The Relativistic Structure of Time

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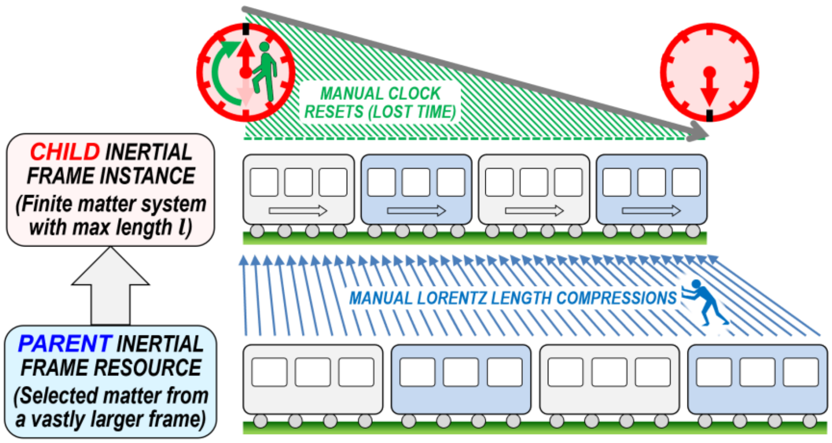


By skipping over acceleration details, Einstein overlooked the hierarchical nature of inertial frames.

Abstract: Correcting a seemingly minor algebraic error in Albert Einstein's 1907 derivation of how to translate between the coordinates of two inertial frames impacts the concept of spacetime in unexpectedly significant ways. Instead of a mathematically smooth entity independent of matter, spacetime becomes a hierarchical system of finite metrical systems that behave similarly to instances of virtual computers. Each generates identical physics down to the level of quantum mechanics yet remains bound by the resource limitations of its parent inertial frame. Another consequence is that time has a triangular relativistic structure that closely parallels the physics concepts of total energy, rest mass, and momentum energy. Instead of being timeless, photons operate solely within momentum time. Pushing the hierarchy down to particle scales should give new insights into the relationship between relativity, quantum mechanics, and quantum uncertainty.

Two years after his revolutionary 1905 pair of relativity papers [1][2], Albert Einstein published a 52-page elaboration [3] of the implications of what we now call special relativity. On page 420 of Section 3, *Coordinate-Time Transformation* [4], of his 1907 paper, Einstein derived a set of transformation equations for converting spacetime coordinates between frames. Replacing his β, which now means v/c, with γ, his equations were:

$$\left.\begin{aligned} t' &= \gamma\left(t - \frac{v}{c^2}x\right) \\ x' &= \gamma(x - vt) \\ y' &= y \\ z' &= z \end{aligned}\right\} \qquad (1)$$

where

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}\,.$$

In Einstein's notation, coordinates t, x, y, z belong to frame S and t', x', y', z' to frame S'. To derive his equations, Einstein made the following assumption on page 418:

> *… we want to choose as the starting point of time in both systems the moment at which the coordinate starting points* $[(\mathrm{t,x,y,z})=(0,0,0,0)$ and $(\mathrm{t',x',y',z'})=(0,0,0,0)]$ *coincide;*

Einstein's first transformation equation

$$t' = \gamma\left(t - \frac{v}{c^2}x\right) \tag{2}$$

allows only these S and S' origins to share the time metric labels t=0 and t'=0. Einstein noted in a famous thought experiment that lightning flashes that appear to occur simultaneously from a train embankment appear sequentially when viewed from a moving train [5]. That is, for time t=0 for all rail locations x≠0 in the embankment frame S, train clocks located immediately above rail locations must display S'-frame times t'≠0. Each such rail-train contact point is thus characterized by a pair of time labels, not one. Moreover, since dual-time values represent direct exchanges of clock readings between two potentially vanishingly close clocks, the values of these time pairs must remain invariant in both frames.

Using Einstein's equation and the embankment frame S, one can calculate the second S' member of each such time label pair. The first step is to transform Einstein's equation [2] into a form convenient for algebraic manipulation:

$$t' = \gamma\left(t - \frac{v}{c^2}x\right) = \gamma\left(t - \frac{\beta x}{c}\right) = \gamma\left(\frac{ct - \beta x}{c}\right) = \frac{\gamma}{c}(ct - \beta x) \tag{3}$$

The slope of the moving train's non-simultaneity, as observed per Δx rail length, defines an *age gradient* α:

$$\alpha = \frac{\Delta t'}{\Delta x} = \frac{t'_2 - t'_1}{x_2 - x_1} = \frac{\frac{\gamma}{c}(ct - \beta x_2) - \frac{\gamma}{c}(ct - \beta x_1)}{x_2 - x_1} = \frac{\gamma}{c}\left(\frac{-\beta x_2 + \beta x_1}{x_2 - x_1}\right) = \frac{\gamma}{c}\left(\frac{-\beta(x_2 - x_1)}{x_2 - x_1}\right) = -\frac{\beta\gamma}{c}.$$

$$\alpha = \frac{\Delta t'}{\Delta x} = -\frac{\beta\gamma}{c} = -\beta\gamma\, c^{-1} \tag{4}$$

The phrase *age gradient* emphasizes that an embankment observer who takes embankment frame snapshots of the train sees clocks at the back as "older" than clocks at the front, though this additional aging turns out to be an illusion created by the need for moving objects to resynchronize their clocks after acceleration. Notice also that data collection instruments use only direct-contact clock readings to avoid any lightspeed ambiguities. Each such pair measurement becomes an irreversible, non-relative event. Fig. 2 shows the age gradient of a fast-moving train.

