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Questioning Special Relativity

Is the World Five-dimensional?

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Abstract

A new approach to motion offers an explanation to the phenomenon of Inertia. By this model acceleration curves spacetime and induces the inertial force. It suggests the existence of an additional metrical scale-dimension, which may be accommodated by certain adjustments to both Special and General Relativity. This additional degree of freedom may also model the cosmological expansion, thus providing an explanation to the progression of time. It would agree with astronomical observations and explain the missing dark energy and the cosmological constant.

PACs: 01.70.+w, 01.90.+g. 02.90.+p. 03.30.+p, 03.65.-w, 04.20.-q

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1. Introduction and background

Previous papers (Masreliez, 2007a, 2008, 2010) propose that the inertial force may result from spacetime curvature, which would make Inertia a phenomenon akin to Gravitation. The Minkowskian line-element with a dynamic scale-factor $S^2=1-(v/c)^2$, where the velocity $v=v(x,y,z)$ is a function of the spatial coordinates and c is the speed of light, has the interesting property that the geodesic equation of General Relativity (GR) becomes an identity. With this line-element an object accelerated by an applied external force will be in a situation similar to an object suspended in a gravitational field (but without tidal effects).

The dynamic scale-factor *S* also appears in Special Relativity (SR) in the context of time-dilation and length-contraction, which suggests a link between Inertia and SR that is explored in (Masreliez, 2010).

Furthermore, a series of papers and essays investigates the consequences an expanding cosmological scale would have when acting on the Minkowskian line element (Masreliez, 1999, 2004a, 2004b, 2004c, 2005, 2006c). This Scale Expanding Cosmos (SEC) model would explain the universe as observed. It passes several cosmological tests and explains the origin of the enigmatic dark energy and cosmological constant as being caused by the cosmological expansion of both space and time.

The present paper further investigates consequences of a dynamic spacetime scale leading to the somewhat unsettling conclusion that SR might not be entirely correct, since it ignores the dynamic inertial scale *S*, which explains Inertia. An alternate model is proposed that observationally agrees with SR, but allows the existence of an absolute temporal reference.

This new approach brings up the question of what might have gone wrong with Einstein's derivation of SR, a question that warrants deeper analysis of "motion" as a fundamental aspect of existence. It will be shown that Einstein made a certain claim in his derivation of the Lorentz transformation, which on the surface seems to be correct, but which actually might have been a mistake. However, the solution to this problem is far from obvious and some additional background is needed before it may be fully appreciated.

This paper proposes an adjustment to our perception of the world with far reaching implications which at first may seem hard to embrace. It would require a reassessment of our treatment of motion, which here will be presented in the context of past history, and in relation to what presently is known. It suggests an extension of the concept of a four-dimensional space and time (spacetime) to include an additional degree of freedom in the form of a dynamically active scale of the metrical components in the line-element of GR. This additional degree of freedom may resolve several outstanding issues in physics.

2. Visualizing and modeling motion in the past

The nature of motion has been subject to scientific thought over millennia. The reason could be that is very difficult to understand how a rigid object may move at all. Motion means that the object at one time is at a certain location in space and at some later time at a different location. But, how does the object move from one location to the next? It appears that it somehow must move in a stepwise manner; that it might jump incrementally. Or perhaps the object is not really rigid; if it could change its dimensions we may then think of motion as being performed by stretching and contracting like an inchworm.

If motion is incremental in nature we face the problems envisaged by Zeno in his paradoxes. No matter how small we make the incremental steps there will still be even smaller steps to transit, and we conclude that an object cannot move continuously unless the number of incremental steps per second increases beyond any limit. The ancient Greeks believed this to be impossible, and they might have been right.

With the introduction of differential calculus in the 17^{th} century motion was modeled mathematically by making the steps arbitrarily small. However, this interpretation ran into problems in the beginning of the 20^{th} century with the realization that the steps cannot be made arbitrarily small due to quantum mechanical constraints.

This is the level of our understanding today; although we still model motion by continuous differential methods we realize that this cannot be quite right.

Something is obviously missing.

One particular aspect of motion has received a lot of attention. It is its simplest form; motion with constant velocity. In the past this kind of "inertial" motion has been modeled mathematically by the so-called Galilean coordinate transformation whereby two coordinate systems (frames) move in relation to each other. We can visualize moving coordinate frames, and we can visualize rigid objects at rest in each of these frames. But, as we saw, it is more problematic to visualize a moving rigid object in a stationary frame.

This makes modeling motion via moving coordinate frames questionable.

However, let's for the moment ignore this potential difficulty and briefly recount the history of the mathematical modeling of motion that began with the Galilean Transformation (GT).

Let (t, x, y, z) represent a fixed coordinate frame and (t', x', y', z') a frame that moves with relative velocity v in the direction of the x-axis. Let all three spatial axes coincide at $t=t'=0$ when the motion begins.

The GT is:

$$\begin{aligned} t' &= t \\ x' &= x - vt \\ y' &= y \\ z' &= z \end{aligned} \qquad (2.1)$$

Consider two observers O and O' each being located at the origin of their respective frame. The location of O' with respect to O is then given by x=vt. We also find that the location of O relative to O' is x'=-vt' and that the times are the same t=t'. This seems to be a reasonable result that agrees with our intuition.

All experience and experiments show that uniform motion does not influence physics as experienced by a co-moving observer. Thus, the object is assumed to be in the same situation whether it is at rest or moves inertially; all inertial frames are physically

equivalent. If inertial frames are equivalent, the pace of time ought to be same in them, which is assumed by the GT.
We understand how an object relates to its rest frame, but it is still unclear how an object actually moves, or if it remains the same as perceived by a stationary observer.
It is possible that a moving object seen from a stationary frame might be perceived differently than by a co-moving observer who locally is at rest in the moving frame.
This possibility has been glossed over in the past, but can no longer be ignored.
With the discovery that the speed of light appears to be the same in all inertial frames regardless of their velocities came the realization that the GT was in need of revision. By the end of the 19th century most physicists believed in the existence of the "aether" as being the carrier of electromagnetic radiation including light.
In an effort to preserve a certain wave equation in the aether the German Woldemar Voigt in 1887 proposed a modification to the GT.
Voigt's Transformation (VT) is:

$$\begin{aligned} t' &= t - vx/c^2 \\ x' &= x - vt \\ y' &= y/\gamma \\ z' &= z/\gamma \\ \gamma &= \frac{1}{\sqrt{1-(v/c)^2}} \end{aligned} \tag{2.2}$$

The VT added a new term in the temporal transformation of GT, and altered the scales for the two spatial dimensions perpendicular to the motion. Voigt found that his transformation left his wave equation unchanged. Although it implied that time during motion changes by the curious term $-xv/c^2$, an observer stationary at x=0 still found that time progressed at the same pace in the moving frame, (since x=0 gives t'=t).
At about the same time the German Henrik Lorentz was investigating the property of the aether in the context of Maxwell's equations. Being unaware of Voigt's work he found that these equations will remain the same if the GT is modified by the Lorentz Transformation (LT):

$$\begin{aligned} t' &= \gamma\left(t - vx/c^2\right) \\ x' &= \gamma\left(x - vt\right) \\ y' &= y \\ z' &= z \end{aligned} \tag{2.3}$$

As can be seen the only difference between the VT and the LT is the constant scale-factor γ in all four relations. It turns out that the VT would have worked equally well for Lorentz, and he later admitted that he might have used the VT instead of the LT had he only known about it at the time. However, with the LT a stationary observer will find that time progresses at a *different pace* in a moving frame, since x=0 implies t'=γt. The general adoption of the LT in the context of SR has caused much confusion and debate over the years.

