A Derivation of Space and Time

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Abstract. Four simple postulates are presented, from which we derive a (3+1)-dimensional structure, interpreted as ordinary space and time. We then derive further properties of space: isotropy and homogeneity; a rapid expansion within the first instant of time (i.e. inflation); and a continual and uniform expansionary pressure, due to a continual influx of (*non*-zero-point) energy that is uniformly distributed (i.e. dark energy). In addition, the time dimension is shown to have an "arrow". These results suggest that the four postulates may be fundamental to the construction of the physical universe.

Contents

1 Introduction

Systems that are based on information typically contain a basic information *element* and a basic information *structure*. In Biological systems, for example, the basic information element is the nucleotide molecule, and the basic information structure is a *sequence* of nucleotides (e.g. a codon, or a gene). Likewise, for computer systems the basic information element is the bit, and the basic information structure is a sequence of bits (e.g. an 8-bit byte). And in natural language the basic information element is the letter or phoneme, and the basic information structure is a sequence of letters or phonemes (e.g. a word or a sentence).

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Such systems must also have a way of translating or computing the information elements and structures into meaningful output. In biology this is accomplished by the operations of ribosomes, enzymes, etc., acting on the nucleotide strings. For computers, the operations of logic gates on the bit strings typically perform this function. And in natural language the operations of lexical analysis, parsing, and context translate a string of letters/phonemes into meaning.

Similarly, if the *physical universe* is based on information (as many have speculated, e.g. [1], [2], [3]), then the following questions arise: (a) What is the basic information element for this system?; (b) what is the basic information structure for the system?; and (c) how are these elements and structures translated (or computed) into the meaningful output that we call the physical universe?

In answer to questions (a) and (b) above, I propose the following two postulates:

1. For creation of the physical universe, the basic information element is a type of *projection* --- more specifically, *a projection from a prior level*.
2. The basic information structure is a *sequence* of such projections.

With respect to the first postulate, we may refer to both projections and levels as "elements" (or *basic* elements) of the system, but will reserve the term "basic *information* element" for the projections alone.

We now add two more postulates:

3. Each such projection is a *one*-dimensional *vector*, constituting a *different*, but related, one-dimensional space. (The basic relations between these projections/vectors are stated in the next postulate.)
4. Prior things (e.g. projections, levels, and constructions from them) are *independent* of subsequent things; and, conversely, subsequent things are *dependent* on prior things. (The terms prior, subsequent, dependent, and independent denote here *logical/ontological* relations. See e.g. [4].)

In [5], I use these four postulates (and two additional ones) to develop a model for the basic construction of the physical universe --- including the construction of ordinary space and time themselves, the fundamental particles and interactions, etc. In the present paper, however, we will (for the sake of brevity) focus simply on constructing ordinary space and time, and their basic properties. That is, using the four postulates above, we will:

- derive a (3+1)-dimensional structure, interpreted as ordinary space and time
- show that the derived 3-dimensional space is isotropic and homogeneous, and that the time dimension has an "arrow"
- show that space undergoes a rapid expansion within the first instant of time (i.e. inflation)
- show that space undergoes a continual and uniform expansionary pressure, due to a continual influx of (*non*-zero-point) energy that is uniformly distributed (i.e. dark energy).

With respect to question (c) above, it will be shown that a method for translating sequences of projections into physical meaning is by taking into account the *relations* between projections --- specifically, their dependence and independence relations (i.e. postulate 4). Once obtained, the above (bulleted) results can then be said to support the proposition that *the four stated postulates are fundamental to the construction of the physical universe*.

From now on, we will often refer to the model for constructing the ***p***hysical universe, developed herein, as *system P*.

2 Levels, projections, and relations: the structure and basic properties of system P

To construct our model for the physical universe (i.e. system P), we must begin with a *state* at which the things of the universe do not exist (otherwise our construction would be circular), i.e. a state that is absent the energy, elementary particles, and even space and time, as we know them. We will call this state *level 0 of system P*, or just *level 0*. We do not, however, presume that level 0 is a state of nothingness, or that nothing exists at level 0. We merely claim that nothing that comes into being with the construction of the physical universe exists at level 0; for level 0 is by definition a state that is immediately *prior* to the construction of the physical universe.

