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Absoluteness–Relativity Duality of Spacetime: Separation of the Mechanical Rest Frame and Optical Moving Frame

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Abstract

Quantum mechanics presupposes a fixed background spacetime, whereas Einstein's special theory of relativity excludes an absolute rest frame. Taking the invariance of the speed of light as the sole first principle, we argue that an absolute rest frame and observer relativity can coexist without contradiction, as a consequence of the operational duality of measuring instruments. In a given reference frame, only points at rest are measured directly with rigid rulers and atomic clocks; a moving point borrows the coordinates of the rest points it passes in its vicinity. In the mechanical rest frame, the rigid ruler and the light ruler, the atomic clock and the light clock, and global synchronization all agree, whereas along the axis of motion of an optical moving frame this agreement breaks down and only perpendicular-plane synchronization holds. Because the rest frame employs rigid rulers, atomic clocks, and light together, it satisfies isotropy and homogeneity, from which the linearity of the coordinate transformation follows. Observer relativity, which arises from the shared use of light, then yields the Lorentz transformation and its inverse. The principle of relativity is therefore not an independent axiom but a measurement-theoretic consequence of light-speed invariance. Observer relativity holds on the foundation of an absolute rest frame, and the spacetime of inertial frames accordingly exhibits an absoluteness–relativity duality of spacetime.

Keywords: Special Relativity, Lorentz Transformation, Clock Synchronization, Rest Frame, Operationalism, Light-Speed Invariance

1. Introduction

Quantum mechanics and Einstein's special theory of relativity, the two pillars of modern physics, are in tension over the definition of spacetime. Quantum mechanics and quantum field theory in curved spacetime require a fixed background spacetime in order to formulate the time evolution of states and to apply the uncertainty principle [1-3]. Einstein, by contrast, in his 1905 paper adopted the principle of relativity and the invariance of the speed of light as two axioms, thereby excluding an absolute rest frame and adhering to a relative spacetime determined by the state of motion of the observer [4]. This tension between the background rest frame required by quantum mechanics and the absolute rest frame excluded by special relativity is a recurring difficulty whenever one attempts to unify the two theories within a single spacetime [3,5].

The historical root of this tension lies in the axioms adopted in deriving the Lorentz transformation. Lorentz sought to explain electromagnetic phenomena in moving systems while retaining a stationary ether [6,7], whereas Einstein rendered that ether superfluous by unifying mechanics and electromagnetism under a symmetry between inertial frames [4,8]. Each approach pushed absolutism or relativism to the exclusion of the other, and neither asked whether absoluteness and relativity might coexist within a single operational framework [9]. In particular, the axiomatic method introduced by Einstein compresses the operational procedures undergone by actual measuring instruments into a single notion: a geometric transformation [4,10].

To preserve both the rest frame as the fixed background required by quantum mechanics and the relative spacetime retained by special relativity, the two axioms of special relativity must be reread from the standpoint of measurement mechanics. Einstein disregarded the dynamical difference between massive measuring instruments (rigid rulers and atomic clocks) and massless light (photons), and interpreted the Lorentz transformation as a single spacetime geometry [4,11]. When the material interactions internal to measuring devices and the conventions of optical signaling are mixed within one transformation, however, the distinction between what is directly measured and what is conventional is erased [12,13].

Just as quantum mechanics transformed the description of the microscopic world through wave–particle duality [1,14], the present work shows that absolutism and relativism coexist within a single operational framework by making explicit the following measurement-theoretic asymmetries that have lain hidden behind the development of relativity: the asymmetry between a point at rest and a moving point; the asymmetry between two-way light-speed invariance and borrowed light-speed invariance; the asymmetry between the mechanical rest frame and the optical uniformly moving frame; the duality of the rigid ruler and the light ruler; the duality of the atomic clock and the light clock; and the asymmetry between global synchronization and perpendicular-plane synchronization.

On the basis of these six dualities, and taking only the invariance of the speed of light as the first principle, we deduce the isotropy and homogeneity of the rest frame. By making explicit the operation whereby rest points measure and moving points borrow, and by elucidating the mechanism through which the linearity of borrowed coordinates and observer relativity hold between inertial frames, we argue that the physical reality of an absolute rest frame (the mechanical rest frame) and the relativity between observers (the optical uniformly moving frame) coexist without contradiction in a single framework. The experimental success of the Lorentz transformation itself—the Michelson–Morley, Kennedy–Thorndike, and Ives–Stilwell experiments and their subsequent refinements—is accepted in full [15-19]. What changes is the interpretation: the transformation is not a mechanical transformation of space but an optical addition of borrowed coordinates.

2. Isotropy and Homogeneity of the Rest Frame

A. Physical Status of the Rest Frame and Three Measuring Instruments

Elucidating the geometric structure of space and time requires first establishing a coordinate system that serves as the standard of measurement [10,20]. In developing the special theory of relativity in 1905, Einstein reinterpreted the transformation obtained by Lorentz on the basis of two axioms [4,6]. In that development he regarded relativity not as a relation between points but as an equivalence between inertial frames, and consequently denied an absolute rest frame under the hypothesis that all inertial frames are physically indistinguishable [4,11]. The rest frame redefined in this paper is a geometric reference frame that fully preserves the isotropy and homogeneity of space by means of rigid rulers, atomic clocks, and light, and that can play the role of the background spacetime of quantum mechanics [2,3,5].

