Cosmos, Logos and the Limits of Science

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ABSTRACT. Following the introduction of the special and general theories of relativity and development of consequent cosmological models, the extent to which time and space play a starkly abstract role in physics has become more and more apparent. We examine here whether the full force of such abstract characterizations comes ultimately into opposition with the practice of science and imply some hard limitations on the scope of scientific discourse.

Introduction

Time and space have long been recognized as inescapable elements of the framework of human cognition, either in the private domain of making sense, to ourselves, of the phenomenal world, or in the public domain, which begins in shared concepts and ends in the formal inquiries of science. In the latter domain, an examination of the conduct of science itself leads us away from any easily captured, concretized definition of these apparently naïve and immediate ideas and into the austere realms of abstract characterizations. One might assert that, in part, this owes to the ineffably private nature of our experience of time and space, but whatever the truth of this claim, time and space, quantified as duration and extent, remain so to fundamental scientific discourse that they appear in the definitions of other physical concepts, and not the other way around.[1] Much like the notion of a straight line in Euclidean geometry, we seem well able to *use* the notions quite unambiguously in normal public discourse. Hence when our high school physics teacher gravely pronounces that velocity is measured in units of distance divided by time (say, meters per second), we nod with the full confidence that we can indeed speak this language.

When someone from outside of science, such as Kant, or someone from inside science, such as Newton or Einstein, or someone who overtly straddles both worlds, such as Whitehead, tries to get underneath this intuitive agreement implicit in our altogether consonant use of language, it is then that myriad difficulties arise. Although we shall cite a few specifics below—this is no place for any substantive historical review—suffice it to say that attempts at the entification of time and space have suffered from both philosophical and scientific defects, leaving us with, at best, an analysis of how these concepts are used in science. In this note, we shall begin with a look at one particular cogent abstract characterization of time given by Lindsay and Margenau and argue for its extension to time-space by virtue of the very framework of current cosmological theories. Our goal, then, is to examine the *completeness* of science in light of this characterization. Our conclusion is paradoxical: what survives in characterizations of time and space and what science requires of them would seem to point at a lacuna in any description of reality that we would countenance as scientific. This will naturally lead to some speculation on what, if any, supplement to the epistemological principles of science might enlarge our knowledge of the world and its origins.

Objective Time: The Newtonian View

The dual nature of time with regard to its subjective (private, experiential) and objective (public, perspective invariant) aspects has been well remarked upon. (See Fagg, for a beautiful exposition of this duality, including even its relationship to process metaphysics.) In our present discussion of *objective time*, we need only make clear that we mean by this term the latter sense, or the sense in which it is used—with whatever latent ambiguity—in science.

Of course, the most natural way both linguistically and epistemologically to legitimate the attribute of objectivity is to associate it with an object: something of independent existence automatically carries some essential perspective invariance. In this light, Isaac Newton's famous ontological move to characterizing (objective) time as something that "flows equably without relation to anything external" is certainly a natural one. Many, indeed, have lamented the insufficiency of this characterization (see, for instance, Harrison), which goes to the practice of physics—or even the conduct of civilization—insofar as no objective use of the term can be detached from spatial events. Still, it seems worth noting what Newton might have intended in associating time with something akin to the uniform unthreading of an endless spool that proceeds independently of any event in the material universe. We would suggest that it provides three key features beyond the epistemological comfort of objectification indicated above:

1. The most obvious and yet ultimately subtle aspect of the metaphor is the chain of associations from a linear flow, to a geometric line, to the real line, which is to say the real numbers. The obvious element here is that Newton, the transcendent mathematician, was using time in connection with the newly emerging mathematical processes associated with calculus.[2] The subtlety—and this in ways that Newton was two centuries too early to understand—lay in the topological properties of the real numbers that calculus assumes. This is perhaps the most technically sophisticated feature of the metaphor.

2. The metaphor also speaks to a much more basic feature of the real numbers: they admit a linear ordering that is compatible with their arithmetic properties. All we need say about this here is that given any two real numbers x and y, the following well known trichotomy holds: either $x < y$, $x = y$ or $x > y$. The point here is that real numbers in their linear ordering reflect an even more basic notion of time as constituted relations of precedence, simultaneity and succession.