Recalling our first three postulates, we say that a projection from level 0, to be denoted as $\mathbf{p}_0$, generates a *new* state, which we call *level 1*. Likewise, a projection from level 1, denoted as $\mathbf{p}_1$, generates another new state, which we call *level 2*. And a projection from level 2, denoted as $\mathbf{p}_2$, yields *level 3*; and so on. So, in general, the projection $\mathbf{p}_k$ represents a sort of *displacement* from level k that generates level $k + 1$ (for $k = 0, 1, 2, \ldots$); thus, relative to each other, level k is *prior*, and level $k + 1$ is *subsequent*; also, relative to each other, $\mathbf{p}_k$ is prior, and $\mathbf{p}_{k+1}$ is subsequent. (Again, the terms "prior" and "subsequent" refer to logical/ontological priority and subsequence.)

In Fig. 1, where levels are represented by horizontal lines, and projections are represented by vertical arrows from a prior level to the next subsequent level, we illustrate the construction of levels 1 through 3 via the projections $\mathbf{p}_0$, $\mathbf{p}_1$, and $\mathbf{p}_2$. To the right of each level in Fig. 1 is shown the sequence of projections that is required to construct that level (the round brackets indicate a sequence, as is common in mathematics). Thus, the sequences of projections that are required to create levels 0, 1, 2, and 3 are ( ), $(\mathbf{p}_0)$, $(\mathbf{p}_0, \mathbf{p}_1)$, and $(\mathbf{p}_0, \mathbf{p}_1, \mathbf{p}_2)$, respectively; moreover, the latter sequence constructs *all* of the levels (above level 0) in Fig. 1.

As just described, the *order* of construction in system P starts with level 0 at the bottom of Fig. 1 and proceeds in the upward direction. Thus, level 0 is *prior* to all other elements (levels or projections) in system P, and *subsequent* to none; $\mathbf{p}_0$ is subsequent to level 0, but prior to level 1, $\mathbf{p}_1$, level 2, etc.; and so on. So, in general, a given element x in system P is subsequent to everything below it in Fig. 1, but prior to everything above it. By postulate 4, this means that element x is *dependent* on everything below it in the Figure, but *independent* of everything above it. Thus, for example, level 0 is independent of all other elements in system P, and dependent on none.

Since level 0 is our *starting point* (or starting *state*) for constructing system P, then we must say that it is a *nonconstructed* element of that system, whereas the subsequent projections and levels ($\mathbf{p}_0$, level 1, $\mathbf{p}_1$, level 2, etc.) are *constructed* elements of system P. So anything subsequent to level 0 is a *constructed* entity of the system.

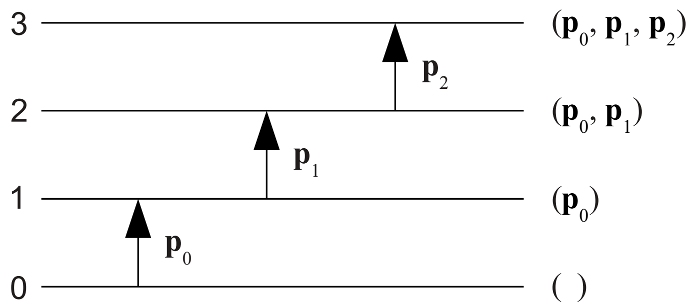

Fig. 1 Construction of levels 1 through 3 of system P via the projection sequence ($\mathbf{p}_0$, $\mathbf{p}_1$, $\mathbf{p}_2$). The projection sequence that is required to construct a given level is shown to the right of that level.

2.1 Some properties of system P

Let x be a thing of system P (e.g. x is a level, a set of one or more projections, or something constructed from them). By postulate 4, things that are subsequent to x are (logically/ontologically) *dependent* on x. Such dependence implies that x is **in effect**, effective, operative, or **operant** at those subsequent things; or, alternatively, we say that those subsequent/dependent things are *within the* **scope** *of* x. Conversely, since things that are *prior* to x are *independent* of it, we say that x is *not* in effect or operant at those prior things; or, alternatively, we say that those prior/independent things are *not* within the scope of x. All of this is summarized in what will be called the **scope rule** for system P, stated as follows:

> A given thing in system P is in effect/operant at (i.e. contains within its scope) those things which are *subsequent*, and is not in effect at (does not contain within its scope) those things which are *prior*.

From this we may deduce the following corollary to the scope rule:

> A given *element* in system P (i.e. a projection or level) is in effect/operant at (contains within its scope) those elements that are *above* it in Fig. 1, and is not in effect at (does not contain within its scope) those elements that are *below* it in Fig. 1.

