Existence in Physics

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Abstract

This is the second in a two-part series of papers which re-interprets relativistic length contraction and time dilation in terms of concepts argued to be more fundamental, broadly construed to mean: concepts which point to the next paradigm. After refining the concept of existence to duration of existence in spacetime, this paper introduces a criterion for physical existence in spacetime and then re-interprets time dilation in terms of the concept of the abatement of an object's duration of existence in a given time interval, denoted as *ontochronic abatement*. Ontochronic abatement (1) focuses attention on two fundamental spacetime principles the significance of which is unappreciated under the current paradigm, (2) clarifies the state of existence of speed-of-light objects, and (3) leads to the recognition that physical existence is an equivalence relation by absolute dimensionality. These results may be used to justify the incorporation of the physics-based study of existence into physics as physical ontology.

Keywords: Existence criterion, spacetime ontic function, ontochronic abatement, invariance of ontic value, isodimensionality, ontic equivalence class, areatime, physical ontology

1 Introduction

This is the second in a two-part series of papers which re-interprets relativistic length contraction and time dilation in terms of concepts argued to be more fundamental, broadly construed to mean: concepts which point to the next paradigm. The first paper re-conceptualized relativistic length contraction in terms of *dimensional abatement* [1], and this paper will re-conceptualize relativistic time dilation in terms of what I will call *ontochronic abatement*, to be defined as the abatement of an object's duration of existence within a given time interval.

The study of the nature of existence, or ontology, currently falls under metaphysics, a branch of philosophy [2]. Yet, it obviously impinges on physics in a fundamental way, as physics is at bottom the study of things that exist in nature. Indeed, physicists talk about the existence of particles, fields and systems all the time, yet there is currently no definition, or at least a physics-based criterion, which captures its formal meaning *in physics terms.* This is the case even though questions pertaining to physical existence arguably permeate many open problems in fundamental physics today. For that reason, it is at least plausible that making precise how the concept of existence connects to established physics might help attain a deeper understanding of nature.

This paper will, after covering some preliminary considerations, propose a criterion that directly relates the concept of existence to being characterized by a timelike spacetime interval, and then, using some suitable definitions, examine some of its consequences. Combining these with some of the consequences of the first paper yields a surprising and remarkable result, namely that physical existence in spacetime as defined here is an *equivalence relation by absolute dimensionality.* By way of conclusion, I will propose that the study of existence based on physics be incorporated into the field as physical ontology.

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2 Refining the Concept of Existence

One could think of a number of different possibilities for defining a criterion for what could intuitively be called 'physical existence' i.e. existence as applied to physical objects. Examples range from instrumentalist varieties, like "Something exists if and only if it produces directly observable effects" to more theory-oriented ones, like "Something exists if and only if it constitutes an ontic component in the structure of our theories of reality", and so on. Whatever criteria for existence in physics terms one might think of, it is probably fair to say that under the presently prevailing paradigm

- We regard space and time generally if tacitly as the repository for the physical existence of everything[1] (i.e. everything in space and time to which existence applies *is* everything); and
- We tend to intuitively think of physical existence as a concept with undifferentiated applicability (i.e. existence applies *equally* to everything)

These assumptions seem so natural that we may not even be fully aware of them. Yet, together they are bound to render any concept of existence based on them empty of non-trivial physics content, as they preclude the introduction of distinctions which are physically relevant, important and finer than than the obvious one between physical existence and physical non-existence.
This potential problem can be addressed by refining the concept of existence first, before putting it into correspondence with a physics-based criterion. I propose a refinement in two steps. We should consider

(a) ***Existence in spacetime*** **rather than just existence** ***per se.*** There is a rich history of philosophical debate on what precisely existence means, but as far as I can tell, such discussions, when they focus on the existence of physical objects, hardly ever explicitly (or even implicitly) seem to incorporate the central lesson of special relativity: that the arena of our reality, the repository of our existence, is *spacetime*. This may be in part because relativity is more recent than many discussions of and ideas about existence. Nonetheless, if existence is to be integrated as a physics concept, then whatever criterion for existence one wishes to consider should take this central lesson into account. That, in turn, addresses the first of the two above tacit assumptions.