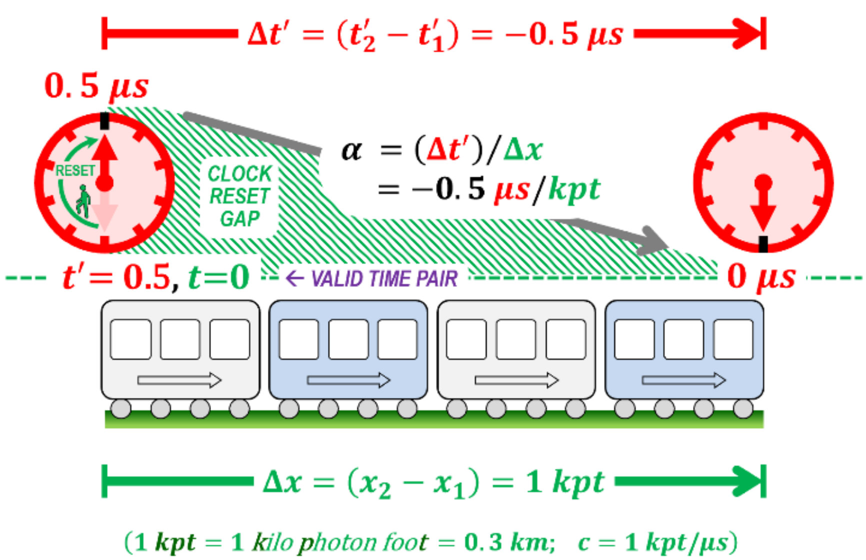


Figure 2. *Example of an age gradient in a fast-moving train.*

Given an age gradient α, the observed difference $\Delta t'$ in train times for embankment distance $\Delta x = (x_2 - x_1)$ is:

$$\Delta t' = \alpha \Delta x = -\frac{\beta\gamma}{c}\Delta x = -\beta\frac{\gamma}{c}\Delta x = -v\frac{\gamma}{c^2}\Delta x = -v\frac{\gamma}{c^2}(x_2 - x_1)\,. \tag{5}$$

As shown on the left-side dial in Fig. 2, Equation (5) says that to keep an accelerated object internally synchronous, someone or some process must actively reset the dials of rearward clocks forward in time to match the object's age gradient. It is important to note that this reset process is manual and has no more to do with causality or the creation of new history than resetting a clock forward at the start of Daylight Savings Time. Omitting the clock resetting procedure causes the train clocks to lose internal clock synchronization, with clocks at the back of the train appearing to have lost time to observers at the front. This loss would seem mysterious to anyone inside the train since all such observers would see the *same* duration during the acceleration process.

This loss of synchronization during acceleration is extremely small for ordinary scales, including even for a train moving at close to lightspeed. However, in sharp contrast, the loss of synchronization can become enormous for astronomical objects such as cosmic jets millions of light years long with velocities of over $0.99995\,c$.

Large $\Delta t'$ reset gaps affect the interpretation of causality in large relativistic objects. The general rule of thumb is that causality stays with the frame that boosts the system or object. For example, if one attempts to interpret a large cosmic jet as a single object, equation (5) says that the jet components closest to the active galactic nucleus acquire non-physical reset gaps of millions of years. These non-physical time-tracking gaps at the backs of large objects forbid the intuitive idea that the spacetime associated with relativistic objects "dips" into the distant past. Since no such historical records exist within the reset gap, such assertions have no experimental meaning.

Despite being nothing more than simple expansions of math already in Einstein's 1907 coordinate transformation equations, equation (5) conflicts with an explicit assumption Einstein made in that same paper:

> *"... this substitution [of v and -v] is identical [1]). ... Furthermore, since the relationship between [inertial frames] y and y' cannot depend on the sign of [the relative velocity between the two frames] v, the [coordinate] transformation equations [between the frames] are [equation set] (1). ... [Footnote] 1) This conclusion is based on the physical assumption that the length of a ruler and the speed of a clock do not suffer any permanent change as a result of these objects being set in motion and brought to rest again."*

The clear implication is that *the simple two-way frame symmetry Einstein assumed in his frame translation equations is invalid*. To participate fully in the desired coordinate system, an accelerated system under metrical observation and having a non-zero length in the direction of motion must undergo a manual clock reset process that introduces an increasing reset gap toward the back of the object. No such break occurs in the non-accelerated system. Thus, Einstein's coordinate translation equations are valid only for the case of an object of zero length in the direction of motion, such as an accelerated particle. The fact that the time gap gradient has its zero point at the *leading* edge of the accelerated system, rather than at the back or trailing edge, invalidates another assumption by Einstein on page 418:

> *"Furthermore, we want to choose as the starting point of time in both systems the moment at which the coordinate starting points coincide; then the linear transformation equations sought are homogeneous."*

This seemingly innocuous assumption creates the situation described in Fig. 3.

