flight are successive in the frame of a ground observer – then a universally-applicable present moment has no physical meaning.

Suppose, writes Muller, that New Year's Eve parties are held at ostensibly the same time on Earth (say, Greenwich time) and the moon. Now suppose we take as our frame of reference a pion traveling at .637 *c*. In the pion frame, the parties are not only successive but of indeterminate order. "Which event comes first," he writes, "depends on whether the pion frame is moving toward the moon or away from it" (2016, 38). If the pion is approaching Earth, the New Year countdown in London precedes the one on the moon by 14 minutes. If the pion frame is approaching the moon, the countdown on the moon comes first, again, by 14 minutes.

This certainly seems to establish relative simultaneity between frames. What Muller overlooks, however, is that the pion frame effectively acts as a clock. Because each countdown precedes the other – depending on the direction of the pion – by the same amount of time, the pion clock determines that the New Year celebrations are in fact simultaneous. Successive events would be demonstrated if, for instance, the celebration on Earth precedes the one on the moon by 15 minutes when the pion is earthbound but follows the moon event by only 13 minutes when the pion is headed to the moon. In this case we conclude that the Earth event precedes the moon event by one minute. The pion clock thus tells us not only whether the events are successive but, if so, which one comes first.

Far from demonstrating relative simultaneity from one frame to another, Muller's thought experiment – and others like it (e.g. Penrose 1989, 392-93) – overturns the long held belief in the impossibility of an operational definition of a universal present moment. That we can establish, at least in principle, a shared present embracing multiple frames of reference falsifies the relativity of simultaneity while leaving intact the observational fact of the relativity of synchrony.

The objective present moment shared by each frame poses no obstacle to Lorentz invariance between frames, which depends solely on time dilation and length contraction, not relative simultaneity. Moreover, as I demonstrate below, a universal "now" is *required* for time dilation and therefore Lorentz invariance.

Suppose an astronaut takes a three-month journey at .97 *c* (assuming as our frame of reference the local area of Earth's surface where the rocket launches). Because this speed has a time dilation factor ($γ)$ of four relative to Earth, one year passes on Earth during the astronaut's journey (Muller 2016, 30). Upon returning, the astronaut has aged only three months compared to one year for Earth. However, if simultaneity is actually relative – that is, if every frame of reference has its own present moment – the astronaut's present would recede to a moment nine months into Earth’s past. Upon his return, no one would greet him since, after all, we perceive what is present to us, not past. The same outcome applies to high-speed muons descending from the top of Earth's atmosphere. Reverting to our past as a result of relative simultaneity, they would simply vanish.

Thorne (1994, 500-04) has argued that a wormhole can in principle be adapted into a time machine that delivers users into the past as far back as the creation of the time machine. This can be accomplished, for instance, by rotating one end of the wormhole to a speed very near *c* so as to dilate it in time relative to the other end. Thus anyone passing through the wormhole from the unmodified end to the previously rotated end would be shuttled back in time. Insofar as different frames can occupy different present moments, Thorne's conclusion is in keeping with the principle of relative simultaneity. Yet his thought experiment defies special relativity as an explanation of relativistic phenomena since the actual effect of time dilation is reduced rate of decay or aging, not relativistic reversion to a prior moment. That the modified end of the wormhole is "younger" than the unmodified end does not make it a portal to the past.

In a world of relative simultaneity, how do we account for the fact that the observed phenomenon is time dilation and not time regression? In the absence of a universal present moment uniting all frames, the reduced rate of time for the high-speed frame – though maintaining the measure of the speed of light at *c* – ought to drag that frame into a past moment relative to a low-speed frame. Yet this is not the case, and the reason is simple: simultaneity is absolute. The present moment, like *c*, is frame-independent. No matter how great the difference in lightspeed between two frames, they must remain in the same present. Explaining relativistic phenomena thus requires *three* postulates: the equality of all inertial frames with respect to physical law, the lawfulness of *c* and the lawfulness of time-presence. Without an absolute time-present, the relativity of time-passage would result not in time dilation but the absurdity of time regression.

Establishing an absolute time-present in no way implies recourse to a neo-Lorentzian preferred frame of reference. All frames are equal under physical law, including the lawfulness of time-presence.

Fundamentally, the relativity of simultaneity is falsified by its reliance on subjective choice of reference frame to generate an objective physical effect. Beyond this, Einstein's principle fails because (1) it implies the impossibility of measuring a single present moment independent of frame, though the theoretical viability of such a measurement can be demonstrated with a simple thought experiment, and (2) it leads to time regression rather than time dilation since the reduced rate of time of the greater-lightspeed frame causes it to revert – in the absence of a shared present moment – to a past moment for the lesser-lightspeed frame.

