Higher-Dimensional Relativity and the Wavefunction

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Abstract

We approach the Nature and Ontology of Spacetime by considering the properties of the wavefunction. On the basis of observed retrocausal effects and consequent time-symmetric approaches to QM we conclude that the wavefunction is extended in time as well as in space, and hence is minimally a 4-dimensional entity occupying a 4-space resembling the Block Universe. On this basis we erect a higher-dimensional spacetime framework accounting for nonlocality and retrocausality while providing insight into the origins of time, space, mass and inertia. We elucidate relativistic mass and derive the mass transformation equation according to Special Relativity from quantum mechanical and relativistic principles. The framework is shown to provide a spatial context for Kaluza's 5D Einstein-Maxwell theory and the internal symmetries of the Standard Model.

Keywords: wavefunction, relativity, nonlocality, retrocausality, mass, inertia.

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Contents

Figures

1. Introduction

While Special Relativity has proven to be universally applicable to the material realm, it cannot be said to account for the properties of the wavefunction. Consequently we approach the nature of spacetime by looking squarely at the wavefunction, focusing in particular on the following:

a. Reality of the wavefunction. Is the wavefunction an objective entity (ontic), extended in space, or is it an abstract mathematical artifact providing knowledge of the system (epistemic)? The PBR Theorem [1] established the reality of the wavefunction given the mild assumption that quantum systems can be prepared independently, and related theorems have followed, though not without loopholes [2]. In 2017 a groundbreaking experiment by F. Piacentini et al. measured the quantum expectation value of a single photon, in what is claimed to be the first realization of a protective measurement, lending powerful support to the ontic view [3] – if the wavefunction is not objectively present in space, then what in fact were they measuring? Moreover, by introducing orthogonalizing measurements, Joshua Ruebeck et al. have shown that known epistemic models cannot represent state update correctly [4].

b. Nonlocality. Is quantum nonlocality a fact of Nature and can it be explained in terms of 3+1 spacetime? At least two Bell tests in 2015 claim to have closed “all significant loopholes” while demonstrating the violation of a Bell inequality with high statistical significance [5]. Moreover, experiments have established correlations between particles which never existed at the same time, suggesting nonlocal effects over time as well as space [6]. While the case is not closed, the experimental evidence increasingly supports nonlocality as a fact of Nature.

c. Retrocausality. It has been amply demonstrated in the laboratory by various “delayed choice” experiments that the choice of an observable can influence phenomena occurring in the past. For instance, Jacques et al. write [7]:

> Our realization of Wheeler’s delayed-choice GendakenExperiment demonstrates beyond any doubt that the behavior of the photon in the interferometer depends on the choice of the observable which is measured, even when that choice is made at a position and a time such that it is separated from the entrance of the photon in the interferometer by a space-like interval. In Wheeler’s words, since no signal traveling at a velocity less than that of light can connect these two events, “we have a strange inversion of the normal order of time …”.

The philosophical implications of these questions are sufficiently profound that advocates take an almost “religious” stand on one side or the other. In particular, the prospect of an ontic wavefunction raises the specter of ontic imaginary (or complex) dimensions, crossing a long-established philosophical divide within physics.

While much current work in quantum foundations is focused on resolving these questions by proving theorems, closing loopholes and finding new ones, here we take a more pragmatic approach. We simply ask the rhetorical question: What if these three fundamental phenomena do in fact occur objectively in Nature? That is, what are the consequences if the following three assertions are true?

a. The wavefunction is ontic (an objectively present, holistic entity).
b. The wavefunction is nonlocal (holistic over space).
c. The wavefunction is time-symmetric (holistic over time).

What are the logical consequences of these assumptions? In particular, could it be that Special Relativity represents a limiting case of a higher-dimensional spacetime structure that can accommodate the wavefunction?

2. Time Symmetry

Since time is a global phenomenon it makes no sense to speak of time "reversing" for one object but not for another alongside. Time is observed to march inexorably onward. So we are forced to conclude the following:

- Retrocausal effects demonstrated in delayed-choice experiments imply that the wavefunction evolves both forwards and backwards in time.

This is the central insight of time-symmetric approaches to QM such as Cramer's Transactional Interpretation (TI) [8] and the Two-State Vector Formalism (TSVF), originally proposed by Aharonov, Bergmann and Lebowitz in 1964 [9]. While there are significant differences between these proposals, here we are interested in what they have in common. Firstly, both schemes rely on the wavefunction being time-symmetric under conjugation ($i \rightarrow -i$), whilst suggesting a connection between time and the imaginary axis of the wavefunction.

In TI a quantum event is regarded as a "handshake" across time between an emitter and an absorber. The offer wave (forward-evolving) and confirmation wave (backward-evolving) can be considered standing waves extended in four dimensions – our three ordinary dimensions plus "pseudo-time". Hence, the wavefunction is regarded as a holistic entity extended over time as well as over space.