3. Finally, Newton's ascription of complete independence of pure time from any physical event or instrumentation seems to imply both universality and non-locality. In its way, this supplements and extends the previous point insofar as it renders absolute the three relations among events in precisely the way that the theory of special relativity will subsequently deny. Perhaps—and we

have, of course, no way of knowing this—Newton sought here also to encode something of the subjective nature of time: our own interior sense, especially taken without regard for our current understanding of the raw physics of neurology, seems capable of sensing the passage of time independently of any physical events.

Thus one must admit that the Newtonian view of time, despite its ultimate failure to provide an adequate objective characterization, is insightful, both mathematically and philosophically.

Moving forward across roughly three centuries of mathematics, physics and philosophy, it is, in my view, fair to say that very little of the Newtonian account of objective time survives. Time as object seems to have been completely rejected vis-à-vis time as relation. The reconciliation of subjective time with objective time is hardly imminent and would seem to many to implicate the whole mind-body problem. Time as a relation of precedence is now thoroughly relativized, and indeed temporal properties are now regarded as inextricable from spatiotemporal properties.[3] What then remains of Newtonian time? Perhaps only its most abstract feature, as identified somewhat vaguely in the first point above. We need a clearer statement of this feature before proceeding further.

Objective Time: The Parametric View

Philosophers who wish to say something substantive about objective time are very much akin to psychologists who want to say something objective about the mind. The latter group, at least for a while, took comfort in the approach known as *behaviorism*, which completely bypasses the problems of essential subjectivity and ontological posits. The analogous approach for the former group has been given a very articulate voice by Robert Bruce Lindsay and Henry Margenau in *Foundations of Physics* (see especially Chapters II and X.) We shall now briefly review their position, which we shall accordingly call *the parametric view of time*.

Lindsay and Margenau certainly acknowledge that temporal measurements cannot be divorced from spatial events, and thus even consider the possibility of the elimination of time from the foundations of physics. Measured time, which is the only clear meaning of objective time in physics, is thus a sort of convenience in describing the world that ultimately refers to mechanical, celestial, or even atomic devices and observations. Such devices and observations thus provide an index for a parameter t that subsequently occurs as an independent parameter in physical models. Thus time as in fact used in the discourse of physics is no more than a formal parameter that occurs in classical expressions such as

$$p = m\frac{ds}{dt}$$

(the definition of momentum as the product of mass and velocity). Now in the very formation of this and associated abstract expressions, the physicist has made some assumptions about the mathematical and specifically topological nature of the space in which the parameter t resides along the lines suggested above (and so too for the implicit spatial parameters). In tying such expressions to reality via observations, the abstract parameter *t* must be assumed to correspond to some sequence of presumably regular events. Of course, such regularity is only possible to assert in terms of a complicated and implicit set of relations that operate in reciprocity with the laws which in fact make appeal to *t*. The point is that even if there were a Newtonian master clock for the universe, its uniformity could never be confirmed, just as nothing within a digital computer can detect an irregularity in its system clock.

To summarize, the parametric view of time identifies objective time with a parameter that occurs in certain physically descriptive forms of mathematical abstraction. Its observational correlates are nothing more than systems of events which we postulate as indicative of this parameter. The aptness of a physical theory involves a sort of coherence or reciprocity that holds between its non-temporal referents and its clocks. Beyond that, we dare not go. In particular, physical time is not something given by the world: there is no spool, and time, even as a formalization of precedence, does not adhere to the world as a whole.

Extension of the Parametric View to Space

While it seems impossible to dissociate objective time from events and hence from space, we can and do, at least in the abstract, sometimes dissociate space from time, as in the case of the state vector of a classical mechanical system. To this extent, space seems more given. Notice, for instance, that metaphysical discussions of space are far less likely to introduce a distinction between its subjective and objective aspects. Indeed, prior to the theory of general relativity, one might have felt that clear analogs of the three attributes that Newton implicitly ascribed to time (i.e., topology, spatial relationality, and homogeneity) presented hardly any problems. Following the introduction of general theory, some of this needed a fresh look (homogeneity certainly), but nonetheless, it is fair to say that at first blush, relativity was kinder to our basic sense of space than it was to time.