The LT transformation introduces a new aspect of motion, because it implies that the dimensions of a moving object seem to change. Some thought that motion relative to the aether somehow deforms rigid bodies. Henrik Lorentz and Henri Poincaré tried to find an electro-dynamic explanation to the phenomenon of length contraction implied by the LT.

Then Einstein introduced his Special Relativity (SR) theory in 1905. Rather than trying to untangle the Gordian Knot of length contraction by finding some physical mechanism causing it he simply parted this knot by *postulating* that all inertial frames are physically equivalent and that the measured speed of light is the same in them. Based on these two postulates he re-derived the Lorentz transformation.

By this approach changes experienced by an object in motion became direct consequences of his two postulates. It was no longer necessary to try to explain them by some kind of physical mechanisms; they simply became consequences of "how the world is".

This development suggests that motion somehow is associated with changing physical dimensions. However, by the postulated symmetry between inertial frames this change should only be relative and apparent, a fact that has been insufficiently understood in the context of SR.

In particular, clocks in inertial frames should always run at the same pace since inertial frames are physically equivalent.

Regardless of this development, the mystery of "motion" was still not explained by the VT or the LT, since these transformations only consider constant velocities while ignoring acceleration and the resulting inertial force.

3. A potential problem with Special Relativity

Most people, active in physics today, are familiar with Einstein's derivation of his SR theory. However, there is one aspect of this derivation that needs to be carefully reexamined because of an implicit assumption, which at the time seemed eminently reasonable.

In deriving the Lorentz Transformation (LT) Einstein used symmetry between inertial frames to arrive at the conclusion that the forward transformation must be identical to its inverse. Einstein's reasoning in his 1905 paper is here recalled in detail. Coordinates of the rest frame K are denoted *(t,x,y,z)* and those of the moving frame Ξ are denoted *(τ,ε,η,ς)*:

> *In the equations of transformation which have been developed there enters an unknown function Φ of v, which we will now determine.*

For this purpose we introduce a third system of co-ordinates K', which relatively to the system K is in a state of parallel translatory motion parallel to its x-axis such that the origin of co-ordinates of system K', moves with velocity -v on the axis of Ξ. At the time t=0 let all three origins coincide, and when t=x=y=z=0 let the time t' of the system K' be zero. We call the co-ordinates, measured in the system K', x', y', z', and by a twofold application of our equations of transformation we obtain

$$t' = \Phi(-v)\gamma(-v)(\tau + v\varepsilon / c^2) = \Phi(v)\Phi(-v)t$$

$$x' = \Phi(-v)\gamma(-v)(\varepsilon + v\tau) = \Phi(v)\Phi(-v)x$$

$$y = \Phi(-v)\eta = \Phi(v)\Phi(-v)y$$

$$z = \Phi(-v)\varsigma = \Phi(v)\Phi(-v)z$$

Since the relations between x', y', z' and x, y, z do not contain the time t, the systems K and K' are at rest with respect to one another, and ***<u>it is clear that the transformation from K to K' must be the identical transformation</u>****. Thus*

$$\Phi(v)\Phi(-v) = 1$$

We now inquire into the signification of Φ. We give our attention to that part of the axis of Y of system k which lies between ξ=0, η=0, ς=0 and ξ=0, η=l, ς=0. This part of the axis of Y is a rod moving perpendicularly to its axis with velocity v relatively to system K. Its ends possess in K the co-ordinates

$$x_1 = vt, y_1 = 0, z_1 = 0$$

and

$$x_1 = vt, y_2 = 1/\Phi(v), z_2 = 0$$

The length of the rod measured in K is therefore 1/Φ(v); and this gives us the meaning of the function Φ(v). From reasons of symmetry it is now evident that the length of a given rod moving perpendicularly to its axis, measured in the stationary system, must depend only on the velocity and not on the direction and the sense of the motion. The length of the moving rod measured in the stationary system does not change, therefore, if v and -v are interchanged. Hence follows that 1/ Φ(v)= 1/ Φ(-v), or

Φ(v)= Φ(-v)

It follows from this relation and the one previously found that Φ(v)= 1, so that the transformation equations which have been found become

$$\tau = \gamma(t - vcx / c^2)$$
$$\varepsilon = \gamma(x - vt)$$
$$\eta = y$$
$$\varsigma = z$$

In this line of reasoning Einstein's claim that the transformation from K to K' must be the identical transformation is highlighted.

However this claim is not necessarily correct.
It may in fact have been a mistake because it is possible that acceleration may change the metrics of spacetime *as perceived* by an observer in K.
The coordinates obtained by the LT may not be the same as the coordinates experienced by a co-moving observer.
Although the relationship between space and time might remain the same, it is possible that coordinate increments in the two frames do not have the same meaning. This would put into question the use of the Lorentz transformation in modeling motion, since it implicitly assumes that the transformed, moving, coordinates have the same meaning and metrics as the stationary coordinates.
Of course, in 1905, when SR was proposed, the concept of different spacetime metrics was unknown and therefore this possibility was overlooked. Unfortunately this may have prevented us from discovering the origin of Inertia, and resolving an inconsistency that has plagued SR ever since its inception.

4. The Twin Paradox

The most infamous and widely debated inconsistency of SR is undoubtedly the Twin Paradox whereby twins who travel apart and later reconvene both claim that the other twin's clock must have been running slower. But, since by SR inertial frames are physically indistinguishable the elapsed times in them ought to be the same. Many have attempted to resolve this incongruity, including Einstein, but in the author's opinion, which many share, the controversy has never been unambiguously settled.
The problem may be traced to the assumption of symmetry between inertial frames, and the in SR *implicit assumption that they belong to the same 4D manifold*. As confirmed by numerous experiments, processes appear to run slower in moving frames, which is inconsistent with the meaning of symmetry by which clocks always run at the same pace in inertial frames. Thus SR seems to be logically inconsistent when taking into account its claimed symmetry between frames.

5. Where SR might have gone wrong

Einstein was right with his two SR postulates that all inertial frames are physically equivalent and that the speed of light is the same in all of them. Yet he might have been wrong in assuming that coordinates related by the LT have the same meaning so that coordinate intervals in the two frames may be directly compared. It is possible that *the observed coordinate metrics in a moving frame might be different* compared to those of the stationary frame; as we will see, both frames may experience a contracted spacetime scale in the other, moving, frame.

If this turns out to be the case Einstein can hardly be blamed for this mistake, because in 1905 the possibility that the metrical scale could change with location or motion was inconceivable. But nowadays this idea is not too far-fetched in the context of GR.

Einstein's two SR postulates bypass the question of the nature of the mechanism that causes time-dilation and length contraction. However, it is possible that these phenomena may be caused by a changing metrical scale of spacetime during acceleration. As we shall see, this changing scale could also explain the inertial force.

6. A previously overlooked conceptual difficulty

In modeling moving frames we encounter a difficulty that was briefly alluded to in the introduction above; it is unclear how the observed coordinates of a moving frame relate to those of a stationary frame.