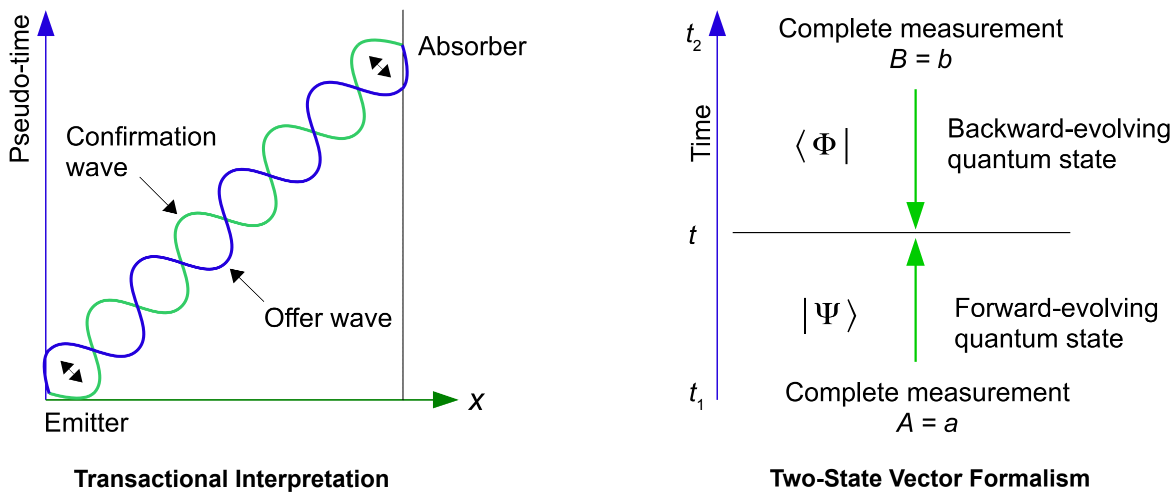

Figure 1: Time-Symmetric Quantum Mechanics

The TSVF also invokes quantum states moving forward and backward in time. Figure 1 (right) illustrates a quantum system that has been both pre- and post-selected, involving a complete (projective) measurement at times t_1 and t_2 yielding eigenstates a and b. According to Aharonov and Vaidman [10] the forward- and backward-evolving quantum states together yield "maximal information about how this system can affect other systems (in particular, measuring devices) interacting with it at time t" ($t_1 < t < t_2$). They add:

> The TSVF approach is time symmetric. There is no preference to [sic] the results of measurements in the past relative to the results of measurements in the future: both are taken into account. Then, there is more information about the system at time *t*.

Once again the implication is that the wavefunction is a holistic entity extended over time as well as space. Why is this so important? The reader may be reminded of a similar conception arising out of Special Relativity, known as the Block Universe, wherein world lines and world tubes are similarly extended over both space and time.

3. Logic of the 4-Space

On the basis of Special Relativity theory it has been argued by Minkowski and others that our world must in fact be at least 4-dimensional [11]. That is, Special Relativity requires that our time dimension be extended, not unlike a spatial dimension, which along with our three familiar spatial dimensions forms a 4D spacetime. It has been pointed out that there are serious logical deficiencies with this picture, however [12]. The present moment is given no special status – past, present and future are treated equally, in conflict with our experience. Further, since the time dimension t is already taken up in the Block Universe, there is no time dimension in which the Block Universe can evolve, so it remains static, unchanging, a “frozen river”, leaving no mechanism to explain the passage of time.

A conscious observer located anywhere in the Block Universe will not experience time but timelessness – an unchanging 3-space frozen in time. Even while the observer is located at a particular coordinate t she does not experience time, revealing that time and the fourth dimension t are not identical. Rather, time is experienced as *motion* of the present moment over the fourth dimension.

So we come to a fundamental paradox: while both QM and Special Relativity require that the time dimension be extended, we observe our 3+1 spacetime only at the present moment (even light from stars is observed in the present). Or, we could say that objective reality is always right now. So experience tells us that we live in a 3-space located at the present moment – nowhere in our physical world are the past or future to be found.

To resolve this paradox we take a conceptual leap. Since the wavefunction of QM and the world lines and world tubes of Special Relativity are extended in 4 dimensions, they obviously live in a 4-space, while we obviously live in a 3-space. Both statements are true. So we are talking about two different spaces, which must necessarily be superimposed. Further, the fourth spatial dimension (normally denoted t) cannot be considered time, but the *spatial precursor* to time, which we denote w.

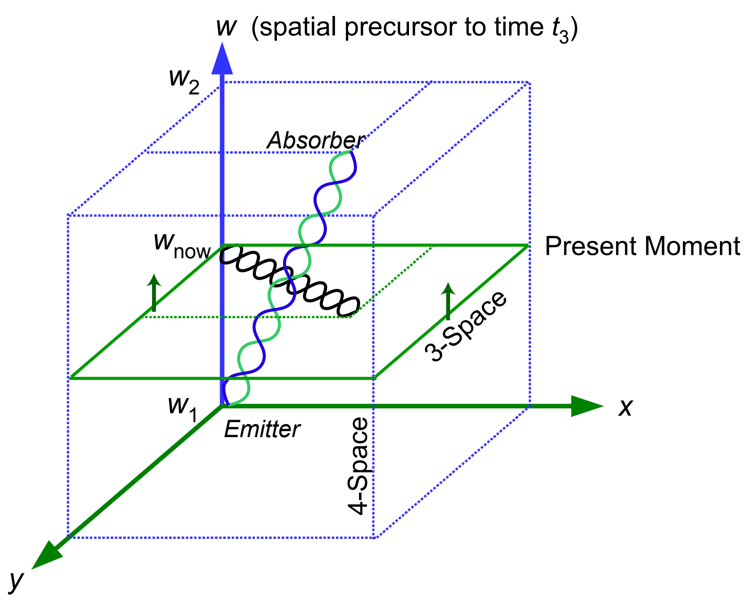

Figure 2: The 4D Wavefunction in the 4-Space

Note the following:

- Empirically, our 3-space is pinned to the present moment and cannot exist anywhere else in time.
- Physical time derives from the motion (translation) of the w dimension relative to the present moment, and hence to the 3-space. It is this *relative spatial motion* that manifests as the phenomenon of time.

- The wavefunction evolves holistically whilst it intersects the present moment. The instant the wavefunction passes off the present moment it ceases to evolve, being frozen “forever” in its final state in the 4-space [13].
- It follows that the wavefunction is energized by its passage over the present moment. By extension, objective energy appears only at the present moment, and the passage of the *w* dimension relative to the present moment yields both energy and time.
- While the 4D wavefunction intersects the present moment a 3D representation is projected into our 3-space. When the wavefunction passes off the present moment it disappears from the 3-space.
- Since the wavefunction evolves in the 4-space, the 4-space itself requires a time dimension, denoted t_4, yielding a 4+1 spacetime (the time dimension of 3+1 spacetime we denote t_3).

It follows that the present moment holds a very privileged position within this logical scheme – our 3-space is pinned to it, while the 4D wavefunction evolves only while intersecting it. Being so privileged, what exactly is, or what defines, the present moment? We will return to this question in due course.