In the measurement-mechanical thought experiment, the isotropy and homogeneity of the space constituting the rest frame rest on the following three basic propositions, which pertain, respectively, to the spatial scale, the temporal scale, and the synchronization signal.

- **First, the Law of Invariability of Rigid Rulers:** A rigid ruler (or rigid rod), the physical standard for measuring space in the rest frame, maintains its proper length irrespective of its position and orientation.
- **Second, the Principle of the Atomic-Clock Period:** The proper period of an atomic clock, which measures the passage of time in the rest frame, is constant irrespective of the position of the clock.
- **Third, the Constancy of the Speed of Light:** In the rest frame, the speed of light is measured by a round-trip experiment using a rigid ruler and an atomic clock, and it is invariant irrespective of the position and orientation of the rigid ruler.

The physical distinguishability of the rest frame follows from the conjunction of these three propositions. A coordinate system in which the round-trip time of light in the round-trip experiment is the same regardless of direction and position is defined as a rest frame, and a coordinate system in which this condition fails is defined as a uniformly moving frame.

B. Isotropy of the Rest Frame

The construction of inertial frames begins with the determination of the rest frame by means of a round-trip light experiment. A light source O is placed at one end of a rigid rod of length L, and a mirror P at the other end. If T_0 denotes the time taken for light emitted from the source O to be reflected by the mirror P and return to O, the two-way speed of light c satisfies

$$c = \frac{2L}{T_0} \qquad (1)$$

[15,16]. Fixing the speed of light by a round-trip experiment means that the coordinates of a point at rest can be measured with a rigid

ruler and an atomic clock; we denote this observer by $P(x,y,z,t)$. Here x, y and Z are three-dimensional Euclidean coordinates measured with rigid rulers, and is the proper time of an atomic clock at rest at that position.

The isotropy of space is the symmetry whereby all directions about a point are physically equivalent. Standard developments of relativity often posit isotropy as an a priori axiom that a coordinate system must satisfy [4,11,20]. Since the present work takes only the invariance of the speed of light as the first principle, the isotropy of the rest frame is read as a consequence of that principle.

Consider a light signal emitted in all directions from the origin $O(0,0,0)$ of the rest frame S at $t = 0$. If the speed of light c is independent of direction, the locus reached by the wave front at time t is a sphere of radius $r = ct$ [4,21].

$$x^2 + y^2 + z^2 = (ct)^2 \qquad (2)$$

In differential form, this becomes the null interval,

$$dx^2 + dy^2 + dz^2 - c^2dt^2 = 0 \qquad (3)$$

C. Homogeneity of the Rest Frame

The homogeneity of space is the symmetry whereby physical properties are the same irrespective of position, and the homogeneity of time means that physical laws are invariant under translations along the time axis. In Einstein's framework these properties are likewise often posited a priori [4,20]; here, instead, we deduce that light-speed invariance, independent of position and time, entails the homogeneity of spacetime. For an arbitrary emission event (x_1,y_1,z_1,t_1),,

$$(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2 = c^2(t - t_1)^2 \qquad (4)$$

holds. The linearity of transformations between inertial frames follows precisely from this homogeneity [18,22].

D. Asymmetry between a Rest Point and a Moving Point

In the rest frame, coordinate measurement differs between points at rest and moving points. In the round-trip experiment described above, the rigid rod and the atomic clock are points at rest, whereas light is a moving point. The spatial coordinates of a point at rest $P(x,y,z,t)$ are read with rigid rulers, and its time is read directly from a fixed atomic clock; these are therefore measured coordinates.

The spacetime coordinates of a moving point, however, cannot be measured directly with rigid rulers and atomic clocks. A moving point borrows the measured values of the rest points that it passes in its vicinity. This is equivalent to the requirement of Bridgman's operationalism that "a concept is defined together with its measurement procedure" [10].

To label the spacetime coordinates of a point at rest P as $P(x,y,z,t)$, as , the atomic clocks at rest must be synchronized. Synchronization is performed with rigid rulers and light. Let t_O be the reading of the atomic clock at the origin O; the clock at a point whose distance measured with rigid rulers is $r = \sqrt{x^2 + y^2 + z^2}$ is then set to

$$t_P = t_O + \frac{r}{c} \qquad (5)$$

Synchronization in the rest frame corresponds to the choice ε =1/2 in Reichenbach's simultaneity convention [4,13,23,24].

Because the rest frame is isotropic and homogeneous, this procedure can be repeated at every lattice point, so that the entire frame shares a single time. We call this global synchronization.

Once global synchronization of the rest frame by rigid rulers and light has been completed, distances can be measured using atomic clocks synchronized with light. We call this the light ruler. The light ruler determines the distance between two points by multiplying the time interval taken by light to travel between them by the speed of light C [4].

If light leaving the origin O at time t_O arrives at time t_P at a point P located at a distance r measured with rigid rulers, then

$$r = c(t_P - t_O) \qquad (6)$$

holds. The left-hand side is given by the rigid ruler and the right-hand side by the light ruler. Owing to the isotropy and homogeneity

of the rest frame, the two scales agree irrespective of direction and position; we call this the agreement of the rigid ruler and the light ruler. According to the equivalence of inertial frames asserted by Einstein, the rigid ruler and the light ruler should always agree. In fact, however, they agree only when the two ends of the rigid ruler are simultaneous.