Thus, for example, since all of the *constructed* elements of system P (i.e. $\mathbf{p}_0$, level 1, $\mathbf{p}_1$, level 2, etc.) are subsequent to level 0 (or, conversely, level 0 is prior to them), then level 0 is in effect/operant at all of those things; or, all of those things are within the scope of level 0. Likewise, $\mathbf{p}_1$, level 2, $\mathbf{p}_2$, and level 3 are within the scope of level 1; but level 0 is *not* within the scope of level 1. And so on.

Since $\mathbf{p}_k$ is *not* in effect at level k, but *is* in effect at level $k + 1$, then level $k + 1$ represents the *state* at which the projection $\mathbf{p}_k$ first comes into effect; by the scope rule, $\mathbf{p}_k$ then *stays* in effect for all subsequent levels. Thus, the projection $\mathbf{p}_0$ first comes into effect at level 1, and stays in effect for levels 2 and 3; likewise, $\mathbf{p}_1$ first comes into effect at level 2, and stays in effect for level 3. Let us say that the level at which a projection first comes into effect is its *native level*. Thus, level 1 is the native level for $\mathbf{p}_0$; level 2 is the native level for $\mathbf{p}_1$; and so on. That is, the native level for $\mathbf{p}_k$ is level $k + 1$. Moreover, the concept of native level can be extended to things that are *constructed from* projections; thus, for example, something that is constructed using $\mathbf{p}_0$ and $\mathbf{p}_1$ (and no other projections) is native to level 2, since those two projections are first *jointly* in effect at that level. We note also that the projections that are in effect/operant at a given level are the *same* as the ones that are required to *construct* that level (as described earlier, and as listed in the sequences to the right of each level in Fig. 1).

In constructing the sequence of projections ($\mathbf{p}_0$, $\mathbf{p}_1$, $\mathbf{p}_2$), since any projections that are in effect at level k are also in effect at the subsequent level $k + 1$, then we can think of the latter level as *inheriting* all of the projections that are in effect at the former level. And since this is true of projections, then it is also true of anything that is associated with or constructed from them. This aspect of system P --- whereby that which is in effect at one level (or, if you will, *generation*) is passed on to the next subsequent level (and thus, by extension, to *all* subsequent levels) --- will be called the **inheritance rule**.

3 Constructing space and time in system P

Following postulate 3, let us model each projection as a one-dimensional *vector*; i.e. we model each $\mathbf{p}_k$ ($k = 0, 1, 2$) as a one-dimensional vector going from level k to level $k + 1$. Thus, $\mathbf{p}_0$ is a one-dimensional vector from level 0 to level 1; $\mathbf{p}_1$ is a one-dimensional vector from level 1 to level 2; and so on. These vectors are represented graphically by the vertical arrows in Fig. 1.

Moreover, each $\mathbf{p}_k$ constitutes a *different* one-dimensional space. Though they are different in this respect, the $\mathbf{p}_k$ are nevertheless *related* by the dependence and independence relations that have been postulated and discussed.

3.1 Constructing a (3+1)-dimensional structure at level 2 (and above)

Since $\mathbf{p}_0$ is the only projection in effect at level 1, and since (by postulate 3) it is *one* dimensional, then it is fair to say that system P is *one dimensional* at level 1.

Since both $\mathbf{p}_0$ and $\mathbf{p}_1$ are in effect at level 2, and since (by postulate 3) each of these constitutes a different one-dimensional space, then it might seem --- at first glance --- that system P should be *two* dimensional at level 2. But this would be wrong.

To get the correct dimensionality at level 2, we must take into account the *relations* between $\mathbf{p}_0$ and $\mathbf{p}_1$, as per postulate 4 --- i.e. the fact that $\mathbf{p}_0$ is *independent* of $\mathbf{p}_1$, and that this relation is *asymmetric* ($\mathbf{p}_1$ is *dependent* on $\mathbf{p}_0$). Since $\mathbf{p}_0$ and $\mathbf{p}_1$ are *vectors*, we interpret that these relations imply a kind of (asymmetric) *linear* independence, with the following property: from the perspective of $\mathbf{p}_1$, the vector $\mathbf{p}_0$ may be collinear with $\mathbf{p}_1$, but is also free to be *noncollinear* with $\mathbf{p}_1$. With these considerations in mind, we ask the question: What is the *direction* of $\mathbf{p}_0$ with respect to $\mathbf{p}_1$? Or, in other words, how does $\mathbf{p}_0$ "look" relative to $\mathbf{p}_1$?