To help visualize this arrangement one might imagine the wavefunction occupying a 4-brane which is superimposed upon (interpenetrating) a 3-brane. While anathema, it solves the logical crisis. In fact, it may be the only way to solve the logical crisis. We have arrived at two different worlds: the world we experience as our physical universe, 3+1 spacetime, and the higher-dimensional world of the wavefunction, a 4+1 spacetime which is somehow superimposed upon our own. Since we don’t directly observe this higher-dimensional world, we surmise that it constitutes a separate space, isolated from our 3-space yet intimately related to it by virtue of the higher-dimensional wavefunction.

4. The 4D Wavefunction

Figure 3 illustrates the most regular of wavefunctions, a pure momentum state. While the general wavefunction won’t look like this, the dimensionality remains. That is, the wavefunction is a complex wave, extended in the three real spatial dimensions (represented by the *x* axis) and with complex phase, commonly understood as a total of five dimensions to represent the wavefunction.

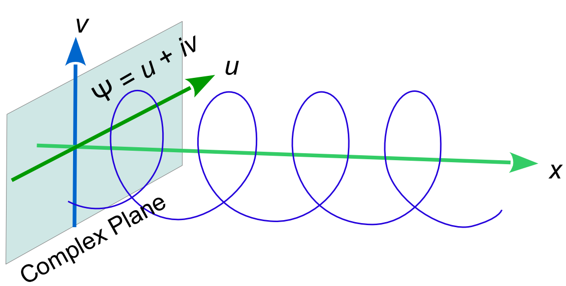

Figure 3: The Wavefunction (pure momentum state)

When we admit imaginary dimensions, however, the wavefunction becomes 4-dimensional, with the real axis of the complex plane *u* corresponding to one of the three real dimensions (say *y*). By this simple reinterpretation the wavefunction lives happily in the 4-space, with one caveat: the fourth dimension must be imaginary. Once again this is simple deduction, but with profound consequences.

The fourth, imaginary axis of the wavefunction corresponds to the fourth dimension of the 4-space, which we have established is the precursor to time in our 3-space. It follows that the fourth dimension of the 4-space is imaginary and the imaginary axis of the wavefunction corresponds to time; hence time enters quantum mechanics as a dynamical variable rather than an input parameter as it is today.

Because the quantum formalism describes a system of N particles in terms of a 3N-dimensional configuration space, it is generally understood that the wavefunction lives in 3N dimensions [14]. According to the current framework, however, technically this proliferation of dimensions is required to represent four-dimensional objects in 3+1 spacetime. When the wavefunction is formulated in four spatial dimensions (in Minkowski 4-space, with all N particles being confined to the same null cone, see below) and governed by the appropriate metric, the 3N dimensions will be seen to be a purely technical (calculational) requirement.

5. Minkowski 4-Space

The idea of a space including three real dimensions and one imaginary dimension is not new. In the early days of relativity theory Minkowski and others noted that rotating the time dimension on the complex plane yields a positive-symmetric metric. Theorists in both relativity and quantum theory commonly apply Wick rotations, yielding "imaginary time", $\boldsymbol{\tau} = \mathbf{i}t$. (Note that for the sake of logical clarity all imaginary terms are bolded.) Here we take this idea a step further by considering the fourth (imaginary) dimension $\boldsymbol{w}$ to be spatial, where $\boldsymbol{w} = \mathbf{i}t$. That is, the dimension $\boldsymbol{w}$ denotes not imaginary *time* but imaginary *space*. The metric becomes:

$$ds^2 = dx^2 + dy^2 + dz^2 + d\boldsymbol{w}^2 \qquad (1)$$

Note that time t_4 is not included in the metric for Minkowski 4-space, which is purely spatial. Since all four dimensions are spatial, the interval s must also represent a spatial distance, which may be real or imaginary. This is crucial to what follows. Minkowski 4-space becomes a viable home for the 4D wavefunction, offering the correct dimensionality while supporting retrocausality and nonlocality, as we shall see.

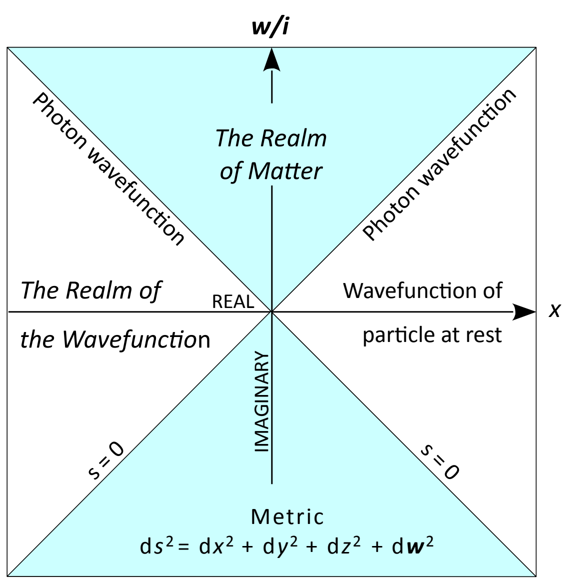

Figure 4: Minkowski 4-Space

Figure 4 provides a static picture of Minkowski 4-space. A more realistic picture is the dynamic one: if we take the horizontal axis as the present moment, then the vertical ($\boldsymbol{w}$) axis is in a state of constant downward motion as our present moment evolves into the future. It is this passage of the $\boldsymbol{w}$ dimension (along with the wavefunction) over the present moment that underpins the flow of time (change) in the 3-space.

This leaves us with an important question: How does the motion of an *imaginary* dimension $\boldsymbol{w}$ in the 4-space mysteriously manifest as *real* time t_3 in the 3-space? In other words, what is the basis for the Wick rotation when passing between 3+1 spacetime and the 4-space? We shall return to this question in due course.