(b) ***Duration of existence in spacetime*** **rather than just existence in spacetime.** As Euclidean space is completely separate from time, it seems unproblematic to divorce the concept of existence in that space from any temporal connections. But in spacetime, the intertwining of time and space permits a richer conception, one in which time plays an integral role. Thus, if we refine the concept of 'existence' to 'existence in spacetime', then this opens the door to incorporating the relationship between existence and time. For example, an unstable particle which decays after time t_1 and an identical one which decays after time $t_2 \neq t_1$ might both exist in 'the same way' in space, but if we take their difference in duration of existence into account, we can make an ontic distinction in the four dimensions of spacetime even for objects that are identical in three-dimensional space.
Existence duration turns the binary concept into a richer spectrum of gradations in which *non-existence in spacetime*, for any object that is taken to be physical, is naturally mapped to the extreme of *zero duration of existence* in spacetime. In essence, I take duration of existence to be the *spacetime analog* of our tacitly Euclidean intuitive concept of existence. This addresses the second of the above assumptions.

With this refinement, I can now proceed to define a physics-based existence criterion.

3 The Existence Criterion

In general, a good criterion

- **captures an intuition about the concept under consideration in a precise manner.** Finding a precise criterion for an informally used concept has been a highly effective means

[1] Relatively recent speculations like the multiverse notwithstanding

by which historically progress was made in mathematics and the sciences. It is possible that the absence of a physics criterion for existence so far is in part due to an unspoken assumption that it is either useless or impossible to make it precise in physics terms.

- **uses previously defined or established terms and concepts.** Without this feature, a criterion should really be considered a *primitive concept.* One may well consider existence to be a primitive concept in physics. But if so, then it has thoroughly *failed* in that function: primitive concepts are building blocks for definitions, laws and other criteria, but existence does not seem to have been used as building block for anything in physics so far: as a *physics concept*, it has been sterile. It seems therefore far more promising to make existence precise in terms of already established physics concepts than to use it as a building block for these.
- **classifies the entities to which it applies in the appropriate categories to which they belong.** In other words, well-defined criteria do not misclassify things by putting them in categories in which, by virtue of other considerations, they do not belong. Related to this concern is that a criterion which is satisfied by *everything* is useless, for if it is discarded, nothing changes, as all *other* relevant distinctions remain.
- **has no counter-examples.** If counter-examples for a criterion are found, then the criterion must meet one of two possible fates: Either it must be discarded, or its domain of applicability must be modified in such a way that the counter-examples lie outside that domain. For example, the classical definitions of momentum and kinetic energy are left intact despite their re-definition in special relativity, so long as it is understood that the old definitions only apply in a non-relativistic regime.
- **clarifies the relationship between established concepts in a way that is not possible in its absence.** A good criterion itself adds to our knowledge by helping to understand how previously understood concepts which seemed unrelated hang together. In the best case scenario, it unifies concepts which theretofore seemed unrelated.
- **points the way toward new or deeper insights or ideas unavailable prior to the formulation of that criterion** The first paper in this series argued that an essential feature of fundamental concepts is that they point to, or at least hint at, the next paradigm. Few things could be reasonably considered more fundamental than a criterion for physical existence, and so this consideration should apply here, if it applies anywhere.

I will now propose the criterion:

Proposition 1. *A physical object exists in spacetime if and only if it is characterized by a timelike spacetime interval.*

Since the spacetime interval is proportional to proper time τ and for timelike intervals the proportional proper time is real and positive, *this criterion re-interprets real positive proper time τ as duration of existence observed during a given coordinate time interval.*
Notice how this criterion subsumes Lorentz invariance, an aspect of nature that would be reasonable to incorporate into existence in spacetime. By this criterion, Lorentz invariance is a necessary but not sufficient condition for existence in spacetime: null intervals are Lorentz invariant but, by the given definition, fail to signify existence in spacetime. I will address this unfamiliar notion in detail in section 6.