**6 Time and Space-time**

"Special relativity," writes Tim Maudlin, "is, fundamentally, a postulate about the structure of space-time" (2012, 83). Quite the contrary, special relativity is a *theory* that explains time dilation, length contraction and mass increase. While the theory can be illustrated by the use of Minkowski space-time, it stands or falls on the basis of experimental evidence. To put time dilation to the test, we need objects with objectively different speeds, that is, different ratios of *c* as measured in an arbitrary frame. On this basis a muon descending from the sky has a greater lightspeed than a laboratory on Earth's surface. Only by establishing different lightspeeds for different objects can we arrive at time dilation (and time gain). By contrast, no space-time diagram has ever verified or falsified a prediction of special relativity.

Likewise, in opposition to Feynman and others, Maudlin (2012, 81) claims to have resolved the twin paradox "without calculating the acceleration of anything: all we computed was the ratio of the lengths of the trajectories" of the twins in a space-time diagram. However, without one of the twins undergoing acceleration, the lengths of their trajectories in space-time would not differ in the first place.

In accord with the Lorentz transformation, the rate of time decreases for an object as its speed increases and, conversely, its rate of time increases as its speed decreases, thereby preserving space-time interval. Events are separated not by a definite amount of time but instead by a definite amount of space-time. Indeed, space and time are frame-dependent variables only when considered separately. Even in special relativity, space-time is absolute.

Does this pose a problem, as Christian Wüthrich claims (2011, 3), for the concept of a universal present moment? Not at all. As we have seen, rather than revert to a past moment, an object dilating in time merely undergoes a reduced rate of aging while remaining present to an object traveling at a lesser lightspeed. Whereas Minkowski space-time makes no room for a universal present, time dilation requires it. Though the rate of temporal passage is inextricably bound to motion across space, temporal presence is indifferent to motion. Time exists not only in relation to space but in relation to itself. To complete our understanding of time we need intrinsic time in addition to space-time.

If, like Maudlin, our starting point is Minkowski's geometrical interpretation of special relativity, the relativity of simultaneity is taken at face value. In a universe where time has no attributes not found in a diagram, time is stripped of temporality – that is, passage and presence – and reduced to a dimension as static as the three dimensions of space. No longer inherently temporal, the world is a four-dimensional *block* in which "past" and "future" are equally pre-determined and even interchangeable depending on what moment is arbitrarily defined as the present (Smolin 2013, 55). If events that are simultaneous in one frame are successive in another, no definitive present moment can be said to unify all frames. Without an objective and universal present moment, the concept of an orderly passage of time has no physical meaning.

Yet temporal flow is implicit in time dilation, which after all is manifested by the slowed ticking of a clock. As Einstein puts it, the clock that is set in motion "lags behind" the stationary clock (Lorentz, et al, 1923, 49). Special relativity reduces time to a static dimension only insofar as it consists of a theory of time on the basis of the relativity of simultaneity. Insofar as special relativity is a theory of time *dilation* on the basis of relative motion in the context of the absolute speed of light, time retains its flow. The rate of time varies from one frame in relation to another but always in the context of an absolute present.

Vesselin Petkov denies a universal present moment on the basis of his thought experiment illustrating relative simultaneity. Petkov (2005, 128-129) places two observers in motion such that only one of them, observer A, considers a pair of clocks to be synchronized. The other observer, B, is in motion toward one of the clocks, C1, and away from the other, C2. When the observers meet, A says both clocks read five seconds into the experiment, whereas B, in keeping with the relativity of synchrony, says that C1 reads eight seconds and C2 reads two seconds. According to Valente (2012, 7)

It is clear from this that B is not ‘seeing’ clock C1 three seconds in the future or ‘seeing’ clock C2 three seconds in the past… B is simply measuring, due to the fact that the synchronization procedure adopted by A is relative to A’s reference frame, a phase lag in the clocks synchronized in A’s reference frame. In this way, Petkov is wrong when considering that “for B clock C1 exists at the 8th second of its proper time (at its ‘now’) and clock C2 exists at the 2nd second of its proper time (at its ‘now’)."

So long as we inhabit a block universe in which all times, like all places, exist at once, the reality of a clock three seconds in the past and another clock three seconds in the future is perfectly reasonable. For Petkov the problem arises when we assume that existence is limited to the present moment. If so, he writes, then for A and B to observe different times, the clocks must double in number such one set exists for A and another for B. Acknowledging an absolute present thus entails relativizing *existence* (2005, 129). Petkov's mistake is to assume that the relativity of synchrony implies a relativity of time itself rather than simply the frame-dependence of Einstein's clock synchronization procedure. Regardless of the variant readings of the clocks for A and B, both observers perceive the same clocks in the same present moment, precisely the moment occupied by the observers. Though our attempt to label the present with a specific time is frame-dependent, the present moment itself is absolute.