6. Nonlocality and Mass

A key piece to this puzzle is the following well-known formula for the propagation of the wavefunction, originally due to de Broglie:

$$v_{ph}\, v_g = c^2 \qquad (2)$$

where v_{ph} is the phase velocity (associated with the propagation of the wavefunction itself), v_g is the group velocity (generally associated with particle velocity, or more fundamentally the propagation of energy), and c is the speed of light.

A photon emitted at the origin of Minkowski spacetime will travel at speed c while adhering to the light cone, where the interval $s = 0$. From the propagation formula (2) it follows that the wavefunction itself will also propagate at phase velocity c and hence will adhere to a null cone in Minkowski 4-space. It follows that there is no spatial distance between any parts of the wavefunction. Hence, as unintuitive as it may seem from our perspective in 3+1 spacetime, technically the entire photon wavefunction is a holistic entity in Minkowski 4-space. Moreover, for multiple photons emitted in a quantum event, all branches of the wavefunction will be on the one null cone, which accounts for the three key characteristics of nonlocality [15]:

• The quantum connection is unattenuated (over any distance).
• The quantum connection is discriminating (i.e. confined to a specific null cone).
• The quantum connection is faster than light (instantaneous).

The key idea is that wavefunctions always adhere to null geodesics, hence always remaining holistically connected over both space and time, thereby accounting for both nonlocality and retrocausality. Accordingly, whilst the holistic ($s = 0$) wavefunction intersects the present moment a complete 3D projection spontaneously manifests in the 3-space along with time and energy.

As elegant as this principle is, however, the properties of Minkowski 4-space do not account for massive particles. According to the propagation formula (2) the wavefunction of a massive particle at rest will travel at infinite velocity, corresponding to zero extension on the $\boldsymbol{w}$ axis, which is definitely not on a null cone. The solution is hidden in the fact that the 4-space itself requires a time dimension, which implies the presence of a higher-dimensional spatial precursor to time t_4. Accordingly we introduce a fifth spatial dimension $\boldsymbol{v}$, which is directly related to energy and mass. To accomplish this while retaining a positive-symmetric metric the fifth dimension is imaginary like the fourth, constituting *Minkowski 5-space*, where:

$$ds^2 = dx^2 + dy^2 + dz^2 + d\boldsymbol{w}^2 + d\boldsymbol{v}^2 \qquad (3)$$

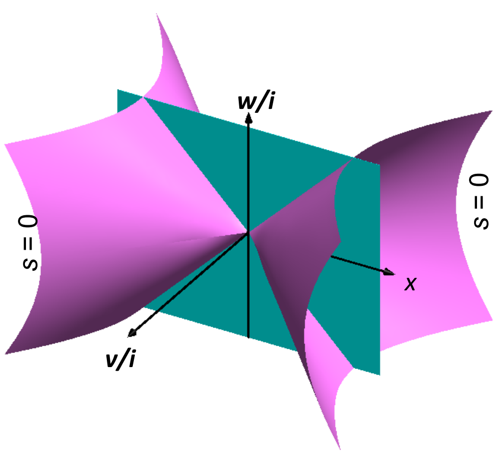

Figure 5: Null Surfaces in Minkowski 5-Space

The structure of Minkowski 5-space is illustrated in Figure 5, with the green rectangle representing Minkowski 4-space. The hyperbolic 5-dimensional null surfaces intersect the 4-dimensional null cone and extend out over the "superluminal" quadrants only (inside which the interval s is real).

Let us assume that the wavefunction always adheres to a null geodesic – to a null cone in Minkowski 4-space for a massless particle, or a null surface in Minkowski 5-space for a massive particle. Figure 6 illustrates Minkowski 5-space from a similar perspective to Figure 5, but with the null surfaces removed for clarity. The shaded area represents inside the null cone in Minkowski 4-space, with the $\boldsymbol{v}$ dimension projecting out from the origin. Four wavefunctions are depicted:

A. The wavefunction of a massless particle, which is extended only in the x and $\boldsymbol{w}$ dimensions, hence adhering to a null cone in Minkowski 4-space while propagating at velocity c in 3+1 spacetime.
B. The wavefunction of a massive particle at rest. Since d$\boldsymbol{w}$ = 0, the wavefunction adheres to a null surface in Minkowski 5-space according to the positive-symmetric metric (3).
C. The wavefunction of a massive particle in motion (relative to this frame). Phase velocity becomes finite, so the wavefunction extends into the $\boldsymbol{w}$ dimension; d$\boldsymbol{w}$ increases while d$\boldsymbol{v}$ decreases to satisfy $s = 0$.
D. Wavefunction C projected onto the $\boldsymbol{v}$ axis.

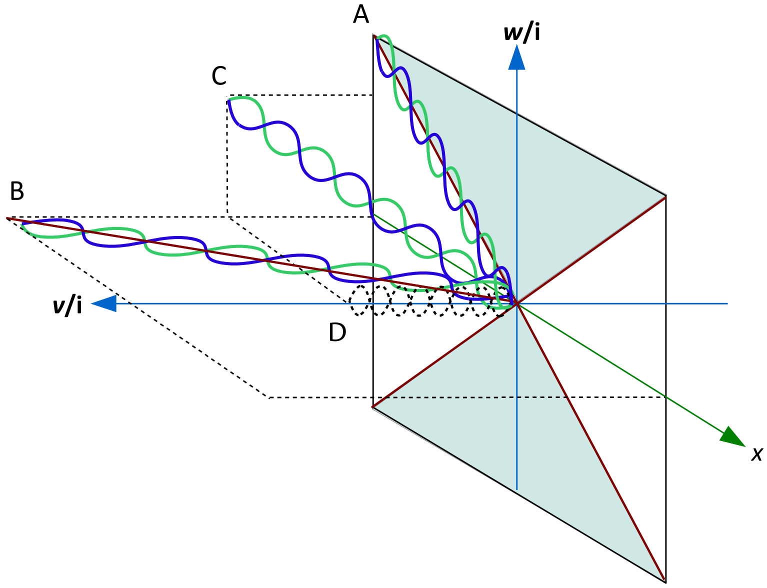

Figure 6: The Wavefunction in Minkowski 5-Space

Consider a wavefunction with real spatial extension x (dy = dz = 0), measuring from the origin, while adhering to the null metric:

$$x^2 + \boldsymbol{w}^2 + \boldsymbol{v}^2 = 0$$

Let $\boldsymbol{w} = \mathbf{i}ct$, $\boldsymbol{v} = \mathbf{i}V$. Therefore:

$$x^2 = (ct)^2 + V^2$$

or,

$$V = \sqrt{x^2 - (ct)^2} \qquad (4)$$

The wavefunction phase velocity will be observed in 3+1 spacetime as real distance over time:

$$v_{ph} = \frac{x}{t}$$

While phase velocity can also be expressed in terms of (2):

$$v_{ph}=\frac{c^2}{v_g}$$

Hence:

$$\frac{x}{t}=\frac{c^2}{v_g}$$

or,

$$t=\frac{x\,v_g}{c^2}$$

Substituting for t in (4):

$$\frac{V}{x}=\sqrt{1-\left(\frac{v_g}{c}\right)^2}$$

From Figure 6 (D) it is clear that the frequency relative to the ***v*** axis, hence energy and mass, will be inversely proportional to d***v***, such that the mass m of an accelerated particle with rest mass m_0 is given by $m/m_0 = V_0/V$. For a particle at rest, to satisfy the propagation formula (2) and the null metric, ***w*** = 0 hence $V_0 = x$. So:

$$m=\frac{m_0}{\sqrt{1-\left(\frac{v_g}{c}\right)^2}}$$

This of course is the mass transformation equation according to Special Relativity, where the group velocity v_g is taken to be the velocity of the particle in 3+1 spacetime.

By similar reasoning, accelerating a particle from its rest frame in 3+1 spacetime equates to some reduction in the ***v*** coordinate in that frame, which requires energy, this being the mechanism of inertia.

Since the ***v*** dimension is orthogonal to the 4-space, and hence to 3+1 spacetime, a geometrical mechanism is suggested by which the wavefunction of a massive particle "curves" spacetime.

The framework may well provide a resolution to Maudlin's objection to the Transactional Interpretation [16]. Broadly speaking, the energy required to move an absorber will displace it on the ***v*** dimension so as to remain on a null geodesic along with the emitter in Minkowski 5-space.

7. Dimensions of Time

We have arrived at a 5-dimensional wavefunction extended in a 5-space, which itself requires a time dimension t_5 underpinning dynamical processes in the 5-space. This implies spatial motion over a still higher dimension – also imaginary, call it ***u***. So we are facing an infinite regression: where does it end?

For both technical and philosophical reasons [17] the dynamical system ends (or rather, originates) right here; it is proposed that the imaginary dimension ***u*** is static and hence anchors the present moment. All dynamical processes in our Universe originate in the passage of just two "prime movers" in the 5-space – the dynamic imaginary dimensions ***w*** and ***v*** – relative to the present moment, the dimension ***u***. These prime movers are taken as a priori – that is, the *motions* are primary, generating both time and energy. To complete the logic, as the ***w*** and ***v*** dimensions pass over the present moment ***u*** they conspire to move along it. It follows that time t_5 can be understood as displacements on the ***u*** dimension relative to displacements of the ***w*** and ***v*** dimensions. That is:

$$dt_5 \leftarrow d\boldsymbol{u}/d\boldsymbol{v}\ ,\ d\boldsymbol{u}/d\boldsymbol{w}$$

The units of time in the 5-space are therefore dimensionless real. Simply the real numbers. Time in the 4-space therefore derives from the motion of the imaginary dimension $\boldsymbol{v}$ in real time t_5.

$$d\boldsymbol{t_4} \leftarrow d\boldsymbol{v}/dt_5$$

Units of time in the 4-space are therefore an imaginary distance, consistent with time $\boldsymbol{t_4}$ corresponding to a displacement on the $\boldsymbol{v}$ dimension. It follows that time in our 3-space derives from the motion of the imaginary dimension $\boldsymbol{w}$ in imaginary time $\boldsymbol{t_4}$.

$$dt_3 \leftarrow d\boldsymbol{w}/d\boldsymbol{t_4}$$

So it is that time in our 3-space is real, with natural units being dimensionless real – the real numbers.

Here we have resolved a long standing mystery: What is the basis for the Wick rotation when moving between 3+1 spacetime and the 4-space? More specifically, how does motion of the *imaginary* dimension $\boldsymbol{w}$ become *real* time t_3 in our 3-space? In a nutshell, physical time is real because time in the 4-space is imaginary.