Since $\mathbf{p}_0$ may be both collinear and noncollinear with $\mathbf{p}_1$ (from the latter's perspective), then $\mathbf{p}_0$ may have a component parallel to $\mathbf{p}_1$, and may also have a component *perpendicular/orthogonal* (i.e. at 90 degrees) to $\mathbf{p}_1$. But, by symmetry, the perpendicular component can be anywhere in a two-dimensional *plane* orthogonal to $\mathbf{p}_1$. The two dimensions of this orthogonal plane, plus the one dimension parallel to $\mathbf{p}_1$, makes three dimensions. Thus, from the viewpoint of $\mathbf{p}_1$ (and from the perspective of level 2), $\mathbf{p}_0$ has *three* dimensions; i.e. $\mathbf{p}_0$ constitutes a *three*-dimensional space (whereas, recall that $\mathbf{p}_0$ has only one dimension at level 1). We might say, therefore, that the view of $\mathbf{p}_0$ from the perspective of $\mathbf{p}_1$ "bootstraps" the former from a one-dimensional vector into a three-dimensional space.

In summary, to construct its interpretation of $\mathbf{p}_0$, we can think of $\mathbf{p}_1$ as applying postulates 3 and 4 in succession: first, by postulate 3, $\mathbf{p}_0$ is a one-dimensional vector; second, by postulate 4, $\mathbf{p}_0$ is independent of $\mathbf{p}_1$ --- which allows the former to have a component that is orthogonal to $\mathbf{p}_1$, with the result that $\mathbf{p}_1$ sees $\mathbf{p}_0$ as three dimensional.

Conversely, we can ask, how does $\mathbf{p}_1$ "look" relative to $\mathbf{p}_0$? Since $\mathbf{p}_1$ is *dependent* on $\mathbf{p}_0$, then the former is *not* free to have a component that is orthogonal to the latter, and so $\mathbf{p}_0$ sees $\mathbf{p}_1$ as being collinear; or, more simply, $\mathbf{p}_0$ sees $\mathbf{p}_1$ strictly as per postulate 3: as a *one*-dimensional vector.

So, at level 2 we have the three dimensions of $\mathbf{p}_0$, plus the one dimension of $\mathbf{p}_1$, for a total of *four* dimensions. Since system P is a model for constructing the physical universe, we interpret that the three dimensions of $\mathbf{p}_0$ are just the three dimensions of *ordinary space*, and the one dimension of $\mathbf{p}_1$ is the dimension of *time*; thereby yielding at level 2 the signature 3+1 space and time dimensions of our experience. The dimension of time, therefore, being a consequence of $\mathbf{p}_1$ (and $\mathbf{p}_0$), does not exist at levels 0 and 1, but only comes into existence at level 2; likewise, since ordinary, three-dimensional space is a consequence of $\mathbf{p}_0$ and $\mathbf{p}_1$, it also does not exist at levels 0 and 1, but only comes into existence at level 2.

Note that, although $\mathbf{p}_0$ itself is independent of $\mathbf{p}_1$, the triple dimensionality of $\mathbf{p}_0$ at level 2 is *not* independent of $\mathbf{p}_1$. That is, in the process described above, $\mathbf{p}_0$ only manifests as *three* dimensional when it is related to, or juxtaposed with, $\mathbf{p}_1$. Thus, the triple dimensionality of $\mathbf{p}_0$ at level 2 (i.e. the triple dimensionality of ordinary space) is in fact *dependent* on $\mathbf{p}_1$. Conversely, both $\mathbf{p}_0$ and $\mathbf{p}_1$ are *prior* to, and thus independent of, ordinary space.

We have shown, among other things, that $\mathbf{p}_0$ manifests differently at levels 1 and 2. At level 1 it is *one* dimensional. But when juxtaposed with $\mathbf{p}_1$ at level 2 it manifests as a *three*-dimensional space. Note that $\mathbf{p}_0$ itself does not change from level to level: it represents a projection from level 0 to level 1 wherever it appears (i.e. wherever it is in effect). This is analogous to e.g. the G nucleotide in biology, which is always the same molecule wherever it appears, but yields a different output (i.e. amino acid) depending on what other nucleotides/letters it is juxtaposed with in a sequence. In other words, like the letter G in a DNA sequence, the *meaning* of $\mathbf{p}_0$ is context dependent; which is just what we might expect for an element of a *language*, thus supporting our earlier notion that the basis of the physical universe is, to some degree at least, informational in nature.