4 Time Dilation as Ontochronic Abatement

As in the first part of this series, we begin by considering the Lorentz coordinate transformations of a boost in the standard configuration [3]:

$$\begin{aligned} t'_B - t'_A &= \gamma\left((t_B - t_A) - \frac{\beta}{c}(x_B - x_A)\right) \\ x'_B - x'_A &= \gamma\left((x_B - x_A) - \beta c\,(t_B - t_A)\right) \\ y'_B - y'_A &= y_B - y_A \\ z'_B - z'_A &= z_B - z_A \end{aligned} \tag{1}$$

where $\gamma = \frac{1}{\sqrt{1-\beta^2}}$ is the Lorentz factor, $\beta = \frac{v}{c}$, v is the relative speed between the primed and unprimed coordinate frames, c is the speed of light, and the primed coordinates belong to a coordinate frame which is in inertial motion relative to the unprimed frame along the positive x-axis.

Consider now a clock at rest in the primed frame, which therefore moves at speed v in the unprimed frame in the direction of the positive x-axis. Suppose that it records time t'_A as it passes a clock at rest in the unprimed frame which records time t_A, and then, a short while later, records time t'_B as it passes a second clock at rest in the unprimed frame which records time t_B. The distance between the two clocks in the unprimed frame is $x_B - x_A = \beta c(t_B - t_A)$ which, substituted into the first line of equation (1) yields

$$t'_B - t'_A = \gamma \left((t_B - t_A) (1 - \beta^2) \right) = \frac{1}{\gamma}(t_B - t_A) \tag{2}$$

As $\frac{1}{\gamma} < 1$ for $v > 0$, we have $t_B - t_A < t'_B - t'_A$, which is the familiar result that a clock observed in motion will be observed to tick more slowly than a clock which is observed at rest.

Under the special relativistic paradigm, this result is directly a consequence of the invariance of the laws of physics in different inertial frames and the invariance of the speed of light: If one wants the laws to "look the same" in all inertial frames and the speed of light to be invariant in all inertial frames, then measured time intervals *must* transform according to these equations.

I would like to now propose a different conceptualization of relativistic time dilation, which I will attempt to demonstrate in the following sections to be more fundamental. Before I do so, I need to define the relevant terminology for the sake of clarity.

Definition 1. *Spacetime Ontic Function:* The spacetime ontic function is a map[2] $\exists_S : \mathfrak{O} \to \{0, 1\}$ where $\mathfrak{O}$ is the set of all physical objects taken to be within the domain of physics and $S \subset \mathfrak{O}$ is the subset of $\mathfrak{O}$ of all objects that physically exist in spacetime. In other words, the spacetime ontic function is an indicator function which maps physically existing objects to a state of existence or a state of non-existence in spacetime, coded by the dimensionless numbers 1 and 0, respectively. Thus, the *spacetime ontic value* of an object o, symbolized by $\exists_S(o)$, can be $\exists_S(o) = 0$, which signifies that o does not exist in spacetime (but may still exist *per se* in some other to be specified sense), or $\exists_S(o) = 1$, which signifies that o exists in spacetime.

Example 1. By the existence criterion, $\exists_S(o) = 1$ if and only if o is characterized by a timelike spacetime interval.

Note that when the context makes it clear, the "spacetime" qualifier may be omitted. By the existence criterion, photons, unicorns, pure numbers and qualia all fail to exist in spacetime. However, it is clear that only the first item in this list is a physical object that falls within the domain $\mathfrak{O}$, and for the purposes of this paper I assume that it is always possible to discern whether a given object falls within $\mathfrak{O}$ or not.

Definition 2. *Ontochronicity:* Ontochronicity is defined as the quality of having a duration of physical existence.

Example 2. Any object characterized by a timelike spacetime interval is ontochronic in spacetime.

Definition 3. *Relative Ontochronicity:* Relative ontochronicity is the dimensionless ratio of the the observed duration of existence of an object compared to that of a reference object, usually the observer. As a matter of practice, the latter turns out to be what we call coordinate time t.

Example 3. Taking the term 'having aged' to be short-hand for 'having existed over a given duration', an object which is observed to have aged the same amount as a spacetime observer within a given time interval has a relative ontochronicity of 1, while one that is observed to have aged less relative to the spacetime observer has a relative ontochronicity less than 1.