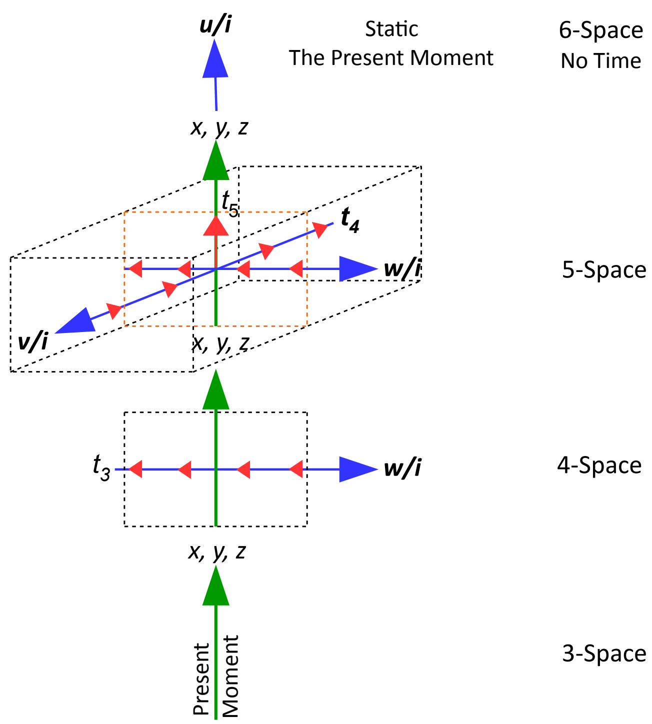

Figure 7: The Dynamical World System

Figure 7 illustrates the central structure of the framework. The vertical arrows represent the intersection of real 3-space and the present moment (the vertical axis $\boldsymbol{u}$), where objective energy is to be found. (While $\boldsymbol{u}$ is orthogonal to real 3-space, for want of graphical dimensions they are aligned to indicate they are pinned.) The present moment thus assumes ontological status as the central axis around which the whole dynamical system evolves, which turns the problem of presentism on its head; if the present moment is an objective structure in Nature, how may that be reconciled with the relativity of simultaneity? [18] The question of simultaneity requires reevaluation in the context of the framework; one might imagine the spaces tilting relative to the central axis according to frame. Given that the wavefunction is transformed by relativistic effects in the 4-space and 5-space, the usual arguments against our world being three-dimensional do not apply [19].

8. Kaluza and the 5-Space

Kaluza's 5-dimensional Einstein-Maxwell theory formally unites Einstein's gravity and Maxwell's electromagnetism in 4+1 real dimensions. While its power and elegance are undisputed, the theory has never found a satisfactory context in our 3+1 spacetime; where is the fourth spatial dimension? Despite efforts by Klein and others to curl up the extra dimension, along with efforts by the late Paul Wesson and the Space-Time-Matter Consortium to extend Kaluza's work [20], a consistent context for the theory remains elusive.

Our immediate task, then, is to find the correct context for Kaluza's 5-dimensional theory within the current framework, which at first glance doesn't look promising. While Kaluza's theory is formulated in four real spatial dimensions, the extra dimensions in the 4-space and 5-space are imaginary. Having deduced that gravity is intimately related to the imaginary dimension ***v***, Kaluza's theory would consistently apply to the 5-space, if only the dimensions were to match. What might Nature be telling us? Might it be possible that the two imaginary dimensions ***w*** and ***v*** combine or interact in the 5-space, perhaps in some sense as a cross product, to project a mutually orthogonal real dimension?

I wish to argue that this not only can but will occur, on the basis of the following premises:

a. The two imaginary dimensions constitute an imaginary 2-space (subspace) within the 5-space.

b. Nature employs the cross product in imaginary space as it does in real space (e.g. electromagnetism).

Accordingly, the cross product of any two vectors in the imaginary 2-space will project a mutually orthogonal real vector. Generalizing to a dimensional level, we could say that the two imaginary dimensions will project a mutually orthogonal real dimension (denoted *l* in accordance with Space-Time-Matter theory).

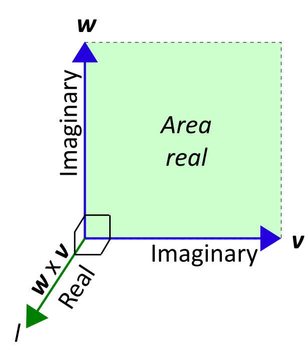

Figure 8: Cross Product of Imaginary Dimensions

We thus have the 4+1 real dimensions required by Kaluza's theory as a particular configuration of the 5-space. According to the algebra of imaginary numbers, similar imaginary dimensions will project a real dimension of negative norm, raising the question of *polarity* or *handedness* in our descriptions. A "negative" real dimension may account for the fact that the fourth dimension is treated differently in Kaluza's theory, having the "cylinder condition" imposed upon it, to the effect that it is not directly involved in the resulting physics.

Figure 9 illustrates the central logic of the dual process taking place at the very heart of objective manifestation. A full understanding of these logical relationships will require a rigorous mathematical treatment.

a. The motion of the two prime movers ***w*** and ***v*** relative to the present moment generates displacements on the ***u*** dimension, hence real time t_5 in the 5-space.

b. The motion of the two prime movers relative to each other projects a (negative) real dimension *l* into the 5-space, which accordingly is also in motion, meaning *energetic*.

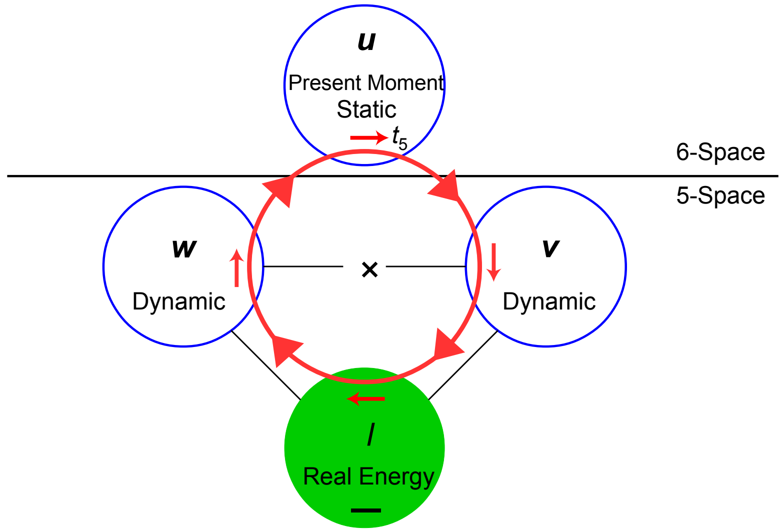

Figure 9: Origins of Energy and Time

9. Symmetry and Imaginary Space

Having established a logical mechanism by which real dimensions may emerge from imaginary dimensions, it is natural to ask whether our real 3-space itself might be fundamentally imaginary. It would seem extraordinary that Nature would employ two types of real dimensions: those that are real *a priori* and those projected from imaginary dimensions. Occam's Razor would therefore suggest that *all spatial dimensions are fundamentally imaginary.* It follows, of course, that Reality is fundamentally imaginary (subjective) [21].

Under the cross product rule the most economical way to project three real dimensions from imaginary dimensions is illustrated schematically in Figure 10. The positive "intrinsic" dimension interacts with the three mutually orthogonal negative dimensions to project a real 3-manifold, represented by the triangular outline. (The polarities of the imaginary dimensions could be reversed, of course, to the same effect.)