Assigning coordinates is a convenient way of specifying locations in space and time; we may think of the world as being spanned by three spatial coordinates and one temporal coordinate. We are free to assign these coordinates in various ways; in fact it can be done in infinitely many ways. And, if we interpret the coordinates as giving locations in spacetime we may specify metrics for space and time, and assign physical meanings to coordinate increments. Together they specify a *geometry* of spacetime as is done by the line-element of GR. This geometry relates fixed points; *points do not move in geometry*.

However, the coordinate transformations mentioned above attempt to model motion via moving coordinate points.

But, as noted these moving points do not belong to the stationary frame's geometry.

In personal communication with the author the mathematical logician Dr. Akira Kanda has forcefully pointed out that:

"In geometry, no point moves as it breaks the continuum of geometric space. Geometric transformations are not physical motions. Relation between points and motion are different things."

Hence, in mathematics geometrical points do not move. Therefore, if we want to use geometry and assign metrics to coordinates we are constrained to relations between fixed

coordinate locations in respective frames. The geometries of two different frames in relative motion are conceptually unrelated; their kinematic relationship cannot be described by geometry. They belong to different spacetime manifolds.
Again, this puts into question the use of coordinate transformation in modeling motion.
In his SR paper Einstein attempted to bridge this conceptual gap by using light signals and assigned the coordinates in the moving frame so that his constant speed of light postulate was fulfilled *from the perspective of a stationary observer*. However, as we saw, this procedure left him with one undetermined constant $\Phi(v)$, which scaled the four transformation relations. He determined the value of this constant by assuming that each inertial frame has identical local geometries, and that the geometry of a frame observed in relative motion belongs to the same spacetime geometry with the same metrics as those of the stationary reference frame. But, this assumption might not be true since moving points do not belong to the stationary reference frame's geometry.
This is a previously unrecognized difficulty with SR, which for over a century has caused puzzling problems, for example the Twin Paradox.

7. A geometric interpretation of motion

Both the LT and the VT modify the classical GT by introducing the term $-xv/c^2$ in the temporal transformation. These two transformations "work" because they correspond to flat Minkowskian-type geometries in GR, which automatically support Einstein's two SR postulates. Spacetimes with different constant scales are physically equivalent in GR in the sense that Einstein's field equations are identical because the Christoffel symbols are the same. The geometries corresponding to the VT and LT are therefore physically equivalent; they are *scale-equivalent*.
Thus, these transformations may have less to do with motion than with coordinate transformation in GR. This suggests a new way of modeling motion. Rather than relating moving coordinate locations in space and time we instead relate spacetime geometries. I will call this "*the geometric interpretation*".
By this novel point of view the LT is interpreted as relating identical Minkowskian GR geometries, and therefore does not model time-dilation or length contraction. This agrees with the postulate that all inertial frames are equivalent. On the other hand, as we shall see, with the geometric interpretation the VT models both time-dilation and length contraction but seemingly implies that inertial frames have different relative scales.

8. Einstein's comment on Inertia

Einstein had hoped that his General Relativity (GR) theory would explain the inertial force, but he found that it will not do this. If GR cannot explain Inertia there must be something else that explains it, and Einstein seemed to have considered the existence of some kind of aether, albeit of a more nebulous form. Here is one of his comments taken from [Einstein 1924]:

> *The inertia producing properties of the aether [Newtonian spacetime], in accordance with classical mechanics, is precisely not to be influenced, either by the configuration of matter, or by anything else. For this reason one might call it "absolute". That something real has to be conceived as the cause for the presence of an inertial system over a non-inertial system is a fact that physicists have only come to understand in recent years…*

This comment reveals that Einstein in 1924 was thinking about the possible existence of some unknown aspect of the world that explains inertia. Although GR changes the properties of spacetime and alters trajectories of freely falling particles, it does not explain why Inertia exists even in the absence of a gravitational field. This makes the presence of Inertia mysterious and unexplainable. Something is obviously causing it, but what?

If Inertia and Gravitation are intimately related it appears that acceleration somehow should curve spacetime. This would introduce a new "aspect" of the world of the kind Einstein was looking for.

9. The origin of Inertia

According to Newton's second law of motion acceleration is resisted by an inertial force, but no generally accepted explanation to the origin of this force has been available in the past. *This must be considered a major epistemological shortcoming of physics.*

Since the time of Newton it is generally believed that Inertia is closely related to Gravitation; Einstein based his GR theory on this assumption, and compared an accelerating object to an object suspended in a gravitational field.

Since by GR gravitation curves spacetime, Inertia should also be caused by spacetime curvature, yet such curvature does not seem to exist, since by SR all inertial frames have the same flat Minkowskian spacetime geometry.

It is possible that a solution to this puzzle may be found by making use of scale-equivalence. If the scale of spacetime were to change during motion all laws of physics would still hold true; in other words, Einstein's two SR postulates would still be valid.

This makes it interesting to investigate the role of a *dynamic* scale-factor for the Minkowskian line-element, assuming that it changes with spatial location like the metrics do in a gravitational field.

We find that there is a certain "inertial scale-factor" for which *all motion takes place on a geodesic of GR*.

Let me clarify this statement. An accelerating object experiences an inertial force similar to the gravitational force acting on an object suspended in a gravitational field. The magnitude and direction of this gravitational force is given by the geodesic relation, *which becomes an identity* with the inertial scale-factor. Therefore, the force induced by spacetime curvature via the inertial scale-factor always exactly counteracts any applied accelerating force regardless of its magnitude and direction, just like the gravitational force is counteracted by the ”applied” force that suspends an object in a gravitational field. Thus, inertia may have the same origin as Gravitation; it could be caused by curved spacetime. If this dynamic scale-factor actually exists it would explain Inertia as being a gravitational-type phenomenon [Masreliez, 2006b, 2007a, 2008].
There is a dynamic scale-factor for which all motion always takes place on a geodesic of GR:

$$S = \sqrt{\left(1-(v/c)^2\right)} \qquad (8.1)$$

We recognize this from SR where it appears in time-dilation and length contraction. It will be denoted the "*inertial scale-factor*". It suggests a connection between Inertia and SR [Masreliez, 2008, 2010]. The Minkowskian line-element scaled by (the square of) the dynamic inertial scale-factor will be denoted "*the inertial line-element*":

$$ds^2 = \left(1-(v/c)^2\right)\left(\left(cdt\right)^2 - dx^2 - dy^2 - dz^2\right) \quad (8.2)$$

The dynamic inertial scale-factor models Inertia. With constant velocities the physics are identical to that of the Minkowskian line-element; the corresponding spacetimes are scale-equivalent. This suggests that both inertial and accelerating motion may be modeled geometrically by GR.

10. Voigt's transformation yields the inertial line-element

The finding that there might be an explanation to Inertia that implies the existence of a dynamic spacetime scale is surprising, since by SR inertial frames have the same Minkowskian line-element. Here we encounter an ironic twist of history; Voigt's transformation, which preceded the Lorentz transformation, actually implies the inertial scale-factor.
The VT yields the inertial line-element if the velocity is constant.
Since the inertial line-element implies a contracted scale it will by the geometrical interpretation of coordinate transformation model both time-dilation and length-contraction. And, as already mentioned, the VT also has the desirable property that observers will agree on the pace of time. In other words, an observer in any inertial reference frame will find that clocks in moving frames run at the same pace as in her local frame, which is not the case with the LT. Since this is true regardless of velocity or selected reference frame, it suggests that time actually runs at the same pace in all inertial

frames as judged by observers in respective frames. This is consistent with the postulate that inertial frames are equivalent.