In *The Principle of Relativity with Applications to Physical Science* (1922) Alfred North Whitehead identified a foundational problem with a theory of gravity based on the dependency of the space-time metric on mass distribution. Whitehead summarizes and concludes his misgivings as follows: "[W]e could not say how far the image of a luminous object lies behind a looking–glass without knowing [in advance] what is actually behind that looking-glass." (p. 83) His point goes to an implicit circularity lurking in the relationship between metric and mass: The very notion of a mass distribution presupposes the possibility of uniform spatial measurements without reference to the mass properties of the body or bodies in question. Yet in Einstein's system, the *a priori* dependence of such measurement on the very distribution in question seems to render this impossible; hence the circularity.

While I am unaware of any explicit response to Whitehead's criticism, the conduct of physics and especially cosmology in the twentieth century tells the tale, and it is somewhat reminiscent of the response of physics to the metaphysical problems of time or the response of mathematics to the epistemological hornet's nest in its foundations that culminated in Gödel's limitative theorems: "This is all very interesting, but we have work to do!" The point is, that we may, in the spirit of Lindsay and Margenau, simply look at what happened to see what may be seen and to say what may be said.[4]

It is an old story that general relativity had immediate implications for cosmology and that we have been chasing down those implications for nearly a century now. What is most important for the development of our present thesis relates to the notion of an expanding universe, and how, in particular, one makes sense of the notion of distance in light of this expansion. To explain this, we look at the following highly simplified picture of a universe of only two spatial dimensions, with attendant coordinate system and two objects, *A* and *B*, in that universe.

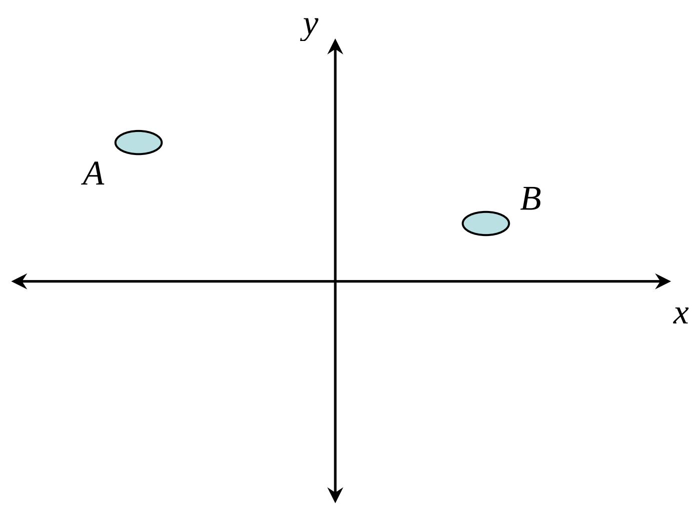

Figure 1.

In the classical view, to know the coordinates of both objects is to know the distance between them, essentially by the Pythagorean theorem. In other words, that distance is intrinsic to nothing more than the standard coordinate system. But suppose now that Figure 1 represents an expanding universe. We have two ways to interpret the situation. One is to say that the coordinates themselves are changing to reflect the expansion. The other is to leave the coordinate system intact, but to declare that the physical distance between *A* and *B* is now given by some expression involving new parameters that are attached to the world, but extrinsic to the coordinate system. In this case, to know the coordinates of both objects is *not* to know the distance between. The very notion of a coordinate system has become more abstract insofar as it has become dissociated from distance. This is in fact the view of modern cosmology. One speaks of a fixed grid, the so-called *comoving frame with comoving distances*, with respect to which the objects of the universe may be assigned coordinates. But these coordinates no longer encode physical distance, which requires a fresh bouquet of new parameters introduced by the theory of general relativity. The expansion of the universe is seen in the increasing physical distances between cosmological objects, while in a more abstract sense, these objects hold their positions (except for their local velocities) in the comoving frame. (See, for instance, Dodelson, Chapter 2.)