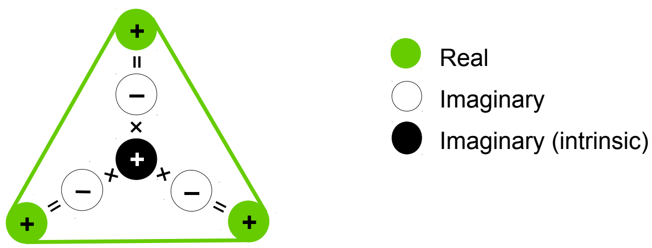

Figure 10: Imaginary Foundations of Real 3-Space

As fanciful as this conjecture might appear, it is logically consistent while delivering unforeseen technical and philosophical opportunities. For instance, it suggests a solution to one of the most perplexing questions in theoretical physics: a context for the internal symmetries of the Standard Model, as follows:

$SU(2)$	Governs quantum spin phenomena.
$SU(2) \times U(1)$	Governs the Electroweak interaction.
$SU(3)$	Governs the Strong interaction.

The question is: Why these particular symmetry groups and not others? The gauge symmetries of the Standard Model are essentially *property spaces*, such as the three quark colors, for instance, or the colors of the eight gluons (two of nine being overlapping). Why do these colors adhere to the particular transformations represented by the $SU(3)$ symmetry group?

Figure 11 illustrates a consistent answer to this question. The general principle is that the imaginary dimensions comprising each space may present themselves in either of the following ways:

a. Configured around an "objective" real 3-manifold.

b. Configured for maximal symmetry while allowing complex dimensions.

For the 3-space and the 6-space these alternatives coincide. However, the five imaginary dimensions of the 4-space can present themselves as a real 3-manifold plus one orthogonal imaginary dimension, or as two complex dimensions, reflecting the dimensionality of the $SU(2)$ symmetry group. The 5-space can present itself as a real 3-manifold along with two imaginary dimensions, which together project a fourth (negative) real dimension l; or as three complex dimensions reflecting the dimensional configuration of the $SU(2) \times U(1)$ symmetry group.

Note that these schematic diagrams are intended to demonstrate the dimensional logic of the various spaces and certainly not their geometry. Real and imaginary dimensions joined represent one *complex* dimension.

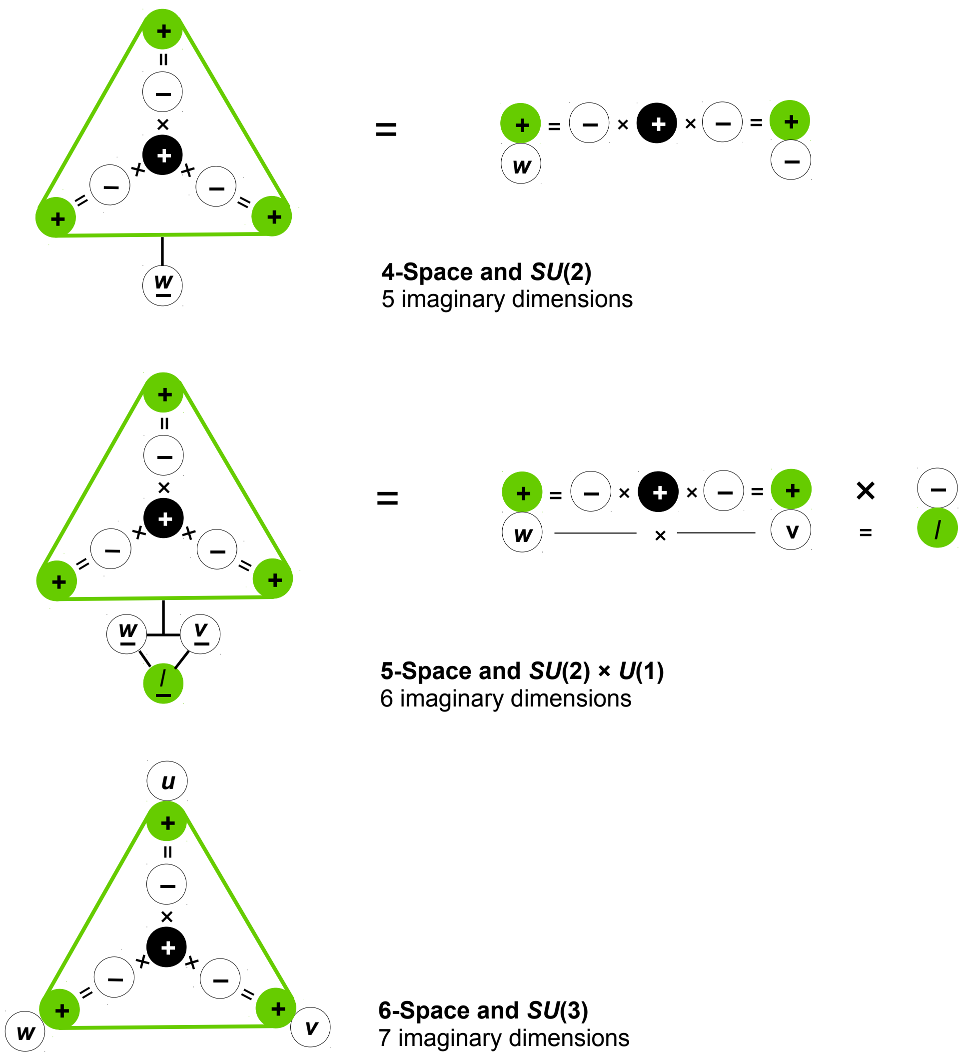

Figure 11: Space and Symmetry

These correlations are of course fully reliant upon the imaginary underpinnings of real 3-space, as described, the intent being to lend credence to the proposal while further substantiating the application of Kaluza's theory to the 5-space. Being locked up within real 3-space, the imaginary dimensions remain unobservable, but their *effects* become apparent at the quantum level – when performing a spin measurement, for instance. Nevertheless, to establish theoretically the imaginary foundations of space would mean forever abandoning the assumption of physicality, which not all will be willing to do.