When a moving point P' passes in the vicinity of an observer at rest $P(x,y,z,t)$, the coordinates of the moving point are written as $P'(x,y,z,t)$. When P' passes in the vicinity of the next observer at rest $P_1(x+\Delta x, y+\Delta y, z+\Delta z, t+\Delta t)$, its coordinates are updated to the measured values of that rest point:

$$P'(x+\Delta x, y+\Delta y, z+\Delta z, t+\Delta t) \qquad (7)$$

We call this operation coordinate borrowing. The coincidence in the vicinity referred to by Einstein is precisely this procedure [4]. The velocity and acceleration of a moving point are defined solely through the time variation of the borrowed rest-point coordinates.

E. Uniform Motion of Massive Bodies Versus Light

When the coordinates of a moving point are defined as borrowed coordinates, treating the uniform motion of a massive body and the propagation of massless light together as "motion at constant velocity" makes it impossible to distinguish the body, which is a point fixed in the uniformly moving frame, from light, which is a moving point.

A massive body in uniform motion does not accelerate from the origin, travel in a straight line, and then decelerate to arrive in front of the observer. In the absence of external forces, it is already in uniform motion, so its world line passes through the vicinity of the origin and also through the vicinity of the observer. The origin and the observer are points at rest that the body sweeps past, and the body is a moving point that passes the two points in succession. Assuming a launch trajectory of acceleration–uniform motion–deceleration from the origin to the observer contradicts the very definition of uniform motion.

Likewise, light emitted from a source at rest O does not undergo acceleration–uniform motion–deceleration on its way to the observer P. Leaving the source at rest, light propagates at speed c, passing successively through virtual observation points $P_1, P_2, \ldots, P_n$ separated by the wavelength λ. Macroscopically it appears as a straight line traversed at mean speed c, but each step is a transition through a neighboring rest point at speed c. Within the rest frame, the source and the observer are points at rest in that frame, and light is a point moving at constant velocity [25].

That is, in the rest frame the coordinates of the source and the observer are measured coordinates obtained directly with rigid rulers and atomic clocks, whereas light, as a point moving discontinuously in units of one wavelength and one period, uses the borrowed coordinates of rest points.

3. Linearity and Relativity in Inertial Frames

A. Two-Way Invariance Versus Borrowed One-Way Invariance

The rest frame equips its points at rest with rigid rulers, atomic clocks, and light (sources and observers), whereas the uniformly moving frame equips its uniformly moving points with light (sources and observers) only. Suppose now that there exists a uniformly moving frame O' moving at constant velocity v relative to the reference frame O. The observer $P'(\xi,\eta,\zeta,\tau)$ of the moving frame moves at constant velocity v in the $+x$ direction relative to the observer P(x,y,z,t) of the reference frame. For $P(x,y,z,t)$ and $P'(\xi,\eta,\zeta,\tau)$, the x axis coincides with the ξ axis, and the y and η axes and the z and ζ axes are respectively parallel. The uniformly moving frame must satisfy the following condition.

To construct the uniformly moving frame, the speed of light must also be fixed in that frame. Light emitted together from the source $O(0,0,0,0)$ of the rest frame and the source $O'0(0,0,0,0)$ of the moving frame travels discontinuously in straight lines and arrives together at the rest-frame observer $P(x,y,z,t)$ and the moving-frame observer $P'(\xi,\eta,\zeta,\tau)$. Through coordinate borrowing, the rest-frame observer $P(x,y,z,t)$ regards the two sources O and $O'0$ as one and the same source, and therefore assigns the speed c to all light. Likewise, since light emitted together from the rest-frame source O and the moving-frame source O_0' arrives together, the moving-frame observer P' also concludes, again through coordinate borrowing, that the speed of light is c irrespective of the velocity of the source. In other words, because light that departs together arrives at the observers together, the speed of light is always c irrespective of the motion of the source or the observer. Hence the two equations

$$x^2+y^2+z^2=c^2t^2 \Rightarrow \xi^2+\eta^2+\zeta^2=c^2\tau^2 \qquad (8)$$

are mathematically equivalent but physically distinct. The left-hand equation uses the measured speed of light obtained from the round-trip experiment, whereas the right-hand equation uses the borrowed speed of light transcribed according to borrowed coordinates.

The conventional special theory of relativity assumes the invariance of the speed of light as an equivalent axiom holding independently in every inertial frame [4]. The law of light-speed invariance does hold in inertial frames, but the rest frame and the uniformly moving frame differ in that the former exhibits two-way light-speed invariance whereas the latter exhibits borrowed light-speed invariance.

B. Asymmetry between Mechanical Rest Frames and Optical Uniformly Moving Frames

The distinction between the measurement procedures for points at rest and moving points recurs within a uniformly moving frame that moves at velocity relative to the rest frame. Only a point $P'(\xi,\eta,\zeta,\tau)$ fixed in the moving frame measures the coordinates of that frame with light, and it borrows the coordinates of any other frame sweeping past it. In both the rest frame and the moving frame, the coordinates of a point at rest in a coordinate system are measured directly by an observer at rest, whereas the coordinates of a moving point are borrowed from fixed observers. The claim that the two frames are interchangeable stems from treating the measurement by a rest point and the borrowing by a moving point as the same operation.

