A physics-based metaphysics is a metaphysics-based metaphysics

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Abstract: The common practice of advancing arguments based on current physics in support of metaphysical conclusions has been criticized on the grounds that current physics may well be wrong. A further criticism is leveled here: current physics itself depends on metaphysical assumptions, so arguing from current physics is in fact arguing from yet more metaphysics. It is shown that the metaphysical assumptions underlying current physics are often deeply embedded in the formalism in which theories are presented, and hence impossible to dismiss as mere motivational or interpretative speculation. It is then shown that such assumptions, when made explicit, can wreck havoc on otherwise-sensible philosophical arguments. It is argued in conclusion that this situation is both unlikely to be reparable just by being more careful, and unlikely to go away as further, presumably more subtle physical theories are developed.

Keywords: Monism; Pluralism; Substantivalism; Mereology; Quantum entanglement; Quantum field theory

1. Introduction

In his recent "Prolegomena to any future physics-based metaphysics," Bradley Monton (2011) warns that current physical theory is a "shaky foundation" on which to ground metaphysical conclusions (p. 143). The reason that the foundations of physics-based metaphysical conclusions are shaky, according to Monton, is that not just the history of science but current physics itself suggests that our current physical theories may be false. For example, Monton points out that metaphysical arguments against presentism that rest on either special or general relativity as a foundation are at risk if quantum theory is true, since it is well known that quantum theory and relativity theory are mathematically incompatible. Monton offers seven suggestions for carrying on with the project of physics-based metaphysics despite this difficulty, ranging from calling a halt to metaphysics until physics resolves its contradictions to basing metaphysical claims only on uncontroversial parts of physics, even if the explanations of these uncontroversial parts in terms of deeper physical theory are unknown, uncertain, or even mutually contradictory.

The present paper suggests that the difficulty with grounding metaphysics on physics is deeper than Monton lets on. The deeper difficulty facing any metaphysics grounded on physical theory is that current physical theory – and I will argue, any future physical theory as well – is itself grounded on metaphysics. Physics being itself grounded on metaphysics might not present a problem if the metaphysical assumptions involved were coherent and uncontroversial, or if they were not actual *grounds* of physics but rather only temporary props employed in the construction of physical theories, which could all be removed at some point without damage to the theories themselves. In the case of current physical theory, however, neither of these potentially-mitigating conditions hold. The metaphysical assumptions grounding current physical theory are diverse, often highly counter-intuitive, and occasionally mutually contradictory. They are, moreover, in many cases embedded deeply into the mathematical formalism employed to construct the overlying theories, and they play largely unnoticed but crucial roles in determining how experiments to test the overlying theories are designed and carried out. Basing a metaphysical position on current physics is, therefore, not just basing it on more metaphysics, but basing it on metaphysics that is often hidden, difficult to articulate, and once discovered and articulated at least as controversial as the metaphysical position it is intended to support.

The next section sets the stage for the main argument by briefly surveying metaphysical assumptions that have been advanced explicitly by three leading theorists in quantum information and quantum cosmology: Max Tegmark, Christopher Fuchs and Wojciech Zurek. While these particular assumptions are by no means made by all physicists, they illustrate both the diversity and the counter-intuitive nature of the metaphysical assumptions underlying a prominent segment of current physics. In each case, moreover, a kernel can be identified that is advocated quite broadly. The third section more closely examines one of these assumptions, the assumption that physical "systems" exist, and shows how this assumption is embedded in the Hilbert-space formalism employed to represent quantum states. The fourth section shows how this embedded metaphysical assumption can turn what look like cogent physics-based metaphysical arguments, for example those of Jonathan Schaffer concerning material objects and spacetime (2009) and the universe and its component parts (2010), into a muddle. The fifth section considers a possible Montonian rejoinder that taking greater care in describing the physics on which a metaphysical argument is based will solve the problem. The paper concludes by suggesting that the metaphysical issues in greatest need of sustained attention are to be found not in the airy space above current physical theory, but in the murky netherworld beneath it.

2. The metaphysics underlying physics: Three examples

The recent willingness of physicists to advance overtly metaphysical positions in the course of proposing new or refined physical theories can perhaps be traced to the late John Archibald Wheeler (1911-2008),[1] who famously stated that "philosophy is too important to be left to the philosophers" (quoted in e.g. Bičák, 2009, p. 689), and advised physicists to pursue such questions as "How come existence?" or "How come 'one world' out of many observer-participants?" (Wheeler, 1989, p. 4). A steady stream of books by such high-profile physicists as Steven Hawking, Steven Weinberg, Lisa

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1. Wheeler was a student of Niels Bohr and a close colleague of Albert Einstein; his work stands at a confluence between Einstein's Spinozan inclination to view the world *sub specie aeternitatis* and Bohr's emphasis, following Ernst Mach, on physical observables as the only reality that can be discussed.

Randall and Brian Greene have bundled what anyone would call metaphysical positions – about the nature of time, the dimensionality of space, and the properties of the “basic stuff” of the universe – together with current physical theory into seamless packages accessible to the general public. The metaphysics in such books is, however, dressed in a way makes it look innocent: it is presented as supporting, rather than challenging, an essentially optimistic and positivistic notion that theories at the frontiers of physics, however odd they may seem, will eventually provide a coherent conceptual framework from which “ordinary reality” will emerge unscathed. To find metaphysics with an edge, one must dive into the literature that physicists write for each other. Wheeler (1989), for example, straightforwardly asserts that the universe is composed at the fundamental level out of information, not stuff, that there are really no such things as physical laws, and that space and time are human constructs that must emerge from, instead of being assumed by, physical theory. Whatever one may think of these claims, they are clearly *not* innocent: they demand a change in worldview from that of “ordinary reality.”