We might say that level 2 has *two* dimensions as *input* (one dimension for $\mathbf{p}_0$, plus one for $\mathbf{p}_1$), but has *four* dimensions as *output* --- three for $\mathbf{p}_0$, and one for $\mathbf{p}_1$. Which brings us back to question (c) in the introduction: How are the basic information elements of the model (which at level 2 are the inputs $\mathbf{p}_0$ and $\mathbf{p}_1$) translated (or, if you will, computed) into the meaningful output that we call the physical universe? We now see that at least a partial answer is that the *relations* between prior and subsequent elements are what translate them into meaningful output. In the present case, the independence relation between $\mathbf{p}_0$ and $\mathbf{p}_1$ at level 2 translates/transforms the manifestation of the former from a one-dimensional entity into a three-dimensional space.

We can thus say that the construction of each space at level 2 requires the participation of an *observer*, in the sense that $\mathbf{p}_1$ "observing" $\mathbf{p}_0$ constructs ordinary, three-dimensional space, and $\mathbf{p}_0$ "observing" $\mathbf{p}_1$ constructs one-dimensional time. With ordinary space *itself* constructed by an observation of sorts, it becomes more plausible that e.g. the *position* of an object *within* ordinary space might also be constructed by some type of observation, as seems to be the case in quantum mechanics (more about that in [5]).

The projections $\mathbf{p}_0$ and $\mathbf{p}_1$ are also operant at *level 3* (as per the scope rule), and the relations between them are the same as at level 2 (i.e. $\mathbf{p}_0$ is independent of $\mathbf{p}_1$, but not the converse). Thus, at level 3 --- as at level 2 --- $\mathbf{p}_0$ will appear to $\mathbf{p}_1$ as a three-dimensional space (i.e. ordinary space), and $\mathbf{p}_1$ will appear to $\mathbf{p}_0$ as a one-dimensional space (i.e. time). In other words, the spaces that exist at level 2 also exist at level 3. Indeed, as per the inheritance rule, we might say that level 3 *inherits* these spaces from level 2; or, more precisely, level 3 inherits $\mathbf{p}_0$, $\mathbf{p}_1$, and the relations between them from level 2, and uses them to *construct* ordinary space and time.

3.2 Isotropy and homogeneity of space

Recall that ordinary, three-dimensional space is created when $\mathbf{p}_0$ is viewed from the perspective of $\mathbf{p}_1$. So it follows that (a) the creation/construction of ordinary space is *dependent* on $\mathbf{p}_0$ and $\mathbf{p}_1$; and (b) $\mathbf{p}_0$ and $\mathbf{p}_1$ are *prior to*, and thus (by postulate 4) *independent of*, ordinary space.

Suppose now that an outcome of constructing ordinary space is that $\mathbf{p}_0$ (or $\mathbf{p}_1$) manifests with a particular orientation or direction within that space. Since this would make $\mathbf{p}_0$ (or $\mathbf{p}_1$) functionally dependent on ordinary space, and thus contradict (b) above, we conclude that the construction of ordinary space cannot result in $\mathbf{p}_0$ (or $\mathbf{p}_1$) having a particular direction/orientation within that space. Presumably, then, there is no way for the process that constructs ordinary space to establish a distinctive (i.e. special or preferred) direction within that space. We thus conclude that, as constructed above, ordinary space is perfectly *isotropic*.

Now suppose that an outcome of constructing ordinary space is that $\mathbf{p}_0$ (or $\mathbf{p}_1$) manifests with a particular *position* within that space. This, again, would make $\mathbf{p}_0$ (or $\mathbf{p}_1$) functionally dependent on ordinary space and thereby contradict (b) above; and so we conclude that the construction of ordinary space cannot result in $\mathbf{p}_0$ (or $\mathbf{p}_1$) having a particular position within that space. Presumably, then, the process that constructs ordinary space cannot establish a distinctive (i.e. special or preferred) position within that space. We thus conclude that, as constructed above, ordinary space is perfectly *homogeneous*.