The upshot of these considerations is that the accustomed spatial parameters (i.e., our familiar *x*, *y* and *z* coordinates) which we learn to plot as distances from axes or planes in high school have suffered a fate similar to that of time: their naïve characterization as placement in space in a sense both defined by and defining distance has been replaced by something far more abstract. We should then like to say, that space, like time, must succumb to the parametric view: spatial coordinates as well simply occur as parameters in certain physically descriptive forms of mathematical abstraction, and its observational correlates likewise constitute part of complex system which we postulate as indicative of these parameters. In particular, global positions are not something given by the world: there is no fixed objective physical spatial framework, inertial or otherwise.[5]

Where Does This Leave Us?

So, if a kind of behaviorist deconstruction of time, space and space-time leads us away from the physical world as given and toward the realm of useful formalisms, what remains? This is exactly the spirit of Whitehead's deconstruction of cognitive discourse in reaching the key tenets of process metaphysics. Let us abstract and model just two features of his theory, using as little technical jargon as possible:

1. The actual entities of the world are completed events that consist of a binding of attributes and feelings in the fundamental process called concrescence. Some chains of such events cohere into hierarchical structures in a part-whole relationship. These are called *societies*.

2. The largest conceivable context or domain for such societies is the *extensive continuum*, the "ultimate vast society [that] constitutes the whole environment in which our cosmic epoch is set, so far as systematic characteristics are discernable by us in our present stage of development." (*Process and Reality*, p. 97) Moreover, the extensive continuum is in its way the first specification of the structure of the world beyond the metaphysical constraints imposed by logic insofar as the subsequent evolution of the world is genetically constrained by this primary coalescence.[6] (See *PR*, Chapter II.)

One is immediately struck here by the affinity of this picture with the account given by the standard cosmological model of the first moments of the universe, during which the fundamental forces and particles evolved (Coles, p. 113). This remains astonishing even in light of the full title of Whitehead's treatise, which is, in fact, *Process and Reality*: *An Essay in Cosmology*. Furthermore, it indicates, again in accord with a good deal of current cosmological thought, that the concepts of physics cannot reach beneath or behind this primary coalescence. In the balance of this paper, I will attempt to illustrate and speculate upon this idea.

Dissolving and Reconstructing Space-time: GAZ Worlds

What would a world without spatiotemporal organization look like? To a small extent the arts can help us here: a simple painting suggests space without time; music suggests time without space. How can we imagine a world with neither? We need a metaphor.

Following Whitehead and reducing his metaphysics to the simplest case, let us imagine a world that consists of the bundling of two possible attributes. Figure 2, when properly understood, is one possibility.

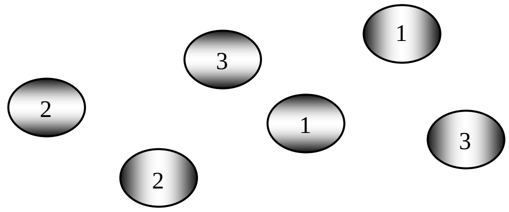

Figure 2.

This figure must be viewed through a very dark filter of abstraction. We must throw away all of the information except that there are six instances for which two attributes are bound to single entities or occasions. We retain the notion of distinctness: the horizontally shaded object bearing the numeral 2 at the far left is distinct from the vertically shaded object bearing the numeral 3 at the far right—*but not by virtue of position*. Hence one can imagine the example being described orally, in which case the advisory above might go as follows: the instance described as being horizontally shaded and bearing the numeral 2 announced first is distinct from the one described as vertically shaded and bearing the numeral 3 announced last—*but not by virtue of its position in the (temporal) sequence*. Notice that the collection is in fact constructed so that there are no repetitions of any one combination of label and shading, so that no other cues for distinctness need be assumed. The point is that the only meaningful statements we are allowed to make about this figure involve the binding of one of two shading patterns with one of three numerical labels.