This section surveys three prominent “post-Wheelerian” metaphysical positions – Max Tegmark's Platonic realism, Christopher Fuchs' Jamesian instrumentalism, and Wojciech Zurek's hybrid of realism and instrumentalism – that will serve as reference points when considering the questions regarding material objects and parts discussed by Schaffer (2009, 2010). The setting is quantum theory and its recent extensions into quantum information theory and quantum cosmology. The proposals of Tegmark, Fuchs and Zurek all concern the continuing question of the physical interpretation of quantum theory (for recent reviews, see Landsman, 2007; Schlosshauer, 2007; Wallace, 2008), the question of how to relate what can be predicted using the mathematical formalism – a quantum state – to what can be experimentally registered and recorded – a determinate, apparently-classical observational outcome. They are, in particular, attempts to achieve a more satisfactory account of “the emergence of classicality” than that offered by the traditional “Copenhagen” interpretation advocated by Bohr (1928) and formalized by von Neumann (1932), with its mysterious measurement-induced “collapse” of the quantum state.

2.1 Tegmark: From many worlds to a mathematical world

One straightforward response to the mystery of quantum state collapse is simply to deny that it occurs.

The “relative state” or “many worlds” conception of quantum theory introduced by Everett (1957) assumes that the universe as a whole is an isolated quantum system, that its evolution in time is fully deterministic and unitary as required by the Schrödinger equation, and hence that its physical state remains a quantum superposition at all times. In such a universe, tables and chairs have multiple locations, you and I have multiple occupations and personalities, and Schrödinger's cat is both dead and alive. Any particular determinate measurement outcome describes just one singled-out component of the universal quantum state, one temporally-extended “branch” of reality among many. How many? As many as the number of possible outcomes of measurements, summed over every observer that has ever existed and every measurement that has ever been made since the dawn of time. How “real”? Opinions vary from as real as anything (Deutsch, 2010) to functional but not necessarily ontic reality (Wallace, 2010) to “course grained” approximate reality (Hartle, 2010) to streams of consciousness (Zeh, 2000).

Despite its formal simplicity, explanatory power, and complete agreement with all experiments, Everett's approach to quantum theory is nothing if not controversial, with accusations of metaphysical exuberance among the many thrown against it (Saunders *et al*., 2010 provides a recent snapshot of the ongoing discussion). To this, quantum cosmologist Max Tegmark says nonsense: the profusion of classical universes that results from treating quantum mechanics as universal in its applicability is no greater than that entailed by standard inflationary cosmology (Tegmark, 2010); in an infinitely-expanding spacetime, both are infinite. Adding the assumption that cosmological inflation is chaotic, as required by some approaches to string theory, adds infinitely *more* parallel universes to the mix. If this is correct, being a realist about physics – about inflation, about the quantum state of the universe, about string theory – commits one not just to metaphysical exuberance, but to *infinite* metaphysical exuberance. Tegmark argues that this exuberance is a good thing: by declining to specify the messy details that distinguish individual possible universes, metaphysically exuberant models achieve not just greater predictive generality, but also lower algorithmic complexity, greater symmetry, and greater mathematical beauty than models that postulate cumbersome *a priori* “initial conditions” from which to derive the details of some singled-out “actual” world. They save the theorist, moreover, from the empirically unsupportable task of coming up with reasons why there should be just *these* initial conditions, and hence just *one* actual world, i.e. this one.

Tegmark does not, however, stop there. He urges us to acknowledge the possibility of alternative universes not just governed by different laws or characterized by different values of physical constants such as *c* or *ħ*, but rather structured by entirely different forms of mathematics. He claims that this expanded set of possible universes follows from a simple assumption: the "external reality hypothesis" that what exists – and hence what physics is about – is independent of human beings or any other particular observers (Tegmark, 2008). If external reality is fully independent of us, Tegmark argues, then it must be independent of the interpretative "baggage" that we attach to our theories. Strip away the baggage, and all that is left for external reality to depend on is the formalism, the bare mathematical structure. If external reality only depends on mathematical structure, he continues, it can only *be* mathematical structure. He emphasizes that this view that reality is mathematics "does certainly *not* imply that all imaginable universes exist " (p. 126; emphasis in original); indeed he provides a Gödel-number like scheme for defining mathematical structures, and restricts his existence claim to universes having mathematical structures representable with this scheme. From a metaphysical perspective, however, Tegmark's self-characterized radical Platonism is bracing. It is at least as anti-substantivalist as Floridi's (2008) informational structural realism, an "information-only" metaphysics based explicitly on Wheeler's (1992) "it from bit" thesis that physics ultimately reduces to information theory. Its scope is, however, far broader, as it abandons Floridi's emphasis on the observable world in favor of infinite numbers of parallel worlds that are unobservable in principle either by us or by any observers even remotely like us.