The rest-frame observer P and the moving-frame observer P' are nevertheless distinguishable, because the instruments and methods by which they measure their own coordinates (as points at rest) differ. That is, the rest-frame observer P measures its own coordinates independently using rigid rulers, light, and atomic clocks, whereas the moving-frame observer P' uses the light of the moving frame and the light of the rest frame to match its own coordinates to those of the rest-frame observer $P(x,y,z,t)$ that it passes. We accordingly call the former the mechanical rest frame and the latter the optical uniformly moving frame. Consequently, the rigid ruler and the light ruler agree in the rest frame but disagree in the moving frame; likewise, the atomic clock and the light clock agree in the rest frame but disagree in the moving frame. These points are discussed in detail in Sec. IV, "Discussion: Separation of the rest frame and the uniformly moving frame."

In inertial frames, a transformation means that an observer at rest expresses the coordinates obtained with its measuring instruments in terms of coordinates borrowed from an observer passing by. The Lorentz transformation expresses the coordinates of the moving-frame observer $P'(\xi,\eta,\zeta,\tau)$ in terms of coordinates borrowed from the rest-frame observer $P(x,y,z,t)$. The inverse Lorentz transformation may be said to express the coordinates of the rest-frame observer $P(x,y,z,t)$ in terms of coordinates borrowed from the moving-frame observer $P'(\xi,\eta,\zeta,\tau)$. The speed of light c in the rest frame is a measured speed obtained by timing round trips with rigid rulers and atomic clocks, whereas the speed of light c in the moving frame is a borrowed speed taken over from the measured value c of the rest frame passing in the vicinity. Therefore, with light—the common measuring instrument—as the reference, the mechanical rest frame is a measured coordinate system, whereas the optical uniformly moving frame is a borrowed coordinate system. That the mechanical rest frame and the optical moving frame appear relative to each other does not make them coordinate systems of the same kind.

C. Linearity in Inertial Frames

That the transformation between two inertial coordinate systems S and S' must be linear is often introduced as self-evident [4,22]. In this section we deduce linearity using the isotropy and homogeneity established in Sec. II as the cornerstone. Homogeneity means that the characteristics of measurement do not change when the spacetime origin is shifted. Let us assume a general transformation between intervals (dx,dt) in the rest frame S and intervals $(d\xi,d\tau)$ in the moving frame S' of the form

$$d\xi = \frac{\partial \xi}{\partial x}dx + \frac{\partial \xi}{\partial t}dt \qquad (9)$$

$$d\tau = \frac{\partial \tau}{\partial x}dx + \frac{\partial \tau}{\partial t}dt \qquad (10)$$

If the partial-derivative coefficients were functions of the coordinates (x,t), transforming the same dx at two different locations A and B in the rest frame would yield different $d\xi$. This contradicts the homogeneity established in Sec. II.

For the correspondence of intervals to be independent of position, the partial-derivative coefficients must be constants. Denoting by δ, β, α, and σ the constants for a frame S' moving with velocity v along the x axis relative to the rest frame S, we have

$$d\xi = \delta dx + \beta dt, \qquad d\tau = \alpha dx + \sigma dt \qquad (11)$$

Integrating these yields linear combinations, i.e., linear functions (the integration constants are set to zero by making the two origins coincide):

$$\xi = \delta x + \beta t, \qquad \tau = \alpha x + \sigma t \qquad (12)$$

Since the origin of the moving frame S' ($\xi = 0$) moves with velocity v in the rest frame, substituting $x = vt$ gives $0 = \delta(vt) + \beta t$, and hence

$\beta = -\delta v$. The spatial transformation thus has the linear structure

$$\xi = \delta(x - vt) \qquad (13)$$

This step belongs to the same family as the homogeneity argument used by Robertson in reconstructing Lorentz kinematics from observational data [18].

D. Relativity in Inertial Frames

We now derive relativity by applying only the invariance of the speed of light to the linear transformation. Unlike Einstein or Lorentz, the present derivation does not posit an a priori principle of relativity or an assumption of Lorentz symmetry as an independent axiom [4,6]. At the instant $t = \tau = 0$ when the origins of the two coordinate systems coincide, a light signal is emitted from the origin along the x axis. The position of the light measured by the observer of the rest frame S is $x = ct$, and the position recorded by the observer of the moving frame S' is, by the borrowed light-speed invariance, $\xi = c\tau$. Substituting these into Eq. (13) gives

$$c\tau = \delta(ct - vt) = \delta(c - v)t \Rightarrow \tau = \delta(1 - v/c)t \qquad (14)$$

and comparing this with $\tau = (\alpha c + \sigma)t$, obtained by inserting $x = ct$ into $\tau = \alpha x + \sigma t$ of Eq. (12), yields

$$\alpha c + \sigma = \delta(1 - v/c) \qquad (15)$$

For light propagating in the opposite direction (along the -x axis), $x = -ct$ in the rest frame and $\xi = -c\tau$ in the moving frame, so that

$$-\alpha c + \sigma = \delta(1 + v/c) \qquad (16)$$

Adding Eqs. (15) and (16) gives $2\sigma = 2\delta$, i.e., $\sigma = \delta$. Subtracting them gives $2\alpha c = -2\delta v/c$, i.e., $\alpha = -\delta v/c^2$. Therefore,