It would also resolve the Twin Paradox since SR's relativistic time disappears in favor of an absolute clock time.

However, for this to be true every inertial frame would have to experience other moving frames as being relatively contracted by the inertial scale factor. At first it might seem strange that the scale may be relative in the sense that an inertial frame, which arbitrarily is selected as a stationary reference, always has Minkowskian geometry, while the scales of moving frames are contracted in relation. However, as we shall see, this possibility may be accommodated by introducing a fifth "scale-dimension", taking advantage of the additional degree of freedom offered by scale-equivalence.

11. A fifth "scale-dimension"

If locally all inertial frames have the same Minkowskian geometry but this geometry is contracted in a relative sense in other frames, we may say that we observe a moving frame merely as a "projection" onto the local frame; what we see is not what is experienced locally by a co-moving observer; we see a distorted view.

This may be visualized as illustrated in Figure 1, which is taken from (Masreliez, 2010), where 4D spacetimes are represented by two 1D lines that are separated in two dimensions.

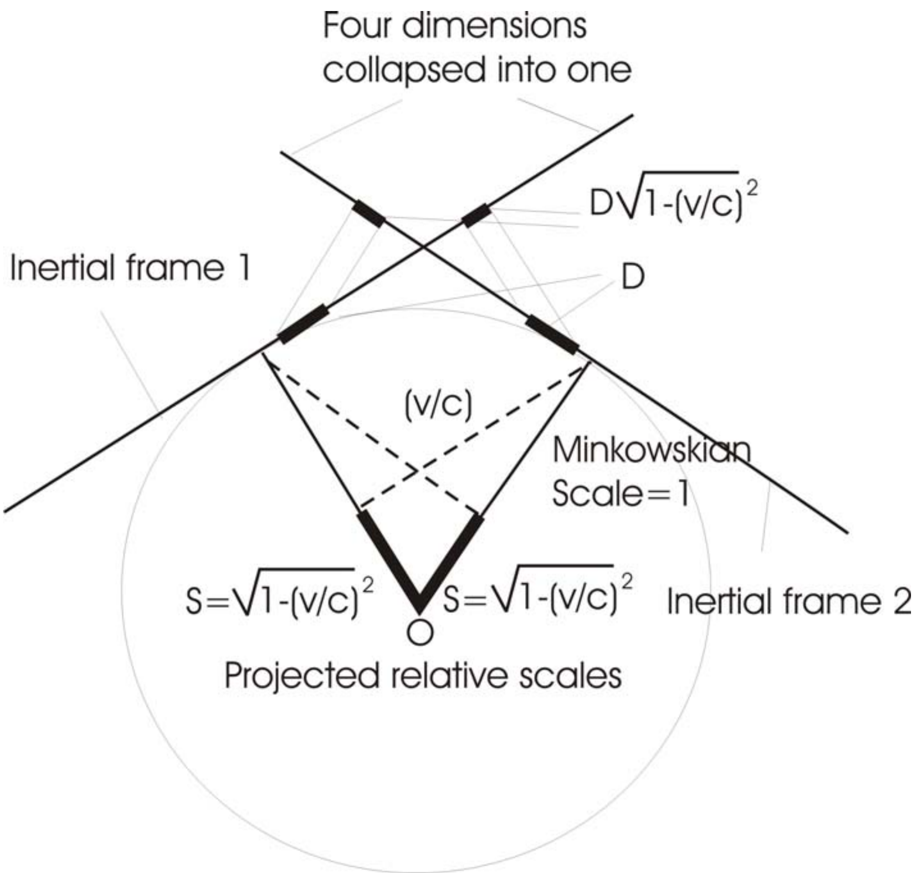

Figure 1: Illustrating relative motion

In this figure length contraction and time-dilation are shown as being caused by "projecting" one spacetime onto another. Acceleration would cause relative rotation of the two lines in the figure. Projected distance increments approach zero when v approaches c and the two lines become perpendicular. This interpretation is further elaborated in Appendix I.

Note that with the geometric interpretation length contraction takes place *in all three* dimensions rather than merely in the direction of motion as in SR. It is obviously impossible to model the situation in the figure simply by 1D coordinate transformation. *Likewise it is impossible to model motion of inertial frames by 4D coordinate transformations*.

However, the VT models the projection of a moving frame onto the stationary frame and breaks the symmetry between the forward and inverse transformation, since only the forward transformation is used when relating moving frames. This invalidates Einstein's claim that the forward transformation must be identical to its inverse. The new interpretation preserves relativity between inertial frames by recognizing that they may belong to different 4D geometries.

12. Reconciling Inertia with Special Relativity

The main aspects of special relativity may be preserved while allowing spacetime curvature during acceleration. However, it requires generalization of our traditional approach to motion.

The Minkowskian spacetime of inertial frames may be retained by a new kind of process, which incrementally and locally "resets" the inertial scale factor and restores the Minkowskian line-element during acceleration. This process, *which models motion as experienced by an observer participating in the motion*, takes advantage if the fact that the scale of spacetime may change in a discrete manner without changing physics as given by Einstein's field equations.

With this new process a dynamic scale of spacetime could enter physics as a new aspect of existence that is active in all motion. We might think of the 4D scale as a "fifth dimension", which allows different Minkowskian spacetimes to co-exist separated by relative velocity and scale. Acceleration will adjust the relative scales of inertial frames. As a consequence all inertial frames will locally have Minkowskian line-elements, yet they may exist in different non-covariant 4D manifolds of GR. Each will see smaller scales in other inertial frames.

The contracted scale in moving frames could explain both time-dilation and length-contraction and would also imply the relativistic conservation of momentum of SR. In addition it would allow the derivation of Newton's second law of motion from the inertial line-element [Masreliez, 2008, 2010].

However, the concept of relativistic time in SR would disappear in favor of a cosmological absolute time.

Newton's absolute time would make a comeback. This would replace light-simultaneity by clock-simultaneity.

Although the addition of a new dimension might seem to complicate the modeling of motion, it would have several important conceptual and philosophical advantages; it would indisputably resolve the Twin Paradox by admitting a universal temporal reference, and it would offer an explanation to Inertia.

13. Modeling acceleration as a two-step process

We may retain both the VT and the LT by introducing a two-step process that takes into account the dynamic scale.

By the first step in this process the scale changes continuously during acceleration via the dynamic inertial scale factor. This first step may be modeled by GR and terminates at some constant (small) velocity increment v. The line element for the moving frame is then given by the VT.

In the second step the scale of the moving frame is altered by multiplying all four VT transformation relations by the factor γ, which locally restores the Minkowskian line-element as modeled by the LT.

Although these two steps *formally* implement the LT, there are important conceptual differences with physical implications. First, a dynamic scale-factor would explain Inertia. Second, it would allow separation of the two inertial frames into different manifolds of GR. Since no coordinate transformations exist that will capture dynamic scale transition, inertial frames are not co-variant. Although the coordinates locally have Minkowskian metrics they do not belong to the same spacetime manifold. Therefore coordinate increments given by the LT cannot be directly compared. This would explain how (the observed) time in a moving frame appears to run slower while clocks in both frames always run at the same pace.