It is probably safe to say that most physicists do not believe that the world is just mathematics. Most physicists do, however, follow Wigner (1960) in assigning mathematics a privileged role in describing the world. In particular, most physicists tend to assume that the formal expressions contained within well-confirmed mathematical models refer to actual entities or properties, even if these entities or properties are unobservable in principle. The multiple alternative worlds of Everettian quantum theory, for example, are unobservable in principle, but because expressions within the quantum formalism appear to refer to them, many physicists take their existence as a given. This example is hardly unique; the metaphysical assumptions underlying physical theories can often be traced to the mathematical formalism with which they are expressed, and the practical predictive value of the formalism renders metaphysical assumptions embedded in it particularly powerful and difficult to challenge.

2.2 Fuchs: A world of autonomous experiencers

Not all physicists accept Tegmark's blanket realism about the supposed referents of formal expressions, even those of the most well-confirmed theories. This "non-ontic" attitude is especially prevalent when it comes to quantum states, particularly the supposed quantum state of the universe as a whole. Quantum information theorist Christopher Fuchs (2010), for example, proclaims that "QUANTUM STATES DO NOT EXIST" (p. 2; emphasis in original). According to Fuchs, quantum states are not only purely informational, they are purely subjective as well. Quantum theory "is not something outside probability theory ... but rather it is an *addition* to probability theory" (p. 9; emphasis in original), specifically "an addition to personal, Bayesian, normative probability theory" (p. 19). This addition is itself normative: the Born rule, the formula for computing probabilities of outcomes of measurements, is "normative ... like the Biblical Ten Commandments" and agents employing the theory are "free to ignore the advice" if they choose to (p. 8, Figure 2 caption). Treating science as normative instead of descriptive separates Fuchs' "quantum Bayesianism" from more traditional instrumentalist approaches to quantum theory, and puts Fuchs to the postmodern side even of limited-applicability instrumentalists like Nancy Cartwright (1999).

Fuchs' anti-realism regarding quantum states neatly removes the problem of quantum-state collapse. Fuchs does not, however, abandon realism altogether; indeed he claims that "the real world ... is taken for granted " in quantum Bayesianism (p. 7). This "real world" is decidedly nominalist, comprising "this and this and this ... every particular that is and every way of carving up every particular that is" (p. 22), where "particulars" are not just material objects: "everything experienced, everything experienceable, has no less an ontological status than anything else" (p. 21), with the "objects" of imaginative experiences explicitly included. Any notion that science can reduce these particulars to, or even explain them in terms of, any kind of fundamental "building block" entities is firmly rejected. Moreover, every particular is regarded as having "an interiority not given by the rest of the universe" (p. 25), the behavior of which would remain unpredictable even if the state of the entire rest of the universe were known. Interiority implies autonomy: "the universe ... should be thought of as a thriving community of marriageable, but otherwise autonomous entities" (p. 14). Fuchs applies Dennett's (1971) intentional stance to these "autonomous entities" across the board. He proposes that all "particulars" be regarded as agents, and that the observer - observed relationship holds for "every two parts of the world" (p. 27). "Does this mean even 'elementary' physical events just after the big bang must make use of *concepts* that, to the reductionist mind, must be 15 billion years removed down the evolutionary chain? You bet it does" (p. 21, fn. 37; emphasis in original). Fuchs' blend of realism, instrumentalism, nominalism and idealism is, therefore, at bottom a kind of pan-agentism, a William Jamesian view of "a world, a pluriverse, that consists of an all-pervasive 'pure experience'" (p. 27).

One might wonder what purpose physics serves in a universe such as Fuchs describes. True to his instrumentalist stance, Fuchs characterizes quantum theory as a "user's manual for decision-making agents immersed in a world of *some* yet to be fully identified character" (p. 23; emphasis in original). He combines this, however, with two profoundly realist claims. The first is that observation is a physical interaction in which the observed system acts on the observer to select one of a specified, finite set of possible "experiences" as the observational outcome (p. 6, Fig. 1). The second realist claim is that all "particulars" have, as a matter of physical fact, a fixed, finite "dimension" that determines the degree of behavioral autonomy they are able to express. Both of these claims are, at bottom, claims that the mathematical formalism of quantum theory – even though the theory is "normative" and just a "users' manual" – literally describes the world. They powerfully constrain Fuchs' world of "pure experience"; indeed, they are what gives his physics a predictive grip on that world.

As with Tegmark's world of mathematics, it is probably safe to say that most physicists do not believe that the world is made of "pure experience." Most physicists do, however, believe that physical systems are literally described by their Hilbert-space dimensions, and that observations literally have the exact sets of possible outcomes that their formal representations as measurement operators say that they have. They believe, in other words, that the mathematical representations of systems by Hilbert spaces and observations by operators are correct, that they state facts. The most basic fact that these representations state, of course, is that the systems described by these representations actually exist. What explains the existence of such systems? Why are there things with one, two, or ten million physical degrees of freedom, and why can such things be observed to have positions, masses, spins, baryon numbers and the like? By rejecting any account that appeals to "building blocks," Fuchs is left with little option but to regard the existence of such things as *a priori* (Fields, 2012a). As we will see, however, the existence of physical systems remains problematic even if the idea that they are constructed out of building blocks is not rejected.