How does Figure 2 serve as any sort of metaphysical metaphor? Notice that there are three instances of the horizontal shading pattern, each distinguished by a unique label, and a similar statement holds with respect to the vertical shading pattern. In a way, this invites us to make two groupings of our six instances, indexed by shading pattern. We might equally well want to say that there are two instances of the numerical label 1, and a similar statement holds for the labels 2 and 3. Thus we are likewise invited to make three groupings of our six instances, this time indexed by numerical label. Now think of the numerical label as a time stamp. The groupings by shading are thus a metaphor for a persistent single object. What then do we make of shading? It serves to indicate distinctness of what we might call contemporary objects. In a very abstract sense, then, this is a metaphor for space.[7] The real point is that there are two degrees of freedom in the binding of attributes which are reflected in two primary degrees of freedom in the distinction of these instances: the temporal and the spatial. The net result is that we may think of Figure 2 as representing two persistent objects in space.

Let us now consider two variations on Figure 2, the first of which we shall draw (Figure 3). Note the appearance of the diagonal shading pattern. If one interprets the numerical labels as time stamps and the shading pattern as an indicator of one of now three positions, certainly one no longer has a world consisting of separated persistent objects. Moreover, the same can be said under the reverse interpretation of shading and labels. If one insists on a spatiotemporal interpretation of these features, the world will simply not cohere as nicely as the one of Figure 2: objects appear and disappear in a way a little reminiscent of particle physics, but without the conservation laws.

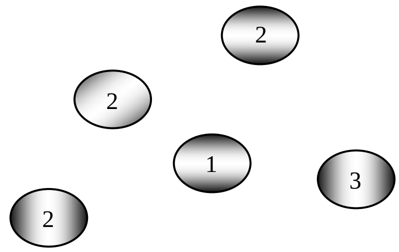

Figure 3.

Our second variation on Figure 2, we shall only imagine: an enormous number of instances of two bound attributes, but now the attributes themselves are drawn from a much larger space. For instance, allow the numerical labels to range without bound and replace the shadings with a rich palette of colors. The point is that we can think of such a picture as the given world and then imagine the possibility or impossibility of imposing a compelling spatiotemporal organization upon it. What would make such an organization compelling? This is a huge question with implications for the entire philosophy of science, but here are the beginnings of a vague, all too general, but possibly still useful and uncontroversial answer:

1. The first point is information theoretic. We would like to be able to say something descriptive of the actual list of binding instances that is much shorter than the list itself. These are indeed the interesting assertions, and this principle applies not only to the glories of actual science in statements such as universal gravitation and Maxwell's equations, but even in the informal language that assumes a substance ontology upon which science is built.

2. The second point is goes to locality, or more generally to topology. Insofar as our efficient descriptive statements might speak of abstract interactions among instances (such and such a configuration implicates such and such a configuration), the organizing principles should recognize some relationship in the various attributes that can count as nearness, both in the sense of space and time. *Moreover, the forms of the descriptive statements would seem even to define the notion of nearness in this context.*

We might add something else to these two, but we must acknowledge that it is much more subtle:

3. The third point goes to asymmetry and causation. Some of the statements describing interactions are asymmetric with respect to at least one of the attributes.

What we have in mind in this last point is apparent: while spatial relations are symmetric, time seems to have at least some asymmetric features and therefore a unique directionality. But is this in fact the case, especially when we speak as scientists and use the objective view of time? Physicists are fond of pointing out that the laws of mechanics work perfectly well with time running backwards, and so, too, in other domains. Yet there is a clear and celebrated case where the world does *not* run backwards, and no subjectivity about it: this is, of course, what is implicitly expressed in the Second Law of thermodynamics.

This then is our quick summary of a world without time and space and how time and space in the abstract might be acquired by doing science with that world. In its way, our metaphor is an extension of the thesis of Lindsay and Margenau applied to the raw data of a Whiteheadian kind of world and taken beyond the real numbers into a more austere topological framework. Time and space here are even less than classical parameters; they have been reduced to adjuncts or features of organizational principles that describe a given world that intrinsically has neither.