On the other hand, Voigt's transformation gives the correct relative coordinate relationship between the two frames as viewed from a stationary frame *regardless of which frame assumes the role as being stationary*.

The discrete scale adjustment is being done locally while preserving the pace of time. The relationship between coordinate time and the three spatial coordinates may change during acceleration but the pace of time always remains the same. When the scale is reset by transitioning into a new spacetime, the local scale increases by the inverse of the inertial scale factor (*1/S)*, and as a consequence the relative scale in the other frame is reduced by the inertial scale factor *S*. The moving frame then assumes the role of a new local reference frame with a Minkowskian line-element. This two-step process models the dynamic spacetime as experienced by an accelerating observer, and may be summarized as follows:

1. Acceleration induces continuous contraction of the inertial scale factor in the moving frame relative to a stationary reference frame.
2. The scale contraction "momentarily" halts as some velocity increment v and the two line-elements are then related by the VT.
3. Scale transition via the factor γ=1/S "resets" the scale factor in the moving frame and contracts it in a relative sense in the stationary reference frame.
4. The previously moving frame becomes the new reference frame for the next step in this iteration process, and so on.

By this new kind of semi-continuous process the scales of all moving frames appear contracted in relation to any reference frame. This dynamic "inchworm" process induces the inertial force as a consequence of acceleration relative to the immediately preceding state of motion rather than relative to some background reference medium. Although motion may be continuous in space and time, the scale could change incrementally.

The continuous part of this two-step process makes use of a dynamically decreasing scale that models Inertia, and the second step restores its metrical reference scale while transitioning to a different 4D manifold. This provides a self-induced reference loop that may resolve the enigmatic origin of the inertial force without the existence of an aether. An inertial reference is provided by the existence of a fifth dimension that acts beyond spacetime via the dynamic scale.

It is possible that this incremental process actually is observed in discrete redshifts from distant cosmological sources [Tifft, 1976, 1977].

14. Dynamic Incremental Scale Transition

In order to model this two-step process a new process denoted Dynamic Incremental Scale Transition (DIST) has been proposed [Masreliez, 2007b] whereby the scale expands continuously during short intervals followed by incremental scale adjustments. This would allow the use of GR within the continuous segments, and will retain Einstein's field equations, since they by scale-equivalence remain the same with discrete scale changes. Therefore, the DIST process formally still allows the use of GR.

At first sight the DIST process may appear *ad hoc* and perhaps a bit speculative since it does not use previously known physics. However, one should realize that an expanding spacetime scale cannot be modeled by GR *as it would be experienced by an observer participating in this dynamic scale process*. The DIST process is an attempt to deal with this situation using known physics.

The figure below illustrates the DIST process operating on a Minkowskian line-element with its dynamic scale-factor $S(\mathbf{x})$, where $\mathbf{x}$ stands for (t, x, y, z):

$$ds^2 = S(\mathbf{x})^2\left((cdt)^2 - dx^2 - dy^2 - dz^2\right) \qquad (2.1)$$

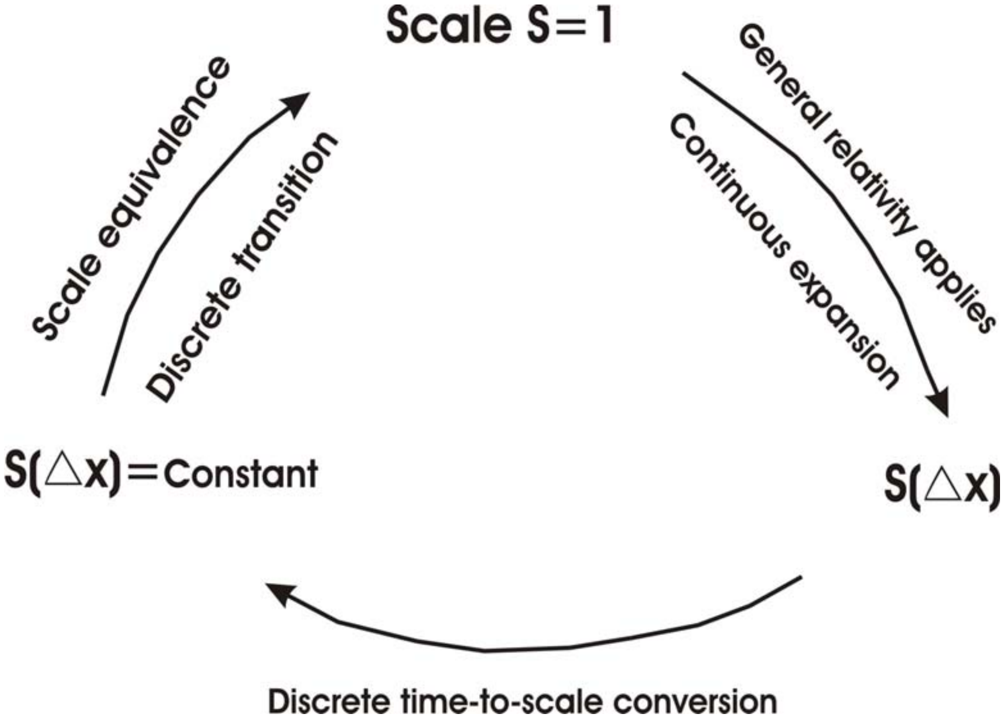

Figure 2: The DIST cycle

Thus, the DIST process combines continuous motion and discrete scale adjustments, and models the spacetime geometry in relation to a co-moving observer.

Since DIST is a new kind of process active beyond the four dimensions of spacetime it might be met with considerable skepticism. However, although we have got used to continuous differential methods over the years, nothing rules out a discretely progressing spacetime scale, which still would allow continuous motion in the four dimensions of space and time.

The DIST process could explain the progression of time, which arguably is the most keenly experienced aspect of our existence, and would also reveal why its origin has remained unknown; the progression of time could be a process in scale “beyond” space and time. Furthermore, the semi-incremental scale expansion could induce very high frequency, low amplitude, oscillations, in the scale of spacetime, which may explain our quantum world.

The here proposed “new physics” would imply major revisions of current epistemology. Therefore, it should be treated as being hypothetical and speculative while offering new possibilities.

A series of papers and essays have demonstrated that four-dimensional cosmological scale expansion would model the universe as observed [Masreliez, 1999, 2004a, 2004b, 2004c, 2005, 2006c, 2008]. As perceived by a co-expanding observer (like we all are) cosmological scale expansion would imply that the universe remains physically the same during its expansion due to scale equivalence. However, it cannot be modeled by GR because it involves transitions between non-covariant 4D spacetime manifolds as modeled by the DIST process.

15. A fifth scale-dimension

A dynamic spacetime scale could enter physics as a new "dimension" corresponding to a new mode of motion via a dynamic 4D scale. The scale acts independently of the 4D spacetime manifold of GR, and may therefore be considered as being conceptually "perpendicular" to the four spacetime dimensions. The influence of a dynamic scale would make its presence felt indirectly via gravitational-type action.

For example, in the Scale Expanding Cosmos model it induces redshift similarly to how a gravitational field redshifts light. Light from distant regions in the universe originates in locations with contracted relative temporal metrics. Just like the temporal metric in a gravitational field is contracted and causes redshift the cosmological redshift is caused by gravitational action; it may be interpreted as a gravitational-type phenomenon induced by the cosmological scale expansion.