2.3 Zurek: The environment as reality-defining witness

As noted, it is probably safe to say that most physicists are inclined toward neither Tegmark's world of mathematical structures nor Fuchs' world of experiences, but rather toward something much closer to the ordinary world of ordinary things. They are, for example, inclined to view both their colleagues and their laboratory apparatus as neither formulae in the void nor phantasms in their minds but rather as independently-existing solid objects, and happy to treat their colleagues, but not their laboratory apparatus, as independently-existing solid objects that happen also to be experiencing, autonomous agents. In a technological environment filled with laptop computers, particle accelerators, and other devices built using quantum-mechanical principles, moreover, quantum systems that exist in quantum states seem as much a part of "ordinary reality" as do tables and chairs. This straightforward, pragmatic view comes, of course, with a price: it demands some means of crossing the explanatory gap between the quantum world of superpositions and the apparently-classical world of colleagues who are either present in the laboratory or not and apparatus that record determinate outcome values that can be relied upon to remain the same after being stored in a computer's memory or printed on a page.

Beginning with the work of Dieter Zeh (1970), a body of ideas and techniques called "decoherence theory" has become the standard approach to bridging this quantum-to-classical explanatory gap (Zurek, 1998; Joos *et al*., 2003; Landsman, 2007; Schlosshauer, 2007). Decoherence theory begins by noticing that any physical system is embedded in and interacts with an environment consisting of everything else. It can be shown that such system-environment interactions destroy quantum coherence, the delicate balance between possibilities that allows an electron to be in two places at once or Schrödinger's cat to be both dead and alive. When quantum coherence is removed, systems appear classical. Decoherence theory thus predicts the *appearance* of "quantum-state collapse" without requiring that such collapse actually occurs. It predicts, in other words, that the quantum world will appear classical to observers, even though it isn't.

Even with decoherence theory, however, there is still an explanatory gap. Any arbitrary collection of elementary particles is embedded in an environment, and is therefore subject to decoherence. The classical world, however, is a world of discrete, identifiable, time-persistent *objects*: colleagues, apparatus, the Moon and so on. What makes some collections of elementary particles into objects, while other collections of elementary particles remain just collections of elementary particles? What, for example, makes the Moon an object? Why does no one regard half of the Moon together with a bunch of the nearby space as an object, with the other half of the Moon together with all the rest of space as its environment? If reality is to be observer-independent, the answer cannot be that observers *decide* what is to count as an object. Whatever picks out some collections of elementary particles instead of others as being objects must, instead, be part of physics itself.

Wojciech Zurek and colleagues have proposed an answer to this question: what picks some collections of elementary particles out as being objects is not an observer or even a group of observers, but rather the environment itself. According to this "environment as witness" framework, the general, shared environment in which both observers and the objects they observe are embedded encodes information some physical properties and not others (Ollivier *et al.*, 2004, 2005). If the environment encodes information about the properties of some collection of elementary particles – say, the collection of elementary particles making up the Moon – observers see it as an object; otherwise it remains just a collection of elementary particles and its properties remain unnoticed. Because the environment is large, moreover, multiple observers can detect the same encodings of properties, and hence agree that they are observing the same objects. This idea of "quantum Darwinism" closes the gap left by decoherence theory alone: the ordinary objects of familiar experience emerge into classicality because their physical properties are successful in competing for environmental encodings in the general environment (Blume-Kohout and Zurek, 2006; Zurek, 2009).[2]

What does all of this have to do with metaphysics? The answer is: quite a lot. Quantum Darwinism elevates the common assumption that "systems" exist to an explicit axiom: Zurek (2003) calls it "axiom(o)" of quantum theory. Unless systems comprising many elementary particles – or many of whatever entities are assumed to be fundamental – physically exist, the only properties physically encoded by the environment are the properties of individual elementary particles. The physical encoding of *collective* properties – such as the familiar shapes, sizes, masses and positions of bulk

2. Zurek was one of Wheeler's postdocs. That quantum Darwinism is an essentially Wheelerian doctrine is made clear by Zurek's (2002) use of Wheeler's iconic image of the universe observing itself, first published in Patton and Wheeler (1975).

material objects – requires the physical existence of collectives that have such properties. In particular, it requires that the physical *boundaries* of such collectives exist, for it is at such boundaries that decoherence acts to create apparent classicality. I have argued elsewhere that this requirement renders the project of quantum Darwinism circular; decoherence cannot, after all, be regarded as explaining classicality if classical boundaries must be assumed up front (Fields, 2010, 2011, 2012b, 2012c). What is significant here, however, is that Zurek's "axiom(o)" is a straightforwardly *metaphysical* assumption: systems and their boundaries must be assumed to exist *a priori*. It is, moreover, a *strong* metaphysical assumption. Nothing in decoherence theory explains how boundaries are created, or how bigger bounded things can be made out of smaller bounded things. The formalism requires the boundaries surrounding "systems of interest" to be *stipulated*. Assuming as an axiom that *some* systems exist is, therefore, not enough; what must be assumed is that *these* systems – the systems that we observers actually observe – exist. This is not just an assumption of commonsense realism about commonsense objects; it is an assumption that commonsense objects are cosmologically *a priori*.

3. Embedded metaphysics

One possible response to the above rehearsal of metaphysical positions recently advanced by physicists is to say: so what? Physicists are not philosophers and are not forced to refine their metaphysical positions in an atmosphere of philosophical critique; hence it is not surprising if their positions are outlandish or mutually contradictory. Surely what is important about physics is not the metaphysical positions of physicists, but mathematically-formulated and empirically-productive physical theory itself. As noted earlier, quantum theory is extraordinarily well-confirmed experimentally (e.g. Schlosshauer, 2006): let the theory stand on its own, and forget about the half-baked metaphysics advanced to "interpret" it.[3]

The argument that physical theory can be taken at face value, and employed to support metaphysical positions advanced by philosophers without regard for the metaphysical positions advanced by physicists, might be sound but for two key facts. First, the metaphysical assumptions made by

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3. This is known among physicists as the "shut up and calculate" approach to quantum theory (Mermin, 1989).

physicists in the course of developing physical theories are in many cases implicit in the mathematical formalism in which the theories are expressed. Second, these metaphysical assumptions influence, generally implicitly, the design of experiments intended to test the theories in which they are embedded. This section illustrates the embedding of metaphysical assumptions into the mathematical formalism of physical theory, and considers how such embedded assumptions influence the course of experimental research.