In addition, the construction of ordinary space cannot result in either $\mathbf{p}_0$ or $\mathbf{p}_1$ manifesting as *vectors*, or *vector fields*, within that space; for if they did, then these projections/vectors would be functionally dependent on ordinary space, which would again contradict (b). Given that *vector* fields have been ruled out, it seems we have little choice but to assume that $\mathbf{p}_0$ and $\mathbf{p}_1$ manifest within ordinary space as uniform *scalar* fields --- *uniform*, because any *non*uniformity would make the manifestations of $\mathbf{p}_0$ or $\mathbf{p}_1$ functionally dependent on ordinary space, which would, again, violate/contradict their independence from that space. Presumably, the uniform scalar field for $\mathbf{p}_0$ is just (raw, unstructured) ordinary space itself, and the uniform (one-dimensional) scalar field for $\mathbf{p}_1$ is just proper time.

Lastly, let us recall that $\mathbf{p}_0$ sees $\mathbf{p}_1$ as a one-dimensional *vector*. This, presumably, would impart some *directionality* to $\mathbf{p}_1$ --- which, as we have concluded, could not manifest as a direction within ordinary space. Since $\mathbf{p}_1$ has been associated with *time*, we interpret that this directionality of $\mathbf{p}_1$ (with respect to $\mathbf{p}_0$) is just the "arrow" of time.

3.3 Rapid expansion of space within the first instant of time

Recall that $\mathbf{p}_0$ at level 1 is *one* dimensional --- having, let us say, a length of p_0. The time dimension, being a result of $\mathbf{p}_1$, does not exist at this level/stage. Given that a one-dimensional object has *zero* volume, then the physical universe at this stage of development has a volume of zero.

Since the time dimension comes into existence with the projection $\mathbf{p}_1$, then the *advent* of $\mathbf{p}_1$ defines the time point $t = 0$, at which point p_0 has the value $p_0(t = 0)$, which may be denoted as $p_{0,0}$. So, at exactly $t = 0$, or within the first instant after it, the existence/perspective of $\mathbf{p}_1$ causes $\mathbf{p}_0$ to manifest as *three*-dimensional ordinary space, with a volume on the order of $p_{0,0}^3$. Thus the volume of ordinary space goes from zero to around $p_{0,0}^3$ within a time interval of zero, or near-zero, length --- which constitutes a potentially very large, perhaps infinite, rate of spatial expansion. I propose, therefore, that this rapid spatial expansion, triggered by the advent of $\mathbf{p}_1$ at $t = 0$, is the process known as *inflation* [6].

Note that, under the above mechanism, inflation has a natural beginning: the advent of $\mathbf{p}_1$ at $t = 0$. And it also has a natural *ending*: it ends when the volume of ordinary space is around $p_{0,0}^3$. So inflation only lasts for the time (if any) that it takes (from the perspective of $\mathbf{p}_1$) for the *one*-dimensional space of length $p_{0,0}$ to become the *three*-dimensional space of approximate volume $p_{0,0}^3$.

3.4 A continual influx of energy associated with $\mathbf{p}_0$, yielding a continual and uniform expansionary pressure on space

In constructing the sequence ($\mathbf{p}_0$, $\mathbf{p}_1$, $\mathbf{p}_2$) for system P, let us assume that *energy* is needed to create each of the projections $\mathbf{p}_k$ (for $k = 0, 1, 2$). We can think of this energy as being stored along the length of $\mathbf{p}_k$, and/or as being stored in the *level* that is created by $\mathbf{p}_k$. So we can speak of "$\mathbf{p}_k$ energy", and/or we can speak of the energy, E_{k+1}, that $\mathbf{p}_k$ inputs into level k+1. Thus, $\mathbf{p}_0$ is a *process* through which energy E_1 is input into level 1 of system P. Likewise, $\mathbf{p}_1$ is a process that inputs energy E_2 into level 2; and $\mathbf{p}_2$ is a process that inputs energy E_3 into level 3. The total energy, E_t, that is input into system P is therefore $E_t = E_1 + E_2 + E_3$. We assume that all of these energies are nonzero and positive, so the energy of system P at level 1 and above, due to contributions from the sources mentioned, is positive.

Now recall that the dimension of time is associated with $\mathbf{p}_1$. Since $\mathbf{p}_1$ does not exist at levels 0 and 1, then time also does not exist there; i.e. all time intervals are zero at those levels. Indeed, we can say that levels 0 and 1 are *independent of time*. But $\mathbf{p}_1$ *does* exist at level 2 and above; so time exists there, and *all* time intervals at those levels are *nonzero* (and presumably positive).