Furthermore, in the standard Big Bang cosmology the "missing dark energy" and the "cosmological constant" are unexplainable, but they become direct consequences of the SEC model [Masreliez, 1999, 2004a] where they appear in the cosmological energy-momentum tensor. (Its T_{00} component equals Einstein's critical density and the spatial components are all negative corresponding to a cosmological constant.) The new model also agrees with astronomical observations and passes several cosmological tests, which the standard Big Bang model fails.

In the context of SR and Inertia the additional dynamic scale-dimension allows transitioning between different 4D spacetime manifolds and thus allows Minkowskian inertial frames to *co-exist in different manifolds* separated by relative velocities. This means that each inertial frame offers its own perspective of the universe while being physically equivalent to other inertial frames, all having identical metrics.

The claim that clocks run at the same pace in inertial frames may be confirmed experimentally by comparing elapsed time intervals of traveling clocks taken on a space mission with those of stationary clocks on the Earth upon return.

Therefore the here proposed theory of inertia is falsifiable.

The 4D scale, which depends on relative velocity, separates inertial frames much like relative distances do in 3D space. Motion in 3D space alters relative distances, and acceleration alters scale-factors that depend on relative velocities.

The fifth dimension introduced by the dynamic spacetime scale is a "real" as the four ordinary spacetime dimensions. Although conceptually different, because it is not a new dimension in the same sense as space and time, it changes the scale as a function of velocity. However, visualizing it as an ordinary dimension may help us understand this new feature of the world.

We may visualize co-existing 4D spaces in a 5D manifold by collapsing the three spatial dimensions into one, making 2D spaces represent 4D spacetimes. Curvature in the fifth dimension may then be represented in three dimensions by a curved surface, for example of a sphere. Figure 3 illustrates how 4D spaces may co-exist on the surface of this sphere with its radius representing the scale.

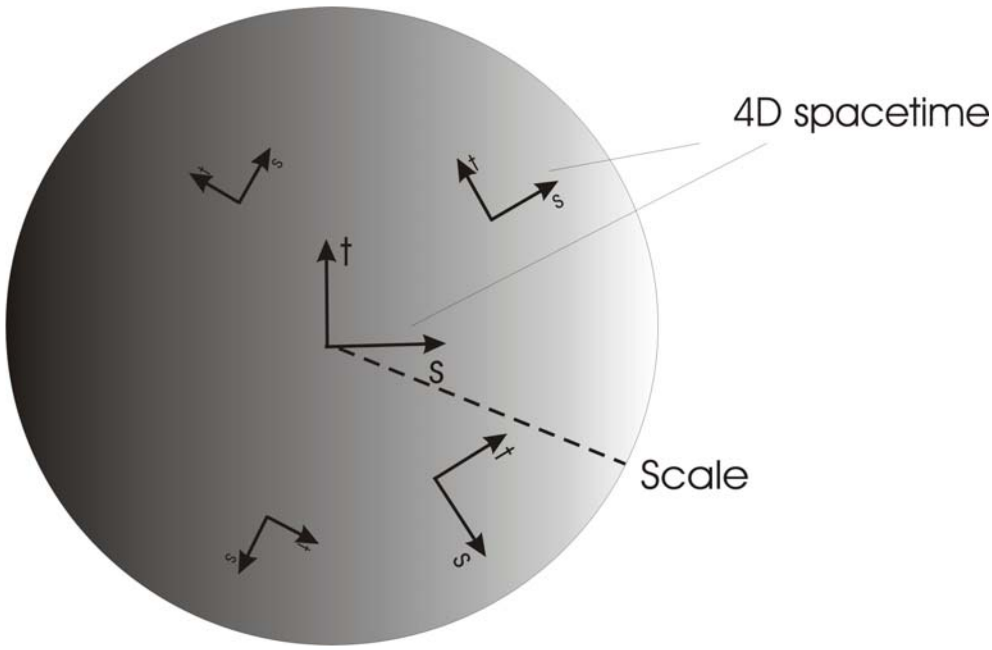

Figure 3: Illustrating 4D spacetimes imbedded in 5D space.

4D spacetimes corresponding to different inertial frames may have the same geometry but their locations and orientations in 5D space may differ resulting in time-dilation and Inertia.

16. Motion in a five-dimensional scale-dependent world modeled by Kaluza-Klein's theory

The DIST process was introduced as a way of modeling a semi-incremental scale transition process, which allows the use of GR while locally retaining the Minkowskian geometry. It may be seen as an attempt to model motion involving a dynamic 4D scale by known physics based on four-dimensional geometry.

However, this process may be modeled more directly by adding a fifth dimension to GR, which in 1919 was suggested by the German mathematician Theodore Kaluza in a letter to Einstein, which was published two years later (Kaluza, 1921). Kaluza showed that off-diagonal elements in the 5D metrical tensor made it possible to model the electromagnetic field, since Maxwell's equations then appear in the 5D version of Einstein's GR equations together with the usual 4D field equations. This fact had actually been discovered earlier in 1914 by the Swede Gunnar Nordström, but had gone unnoticed. In 1926 Kaluza's idea was taken up by another Swede, Oskar Klein, who showed that this expanded version of GR also could model quantum processes if the additional dimension was oscillatory in nature ("curled up").

This idea was later used to model the strong and weak forces by extending Kaluza-Klein's theory to higher dimensions. Further developments along these lines have led to ten and eleven-dimensional string theories.

This is very interesting in the context of the DIST process because there is an often used line-element in Kaluza-Klein's theory that could model this process. It is commonly referred to as the "canonical line-element", which in the DIST context takes the form:

$$ds_5{}^2 = u^2 S(\mathbf{x})^2 \left((cdt)^2 - dx^2 - dy^2 - dz^2 \right) - L^2 du^2 \qquad (15.1)$$

L=Constant spatial increment

Its properties have been thoroughly investigated [Wesson, 2006, 2007]. In this 5D line-element a term representing the usual 4D spacetime line-element is modulated by an additional dimensionless parameter, *u*, which directly could correspond to the incrementally changing scale in the DIST process [Masreliez, 2010].

With this approach inertial frames could be separated in a five dimensional space by the additional coordinate *u*. The canonical line-element therefore models a 4D line-element with a scale that may depend on its four dimensions, plus an additional fifth dimension that may act to periodically "reset" the scale.

In this 5D model we may think of the additional dimension as being active during very short intervals (perhaps on the Planck scale as suggested by Klein) during which it incrementally resets the 4D scale (*l→1/S*) as in the DIST process.

Furthermore, Kaluza's finding that the electromagnetic field may be modeled by four additional components in the 5D metrical tensor (one for each of the four spacetime dimensions) suggests that the electromagnetic field might correspond to modulated spacetime metrics, which could provide a possible ontological explanation to the nature of the electromagnetism.

However, in modeling the DIST process the off-diagonal components of the 5D tensor disappear, leaving only the scalar component.

This suggests that the previously mysterious scalar dimension in Kaluza-Klein's theory could be the dynamic scale of spacetime.

It should be noted that if this scalar dimension only depends on time so that *S=S(t)* it will not contribute any net cosmological energy, since the sum of the diagonal components in the 4D energy-momentum tensor then disappear. This might explain why the net cosmological vacuum energy disappears, and perhaps resolve the problem with the huge unobservable vacuum energy density predicted by quantum mechanics.
It now appears that the Kaluza-Klein's "miraculous" discovery that a fifth dimension in GR will model the electromagnetic field may have been more than merely a mathematical coincidence; it might have been our first glimpse of the true nature of the world. Perhaps a 5D world will better describe our existence. Our local 4D world may merely be one of many possible 4D spacetimes imbedded in a 5D world. The fact that the Scale Expanding Cosmos line-element corresponds to geodesic motion in the 5D canonical space further supports this interpretation, see further Appendix II.