$$\tau = \delta(t - vx/c^2) \qquad (17)$$

On the other hand, substituting $x = 0$ into Eqs. (13) and (17) gives

$$\xi = -\delta vt, \qquad \tau = \delta t \qquad (18)$$

and hence

$$\xi = -v\tau \qquad (19)$$

That is, as seen by the observer of the moving frame S', the observer of the rest frame S is read as receding at velocity v in the -ξ direction. This means that a rest-frame observer and a moving-frame observer in each other's vicinity are relative to each other. To distinguish it from the relativity of inertial frames asserted by Einstein, we call this observer relativity. Owing to observer relativity, the relativity of physical laws can be applied to inertial frames or instantaneous inertial frames. This suggests that the relativity of physical laws is valid for those physical laws to which the law of light-speed invariance applies, that is, physical laws based on electric charge and light. Since, by Eq. (19), S moves with velocity -v as seen by the observer of the moving frame S', Eqs. (13) and (17) imply that the inverse transformation must take the form [4,22].

$$x = \delta'(\xi + v\tau), \qquad t = \delta'(\tau + v\xi/c^2) \qquad (20)$$

E. Lorentz Transformation from Observer Relativity

We now determine the transverse coordinates and the atomic-clock time. Because the moving-frame observer $P'(\xi,\eta,\zeta,\tau)$ moves along the x axis of the rest-frame observer $P(x,y,z,t)$, the η and ζ coordinates measured with light are affected only by the velocity. That is, letting m be a constant that depends only on the velocity v,

$$\eta = my \qquad (21)$$

$$\zeta = mz \qquad (22)$$

Let $S'(\xi,0,\zeta,\tau)$ and $S(x,0,z,t)$ be the feet of the perpendiculars dropped from the moving-frame observer $P'(\xi,\eta,\zeta,\tau)$ and the rest-frame observer $P(x,y,z,t)$ onto the $\xi\zeta$ plane and the xz plane, respectively. The rigid rod $P'S'$ of the moving frame and the rigid rod PS of the rest frame coincide at both ends and are simultaneous. By Eq. (6), the length y measured with the rigid ruler and the distance η measured with the light ruler in the moving frame are equal. Hence m =1 in Eq. (21); that is,

$$\eta = y \qquad (23)$$

Similarly, let $T'(\xi,\eta,0,\tau)$ and $T(x,y,0,t)$ be the feet of the perpendiculars dropped from the moving-frame observer $P'(\xi,\eta,\zeta,\tau)$ and the rest-frame observer $P(x,y,z,t)$ onto the $\xi\eta$ plane and the xy plane, respectively. The rigid rod $P'T'$ of the moving frame and the rigid rod PT of the rest frame coincide at both ends and are simultaneous. Since, by Eq. (6), the length z measured with the rigid ruler and the distance ζ measured with the light ruler are equal, Eq. (22) gives

$$\zeta = z \qquad (24)$$

From Eqs. (23) and (24), we have

$$\eta = y, \quad \zeta = z \qquad (25)$$

Next, using the light of the two frames, the atomic clocks of the moving frame are matched to the atomic clocks of the rest frame. Light emitted together from the moving-frame origin O_0' and the rest-frame origin O arrives at the moving-frame observer Q' on the transverse η axis and at the rest-frame observer Q passing in its immediate vicinity. By Eqs. (13) and (25), the light of the moving frame and that of the rest frame are described, respectively, by

$$\xi = 0, \quad \eta = c\tau, \quad \zeta = 0, \qquad x = vt, \quad y = \sqrt{c^2 - v^2}\,t, \quad z = 0 \qquad (26)$$

Hence,

$$\tau = \frac{t}{\gamma}. \qquad (27)$$

Equation (27) represents the time dilation whereby the atomic clocks of the uniformly moving frame run slow by a factor of $1/\gamma$ relative to the atomic clocks of the rest frame. The time dilation of the uniformly moving frame relative to the rest frame is not relative but absolute.

Substituting $x = vt$ into Eq. (17) gives $\tau = \delta(1-v^2/c^2)t$, and combining this with Eq. (27) yields

$$\delta = \frac{1}{\sqrt{1-(v/c)^2}} \equiv \gamma \qquad (28)$$

From Eqs. (13), (17), (23), (24), and (28), the Lorentz transformation reads

$$\xi = \gamma(x - vt), \quad \tau = \gamma(t - vx/c^2), \quad \eta = y, \quad \zeta = z, \qquad \gamma = \frac{1}{\sqrt{1 - v^2/c^2}} \qquad (29)$$

Substituting Eq. (28) into Eq. (20) gives $\delta' = \gamma$, so that

$$x = \gamma(\xi + v\tau), \qquad t = \gamma(\tau + v\xi/c^2), \qquad \delta' = \gamma = \frac{1}{\sqrt{1 - v^2/c^2}} \qquad (30)$$

From Eqs. (23), (24), and (30), the inverse Lorentz transformation reads

$$x = \gamma(\xi + v\tau), \quad t = \gamma(\tau + v\xi/c^2), \quad y = \eta, \quad z = \zeta \qquad (31)$$