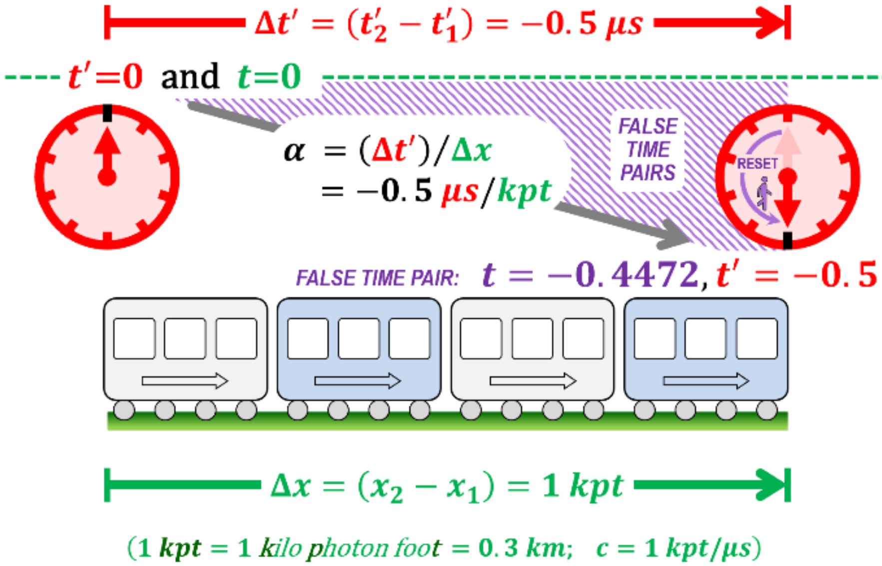


Figure 3. *Einstein's shared-origins strategy creates false time pairs.*

In the earlier Fig. 2, setting the $t' = 0$ point to be the position of the frontmost clock in the accelerated system resulted in a clock rest gap in the rest of the train. This frontmost point then "picks up" on the flow of causality from the unaccelerated or launch frame. This approach is realistic about the steps necessary to insert (boost) a lengthy object into a desired new set of spacetime coordinates. However, notice that the maximum *length* l of the accelerated system axis of relative motion of the two inertial frames — which by designation is also by definition parallel to the coincident-by-design axes x and x' — becomes an integral part of the coordinates transformation process. Without knowledge of and incorporation of this object-dependent system's length, it becomes impossible to prevent the occurrence of false time pairs since only the frontmost clock of the accelerated system can share an origin with the unaccelerated (or *launch*) frame. Attempting to define any point behind the frontmost clock creates the Fig. 3 situation in which train clocks falsely claim to have shared earlier causal points with the launch frame.

In contrast, assigning the zero-time coordinate to the frontmost clock of the accelerated system avoids creating false time pairs between frames. The accelerated frame appears to have lost blocks of time, but the resulting time labels then meaningfully pair off with those of the launch frame and thus avoid false histories. The recorded time appears for what they are: Non-causal labels attached to events solely to enable a new set of coordinates to work properly.

The correct resolution to Einstein's inadvertent conundrum thus is simple: One must recognize that accelerated objects are finite constructions that take time to form and remain fully subject to time and causality as defined in the unaccelerated frame that launched them. Within that launch frame, an accelerated object or system appears as a Lorentz-contracted and time-dilated subset with a positive age gradient (increasing range of clock resets) from front to back. This age gradient necessarily places finite limits on the definition of space and time within the moving frame. At every point, one can correctly describe the behavior of the accelerated system using *launch frame* space and time coordinates, with its own boosted coordinate system behaving as a secondary set of numbers that must always have mappings into the launch frame to remain valid. Fig. 4 shows an example of such primary (launch) and secondary (accelerated entity) coordinate pairs. The times in blue show the results of the leftward age gradients (clock reset gradients) required to create a viable new coordinate system.