17. A cosmological clock

It is possible that a fifth scale-dimension could interact non-locally with distant regions of the universe via a dynamic cosmological scale. Relative to co-expanding inhabitants the cosmological expansion could cause oscillation in the spacetime scale as modeled by the DIST process or by Kaluza-Klein theory. It is therefore possible that atomic time directly reflects the cosmological expansion, and that this time is the same across the universe. Hence a dynamic cosmological scale expansion could define cosmological simultaneity and be the origin of the progression of time. Furthermore, it could act as a cosmological calibration for the spacetime scale of various particles. A common cosmological time would obsolete the use of light signals in the definition of simultaneity in the favor of clock-simultaneity by invoking a fifth scale-dimension.
Although this explanation is speculative it gains support from the finding that an oscillating 4D scale of the Minkowskian line-element modeled in GR would provide a connection between GR with QM. If all particles were associated with scale oscillation at the Compton frequency, motion would induce phase modulation of this Compton oscillation that corresponds to the de Broglie matter wave. Furthermore, with such an oscillating scale the de Broglie/Bohm "pilot wave" as well as the Schrödinger equation may be derived from GR. This could provide a possible ontological explanation to the QM wave functions as being modulations of the scale of spacetime.
It could be the missing link between GR and QM [Masreliez, 2005].

18. Discussion

The main objective of this paper is to pose the question of whether our understanding of motion as a continuous process in 4D spacetime is correct, or if we have overlooked the possibility that the scale of spacetime may change with motion.

Today it is very difficult to publish new ideas that fundamentally challenge our perceptions of the world since people tend to assess new contributions in the context of what currently is believed to be indisputably true, and to reject ideas that are new and different, which do not comply with accepted epistemology. This paper was rejected by half a dozen mainstream journals.

However, scale-equivalence is a fundamental cosmological symmetry that conserves Einstein's field equations and consequently also conserves all physics as modeled by GR. Since it is not unreasonable that Nature takes advantage of this symmetry, it would be a grave mistake to ignore possible consequences of a dynamic spacetime scale.

This paper shows that several advantages would be gained by incorporating a dynamic spacetime scale into physics, for example it would explain Inertia as a curved spacetime phenomenon and it would allow an absolute cosmological time. Furthermore, cosmological scale expansion could explain the progression of time.

It is interesting to note that the development in this paper was anticipated already by Zeno, for example by his Arrow Paradox, which Aristotle summarized as follows:

1. *When the arrow is in a place just its own size, it's at rest.*
2. *At every moment of its flight, the arrow is in a place just its own size.*
3. *Therefore, at every moment of its flight, the arrow is at rest.*

Zeno and Aristotle may have been right when noting that the arrow always remains at rest in its local reference frame. This may be accommodated by introducing a dynamic spacetime scale as an additional degree of freedom beyond the four dimensions of spacetime, which would allow the arrow to be at rest in its own local 4D Minkowskian manifold at each instant. Hence, we may say that although the arrow moves in a stationary observer's space, it remains fixed in its local spacetime, which is in motion in a higher-dimensional "scaled spacetime".

The main "result" of this paper is the proposition that a dynamic spacetime scale should be considered as being an additional freedom in addition to the four spacetime dimensions.

19. Conclusion

It is impossible to summarize the content of this paper without challenging our current understanding of motion. I hope that this will not be a deterrent.

A dynamic spacetime scale-factor acting on the Minkowskian line-element could explain the inertial force. If spacetime curvature is induced by motion it would imply that the dynamic scale of spacetime for a moving object might appear to be contracted relative to an arbitrary inertial frame chosen as stationary reference. This novel aspect of the world may be accommodated by the existence of a new "scale-dimension" in addition to the four spacetime dimensions.

We may be living in a different word than what we previously thought; in a five-dimensional world where the scale of space and time actively participates in all motion, including motion in time via cosmological scale expansion.

In retrospect it should not be that surprising that there might be more to our world than the static 4D geometry of general relativity. This geometry does not take into account the scale of 4D spacetime or the possibility that the scale might change with time. Consequently General Relativity ignores the 4D scale, which could explain why it cannot model the progression of time. The scale would be inconsequential if it were fixed, but if the scale of space and time is fixed we may ask why this should be the case; we may wonder what possibly could determine an absolute cosmological scale of existing objects. And, if it isn't fixed, but changes with time or with spatial motion, it seems reasonable that it might influence our existence and therefore ought to be included in any model of the universe.

With these considerations it becomes clear that a dynamic spacetime scale may have very important implications, which actually seems to be the case. It could be a previously unknown and unsuspected aspect of the world - *a missing dimension*.

Einstein's two postulates of Special Relativity may be retained in the context of relative scale-contraction that would explain the inertial force. This dynamic scale is given by a certain inertial scale-factor, which also would allow the existence of a cosmological temporal reference. In fact, the phenomenon of Inertia might be a direct consequence of the conservation of a temporal reference.

With this proposition a dynamic spacetime scale could enter science as a new but fundamentally important aspect of all existence. Although the location of a moving object as a function of time may be described by traditional methods, these do not take into account the possibility that the scale of spacetime for a moving object may change in a relative sense.

Constraining existence to the four dimensions of spacetime may have prevented us from discovering of the origin of Inertia, as well as finding an explanation to the progression of time. The scale of spacetime offers an additional degree of freedom that could be the key to deeper understanding.

Special Relativity is based on Einstein's two postulates with the implicit assumption that all inertial frames belong to the same 4D spacetime manifold, which leads to the Lorentz transformation. However, adopting Voigt's Transformation instead of the LT is consistent with a dynamically changing scale of space and time in a higher-dimensional space, which explains Inertia. Many have over the years since the introduction of Special Relativity in 1905 pointed out that the theory is contradictive since it postulates that time progresses at the same pace in inertial frames yet predicts that time runs slower in moving frames. This suggests that time-dilation is an apparent relative phenomenon that does not influence the pace of local clocks, but this interpretation is inconsistent with the

Special Relativity theory. The new interpretation based on a dynamic relative spacetime scale eliminates this contradiction by placing moving frames in different 4D manifolds. This clearly differentiates between local and relative phenomena. It allows the same pace of time in local spacetime geometries and different paces of time in moving frames in a relative sense.

An interesting comparison may be made between the change in perspective implied by the Copernican revolution and the new perspective offered by a 5D world. By the Copernican revolution the Earth changed from being the fixed center of all existence to being one of several planets in motion around the Sun. By introducing a 5D space, with the scale of 4D spacetime as the fifth dimension, our local 4D spacetime changes from being the fixed stage of all existence to being one of many dynamic 4D manifolds in a new 5D world. And, as was the case with the Copernican revolution the new perspective explains numerous previously irresolvable mysteries, most prominently it provides explanations to the progression of time and the origin of the inertial force. Furthermore, cosmological scale-expansion would agree with astronomical observations.