Finally, it will be helpful to give a name to the kind of pre-scientific, pre-spatiotemporal world that is suggested by all of this. In a famous phrase in one of his letters, Mozart stated how one of his compositions came to him *gleich alles zusammen*, which might be taken with ear-grinding, word-for-word literality as *in the same moment, all together* or more naturally as *all at once*. The strange ineptness of this phrase in connection with music, which is nothing if not a sequence in time, has mystified, inspired and sent chills down the spines of musicians, musicologists and many of the rest of us now for centuries. With this in mind, let us call the worlds of Figures 2 and 3, and of their imaginary cognates and extensions, *GAZ worlds*.

The Hard Part

There are two related questions for which all of the previous discussion has served as preparation:

1. Grant for the moment that ultimately all that exists in the physical universe is a disjointness of thing-attribute bindings, and that space-time relations and temporality are effective principles of organization, but not given in the primordial structure of things. This suggests the possibility of alternative principles of organization and therefore alternative constructions of space and time. Are such alternatives theoretically or practically accessible to science? If not, can anything that *we* might recognize as science ever reach all the way down and back into the genesis of the cosmos?
2. That any GAZ world admits any organization at all is a matter for wonder. If time is an abstraction, how is it then that it governs even the most approximate coordinated description of physically separated events? This is logos. If the spatiotemporal organization is derivative, what kind of thing could be at its source?

Let us now briefly speculate on the surface of each of these questions.

Can we imagine anything we would recognize as science reaching all the way down to a GAZ world? We should first have to give up on the priority of substances, which I suspect we might manage. We would then see substance as derived from process—as threads of process, so to speak—in some manner at least reminiscent of Whitehead. We should second have to give up on the priority of time and causality, seeing them again as derived principles of organization. To some extent, this is the direction in which the abstraction of objective time and comoving frames take us: time and space as mere parameterization in physical descriptions. But could we go all the way? Here I think the answer must be *no* for reasons that echo well known elements of Kant on epistemology. The objectivity of science, and indeed the very notion of the *physical*, depends on dealing with that which is or may be rendered perspective invariant, but this does not necessarily render science independent of subjectivity.[8] Simple scientific measurements are clearly the residues of particular experiences of particular individuals, but they are residues constructed in such a way to give largely the same results independent of the individual. In this way we learn to read, record, and interpret the results of a given measurement.[9] My point is that the notion of objectivity ultimately assimilates to the notion of *covariance* in a generalized sense, a term I prefer insofar as it de-emphasizes the prejudicial preference of objectivity for objects. Thus any fully shared element of subjectivity (e.g., possible relations between experiences) becomes part of this covariance and hence part of scientific description. In particular, I believe that the subjective view of time that would defeat any full understanding of a GAZ world, including perhaps its directedness, is inherent in science. This conclusion would not be news for Kant, but what would be news for him is that it is science itself, in its own analysis of time, space, cosmology and the structure of scientific theories that is suggesting something beyond its own reach.[10]

Let us turn to the second question. Perhaps the most difficult thing to express about a GAZ world is that its genesis can hardly be talked about. How does a world that admits a spatiotemporal structure that is only derivative take shape? Note that the phrase *take shape* is itself a spatiotemporal usage. We must emphasize this problem because the first and most obvious answer to the question naively conceals gigantic problems in this regard.

That obvious answer is, of course, God. If Mozart could conceive of *Don Giovanni* all at once, why not so, too, for God and the world? But pursue the metaphor: We conjure up our most incandescent and reverent image of Wolfgang Amadeus at his great instantaneous flash of inspiration—the instant of the work's conception. Yet conception and construction are not the same thing. There is a first note and a last note to be written. In connection with God, this will not do. The construction of the world must be atemporal, and this indeed is not the systematic, refining, top-down God of *Genesis*. The point is that it is not at all clear that we would recognize anything of God as an intentional being in the creator of a GAZ world. This is divine inscrutability, indeed, and of an *a priori* kind. This would lead us to a belief that cosmogony is not only beyond science, but also religion. Still, nothing logically rules this possibility out.

Another possibility is related to an extended form of the anthropometric view. A great difficulty with using drawings such as Figures 2 and 3 in connection with metaphysical models is that we then regard these models from the outside, a luxury we do not have in reality. Thus it is possible that the organization of the world, whose source we seek, is already so much a part of *our* organization that that it remains invisible to us. Nagel (1986) in an attempt at reconciling the objective and the subjective views speaks of a "blind spot," and I wonder if something of a more grandiose version of that isn't operating here. If so, science cannot escape an essential tragedy; indeed, it suffers from a self-referential problem similar to that exposed by Gödel in the foundations of mathematics.