As defined here, relative ontochronicity is $\frac{\tau}{t}$, and thus is closely related but not exactly identical to the inverse of the Lorentz factor, $\frac{1}{\gamma} = \frac{d\tau}{dt}$, which gives the rate of aging. For constant velocities, however, we have $\frac{d\tau}{dt} = \frac{\tau}{t}$ and this paper will only consider constant velocities. It is possible to use the term 'relative ontochronicity' in a looser sense so that it subsumes $\frac{d\tau}{dt}$ in contexts where velocities are not constant or when gravity is involved.

[2] The symbol $\exists$ is borrowed from predicate logic, where it denotes the existential quantifier

Definition 4. *Ontochronic Diminution:* Ontochronic diminution is the the decrease of the observed duration of existence of an object in a given time interval by a dimensionless factor in the open interval $(0,1)$.

Example 4. Suppose that in an experiment in the standard configuration involving two synchronized clocks at rest in a frame and an inertially moving clock which coincides with one, then the other, the synchronized clocks show that 10 minutes passed between the two events, whereas 7 minutes passed for the moving clock. The moving clock is therefore observed to have had a lesser duration of existence during that time interval, and is ontochronically diminished by 0.7.

Definition 5. *Ontic Reduction:* Ontic reduction is the reduction of the ontic value of an object to 0.

Example 5. An object which is observed to not age at all over a given time interval $t_2 - t_1$ is ontochronically diminished by a factor of zero, its associated spacetime interval is not timelike and hence, by virtue of the existence criterion, it is ontically reduced.

Definition 6. *Ontochronic Abatement:* Ontochronic abatement is a less specific umbrella term which can either refer to ontochronic diminution or to ontic reduction.

I can now formally state my proposition which re-interprets relativistic time dilation:

Proposition 2. Relativistic time dilation, conceptualized in a more fundamental way, signifies *ontochronic abatement.* More specifically, it signifies *ontochronic diminution for* $0 < v < c$ and *ontic reduction for* $v = c$.

As we already intuitively consider the duration of existence of anything to be a temporal quantity that should be measured in its rest frame, we only need to consider the behavior of the proper time τ of objects observed in moving frames: for $v = 0$, $\tau = t$; for $v > 0$, $0 < \tau < t$; and for $v = c$, $\tau = 0$. Thus, I find that the concept of ontochronic abatement is consistent with relativistic time dilation. But is it more *fundamental*? In the next several sections I will offer some arguments in support of an affirmative answer.

5 Four Spacetime Principles

In the first paper of this series, I attempted to show that the re-conceptualization of relativistic length contraction as dimensional abatement leads to the recognition of the importance of two fundamental spacetime principles, an invariance principle and a symmetry principle:

Principle 1. *The absolute dimensionality of any compact body is invariant under spacetime coordinate transformations.*

Principle 2. *The dimensionality of every space-like hypersurface of Minkowski spacetime is everywhere the same.*

These two principles have analogs when relativistic time dilation is re-conceptualized as ontochronic abatement:

Principle 3. *The ontic value of any compact body is invariant under spacetime coordinate transformations.*

For example, the principle says that if for some object o, $\exists_S(o) = 1$ in one spacetime observer frame, then $\exists_S(o) = 1$ in all spacetime frames. Surely, it makes sense that whether an object exists in spacetime or not should not depend on the coordinate system within which it is considered[3] (as long as the dimensionality of the coordinate system does not change).
Minkowski spacetime satisfies a corresponding symmetry for a global property which ensures that the ontic value of an object does not change in any region of spacetime. I will call this the *homodimensionality of time*:

[3] In quantum field theory, inequivalent representations of the algebra of observables can give rise to different particle concepts, a phenomenon often associated with *Rindler quanta*, and an observer undergoing constant acceleration is predicted to observe blackbody radiation which an unaccelerated observer will fail to observe, a phenomenon called the *Unruh effect*. However, as both of these fall within the domain of quantum field theory, they bring their own set of assumptions and problems outside of special relativity and will be ignored here.