10. Causal Brane-Worlds and the Wavefunction

While theorists and philosophers grapple with the exponentially bifurcating worlds of the Many Worlds picture or the infinite abundance of the cosmological multiverse, our proposal is rather more modest: a "multiverse" of sorts, but with an important difference. The worlds are causally connected by the wavefunction, so in fact the system is not a "multiverse" at all but a single Universe consisting of superimposed discrete spaces. Just four such interpenetrating spaces can account for known physics. It follows that, contrary to common belief, the physical universe (3+1 spacetime) is *not* a closed system.

Since these other worlds are right here, in and around us, why don't we perceive them? The framework logically requires that the superimposed spaces confine matter while not confining the wavefunction – the wavefunction extends into whatever dimensions are available in each space. String theory offers the D-brane, which confines matter fields while being transparent to gravity. (This is not to imply that the discrete spaces *are* branes, but that the D-brane satisfies the logical requirements of the framework.) It follows that from our perspective in the 3-brane we can never interact materially with the 4-brane or the 5-brane, though we share their gravity (which may be revealing itself as Dark Energy, the repulsive effect being due to the imaginary time dimension $\boldsymbol{t_4}$, hence imaginary energy, being dual to time). The branes reside in a higher-dimensional bulk, with each brane excluding those dimensions beyond its own particular dimensionality. That is, each brane shares the same three real dimensions, but because the imaginary dimensions $\boldsymbol{w}$ and $\boldsymbol{v}$ are excluded from the 3-brane they remain in principle unobservable, as do the imaginary dimensions locked up within our 3-space. Since the logic governing imaginary dimensions is simply the algebra of imaginary numbers, it follows that their existence cannot be ruled out on logical or empirical grounds.

Since only gravity (the geometry of spacetime itself) can propagate freely through and between the branes, we are forced to surmise that the wavefunction is a gravitational wave. This bold idea finds support from various perspectives. Since the wavefunction is the universal precursor to matter, the wavefunction must precede matter – that is, the wavefunction itself is immaterial, incorporeal. Moreover, the wavefunction is a more-than-complex wave, spiraling simultaneously through 3 real and 2 imaginary dimensions. We suggest that only one type of wave could accomplish such a feat, being oscillations of spacetime itself – 5-dimensional gravitational waves. Gravitational waves can be of any frequency and propagate in 3+1 spacetime at speed *c* while adhering to null geodesics. While low-frequency (cosmological) gravitational waves don't interact with matter, high-frequency gravitational waves could conceivably excite energetic fields in our 3-space exhibiting the appropriate harmonics. Here we enter the realm of quantum measurement, which is not addressed in this paper, the focus being the properties of the wavefunction itself, along with the space-time structure required to support it [22].

11. Conclusion

Our proposal seeks to derive a consistent space-time framework, built on the minimum of premises and demonstrated facts, which explains the properties of the wavefunction. It is hoped that this bare logical structure will be examined and enriched by those equipped to put mathematical flesh on its bones.

To briefly review, we erect a spacetime framework supporting quantum nonlocality and retrocausality. We derive a mechanism underpinning the flow of time and provide a logical basis for the Wick rotation. We derive the mass transformation equation according to Special Relativity on the basis of *both quantum mechanical and relativistic principles* while providing a geometrical mechanism for inertia. Hence do Special Relativity and the wavefunction meld together in the 5-space, becoming aspects of an overarching framework, with General Relativity looming in the shadows. We then propose a mechanism by which Kaluza's 4+1 Einstein-Maxwell theory becomes directly applicable to the 5-space, while providing a spatial context for the internal symmetries of the Standard Model.

Thus we submit that the essential logical elements are in place supporting the higher-dimensional reformulation of QM as a consistent quantum theory of gravity and electromagnetism, when applied in conjunction with the "quantum" aspect of QM, being a consistent understanding of quantum fields and measurement in our 3+1 spacetime.

The author is very aware that the framework transgresses long-standing philosophical assumptions within physics. At the same time, physics is at an impasse and we constantly hear the call that "new ideas are needed". So we are faced with a choice: adhere to our philosophical predispositions or follow the logic.

Notes and References

1. Pusey et al. (2012).
2. Leifer (2014) presents a review of psi-ontology theorems.
3. Piacentini et al. (2017). Gao (2018) claims to prove psi-ontology on the basis of protective measurements.
4. Ruebeck et al. (2018).
5. See for instance Giustina et al. (2015) and Hensen et al. (2015). See Maudlin (2014) for a lucid presentation of the context and consequences of Bell's Theorem.
6. Megidish et al. (2011).
7. Jacques et al. (2006).
8. Cramer (1986).
9. Aharonov and Vaidman (2007) provide a review of the TSVF.
10. Aharonov and Vaidman (2007).
11. See Petkov (2007), for instance.
12. See Ellis (2008) for cogent criticism of the Block Universe.
13. Aharonov and Vaidman (2007) write: "The two state vector is the complete description of the system at time t starting from time t_2 and forever," raising intriguing questions surrounding memory.
14. Most contributors to Ney and Albert (2013), but not all, argue that the wavefunction lives in 3N dimensions.
15. Maudlin (2011), pp. 21-23.
16. Maudlin (2011), pp. 180-184.
17. For a philosophical context drawing from ancient cosmology, see Part 2 of Carter (2018).
18. See Wüthrich (2012) for a careful analysis of the problems of presentism in the face of the relativity of simultaneity.
19. Petkov (2007) presents a cogent argument for the world having no less than four dimensions (given the standard assumption that there is only one world).
20. See for instance Wesson (2006). Literature at the Space-Time-Matter website: http://5dstm.org
21. See Carter (2013) for a treatment of consciousness in the context of the framework.
22. See Carter (2012) for a discussion of quantum fields and measurement, along with an original perspective on String Theory, in the context of the framework.

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