Finally, there is a variation or specialization of the anthropometric position that has been in the air for some time, and I must admit I do not know of any name attached to it. The idea is that the preconditions for the world to admit creatures that have any coherent experience and intentional knowledge of their surroundings are so stringent that they can only arise in some sort of genetically structured world. Hence logos becomes a precondition for knowing anything at all, and it is no wonder that we live in a structured world: to ask the question is to have part of the answer. One might want to call this the *tautological hypothesis* for cosmology.

I haven't spent much time on these three alternatives because I do not like the look of any of them. In a sense all three—and this is perhaps surprising in the case of the first—drain all the subjectivity out of the world and then ask for an explanation of what is left. Indeed, this is a brief attempt to extrapolate the epistemological stance of science to its limits. But what are the alternatives?

At the top of this section, in introducing the first of the two questions, I led with the hypothesis that all that exists in the physical universe is a disjointness of thing-attribute bindings. The qualification of the term *universe* as *physical* is important. One might contrariwise accept Whitehead's assertion that the universe, without qualification, also admits feelings. In this light, the argument I have been sketching serves as a template for a possible *reductio*, the upshot of which is that science as an exercise in full objectivity will be incomplete, and not only in the obvious sense that it will have nothing to say about the phenomenological features of reality. No, plausibly this incompleteness must also extend into what science would like to claim as part of its proper domain of discourse, namely the genesis of the physical universe. I see this, in its own way, as the cosmological analog of the mind-body problem.

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Endnotes

[1] Indeed, almost any freshman physics book will address the fundamental *dimensions* of physics: duration, length and mass. The first two, of course, answer to time and space. The latter constitutes an independent dimension, but note that insofar as the measurement of mass is linked to the measurement of acceleration, a logical connection remains.

[2] Newton co-invented the business of taking derivatives, hence limits, with respect to time. See, for instance, the definition of momentum given below.

[3] Ironically, in making relations of precedence relative to an observers frame, special relativity pulls us essentially away from an objective view of time but realizes something of an objective view of space-time.

[4] In this connection, I am reminded of something I learned from my complex analysis teacher, the celebrated mathematician Lipman Bers. Prof. Bers decried the assertion that the complex numbers were invented because, "Men wanted to solve the equation $x^2=-1$," and not only for its blatant sexism! He taught instead that in solving higher order equations, radicals of negative numbers sometimes appeared in the manipulations, and if one carried them through with the ordinary rules of algebra and was fortunate enough to have occasion to square them out, one indeed obtained valid solutions. The metaphysics of such expressions were then left for subsequent centuries and generations.

[5] The notion of time as an abstract parameter has also been strengthened by general relativity and modern cosmology in a way that perhaps Lindsay and Margenau did not recognize or anticipate. In the development of the general geodesic equation, one replaces local time with a monotonically increasing parameter which in turn is given its own abstract definition in terms of an energy momentum vector. Again see Dodelson, Chapter 2.

[6] The statement given here is sufficient to our purposes, but more technically Whitehead is referring to the constraints imposed by the logical structure of his eternal objects.

[7] In this development, time seems metaphorically more natural than space, but one might well develop it with space first, in which case perhaps space will seem more natural than time.

[8] Nagel is most enlightening on the relations among objects, objectivity and perspective invariance.

[9] This is something of a different point than Granville Henry and I made about the nature of scientific measurement in our paper from 1997. There we argued in Whiteheadian terms about the mode of perception appropriate to scientific measurements. These assertions, while distinct, are not incompatible.

[10] A related point haunts me in this connection. Once a community or even a single sentient creature accepts a particular time-space worldview considered as one of many possibilities that might fulfill the abstract functionality of time and space, can a competing worldview ever get a look-in? Could there be things happening in the world that are at right angles to such a worldview, mere causal noise? We are perhaps reminded that *Tao called Tao is not Tao.*