Principle 4. *The dimensionality of every timelike hypersurface of Minkowski spacetime is everywhere the same.*

The homodimensionality of time is necessary but not sufficient for the homogeneity of time, whereas the latter obviously implies the former. Timelike hypersurfaces in Minkowski spacetime are generally not isotropic, but as homodimensionality does not require isotropy (but not vice versa), it has no effect on this property of time. The relationships between the four invariance principles can be represented as in fig 1.

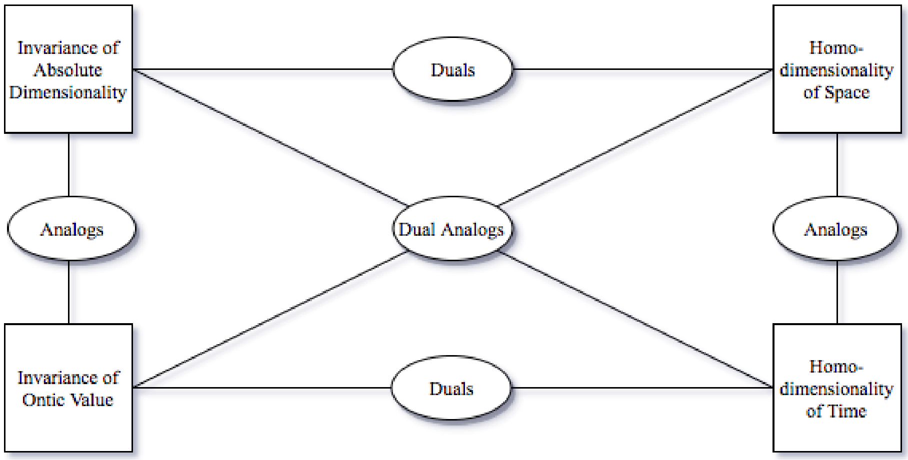

Figure 1: A diagram of the relationships between the four principles

The invariance of absolute dimensionality and that of ontic value are analogous in that they describe invariance properties of objects in space and time, whereas the homodimensionality of space and that of time are analogous as descriptions of the symmetry properties of space and time themselves. The dual relationships relate the invariant property of a compact body in space and time and the corresponding symmetry of space and time, respectively, which ensures that the invariant property remains globally invariant.

6 The Ontic Value of Speed-of-Light Objects

I will now address what is doubtlessly the least familiar aspect of the discussion so far, that by the existence criterion, $\exists_S(\textit{speed-of-light object}) = 0$. There is a difficulty here in that the standard interpretation of special relativity makes no direct reference to the concept of existence. Thus, I cannot refer to definitions of existence within the standard conception of the theory because there are none. Since I essentially put $\exists_S(\textit{speed-of-light object}) = 0$ into the existence criterion, I cannot derive this without it; as with any mathematical framework, one cannot get out what one does not put in. However, I can attempt to show that special relativity is *conceptually consistent* with it.

Consider an object characterized by $v = c$ in some spacetime frame. If the existence criterion is expressed in terms of the equivalent formulation that an object exists in spacetime if and only if time intervals in its rest frame are greater than zero[4], then just assuming the time dilation formula in (2) *without* assuming the full Lorentz transformations, and the invariance of ontic value is enough to deduce the invariance of the speed of light!

To see this, consider that since $v = c$ for an object o in some spacetime observer frame yields $\tau_B - \tau_A = 0$ (substituting τ for t on the right side of equation (2)), by the existence criterion we have $\exists_S(o) = 0$, so the object will in that frame be observed to be ontically reduced. But by the invariance of ontic value, it must be observed to be ontically reduced in *every* spacetime frame. Hence, $\exists_S(o) = 0$ in every spacetime frame, which means $\frac{1}{\gamma} = \sqrt{1 - \frac{v^2}{c^2}} = 0$ in every such frame, which means $v = c$ in every such frame.