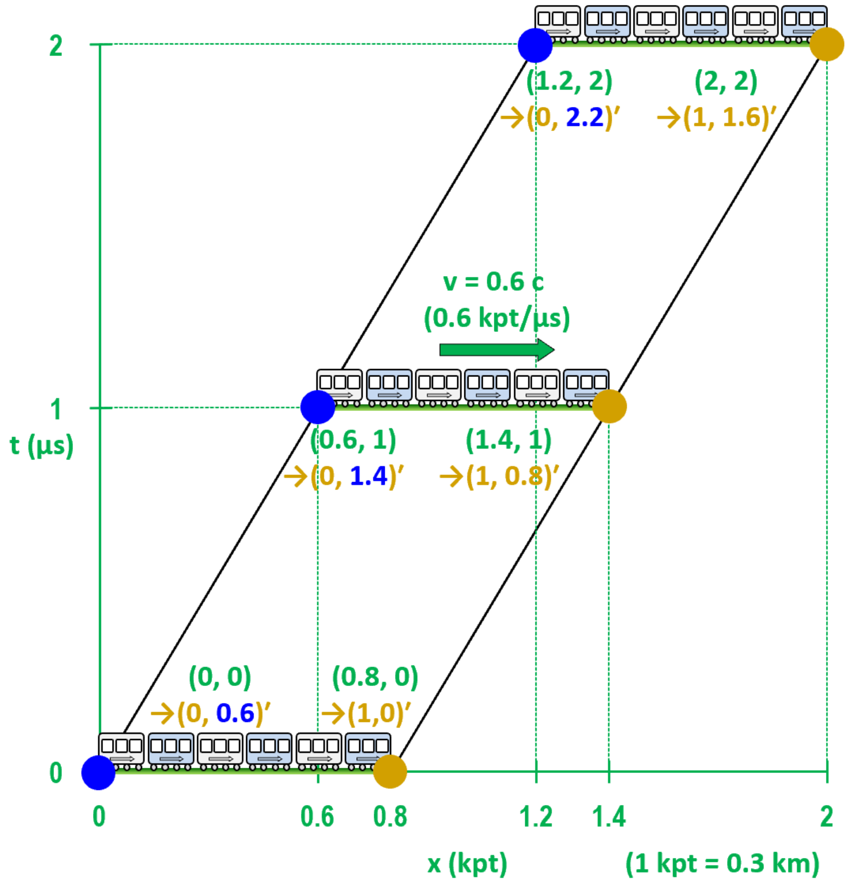


Figure 4. *Launch frame coordinate pairs for analyzing multi-frame causality.*

The first step in correcting Einstein's 1907 frame coordinate transformation equations is to observe or calculate the Lorentz contracted length of the accelerated system. The defining feature of this length variable l is that it must encompass the maximum length of the accelerated system along the axis of the resulting frame motion, which Einstein made parallel to the coincident x and x' axes:

$$l = \Delta x_{back,front} = x_f - x_b \tag{6}$$

Notice also that given the symmetry breaking created by physically resetting clocks along the axis of acceleration, adding l to the transformation means that *one cannot ignore the past acceleration history of a moving system*. One cannot fully and correctly track the causality of such a system without fully accounting for cases in which acceleration transformed the length and clock settings of the accelerated system. In cases where systems in two existing frames interact, full resolution of causality requires tracing the acceleration histories of the two back to when the matter in the two systems shared a *single* launch. The Poincaré symmetries do not care about this history since each resulting frame, once fully settled and operating within its system, provides identical physics as any other frame. The difficulty is that failing to account for acceleration resets of time accounting results in false time accounting and an illusion of causality histories that do not exist. Only the frame from which all frames originated provides fully correct time accounting.

Fig. 5 shows two reasons why unquestioningly trusting frame symmetry can give incorrect metric results. The first point is that every time figure in blue is part of a clock reset gap that breaks the symmetry between the launch (rails) frame and the moving (train) frames. The second point is that the train's motion causes its metrics to spread out over launch space in both space and time. Metrical spreading is not intuitive if one focuses only on the (very real) Lorentz compression of a moving object since this leaves a false impression that metrics measured within that system are also compact in launch space. What happens is the *opposite* since, for example, an extremely relativistic system may not complete a single unit of its space or time metrics until the distant future at a distant location. This effect becomes invisible when viewed from *within* the frame, which is why such an (overly) simple mathematical transformation is so tempting to apply in all situations. Another reason the metrics bloating effect is hard to see is that using mixed-signature Minkowski spaces makes it exceptionally difficult to track what is happening in the very real single-signature space of the launch frame.