According to Eq. (29), mechanically the moving-frame observer $P'(\xi,\eta,\zeta,\tau)$ moves with velocity v relative to the rest-frame observer $P(x,y,z,t)$, whereas according to Eq. (31), optically the rest-frame observer $P(x,y,z,t)$ appears to move with velocity $-v$ relative to the moving-frame observer $P'(\xi,\eta,\zeta,\tau)$. Einstein erased the absolute standard of a rest frame in order to establish the relativity of inertial frames; the present argument, by contrast, holds that Lorentz symmetry operates between observers moving upon a geometric standard precisely because such a standard—light-speed invariance and rigid-ruler invariance—exists. To distinguish this from Einstein's relativity of inertial frames, we call it observer relativity or point-to-point relativity. Observer relativity, of course, also entails the relativity of physical laws based on electric charge and light. The relativity of physical laws thus turns out to be a subsidiary proposition of the law of light-speed invariance. In inertial frames, the law of light-speed invariance gives rise to observer relativity, as manifested in the Lorentz transformation and its inverse, yet the rest frame and the uniformly moving frame remain distinct by virtue of two-way light-speed invariance in the former and borrowed light-speed invariance in the latter.

4. Discussion: Separation of the Rest Frame and the Uniformly Moving Frame

That observer relativity applies between a rest-frame observer and a moving-frame observer, while the absoluteness of inertial frames coexists between the rest frame and the uniformly moving frame, is attributable to the measuring instruments used by the two observers. Point-to-point relativity applies because of the light that both use in common, and absoluteness between inertial frames is conferred by the rigid rulers and atomic clocks used by the rest frame. This is confirmed measurement-theoretically when both observers use rigid

rulers, atomic clocks, and light in the same manner.

A. Duality of the Rigid Ruler and the Light Ruler

In the rest frame the physical standard for measuring space is the rigid ruler, but the light ruler is also used. In the rest frame, lengths measured with the rigid ruler and the light ruler always agree, by Eq. (6). In the uniformly moving frame, however, lengths measured with the light ruler and the rigid ruler do not always agree. Along the axes perpendicular to the direction of motion, the lengths measured with the light ruler and the rigid ruler agree, as shown by Eqs. (23) and (24), whereas along the axis parallel to the direction of motion the coordinates given by the rigid ruler and the light ruler do not agree. Let $V'(\xi,0,0,\tau)$ and $V(x,0,0,t)$ be the simultaneous points at which the perpendiculars dropped from the moving-frame observer $P'(\xi,\eta,\zeta,\tau)$ and the rest-frame observer $P(x,y,z,t)$ meet the ξ axis and the x axis, respectively. If the distance from the moving-frame source O_0' to the simultaneous point $V'(\xi,0,0,\tau)$ is measured with the rigid ruler, the Galilean transformation gives

$$x' = x - vt \qquad (32)$$

Reading the same two points with the light ruler gives the Lorentz transformation,

$$\xi = \gamma(x - vt) = \gamma x', \qquad \gamma = \frac{1}{\sqrt{1 - v^2/c^2}} \qquad (33)$$

Along the axis of motion of the uniformly moving frame, therefore,

$$\xi \neq x' \qquad (\xi = \gamma x') \qquad (34)$$

This does not mean that the rigid ruler is contracted by a factor relative to the light ruler; rather, when the propagation time of light is converted into distance, the light ruler yields a distance times longer than that measured with the rigid ruler. This interpretation is distinct both from Lorentz's dynamical contraction [6,7] and from Einstein's purely kinematical contraction [4]. Only in the rest frame do the two rulers agree in all directions; in the uniformly moving frame they agree only along the perpendicular axes and disagree along the axis of motion. This duality operationally separates the rest frame from the uniformly moving frame.

B. Duality of the Atomic Clock and the Light Clock

In inertial frames the physical standard for measuring time is the atomic clock, but the light clock is also used. An atomic clock measures time by the proper period of an atomic transition and indicates the proper time of a fixed point [17]. A light clock is a device that matches the times of two separated points by means of light, and it comes in two types: the two-way light clock and the one-way light clock. In the rest frame, because the speed of light was measured by the round-trip light experiment, the atomic clock always agrees with both the two-way and the one-way light clocks. In the uniformly moving frame, however, they agree along the axes perpendicular to the direction of motion but not along the axis parallel to it. In the moving frame, suppose that light emitted at time $\tau = \tau_0$ from the source O perpendicular to the direction of motion is reflected at time $\tau = \tau_P$ at a point P located a distance x' away as measured with the rigid ruler, and returns at time $\tau = \tau_1$. Then the round-trip time $T_\perp$ measured with the atomic clock, the time measured with the two-way light clock, and the time measured with the one-way light clock satisfy

$$T_\perp = \tau_1 - \tau_0 = 2(\tau_P - \tau_0) = 2\left(\frac{x'}{c}\right) \qquad (35)$$

If, however, light emitted at time $\tau = \tau'0$ from the source O parallel to the direction of motion is reflected at time $\tau = \tau' V$ at the simultaneous point V' located a distance x' away as measured with the rigid ruler, and returns at time $\tau = \tau' 1$, then the round-trip time $T\|$ measured with the atomic clock, the time measured with the two-way light clock, and the time measured with the one-way light clock satisfy

$$T_\| = \tau'_1 - \tau'_0 = 2(\tau'_{P'} - \tau'_0) \neq 2\left(\frac{x'}{c}\right) \qquad (36)$$