Since there is, in fact, no spacetime frame in which speed-of-light objects are not observed to

[4]the purpose of the slight reformulation is that it expresses the existence criterion in language which, unlike the original formulation, does not already presuppose the full conceptual apparatus of special relativity

be ontically reduced, this result deserves a stronger interpretation: it is not only the case that objects associated with $v = c$ are *observed to be* ontically reduced, but that they *intrinsically are* ontically reduced. There are other 'hints' in special relativity that speed-of-light objects are ontically reduced:

- **It is impossible for any spacetime observer to transform to the rest frame of a speed-of-light object.** If we already operated under the paradigm that speed-of-light objects do not exist in spacetime, then surely our first and most obvious justification for that would be the fact that no spacetime observer can transform to a speed-of-light frame. If a spacetime observer could transform to such a frame, his ontic value would change, he would cease to exist in spacetime, and therefore cease to be a *spacetime* observer! Within the current paradigm, however, this seems like a mere curiosity of special relativity.
- **Objects characterized by $\mathbf{v = c}$ cannot by themselves be associated with four-volumes.** The usual method for arriving at a fourvolume, integrating a 3-dimensional region over a proper time interval, gives a four-volume of zero for speed-of-light objects. Of course, we can imagine a region of space through which such an object is thought to travel and integrate over a finite proper time in some spacetime coordinate frame to obtain a four-volume. But in doing so we have *surreptitiously switched frames* to that of a timelike observer; physically it amounts to inserting an object on a timelike curve as an anchor for those spacetime coordinates. This is illegitimate if we wish to relate exclusively speed-of-light objects to four-volumes. With only null spacetime intervals, there is no four-volume.
- **Speed-of-light objects 'observe' their own entire duration of existence in spacetime to be exactly zero.** Since a null interval denotes a zero proper time, it implies that the moment a speed-of-light object comes into existence in spacetime is in the hypothetical speed-of-light frame the same as the moment it goes out of existence, yielding a zero duration of existence in spacetime in such a frame.
  I addressed the legitimacy of considering the frames of speed-of-light objects in the first paper, where I argued that while spacetime observers cannot describe such objects in terms of spacetime (i.e. 4-dimensional) coordinate frames, the possibility is left open that such objects could describe themselves in their "intrinsic space" in terms of 3-dimensional coordinate frames. I interpreted the non-covariance of coordinate frames in which $r = ct$ as indicating that dimensional reduction puts them outside the domain of applicability of the Lorentz transformations. But now there is an even more compelling interpretation: speed-of-light objects are outside the domain of applicability of spacetime coordinate transformations because, quite simply, they do not exist in spacetime!
  The tendency to dismiss the possibility that speed-of-light objects do not exist in spacetime or, for that matter, that speed-of-light objects could describe their "intrinsic space" in terms of a 3-dimensional coordinate frame is a direct consequence of the unspoken assumption under the current paradigm that spacetime is the repository of everything that physically exists. If that were true, then it would indeed not make sense to consider $3D$-coordinate frames for speed-of-light objects because then the Lorentz transformations for $3+1$ spacetime govern the physical coordinate transformations for *all objects*. But if that assumption is false, then there are objects which fall outside the domain of applicability of the Lorentz transformations, and the current paradigm reveals a subtle anthropocentric bias.

In the first paper of this series, I used an analogous set of arguments based on the total length contraction of speed-of-light objects to argue that they are dimensionally reduced and pointed out that in the absence of timelike curves, a light cone has a 3-dimensional basis, as in that case the time direction and the radial direction in space become linearly dependent.

However, since spacelike hypersurfaces are coordinate-dependent whereas ontic value is invariant, it is *incorrect* to claim that a speed-of-light object exists *in* a given spacelike hypersurface. This seeming difficulty can be resolved by realizing that, by the only available physics criterion for physical existence, a speed-of light object is ontochronic in the space in which it exists. Yet, the notion of ontochronicity is inapplicable to spacelike hypersurfaces of spacetime due to the absence of a constituent time dimension. Hence, speed-of-light objects cannot be said to exist in any spacelike hypersurfaces.

In what space do speed-of-light objects exist, then? Obviously, the norm of this space cannot be the spacetime interval because then they would become ontochronic in spacetime. The dimensional reduction associated with the speed of light indicates that this space should have only 3 rather than 4 dimensions. Ontochronicity requires that the space include at least one temporal dimension, ruling out a $(3, 0)$ space, and by equivalence, also a $(0, 3)$ space. This leaves $(2, 1)$ and $(1, 2)$ spaces, but these are also equivalent to each other. Thus, there is only one sensible choice: A $2 + 1$ analog of spacetime which I call *areatime* [4]. This space has a Lorentzian signature, but with one fewer spatial component than spacetime. Taking areatime to be the space in which speed-of-light objects exist, their ontic value in areatime is 1 whereas in spacetime it is 0. The next section will show that this reflects a key property of physical existence.