In Newtonian terms, absolute simultaneity means each event is simultaneous with other events across the universe. Hence each successive instant, writes Newton, is "diffused throughout all spaces," embracing all the events in those spaces (Maudlin 2012, 153). The question of absolute simultaneity, however, resolves without recourse to the idea that time is somehow smeared across space. Far from implying time as a property of space, the meaning of space-time is that the entire expanse of the universe exists only insofar as it is present.

Contrary to the block universe model, Einstein effectively assumed a temporal three-dimensional world in the form of an observer who chooses a frame of reference from which to examine the passage of events. According to this observer the high-speed frame progresses more slowly in time compared to the low-speed frame. This is no different than Bohr presupposing a classical world in the form of an observer of a measurement of a quantum system (Bohm and Hiley 1993, 4). Either way we cannot make sense of our theories without the use of classical concepts that imply an ongoing world of the senses. To deny temporal flow in relativity and champion the block universe as the objective reality is exactly parallel to rejecting collapse of the wave function in quantum theory in favor of the Everett interpretation, which abolishes a definitive timeline of events and posits as the only physical reality the eternally branching universal wave function. Yet mathematical reductionism in any form was repugnant to Einstein, which is why he insisted in general relativity that the influence between a four-dimensional geometry and the distribution of mass in the universe is mutual (Friedman 1983, 64).

Einstein maintained that the pre-relativistic illusion of universal time followed from ignorance of the limitation of *c* (1954, 299). Yet the realization that light cannot tell us what is happening right now on Jupiter, as illustrated by Minkowski's concept of the light cone (Lorentz, et al, 1923, 83), in no way negates a shared present moment between Earth and Jupiter. Do we deny physical meaning to Jupiter's current state because it has no causal relevance to our current state on Earth? Since when is Earth the center of the universe? Einstein seems to have confused an epistemological observation with an ontological claim. Taking this distinction into account, we might surmise that relativity is all about our knowledge of the world rather than the world itself. This would be a mistake, as time dilation – the relativistic reduction in the rate of temporal passage – is a verified effect.

**7 Conclusion**

As Einstein determined, the Lorentz transformation describes the contraction of length, the increase of mass and the dilation of time as the results of the relative motions of countless reference-bodies in a universe governed by *c*. It must be noted, however, that time dilation is not directly implicated by Einstein's approach. To account for the frame-invariance of *c*, all we need is the variability of time, specifically a relativistic reduction in the rate of time for the greater-lightspeed frame. In the absence of a universally applicable present moment, the logical outcome of a differing rate of time for each frame is differing present moments. Yet the Lorentz transformation implies a common period of elapsed time uniting both frames. The point of modifying *t0* is to maintain its equality with *t*, that is, to keep the frames in the same present moment. So long as the second term is suitably modified, *t* = *t0*. For Lorentz, the time component of his transformation signified merely an "aid to calculation," not an actual effect (Goldberg 1984, 96). So long as time dilation is understood in this way, it poses no problem. Granted, it also poses no (real) solution. Only when we recognize that time dilation explains the invariability of *c* by way of the frame-dependent variability of time-passing are we then compelled to postulate, so as to maintain equality of frames, a frame-independent time-present.

Like quantum mechanics, special relativity has a measurement problem in the sense of a failure in the objectivity of results. Because the act of measurement entangles the quantum system with the device that measures it, measured object and measuring device cannot be precisely distinguished, thereby precluding classical objectivity (Folse 1985, 113). In special relativity the problem follows from the absence of physical meaning in the result of a time measurement, that is, the failure of a clock to actually occupy the time it displays to an observer in a different frame. If it did, the clock would no longer be present to the observer, paradoxically negating the observation in the first place. That we can indeed observe the reading of a clock that differs from that of the clock in our own frame – the relativity of synchrony – indicates the *complementarity* of relative time-passage and its apparent opposite, absolute time-presence.

Like an electron in a superposition of spin up and spin down, special relativity is both right and wrong. If we probe the theory for an explanation of relativistic phenomena on the basis of the Lorentz transformation in the context of differing lightspeeds, it succeeds. If, on the other hand, we investigate it as an account of the nature of time on the basis of the relativity of simultaneity, it fails. Removing it from superposition requires recognizing it solely as a theory of relativistic phenomena and not additionally as a theory of time.

For more than a century, understanding special relativity has been impeded by the entanglement of Einstein's principled derivation of the Lorentz transformation with his false inference of relative simultaneity from the relativity of synchrony. Only with the expulsion of the metaphysics of time from special relativity do we arrive at a strictly physical theory that explains relativistic phenomena according to relative motion in the context of the unwavering speed of light.

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