The most obvious example of an embedded metaphysical assumption appears in general relativity: it is the assumption that space and time not only exist but are continuous. Without this assumption, differentiable manifolds with metrics determined by differential equations could not be used as the mathematical basis of the theory. The continuity of spacetime is what makes the development of a quantized theory of gravity difficult: if spacetime is continuous, any such theory will suffer singularities at which otherwise well-behaved physical quantities explode to infinity. String theory, with its fundamentally discrete conception of space, is one attempt to address this problem. Even Einstein found the assumption of a single, continuous spacetime troubling, saying "Time and space are modes by which we think, and not conditions in which we live " (quoted in Wheeler, 1989, p. 9). Mathematical representations such as the spacetime manifold of general relativity can be treated as metaphysically innocent – as modes by which we think – but not within a realist view of science in which mathematical descriptions are regarded as literal truths, and certainly not within a framework such as Tegmark's in which mathematical entities do not describe reality but rather *are* reality. A physics-based metaphysics cannot, moreover, be based on a purely instrumentalist physics: if physics is to provide a ground for further metaphysics, it must be regarded as realist. The project of interest here, therefore, cannot escape taking seriously the metaphysical assumptions, such as the assumption of continuous spacetime, that are embedded in the formalism of physics.

While it is troublesome theoretically for quantizing gravity, the embedded assumption of a continuous spacetime is not nearly as significant metaphysically as a second embedded assumption: the assumption of systems that Zurek makes explicit as "axiom(o)." The existence of discrete, bounded systems is taken for granted in classical physics, which concerns itself with tables and chairs, stars and planets, and even such items as neurons and DNA molecules. Aside from general relativity, however, all of classical physics can safely be regarded as an approximation, as not *really* true, and so its metaphysical presumptions can be ignored. This is not so with quantum theory: quantum theory is what classical physics approximates. It is, therefore, the assumption of systems in quantum theory that bears examination.

Systems are represented in quantum theory by Hilbert spaces: the Hilbert space $\mathcal{H}_\mathbf{S}$ of a system **S** is the space of all possible quantum states of **S**. Mathematically, a quantum state |**S**> of **S** is a vector in $\mathcal{H}_\mathbf{S}$, and a measurement made on **S** is an operator that acts on $\mathcal{H}_\mathbf{S}$. Decoherence theory characterizes the environment **E** of a system **S** by a Hilbert space $\mathcal{H}_\mathbf{E}$; decoherence as a physical process acts at the boundary between the Hilbert spaces $\mathcal{H}_\mathbf{S}$ and $\mathcal{H}_\mathbf{E}$. Hilbert spaces are fundamental to the mathematical mechanics of quantum theory; Fuchs, for example, maintains the Hilbert-space formalism even though he rejects the physical existence of quantum states.

If viewed in isolation, the assumption that systems have Hilbert spaces is metaphysically innocent. It becomes *non*innocent, however, as soon as time is introduced. Time is, moreover, introduced as soon as one talks about doing an experiment, or talks about some system at time *t* being the same thing as some system at time $t + \Delta t$. The reason for this is the Schrödinger equation. If the system of interest **S** interacts at all with its environment **E**, then propagating the joint state of **S** and **E** forward in time with the Schrödinger equation renders it entangled. Quantum entanglement is even more troubling than superposition: if |**S** ⊗ **E**> is an entangled state, **S** cannot be *distinguished* from **E**. It no longer makes sense, in this case, to talk about |**S**> as a "state of **S**"; one can only say that the composite state |**S** ⊗ **E**> is a state of the composite system **S** ⊗ **E**. Entanglement is the source of the nonlocality of action demonstrated by Bell's (1964) theorem and of the context-dependence of experimental outcomes demonstrated by the Kochen-Specker (1967) theorem.

As Mermin (1981) discusses in the context of Bell's theorem, the empirically well-supported fact that interactions between quantum systems produce entangled states renders the embedded assumption that "objects" like laboratory apparatus or the Moon can be identified with "quantum systems" so restricted in its application that it becomes almost incoherent. An ordinary, bounded object can be treated as a quantum system with a well-defined Hilbert space only if it does not interact with anything else, i.e. only if it is physically isolated and therefore unobservable. As soon as it interacts with its environment, the two become entangled and no well-defined boundary can be drawn between them. As soon as an object interacts with an *observer*, the two become entangled and no well-defined boundary can be drawn between them. If ordinary objects are *physical*, however, then unless quantum theory is thoroughly false they can only be quantum systems. What, then, can the notion of a “bounded object” mean if interaction – hence the possibility of observation – and persistence over time as a re-identifiable thing are mutually exclusive? It is this conundrum that is embedded in the formalism of quantum theory, and which theorists and metatheorists alike ignore at their peril.