Along the ξ axis, parallel to the direction of motion, the light ruler yields a distance γ times longer than that measured with the rigid ruler, so a one-way light clock composed of a rigid ruler and light cannot be used. This disagreement is the temporal counterpart of the same operational fact as the disagreement between the rigid ruler and the light ruler expressed by Eq. (34) in Sec. IV A.
Comparing Eqs. (35) and (36) for the same rigid rod (x') gives

$$T_\perp = 2\frac{x'}{c} \neq 2\gamma\frac{x'}{c} = T_\| \qquad (\gamma \neq 1) \qquad (37)$$

Even though light makes round trips along the same rigid rod, the round-trip times in the perpendicular and parallel directions do not agree. Consequently, if the speed of light is fixed $c = 2x'/T$ as by a round-trip experiment, as in the rest frame, the value depends on direction:

$$c_{\perp} = \frac{2x'}{T_{\perp}} = c, \qquad c_{\parallel} = \frac{2x'}{T_{\parallel}} = \frac{c}{\gamma} \neq c \qquad (38)$$

In the uniformly moving frame, a single speed of light cannot be measured by a round-trip light experiment. The only coordinate system in which such a measurement is possible is the rest frame, in which the round-trip time is independent of direction, as in Eq. (1).

C. Duality of Global and Perpendicular-Plane Synchronization

Synchronization in the rest frame has already been defined as matching the readings of separated atomic clocks by means of rigid rulers and light. Restating it: let t_O be the reading of the atomic clock at the origin O; the clock at a point P whose distance measured with rigid rulers is $r = \sqrt{x^2 + y^2 + z^2}$ is matched according to Eq. (5). Because synchronization in the rest frame uses rigid rulers and light, we call it distance synchronization, and because the procedure can be repeated at every lattice point, we call it global.

Synchronization in the uniformly moving frame, however, does not use rigid rulers. The moving-frame observer P' uses the light of the rest frame and the light of the moving frame together to set its own atomic clock P' to the rest-frame clock P passing in its vicinity. We call this vicinity synchronization. The result is the Lorentz time

$$\tau = \gamma(t - vx/c^2) = \frac{t}{\gamma} - \frac{\gamma v x'}{c^2} = \tau_0 - \frac{v\xi}{c^2} \qquad \left(\tau_0 = \frac{t}{\gamma}\right) \qquad (39)$$

Two points with different ξ have different τ for the same τ_0. Hence the uniformly moving frame as a whole cannot be simultaneous. The points with equal τ are only those with equal ξ, namely the points of the simultaneity plane C' perpendicular to the axis of motion. We call this perpendicular-plane synchronization.

Thus, among inertial frames, the rest frame and the uniformly moving frame employ different synchronization methods. The rest frame synchronizes globally using only rigid rulers and its own light, whereas the uniformly moving frame piggybacks on the clocks at rest using only the light of the two frames, so that only perpendicular planes are simultaneous. The duality of global and perpendicular-plane synchronization is thus read not as an arbitrary difference in clock conventions but as the difference between a frame that can use rigid rulers and a frame that cannot.

D. Model of Coexistence of Absoluteness and Relativity

The "relativity with an absolute rest frame as background," proposed in this work departs from the conventional special theory of relativity in the following two respects.

First, the conventional framework lists the principle of relativity and the invariance of the speed of light as mutually coequal, independent axioms [4]. This listing leaves the causal answer to the question "why must physical laws satisfy Lorentz symmetry?" as an a priori premise. The framework of the present paper takes the invariance of the speed of light as the first principle but distinguishes between two-way light-speed invariance and borrowed light-speed invariance, and thereby develops the following hierarchical deduction:
two-way light-speed invariance → isotropy and homogeneity of the rest frame → borrowed light-speed invariance → linearity of the coordinate transformation → principle of relativity → invariance of rigid rods → atomic-clock dilation → Lorentz transformation and its inverse.

In this structure the principle of relativity is not an independent hypothesis but a measurement-theoretic consequence reached by observers who share atomic clocks and light signals on the basis of light-speed invariance. In replacing two mathematical axioms with three measurement-mechanical laws and linking causes and effects in a single causal chain, the framework accords with the general principle of parsimony in theory construction, which calls for the elimination of unverifiable axioms.

Second, the conventional special theory of relativity has an exclusive structure in which the absolute rest frame of reference is denied in order to establish relativity. As a result, how to connect the nonlocality of quantum mechanics [26,27] or the kinematic rest frame defined by the cosmic microwave background (CMB) radiation [28-30] with the fundamental structure of spacetime has repeatedly been a matter of debate. The present work argues that the mathematical symmetry of the Lorentz transformation (relativity) can coexist with the intrinsic reality of the rest frame (absoluteness) within a single spacetime structure. The interpretation advanced in this paper is that,

like the wave–particle duality of the microscopic world, spacetime dynamics also embodies a dual reality (absolute relativity) in which the relativity between observers coexists with the absoluteness of the coordinate system itself.

This also amounts to extending the three principles introduced in Sec. II A to guarantee the isotropy and homogeneity of the space constituting the rest frame (the law of invariability of rigid rulers, the principle of the atomic-clock period, and the constancy of the speed of light) to inertial frames in which linearity and relativity apply.