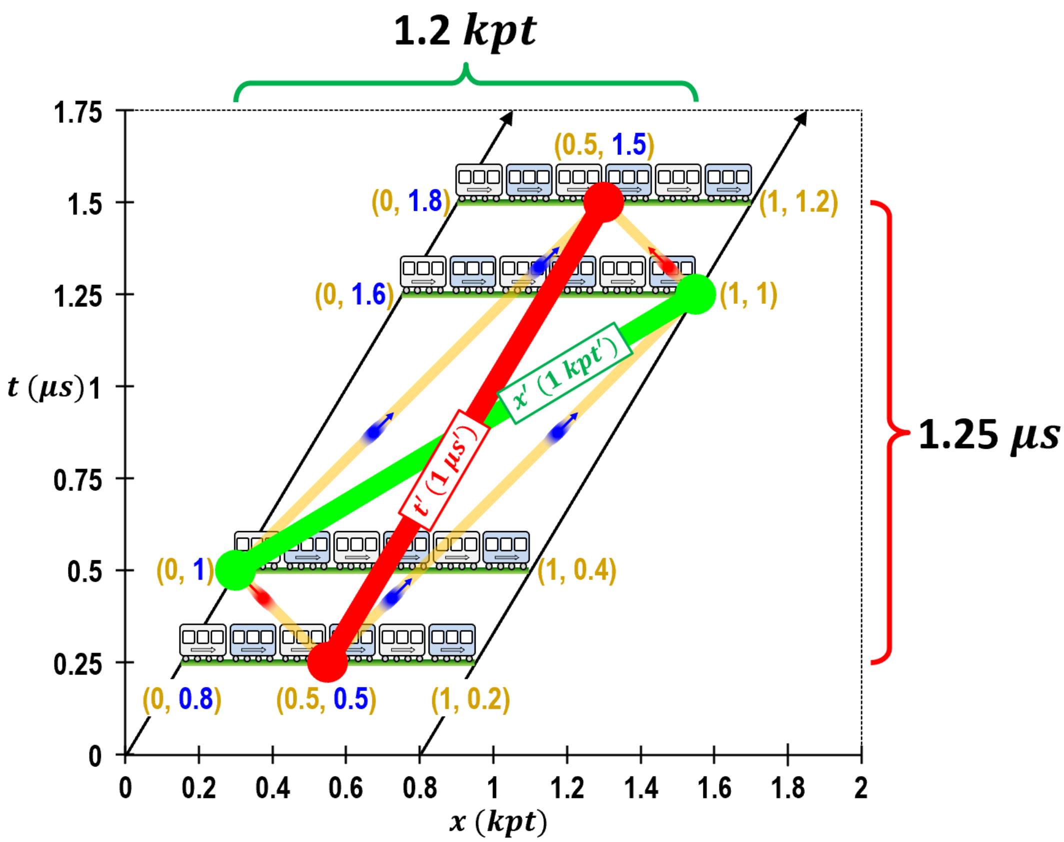


Figure 5. *Casual use of frame symmetry gives invalid metrics if done without recognizing time gaps.*

A javelin light clock maps out internal train metrics to the launch frame. A javelin light clock consists of a calibrated two-way (backward and forward) light pulse generator and receiver at the train's center, with two mirrors at the back and front of the train. It is a "javelin" because it measures time (return time) and distance (separation of the mirrors) only along the one-dimensional path of motion. The light pulse paths are always at 45° in figures with units that guarantee $c = 1$. Due to light speed invariance in all frames, the light pulse paths must reach the back and front of the train *simultaneously* from the perspective of observers within the train. The result is the extended mappings of the train space and time units in the launch (embankment) space.

The Virtual Computer Analogy

One surprisingly apt analogy for capturing the limits of acceleration-aware time accounting is the computer science concept of multiple levels of virtual computers. Each virtual computer sees itself as a real and independent computer that can, in turn, spawn its own set of virtual computers, each of which similarly views itself as a fully independent computer. Each instance exhibits all behaviors that define the original computer, and no program running within any virtual computer instance can tell whether its host is virtual or physical. Only tracking the full history of virtual computer instantiations gives a full understanding of each virtual computer's relationships, limits, and increasingly slow operations (relative to the physical computer). In relativistic physics, creating a new, fully settled, internally self-consistent inertial fame by launching materials from another, older frame corresponds remarkably closely to the indistinguishability of each new frame and their (often severe) limits regarding available material resources.

Repairing Einstein's Coordinate Transformation Equations

Since prevention of false time pairs requires locating $t' = 0$ at the *front* of the moving system — well away from its $x' = 0$ space coordinate — the new location of $t' = 0$ in comparison to Einstein's time transformation equation is displaced by the age gradient times the length:

$$t' = \gamma\left(t - \frac{v}{c^2}x\right) - \alpha l \tag{7}$$

Notice that the new equation converts into Einstein's original time equation for zero-length relativistic particles.

Since α comes from Einstein's time equation, a further simplification is possible:

$$t' = \gamma\left(t - \frac{v}{c^2}x\right) - \alpha l = \gamma\left(t - \frac{v}{c^2}x\right) + \frac{\beta\gamma}{c}l = \gamma\left(t - \frac{v}{c^2}x + \frac{v}{c^2}l\right) = \gamma\left(t + \frac{v}{c^2}l - \frac{v}{c^2}x\right) = \gamma\left(t + \frac{v}{c^2}(l - x)\right)$$

$$t' = \gamma\left(t + \frac{v}{c^2}(l - x)\right) \tag{8}$$

The new, corrected version of Einstein's 1907 frame transformation equations (1) thus is:

$$\left.\begin{aligned} t' &= \gamma\left(t + \frac{v}{c^2}(l - x)\right) \\ x' &= \gamma(x - vt) \\ y' &= y \\ z' &= z \end{aligned}\right\} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \tag{9}$$

The immediate reaction of most folks familiar with special relativity is that the two frames *must* be fully symmetric due to over a century of powerful, extraordinarily persuasive experimental proofs that no system in motion can detect physics deviating from a system at rest. *Observer symmetry between remains fully correct.* What is missing is the recognition that inertial frames are not math-only abstractions with infinite limits but complicated and well-defined local phenomena in which clocks must be Einstein-synchronized before meaningful physics experiments become possible. Once a system meets the criteria for creating a local instance of a local inertial frame, one cannot distinguish its physics from those of any other inertial frame.

However, the relationships *between* inertial frames are another matter. These require a hierarchical approach fully aware of past acceleration histories and scales with properties similar to a virtual computer analogy in which each new accelerate system "executes" a local instance of standard physics. Creating an inertial frame that includes an experimentally meaningful definition of spacetime requires an explicit Einstein-style distribution of synchronized clocks and rulers across the length and breadth of the new instance.