Here one might say: oh, come on. Physicists routinely do experiments that involve manipulations of perfectly ordinary things like power supplies and voltmeters, they re-identify these things effortlessly every morning when they enter the laboratory, and if either the manipulations or the re-identification were somehow problematic in principle, experimental science would be impossible. This argument is compelling, but it misses a crucial point. The interactions between ordinary items of laboratory apparatus and the surrounding laboratory environment are assumed to be generally weak, and the coupling between the many degrees of freedom of a typical item of apparatus and the many degrees of freedom of its environment are assumed to be generally not coherent. As long as these two conditions hold, both the state of the general environment and the question of whether the apparatus-environment boundary can be drawn precisely can safely be ignored. The crucial point is that as long as apparatus-environment coupling is being ignored, no one bothers to measure it, so no one ascertains whether the conditions that allow it to be ignored actually obtain. However, ignoring the possibility that ordinary objects might be ill-defined as quantum systems – in particular, ill-defined as Hilbert spaces – amounts to assuming that they are well-defined. This is a metaphysical assumption, and it has consequences for both the design and the interpretation of experimental observations. Its primary consequence for experimental design has been noted: no one looks for macroscopic entanglement among “ordinary objects,” and no theory suggests where to look. Is there some entanglement-driven, supercharged butterfly effect whereby my going grocery shopping today might determine the course of events on some other planet? No one knows, and no one knows how to find out, so the answer is just assumed to be no. The primary consequences of this assumption for the interpretation of experimental results are faith in “replication” – the very meaning of which is challenged if “systems” are problematic – and a tendency to dismiss statistical outliers as “noise.” No one knows what significant results have been tossed out as “noise” or “fluctuations” from large data sets, or what interesting but unexpected side-effects of experimental manipulations have been lost to history because they were never recorded.[4] Because we *assume* that well-separated macroscopic objects are not entangled, so that manipulating something here has no consequences for some other object somewhere else, we discount the very possibility of what Jung called “synchronicity” between distant events. We ascribe all manner of outcomes to “chance,” knowing full well that they are products of some causal processes or other, but remaining unable or unwilling to trace these processes far enough to understand them. As recently demonstrated at Gran Sasso, moreover, unexpected and unnoticed changes in the degrees of freedom of experimental apparatus can have dramatic effects on what is regarded as a “real” observational result (Adam *et al.*, 2012, Sect. 6.1). Scientific skepticism and “replication” of experiments by different groups using different equipment guard against such consequences, but their efficacy in countering the inherent unpredictability of the quantum world can only be regarded as a matter of faith.

4. Physics-based metaphysics: Two arguments of Jonathan Schaffer

Let us now turn from the writings of physicists to the writings of philosophers, and in particular, to two recent papers of Jonathan Schaffer (2009, 2010) that advance metaphysical arguments based on current physical theory. Schaffer (2009) presents seven arguments supporting a monistic substantivalism about spacetime – the idea that there is only one substance, and it is spacetime – against a dualistic substantivalism about spacetime – the idea that spacetime is a substance, but that there is also a “material” substance that occupies spacetime regions. The last of these arguments, and one supposes given its position in the list, the one that is meant to be most convincing, runs as follows:

> The argument from Quantum Field Theory: Quantum Field Theory, like General Relativity, is a theory of fields (which again are naturally interpreted as states of the spacetime) rather than material occupants … Fundamental physics does not need to explain why, for instance, the geometrical properties of material objects are a perfect fit for the geometrical properties of the spacetime regions they occupy, for the equations do not posit anything distinct from regions. On the face-value reading of the equations, there is the spatiotemporal manifold, and the fundamental properties

4. A possible example of the former can be found in de Boer and Fields (2011).

> are pinned directly to it. Nothing more.
>
> (p. 143)

This argument turns on the idea that “fundamental properties” like electric charge or baryon number can be “pinned” directly to spacetime regions. Field theories, whether classical or quantum, do precisely this by treating fundamental properties as mathematical functions of space and time. As Schaffer notes, the notion of “material objects” as holders of properties makes no appearance in such theories. There are no electrons, for example, in quantum electrodynamics, just an electron field that attaches charge, mass and angular momentum directly to the spacetime continuum.

Schaffer is not, however, content with pointing out that field theories do not postulate particles as entities. Taking the formalism literally, he infers that if fundamental properties adhere in fields, they cannot adhere in particles. To support this, he quotes Halvorson and Clifton (2002) as claiming that “Relativistic quantum field theory... does not permit an ontology of localizable particles; and so, strictly speaking, our talk about localizable particles is a fiction” (Schaffer, 2009, p. 143). The considerations outlined in §3 above show why this is so: if a “particle” cannot be distinguished from its environment, then the claim that “it” is here rather than there is clearly a fiction. Unfortunately for Schaffer, this means that a particle's properties – for example, its electric charge – cannot be “pinned” exclusively to any finite *region* of spacetime. Indeed, the non-localizability of “particles” and hence of properties renders one of Schaffer's primary inferences unsound. Schaffer assumes the mereological axiom that “spacetime regions satisfy unrestricted composition and decomposition ” (p. 135). He then infers that “given unrestricted composition and decomposition for spacetime regions … and the monistic identification of material objects with spacetime regions, unrestricted composition and decomposition for material objects follows immediately.” If “material objects” are non-localizable, both the conclusion and the second premise are false: “material objects” *cannot* be identified with spacetime regions, because they and their observable properties are smeared over all of spacetime.