7 Physical Existence as an Equivalence Relation

This section presents a fundamental idea about the nature of physical existence. I begin by observing that combining the invariance and the symmetry principles leads to novel constraints:

- **Principles 1 and 3 together couple absolute dimensionality to ontic value.** Under the current paradigm, there is no necessary requirement that the absolute dimensionality of any object be related to its existence in any space. This can be seen, for example, by the uncritical acceptance in modern speculative extensions of current theories of notions that 3-dimensional objects could exist in spacetimes with more dimensions than four.
  The combination of principles 1 and 3, however, imposes a constraint because absolute dimensionality and ontic value are necessarily coupled to each other in exactly the same way that relativistic length contraction and time dilation are necessarily coupled to each other: physical objects exist (i.e. are not ontically reduced) in a $4-$dimensional spacetime if and only if they are 3-dimensional (i.e. are not dimensionally reduced). Generalizing this to $n + 1$ dimensional Minkowski spacetimes, this implies that that the only objects which exist in them are n-dimensional objects. Objects of absolute dimensionality other than n have an ontic value of 0 in an $n + 1$-dimensional spacetime.
  This coupling of absolute dimensionality and ontic value does not necessarily hold for heterodimensional spacetimes. For instance, if a heterodimensional spacetime is dimensionally reduced in some region, then ontochronicity could become associated with a different dimensionality of objects inside that region than outside of it. However, the next constraint ensures that this does not happen.

- **Principles 2 and 4 together are equivalent to the isodimensionality of Minkowski spacetime.** Usually, when we define Minkowski spacetime as a mathematical object, we take it for granted that the definition requires its dimensionality to be everywhere the same, which is what I have called homodimensionality. In fact, we take it for granted that the definition requires something even stronger: That even with the same total number of dimensions everywhere, the combination of time and space dimensions does not change anywhere e.g. that there are no regions in which the combination changes from $3 + 1$ to $2 + 2$ or $4 + 0$. I will call the property that disallows this anywhere in spacetime the *isodimensionality* of spacetime.
  An isodimensional spacetime is always homodimensional, but the reverse is not true, as the examples just given show. Principles 2 and 4 together imply isodimensionality. Conversely, requiring isodimensionality of spacetime invokes a combination of principles 2 and 4, which means that they mutually imply each other:

  $$\textit{Homodimensionality of space}\,\&\,\textit{Homodimensionality of time} \Leftrightarrow \textit{Isodimensionality of spacetime} \quad (3)$$

  The isodimensionality of Minkowski spacetime ensures that the coupling of absolute dimensionality and ontic value holds everywhere in it. Note that the isodimensionality of Minkowski spacetime does not necessarily entail that an arbitrary spacetime will also be isodimensional. Indeed, in general relativity other global symmetries of Minkowski spacetime, such as the time- and space-translation symmetries, may hold only locally in some models of spacetime. Perhaps considering violations of principles 2 and 4 can help point toward possible approaches to better understand outstanding problems in general relativity and cosmology. For instance, is it possible that the singularities at the center of black holes are regions of different dimensionality? Or that the the big bang took place in a region with different dimensionality than that of spacetime? I will, however, not further consider these questions here.

The isodimensionality of Minkowski spacetime implies that any change in its dimensionality or that of its constituents must be implemented *globally* (if it were implemented locally, the spacetime would become non-isodimensional), and the coupling between the absolute dimensionality and ontic value of each object in spacetime implies that such global change must be accompanied by a corresponding change in the dimensionality of *all* objects that physically exist in the spacetime (otherwise, that would imply that absolute dimensionality and ontic value have become decoupled). These two implications together directly lead to a most remarkable conclusion:

Physical existence in Minkowski spacetime is an equivalence relation by absolute dimensionality.