In retrospect we may find that Kaluza's discovery that a five-dimensional version of General Relativity may model the electromagnetic field actually was our first indication that the cosmos has five rather than four dynamic degrees of freedom. However, since the nature of the fifth dimension has remained mysterious its importance has not yet been fully appreciated. In the future the fifth scale-dimension might perhaps be recognized as being even more fundamental than the four spacetime dimensions, since the scale expansion causes the progression of time and energizes the cosmos.

This paper suggests a new line of development that could resolve several outstanding issues in physics. Although a dynamic spacetime scale at first might seem speculative it deserves attention because it could lead to further advances.

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I acknowledge Dr. Akira Kanda's pertinent observation that there are no moving points in geometry.

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Appendix I: Relative geometric motion

The new concept of a relative spacetime scale may be elaborated by considering 3D spaces spanned by velocity vectors. Let us call these “relative velocity-spaces”, one for each moving object (reference frame). In these reference spaces relative velocities define the corresponding relative scales of moving frames.

Each inertial frame carries its own particular velocity-space, and experiences relative velocities in relation to this particular frame. Furthermore, distances in this associated velocity-space are given by the magnitudes of the velocity vectors. In the proposed theory of Inertia relative scales depend on the square of these magnitudes, and thus define relative scales associated with a certain inertial frame.

The novel and important point to be made here is that there are as many velocity-spaces as there are inertial frames. Like each location on the surface of the Earth gives its own perspective of other locations on the Earth, each inertial frame defines its own velocity space and gives its particular local perspective. Conceptually we are dealing with innumerable relative four-dimensional geometries imbedded in a five-dimensional space.
In the ancient past, when the Earth was believed to be flat, a tangential plane was mistakenly believed to be the geometry of the world. But, a flat tangential plane cannot contain more than one location on the surface of a sphere. Similarly a local 4D spacetime cannot contain objects in motion; they exist in different "tangential planes", i.e. in different 4D spacetimes.
The "speed of light" may be seen as a maximum possible *observable* velocity in any inertial frame. This speed limit, which is a consequence of curvature in the scale-dimension, is reached when the projected relative scale diminishes to zero. However, the speed of light does not constrain possible actual velocities in terms of distance travelled per second. This is also true in SR.

Appendix II: The cosmological expansion as geodesic motion of 4D spacetime in canonical 5D space

An interesting special case of the canonical line-element is with c=1:

$$ds^2 = u^2(dt^2 - dx^2 - dy^2 - dz^2) - L^2du^2 \qquad \text{(AII.1)}$$

Like in the 4D spacetime of GR we may in this five-dimensional space let a "light-ray" null-geodesic be given by *ds=0.* Since each observer is fixed in her local 4D frame we have *dx=dy=dz=0* and therefore on this null-geodesic:

$$\begin{aligned} u^2dt^2 &= L^2du^2 \\ u &= e^{t/L} = e^{t/T} \end{aligned} \qquad \text{(AII.2)}$$

Let *L* be the Hubble distance and *T=L/c* be the Hubble time. The corresponding 4D line-element is:

$$ds^2 = e^{2t/T}(dt^2 - dx^2 - dy^2 - dz^2) \qquad \text{(AII.3)}$$

This is the line-element of the Scale Expanding Cosmos (SEC) model (Masreliez, 1999).
We find that the cosmological expansion may be a consequence of geodesic motion of dynamically scaled 4D Minkowskian spacetimes (associated with different observers) in 5D space with the spacetime scale as the fifth dimension.
We also find that:

$$dt = T\frac{du}{u} \qquad \text{(AII.4)}$$

In other words, cosmological scale expansion could provide an ontological explanation to the progression of time. By this the Hubble time becomes a cosmological constant that relates motion in time to a changing cosmological scale similar to how the speed of light relates motion in space to a changing time. As we saw, this fifth dimension also allows Inertia to be explained as resulting from a dynamic scale of 4D spacetimes imbedded in 5D space.

Thus, the cosmological scale expansion could be a natural consequence of perpetual existence in a five-dimensional world.

It is interesting to investigate geodesic motion of the temporal coordinate in the five-dimensional space. The geodesic equation is:

$$\frac{d^2t}{ds^2} = -\Gamma^0_{04}\frac{dt}{ds}\frac{du}{ds} - \Gamma^0_{40}\frac{dt}{ds}\frac{du}{ds} = -\frac{2}{u}\frac{dt}{ds}\frac{du}{ds} \quad \text{(AII.5)}$$

Here the index *4* corresponds to the scale *u*.

This may be integrated:

$$\ln(dt/ds) = -\ln(u^2) - \ln(C) = -\ln(Cu^2)$$
$$\frac{ds}{dt} = Cu^2 \quad \text{(AII.6)}$$

C is a constant of integration. From the canonic line element:

$$\left(\frac{ds}{dt}\right)^2 = u^2(1-v^2) - L^2\left(\frac{du}{dt}\right)^2 \quad \text{(AII.7)}$$

Consider the stationary case v=0. Using (AII.6) we get:

$$C^2u^4 = u^2 - L^2\left(\frac{du}{dt}\right)^2$$
$$\frac{du}{u\sqrt{1-C^2u^2}} == \pm\frac{dt}{L} \quad \text{(AII.8)}$$

Note that replacing *u* by *Cu* in the line-element has no physical significance because of scale equivalence. We may choose C=1, which gives *ds=dt* for *dx=dy=dz=du=0*.

The inertial scale factor suggests a change in integration variable:

$$u = \sqrt{1-w^2} \quad \text{(AII.9).}$$
$$\frac{dw}{1-w^2} = \pm\frac{dt}{L} \quad \text{(AII.10)}$$

This may be integrated;

$$\sqrt{\frac{1+w}{1-w}} = e^{\frac{t}{L}} = e^{\frac{t}{T}} \quad \text{(AII.11)}$$

In the SEC model the cosmological redshift is given by (Masreliez, 1999, 2004a):

$$z+1 = e^{\frac{t}{T}} \quad \text{(AII.12)}$$

With the corresponding cosmological distance modulus:

$$d = L \cdot \ln(z+1) \qquad \text{(AII.13)}$$

Therefore:

$$\sqrt{\frac{1+w}{1-w}} = 1+z \qquad \text{(AII.14)}$$

This may be compared to the relativistic Doppler redshift, z, which with c=1 for a receding source is:

$$\sqrt{\frac{1+v}{1-v}} = 1+z \quad \text{(AII.15)}$$

The cosmological redshift is in the SEC model related to the integration variable w as if it were a velocity in space instead of being caused by "motion in scale" via the cosmological scale expansion.

This derivation suggests that:

1. Although with cosmological scale expansion there is no radial spatial motion (in space), the observed redshift gives the impression that a radiating source is receding and that the redshift is due to Doppler shift.
2. The cosmological redshift may be due to an expanding spacetime scale and therefore be a purely geometrical effect induced without spatial motion.
3. The integration parameter *w* may be seen as corresponding to "inertial motion in scale". The "inertial scale factor" corresponding to this motion would then be given by relation (AII.9).

This demonstrates that geodesic motion of four-dimensional spacetime in five-dimensional space could explain cosmos as observed and experienced, and that there is symmetry between motion in scale and in space. Motion in general takes place in the metrical scale as well as in the four spacetime dimensions.

The scale of four-dimensional spacetime is an active cosmological degree of freedom that makes the world fundamentally five-dimensional. This suggests that the scale should be taken into account when modeling motion in space or time.

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