What has happened here is that Schaffer has taken the idea of a “local” field excitation far too seriously. If the electron field, for example, was all that existed, and if the particle number characterizing the field – i.e. the number of “electrons” in the universe – was small, then it would be a reasonable approximation to treat every electron as localized to some region of spacetime. If other fields are present with which the electron field interacts – if a proton field exists, for example – or if the electron particle number is large, however, entanglement between field excitations must be taken into account. Field excitations with local maxima on opposite sides of the universe can be entangled as a result of primordial interactions during or soon after the Big Bang; hence field excitations can be utterly non-localizable. The correlation between a mereotopology of spacetime (Smith, 1996) and a mereotopology of objects then collapses, because the mereotopology of objects itself collapses: if objects can be neither localized nor bounded, talk of their "parts" ceases to have meaning (Fields, 2013). This is *why* general relativity and quantum theory are at odds: spacetime seems continuous and locally well-defined, while mass, charge, angular momentum and the other defining properties of "objects" do not.

It is clear, however, why Schaffer might assume that quantum field excitations are arbitrarily localizable: physicists assume this all the time. A localizable field excitation is simply a particle by another name: it is a "system" that can be talked about *as if* it were isolated. As discussed above, locality and "system-ness" are embedded in the formalism of both classical mechanics and ordinary non-relativistic quantum mechanics, and the intuitions that inform quantum field theory are based on these formalisms. How many terms must be included in a Feynman diagram to represent a physical situation? As many as are required to predict the results of a local experiment to within the relevant measurement resolution. The physical intuitions involved, however, are driven by only the first few terms, the terms that satisfy a rough-and-ready assumption of locality. Indeed, it is only the first few "local" terms that generate any intuitions at all about how they might interact with a local apparatus over the course of a local experiment. But while a physicist can readily admit that localizability is an apparatus-dependent approximation, Schaffer cannot; Schaffer requires a *metaphysical* correspondence between spacetime regions and the defining properties of objects, and the formalism rules any such correspondence out.

Schaffer (2010) argues more broadly for priority monism, the view that the universe as a whole is metaphysically prior to any of its proper parts, while carefully distinguishing this view from existence monism, the more radical view that the universe as a whole is all that exists. Schaffer's primary target is the priority pluralist, who believes that the proper parts of the universe – elementary particles, for example – are metaphysically prior to the whole. The second of Schaffer's four arguments for priority monism appeals directly to quantum entanglement at the scale of the universe: “the argument from quantum entanglement to *Monism* begins from the premise that the cosmos forms *one vast entangled system*” (p. 52, emphasis in original). As Schaffer notes, this is equivalent to the assumption that the universe has a well-defined quantum state, and that this quantum state evolves according to the Schrödinger equation. This is precisely the assumption of Everett (1957) discussed in §2.1, the assumption that generates the “many worlds” view of quantum theory. Following quite well-trodden steps, Shaffer arrives at the conclusion of any Everettian: “the cosmos is a fundamental whole ” (p. 55).

Schaffer's next step, however, is surprising: he supposes that “quantum entanglement is a case of emergence, in the specific sense of a property of an object that has proper parts, which property is not fixed by the intrinsic properties of its proper parts and the fundamental relations between its proper parts” (p. 55). This statement depends on the assumption that the universe has proper parts, a mereological assumption made in the very first section of Schaffer (2010). If the universe has proper parts, existence monism is false. It is clear why Schaffer would want to introduce this assumption; he wants to distinguish priority monism from existence monism, and he finds existence monism implausible. What is less clear, given the reasoning outlined above, is how the notion that the universe has proper parts can be made compatible with universal entanglement.

By “proper parts” Schaffer means “all actual concrete objects … planets, pebbles, particles, and other proper parts” (p. 33). For the purposes of argument, however, “proper parts” can be taken to be fundamental parts – elementary particles, strings, or whatever – since these are the “parts” of greatest interest to pluralists. So the question, as with Schaffer (2009), is whether the notion of universal entanglement is consistent with any coherent mereotopology that yields elementary particles or any other proposed propertied fundamental objects as persistently identifiable, localizable parts. As already argued, this does not appear to be the case, as no observable properties of such fundamental things can be localized in an entangled universe. And fundamental things with *no observable properties* serve no purpose in either physics or metaphysics.

The interesting question, for the present purposes, is once again no so much whether Schaffer's assumption that universal entanglement is consistent with proper parthood is true, but with how Schaffer could take it to be *obviously* true, to be something that can be assumed without question.

Universal entanglement is, after all, hardly an intuitively obvious concept for which consistency or inconsistency with metaphysical or even merely physical claims can generally be grasped at a glance. The most straightforward explanation for a facile assumption of consistency in this case appears, therefore, to be that so many physicists assume it; indeed, the entire project of explaining the emergence of classicality is based on this assumption. If this project is misguided, if quantum effects such as entanglement do not disappear at large scales, then the “classical world” is not an approximation but an illusion, and our ordinary notions of objecthood, locality, independence and causation are not approximately right but rather straightforwardly wrong. Such a conclusion flies in the face of all of our intuitions, and is difficult even to consider as a theoretical option. Hence while Schaffer (2010) quotes warnings from half a dozen prominent physicists that parthood is incompatible with entanglement (fn. 31 p. 53 and fn. 33 p. 55), the unrecognized weight of the assumption that they must, somehow, be compatible after all – that as Zurek puts it, systems *must* exist – carries the day at the end.