The Relativistic Structure of Time

Recognizing the deep connection of coordinate systems to the finite and material nature of well-defined inertial frames allows a more complete examination of their behaviors, particularly those of time. Time as an "operation" on an inertial frame instance is not a simple mathematical abstraction but an algorithm with a hidden algorithmic structure. This structure is a special relativity Pythagorean triangle linked directly to its inertial frame instance's total energy, rest mass, and momentum.

Fig. 2 and Fig. 3 provide a good starting point. Observant readers may have noticed that neither of these figures gives the velocity for a train whose age gradient $\alpha = -0.5\ c^{-1}$. Thus, the next step is to find velocity as a function of the age gradient. In principle, this equation should allow the calculation of the velocity of a fast-moving object from a single mind-bogglingly precise snapshot of all of the perfectly synchronized clocks in the image.

Using a temporary variable $\hat{\alpha} = (-\alpha)$ to protect the sign of α while solving for unitless velocity β gives:

$$\alpha = -\frac{\beta\gamma}{c} \implies \hat{\alpha} = \frac{\beta\gamma}{c} \implies \frac{\beta\gamma}{c} = \hat{\alpha} \implies \beta = \frac{\hat{\alpha}c}{\gamma} \implies \beta = \hat{\alpha}c\sqrt{1-\beta^2} \implies \beta^2 = \hat{\alpha}^2c^2(1-\beta^2)$$

$$\implies \beta^2 = \hat{\alpha}^2c^2 - \beta^2\hat{\alpha}^2c^2 \implies \beta^2 + \beta^2\hat{\alpha}^2c^2 = \hat{\alpha}^2c^2 \implies \beta^2(1+\hat{\alpha}^2c^2) = \hat{\alpha}^2c^2 \implies \beta^2 = \frac{\hat{\alpha}^2c^2}{1+\hat{\alpha}^2c^2}$$

$$\implies \beta = \sqrt{\frac{\hat{\alpha}^2c^2}{1+\hat{\alpha}^2c^2}} \implies \beta = \frac{\hat{\alpha}c}{\sqrt{1+\hat{\alpha}^2c^2}} \implies \beta = \frac{(-\alpha)c}{\sqrt{1+(-\alpha)^2c^2}} \implies \boldsymbol{\beta = -\frac{\alpha c}{\sqrt{1+\alpha^2c^2}}} \tag{10}$$

Velocity with units, $v(\alpha)$, then becomes:

$$v = c\beta \implies \boldsymbol{v = -\frac{\alpha c^2}{\sqrt{1+\alpha^2c^2}}} \tag{11}$$

As an aside, having $\beta(\alpha)$ in hand makes deriving the always-positive $\gamma(\alpha)$ trivial:

$$\alpha = -\frac{\beta\gamma}{c} \implies -\frac{\beta\gamma}{c} = \alpha \implies \gamma = -\frac{\alpha c}{\beta} \implies \gamma = -\frac{\alpha c}{-\frac{\alpha c}{\sqrt{1+\alpha^2c^2}}} \implies \boldsymbol{\gamma = \sqrt{1+\alpha^2c^2}} \tag{12}$$

Applying equation (11) to the train of Fig. 2 with an age gradient $\alpha = -0.5\ c$ gives $v = 0.4472\ c$. Since α is the ratio of two direct measurements $\Delta t'$ and Δx,

$$\alpha = \frac{\Delta t'}{\Delta x} = \frac{t_2' - t_1'}{x_2 - x_1}\ , \tag{13}$$

so one can also solve for the velocity in terms of these direct measurements:

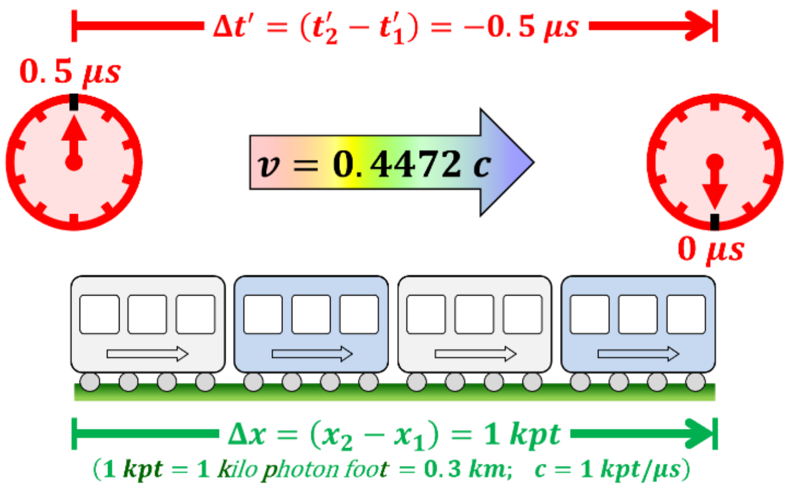
$$v = -\frac{\alpha c^2}{\sqrt{1+\alpha^2c^2}} = -\frac{\left(\frac{\Delta t'}{\Delta x}\right)c^2}{\sqrt{1+\left(\frac{\Delta t'}{\Delta x}\right)^2 c^2}} = -c\frac{(\Delta t')c}{(\Delta x)\sqrt{1+\left(\frac{\Delta t'}{\Delta x}\right)^2 c^2}} = -c\frac{(\Delta t')c}{\sqrt{(\Delta x)^2+(\Delta t')^2c^2}}$$

$$\boldsymbol{v = -c\frac{(\Delta t')}{\sqrt{(\Delta x/c)^2+(\Delta t')^2}}} \tag{14}$$