Thus, at level 1, energy is nonzero, but time is zero. At level 2 (and above), however, both energy and time (intervals) are *nonzero*. Consequently, at level 2 and above, the *product* of energy and time --- the quantity known as *action* --- is nonzero, and thus has a positive lower bound; i.e. at level 2 (and above) the action is *quantized*. We thus have the derivation of an action *quantum*, which we interpret to be the basis for the empirically-known "quantum of action", commonly referred to as *Planck's constant*, and denoted as h.

In the present model, therefore, the quantum of action, h, depends on both $\mathbf{p}_0$ and $\mathbf{p}_1$, and so does not exist at levels 0 and 1, but only comes into being at level 2. Thus, quantum mechanics, which is based on h, also comes into being at level 2 of system P. And therefore, due to the scope rule, both h and quantum mechanics are operant at level 2 and above; i.e. they are *native* to level 2.

The presence of h at levels 2 and 3 can, and we assume *does*, partition the energies E_2 and E_3 into a multiplicity of smaller chunks, yielding *many* objects/particles at those levels. The *absence* of h at level 1, however, means that the energy E_1 *cannot* be broken into chunks; and so the energy E_1 at level 1 constitutes a *single*, continuous entity. In addition, given that time exists at levels 2 and 3, we assume (as per special relativity) that the particles at those levels possess *mass*; and, given that time does *not* exist at level 1, we assume that the single entity at level 1 is *massless*. Furthermore, in [5] it is shown that the objects at level 3 have *internal* structure, whereas the objects at level 2 are *structureless*. These results lead us to identify the level-3 objects as *baryons*, and the level-2 objects as *leptons*. Moreover, since time exists at levels 2 and 3, then the input of energies (E_2 and E_3) into those levels can be, and we assume *is*, time limited --- yielding a *finite* number of baryons at level 3, and a finite number of leptons at level 2.

Recall now that $\mathbf{p}_0$ is native to level 1, but *time* is native to *level 2*. Thus, $\mathbf{p}_0$ is *prior* to time. By postulate 4, this means that the $\mathbf{p}_0$ process, which pumps energy E_1 into level 1, is *independent of time*, and is therefore a *continual* process --- i.e. it never stops, and so it must be happening right now. Consequently, the quantity E_1 is *always* increasing. Moreover, since E_1 is the energy of $\mathbf{p}_0$ at level 1, and since $\mathbf{p}_0$ (as seen by $\mathbf{p}_1$) *is* ordinary space, then it is clear that E_1 is just the energy of space itself. Hence, an always-increasing E_1 should yield a continual *expansionary* pressure on space. Indeed, an increase in E_1 may produce an increase in the *length* of $\mathbf{p}_0$, and thus an increase in p_0^3 (the size/volume of the physical universe).

Suppose now that the $\mathbf{p}_0$ process distributes its energy E_1 *nonuniformly* within space. This would make that process (and thus $\mathbf{p}_0$ itself) functionally *dependent* on space, and thereby contradict statement (b) in section 3.2. Consequently, the energy E_1 must be distributed *uniformly* throughout space. Since this process is also independent of time, then it is *constant in time*. So the continual influx of E_1 energy into the system via the $\mathbf{p}_0$ process yields an input of energy per unit volume of space that is uniform throughout space, and constant in time; in other words, E_1 yields a *cosmological constant*.

Taken all together, the above results suggest that we interpret E_1 to be the phenomenon known as *dark energy* [7]; i.e.

$$\text{dark energy} = E_1.$$

Moreover, since the $\mathbf{p}_0$ process and E_1 are *level-1* phenomena, but h only becomes operant at *level 2*, then dark energy/E_1 is prior to --- and thus independent of --- h and quantum mechanics, and so is *not* a zero-point energy.

4 Conclusion

A truly fundamental model of the universe must *derive* space and time --- not just take them as given. Firstly, such a model should derive the (3+1)-dimensionality of space and time, and the isotropy and homogeneity of space. Secondly, since inflation and dark energy are likely to be important factors in the construction of space, then the model should also derive them. As shown above, the present model meets these basic criteria, which indicates that the four stated postulates may be fundamental to the construction of the physical universe.

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