It is easy to prove this: An equivalence relation is determined by the properties of reflexivity, symmetry and transitivity. Consider an n-dimensional object A. By the the coupling of ontic value to absolute dimensionality, it must exist in an $n+1$ dimensional Minkowski spacetime region. By the isodimensionality of Minkowski spacetime, this region is, in fact, all of $n+1$ dimensional spacetime. In particular, A exists in the $n+1$-dimensional Minkowski spacetime in which it exists. This proves reflexivity. Now consider an m-dimensional object B. By the same argument as given for reflexivity, it must exist in an $m+1$ dimensional spacetime. Suppose A exists in the same spacetime as B. This requires that $n+1 = m+1$, and, consequently, that $n = m$. But that means B has the same absolute dimensionality as A, and therefore exists in the same spacetime as A. This proves symmetry. Finally, consider an l-dimensional object C. By the same argument as given for reflexivity, it must exist in an $l+1$-dimensional spacetime. Now suppose that B exists in the same spacetime as C, and that A exists in the same spacetime as B. This requires $m+1 = l+1$ and $n+1 = m+1$, respectively, from which it follows that $n = m = l$, so A has the same absolute dimensionality as C and therefore exists in the same spacetime as C. This proves transitivity ■
It is well known that an equivalence relation on a set gives rise to equivalence classes which partition that set. The ontic equivalence relation considered here partitions the set of all objects that physically exist *per se* into *ontic equivalence classes* such that for each $n+1$ dimensional Minkowski spacetime, there is a corresponding equivalence class of n-dimensional objects that physically exist in it (fig 2).

0+1 Spacetime	1+1 Spacetime	2+1 Spacetime	3+1 Spacetime	4+1 Spacetime	...
0-dimensional objects	1-dimensional objects	2-dimensional objects	3-dimensional objects	4-dimensional objects	...

Figure 2: A partition of all physically existing objects into ontic equivalence classes by absolute dimensionality. Each class of $n-$dimensional objects exists, i.e. has an ontic value of 1, in only the corresponding $n+1$ dimensional spacetime. The zero-and four-dimensional cases are shown in dashed lines to reflect the greater uncertainty associated with these dimensionalities.

The entire discussion in section 6 can now be summarized by saying that speed-of-light objects belong to a different ontic equivalence class than spacetime objects. Conversely, we can now assign a fundamental ontic role to *rest mass*[5], namely that it confers membership to the equivalence class of spacetime objects. More generally, the equivalence relation imposes the constraint that any physically existing object has an ontic value of 1 in exactly one of the $n+1$-dimensional spacetimes, and an ontic value of 0 in all others. This constraint can be useful as a tool for theory selection, as it appears that some of the current speculative extensions of established theories in physics violate it.

[5] In classical physics, at least. Quantum physics may introduce novel distinctions, see ref

8 Conclusion: Ontology as a Branch of Physics

Ontology, the study of being, has been within the purview of philosophy at least since Parmenides[6]. Formulating a physics criterion for existence in terms of timelike spacetime intervals, and re-interpreting key concepts of special relativity as presented in this 2-part series makes it possible to use the tools of physics to investigate the concept of existence, at least insofar as it pertains to physical objects.

It seems sensible to differentiate the study of the existence of physical systems based on the use of these tools from the rest of ontology, much of which encompasses extraphysical concerns. I propose the term *physical ontology* to denote the physics-based study of existence.

A number of problems in fundamental physics can be considered to fall within the purview of physical ontology. Besides the one area in physics where many researchers have already recognized the need for an ontological investigation, namely the foundations of quantum mechanics, there are a diverse number of other subfields of physics and the philosophy of physics that could serve as subjects of investigation: The ontic nature of physical fields (quantum *and* classical); of emergence in physics and related subjects, such as the renormalization group; of infinities in physics, of objects at the boundaries of theories with different domains of validity, and generally, of phenomena which we currently do not understand very well, such as dark matter and dark energy. Note that meta-ontic questions, such as those about the ontic status of the *laws* of physics, are still part of philosophy, unless the methods of physics can be applied to them as well.

Because of the extreme fundamentality of the concepts of dimensionality and existence, I believe that the ideas presented in this series are the gateway for moving our fundamental knowledge of the physical world into the next paradigm, one in which physical ontology may well be a branch of physics.

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