First, the law of invariability of rigid rulers. A rigid ruler, the physical standard for measuring space, maintains its proper length irrespective of the inertial frame in which it is placed. Accordingly, in the rest frame the rigid ruler agrees with the light ruler, whereas in the uniformly moving frame it agrees only along the axes perpendicular to the direction of motion; along the direction of motion, the length measured with the light ruler is times longer than that measured with the rigid ruler.

Second, the principle of the atomic-clock period. The proper periods of atomic clocks that measure the passage of time are identical when the clocks are at relative rest, but the period of an atomic clock in the uniformly moving frame is γ times longer than that in the rest frame.

Third, the constancy of the speed of light. The speed of light is invariant in inertial frames, but it is measured by a round-trip experiment in the rest frame and determined by coordinate borrowing in the uniformly moving frame.

This claim does not, however, conflict with experiments performed to date. The CMB dipole provides a kinematic rest frame with respect to the distribution of matter in the Universe, but it does not by itself imply a breakdown of local Lorentz invariance [29,30]. Similarly, the violation of Bell inequalities demonstrates quantum nonlocality but does not violate the light-speed limit on signaling [26,27]. What this paper preserves is the numerical validity of the Lorentz transformation [19,31], and it is our interpretation that this validity does not require a background rest frame to be logically forbidden. Traditional relativity has read this as a contraction of space itself [4,11]; from the standpoint of the present work, however, the essence of length contraction and time dilation is not a mechanical deformation of space but an optical addition of borrowed coordinates. The relativity between observers is merely a symmetry arising from the shared use of light and atomic clocks; underlying it, and coexisting separately, is the absoluteness of the mechanical rest frame as a measured coordinate system in which rigid rulers can be used.

In sum, the present construction is an attempt to restore interpretively the connection with the background spacetime of quantum mechanics—severed by the abandonment of absolute space—while retaining the mathematical and electromagnetic achievements of Einstein's theory (the validity of the Lorentz transformation).

5. Conclusion

This work has critically examined the flat juxtaposition of the two postulates of special relativity and has presented a construction in which the geometric and dynamical properties of spacetime are deduced hierarchically from the invariance of the speed of light as the sole first principle. Proceeding without positing an a priori principle of relativity or an assumption of Lorentz symmetry as an independent axiom, we obtained the following results.

First, we showed that the isotropy and homogeneity of the rest frame follow from light-speed invariance.
Second, we showed that the measurement procedures for points at rest and moving points are asymmetric. Only points at rest possess measured coordinates obtained with rigid rulers and atomic clocks, whereas moving points borrow the coordinates of the rest points they pass. This distinction applies to both the rest frame and the uniformly moving frame.

Third, we derived the linearity of transformations between inertial frames from the homogeneity of the rest frame, and obtained the Lorentz transformation and its inverse from observer relativity based on shared light. This relativity is not an independent axiom but the consequence of transcribing the measured speed of the measured coordinate system (the rest frame) as the borrowed speed of the corrected coordinate system (the uniformly moving frame).

Fourth, we showed mathematically that the rigid ruler and the light ruler, the atomic clock and the light clock, and global and perpendicular-plane synchronization agree in the rest frame but disagree along the axis of motion of the uniformly moving frame. In the rest frame Eq. (5) holds and the entire frame is simultaneous, whereas in the uniformly moving frame Eq. (39) holds and only perpendicular planes are simultaneous.

In conclusion, light-speed invariance is the single source that both guarantees the absolute properties of the rest frame (isotropy, homogeneity, global simultaneity, and measured coordinates) and fulfills the relative properties among observers using borrowed coordinates

(linearity, perpendicular-plane simultaneity, and observer relativity).

The absoluteness–relativity duality established in this work has two implications. The first concerns the logical consistency of spacetime geometry. The conventional special theory of relativity had to deny at the outset the physical reality of a rest frame of reference in order to establish relativity. By analogy with wave–particle duality, the present work has argued that spacetime dynamics, too, admits the coexistence within a single framework of the relativity between observers (the optical uniformly moving frame) and the absoluteness of the coordinate system itself (the mechanical rest frame). The second concerns the establishment of distinctions based on measuring instruments. By distinguishing measurement by points at rest from borrowing by moving points, the rigid ruler from the light ruler, the atomic clock from the light clock, and global from perpendicular-plane synchronization, we have operationally separated the rest frame from the uniformly moving frame. Whether or not rigid rulers can be used divides the two frames, and this lays the foundation for reinterpreting time dilation and length contraction not as geometric deformations of space itself but as an optical addition of borrowed coordinates.

The tasks ahead are clear. The first is to extend the separation of the mechanical rest frame and the optical uniformly moving frame to general relativity and gravitational fields. It will be necessary to model mathematically the disagreement between the rigid ruler and the light ruler in curved spacetime, and thereby to elucidate the mechanism separating absolute standards from relative measurements in accelerated and gravitating frames [31]. The second is the connection with quantum mechanics and cosmology. Whether the implications of quantum nonlocality and the kinematic rest frame of the CMB can be recast in the language of a background rest frame without compromising the validity of the Lorentz transformation must be tested against observation and experiment [27,30]. The present interpretation can survive as a physical theory only within the bounds compatible with precision tests of local Lorentz invariance [19,31].

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