Applying (14) to the arbitrarily selected Fig. 2 and Fig. 3 train values of $\Delta x = 10\ pt$ and $\Delta t' = -5\ ns$ gives:

$$v = -c\frac{\Delta t'}{\sqrt{(\Delta t')^2+(\Delta x/c)^2}} = c\frac{5\ ns}{\sqrt{25\ ns^2+100\ ns^2}} = c\frac{5}{\sqrt{125}} = 0.447\ c$$

Fig. 6 shows the train with the velocity calculation added:



$$v = -c\frac{\Delta t'}{\sqrt{(\Delta x/c)^2 + (\Delta t')^2}} = -c\frac{(-0.5\ \mu s)}{\sqrt{(1\ \mu s)^2 + (-0.5\ \mu s)^2}} = 0.4472\ c$$

Figure 6. *Calculating velocity from length and time deltas.*

Reinterpreting Inertial Frames as Virtual Computer Physics

A *frame instance* (or *child frame*) is an internally linked system of material (fermion-containing) entities accelerated as a unit and (eventually) internally synchronized in a fashion that avoids creating false time pairs. Every frame instance has an unaccelerated *launch frame* (or *parent frame*) in which the instance resided before acceleration and transformation into a valid frame instance. The parent frame is typically but not necessarily larger than the frame instance, such as a star field parent frame and a spaceship child frame. The transformations needed to create a valid child frame include preemptive Lorentz contraction (to avoid Bell's Ship Paradox) and resetting clocks forward in time towards the rear of the system. Creating a child frame requires a finite settling time before its internal space and time metrics become fully functional. This settling time is trivially small for classical velocities and sizes but can become enormous for astronomical systems.

Every new frame instance includes a maximum length l along the direction of acceleration. The frame instance length metric l is more fundamental than it might seem since it defines the distance over which material systems are accelerated and required to participate in the new definitions of space and time. More bluntly, the length metric defines the *fragmentation* of spacetime definition in an overall system containing multiple layers of frame instances. While one can extend the mathematical definition of the new coordinates of a frame instance as far as one wishes into the surrounding launch or parent space, the only extensions that have physical meaning in terms of *measuring* reality using the new coordinates are those that stay within the bounds of the length metric l.

The virtual computer analogy provides a solid basis for understanding the relationships between parent and child frame instances. Like a virtual computer instance, each new instance has all the capabilities of the original physical computers but remains bound in what it can accomplish by the resources and history of the earlier frames that led to it. A more striking feature of the analogy is that each new inertial frame instance "executes" the *entire set of known physics rules*, including all behaviors at the quantum and particle levels, as any earlier frame instance.

Creating a new, valid inertial frame does far more than creating a coordinate system. Like a virtual computer, creating a valid new inertial frame instance recreates the *entirety* of known physics attached to the new moving systems, including all of quantum and particle physics. Though outside the scope of this paper, this virtual computer-like behavior becomes significant when the child frames become so small that they contain only one or a handful of fermionic particles. At that point, the concepts of low-resolution (low fermion count) inertial frames and quantum uncertainty merge into a single unified set of behaviors in which acceleration (momentum pair creation) becomes a fundamental operator.

Three Frame Instance Time Metrics

Replacing the generic (any length) Δx with the more fundamental frame-instance length metric l that encompasses the entire mass and energy of the frame instance gives this equation:

$$v = -c\frac{(\Delta t')}{\sqrt{(\Delta t')^2 + (l/\mathrm{c})^2}} \tag{15}$$

Notably, this equation defines velocity in terms of three distinct time metrics:

Expression	New Name	Explanation
$\Delta t'$	t_p	Time difference $(t_f - t_b)$ in clocks at the front and back of frame length l
l/c	t_m	Time needed for light to travel the frame length l
$\sqrt{(\Delta t')^2 + (l/\mathrm{c})^2}$	t_E	Pythagorean sum of t_p and t_m

Fig. 7 shows the right-triangle geometric relationship of velocity to the three distinct types of inertial frame timer interval measurements, with new names for each of the intervals:

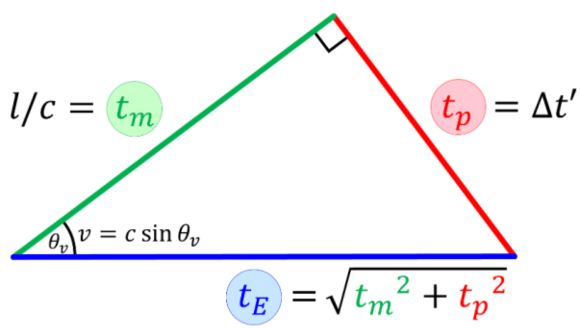


Figure 7. *Velocity as a function of the three inertial frame time metrics.*

Fig. 8 elaborates on the Pythagorean time triangle relationship and adds relationships that reflect the reasons for naming the triangular time metrics t_E, t_m, and t_p:

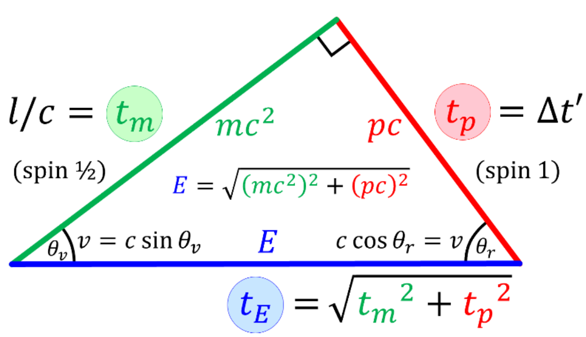


Figure 8. *Links between the Pythagorean time triangle and the energy-momentum equation.*

The energy-momentum equation at the center of the triangle is the fully generalized version of Einstein's $E = mc^2$ equation. This version is the one universally used in particle physics:

$$E = \sqrt{(mc^2)^2 + (pc)^2} \tag{16}$$

Notice that if the momentum term pc is zero — that is, if the object is not moving relative to the observer — then (16) converts back into Einstein's $E = mc^2$, which applies only to objects at rest. An object at rest corresponds to a degenerate time triangle in which rest-mass time consumes all available energy time (Fig. 9):

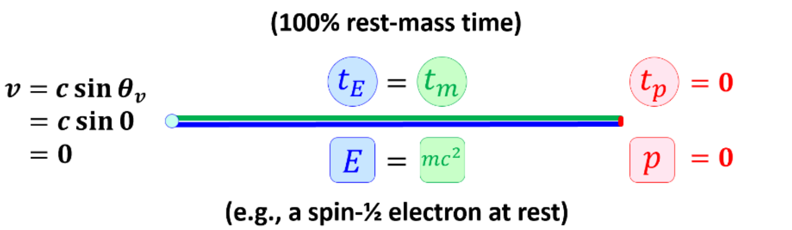


Figure 9. *Rest-mass time is identical to rest-frame (laboratory) time.*

The other limiting case occurs when momentum time consumes all available energy time — that is, when an object such as a photon has no rest mass. In this case, equation (16) converts into the formula for finding the energy of a photon, $E = pc$, which applies only to moving at lightspeed. This case corresponds to the degenerate time triangle shown in Fig. 10 in which rest-frame time is zero and velocity is equal to c. Notice that it is not fully correct to say that photons are "timeless," but rather that they operate entirely in momentum time that is not directly visible to experimental instruments operating in the rest-mass inertial frame of a laboratory.

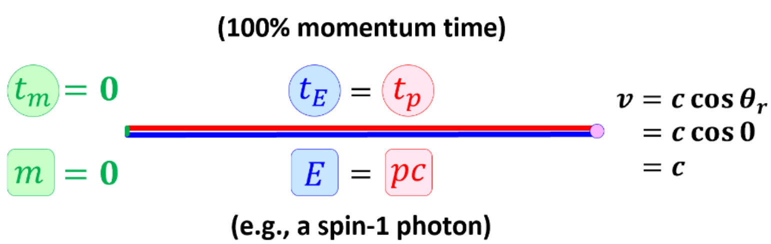


Figure 10. *Rather than being timeless, photons have their definition of time.*

Summary and Future Directions

It is a mistake to separate spacetime from matter. Given the remarkably intimate relationship between finite-scale inertial frame instances and the emergence of both standard physics and the various forms of time, a more constructive approach is to recognize that both space and time are metrical systems that exist only in the presence of matter and energy, and, in particular, fermionic, half-spin particles that enable the concept of rest.

The close relationship between matter in how spacetime emerges also means we cannot accept the concepts of half-spin and spin as passive "givens" that need no further explanation. For example, explaining the remarkable phenomenon of rest mass time requires a deeper and more geometric understanding of the impossible-in-3D half-spin of fermions. Pauli's sidetracking of understanding half spin by declaring it a "given" is insufficient.

Two directions of special interest are quantum mechanics and general relativity. The hierarchy of inertial frame instances does not stop at classical scales but extends deeper (and faster) into any phenomenon in which forces introduce accelerations and, thus, new instances of inertial frames. One way of thinking of this aspect of the inertial frame hierarchy is what happens when the "CPU" of the inertial frame — the collection of fermions and energy that makes its support of standard physics possible — becomes so small that only the most fundamental units of space and time are supported, and even then only incompletely. This avenue of research has excellent potential for giving a deeper explanation for the emergence of both quantum mechanics and quantum uncertainty.

Quantum field theory cannot go unscathed. This magnificent and mostly highly effective work remains the same in its fundamentals but becomes extremely localized. In effect, it becomes the model not of the empty spacetime between starts but of the richly supported local spacetime of well-defined, matter-rich inertial frames. However, the concept of a photon "traversing" an empty space of virtual resonators in deep space cannot stand. It requires replacing with a more subtle set of scaled relationships between distant inertial frames. On the positive side, the vacuum density problem disappears since deep space reverts to what it was before unrestricted quantum field theory: Nothing at all.

Extending upward to general relativity is perhaps the most intriguing direction. Curved spacetime necessarily becomes a set of relationships between multi-scale inertial frames — a network-level emergence.

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