Neither Schaffer's assumption-laden reading of physical theory nor the collapse of his physics-based arguments into confusion are at all unusual. Indeed as discussed above, the physics-based metaphysical arguments of physicists often display the same characteristics and suffer the same fate. Why? The common point at which Schaffer's two arguments fail – the incompatibility of entanglement and mereotopology – suggests an answer: physics-based metaphysical arguments will fail if either their ancillary metaphysical assumptions or their conclusions are consistent with some but not all of the metaphysical assumptions embedded in the formalism of the physical theory on which the argument is based. In Schaffer's case, the formalism holds out the metaphysical assumption that systems exist, while hiding within the notion of entanglement the severe limitations on the meaning of “system” that are imposed by the temporal dynamics that the theory describes. These severe limitations undo Schaffer's arguments by, in effect, limiting the “system of interest” to the universe as a whole. In the end, both of Schaffer's physics-based arguments support not Schaffer's position, but the position he rejects as implausible, i.e. existence monism. If the universe is indeed “one vast entangled system,” then it has no proper parts, full stop.

5. Won't being more careful fix this?

A reader sympathetic to Monton's (2011) suggestions for carrying on with physics-based metaphysics might well say at this point: surely Schaffer's problem is just that he did not recognize the hidden metaphysical conflict between mereotopology and entanglement and take steps to avoid it. Surely, in other words, the metaphysical presumptions of physical theories, whatever they are, can be dragged out into the open and rendered innocent by suitable conditions, limitations or exceptions. Schaffer's (2010) argument from entanglement, for example, tells against “elementary particle” pluralism even if there are only a few entangled systems, all of which are much smaller than the universe as a whole. Perhaps the assumptions that cause the most trouble can be set aside as unnecessary to the parts of physical theory on which more reasonable metaphysical claims can be based. Even if such limitations are not possible, Schaffer could bite the bullet and advocate the existence monism that his arguments appear actually to support.

At least in the case of arguments about space, time or mereology, it seems unlikely that the metaphysical assumptions underlying physical theories can be rendered either innocent or unnecessary by the imposition of conditions, limitations or exceptions. The metaphysics of physics also includes deep assumptions of universality and uniformity. The “laws of physics” are assumed to apply everywhere and at all times, and to characterize all physical processes at all possible scales. These assumptions of universality and uniformity are themselves deeply embedded in the mathematical formalism, for example, in the use of the integers or the real numbers to represent quantities. This is, again, *why* relativity and quantum theory are in conflict; their domains are not sequestered parts of the universe, but rather the whole thing. Such universality and uniformity assumptions are, moreover, inevitable: any restriction on the domain of a physical theory would itself require a physical explanation, and such an explanation could only be couched in a less-restricted theory, with a universal and uniform theory as the natural limit.

What then of the bolder option: of biting the bullet? Is there not a metaphysics that current physics does, unequivocally support? Could Schaffer or anyone propose existence monism, for example, adduce current physics, and rest their case? This seems unlikely for at least two reasons. The first is the threat of circularity. The notion of universal entanglement, for example, depends on the notion of a universal quantum state, and assuming a universal quantum state, once the term “quantum state” has been fully unpacked, is arguably just assuming existence monism. In general, any physics-based metaphysical position that captures the metaphysical subtlety underlying its physical assumptions is likely to be, or at least arguably to be, the metaphysical position underlying the physical assumptions themselves. A physics-based metaphysical position at all inconsistent with the tacit metaphysical assumptions of the physics on which it is based is likely to unravel as we have seen; one that is consistent but leaves crucial components out is unlikely to capture all of the physically or metaphysically-relevant subtleties. If this is the case, however, assuming a particular physical theory as a basis for a metaphysical position is tacitly assuming the metaphysical position itself; the physics is just window dressing. The second reason that simply being more careful is unlikely to work is that physicists, as shown in §2, disagree on the interpretation of, and hence on the metaphysics underlying, their own theories. Tegmark, Fuchs and Zurek, for example, could be expected to answer any metaphysical question differently (Fuchs and Zurek do answer a sample of such questions differently in Schlosshauer, 2011). Hence identifying *the* metaphysics underlying current physics becomes impossible; at best one can attempt a "metaphysics-according-to-X," mustering additional metaphysics, all of which must be carefully checked for both consistency and circularity, to fend off competing views.

6. Conclusion

This paper has argued that physics-based metaphysics rests on even shakier grounds than those pointed out by Monton (2011): physics-based metaphysics rests on metaphysics, and problematic metaphysics at that. This situation is unlikely to change; indeed if the recent century is any guide, the metaphysics underlying future physics is likely to be even more convoluted than what must be coped with today. Increasing the abstraction and generality of the mathematics, moreover, tends to increase both the depth at which metaphysical assumptions may be hidden, and the range of empirically-indistinguishable interpretations, each with its own metaphysical baggage, to which the formalism may be subjected. Tegmark's ideal of a physics consisting only of baggage-free mathematics, in particular, is unlikely to be realized by any theory that includes provisions referring to experimental tests. Metaphysics is, after all, at bottom about the things that we can see – things like power supplies and voltmeters – and it is precisely those things that both current and any anticipated future physics render problematic.

If the arguments advanced here have merit, any physics-based metaphysical argument can be met with a simple rejoinder: what, one can ask, are the metaphysical assumptions underlying the bit of physics just adduced? If this question cannot be answered, the appeal to physics is just an appeal to across-campus authority. If it can be answered, the debate can proceed on proper terms, as metaphysics against metaphysics. History shows that such debates can easily become a muddle, but by leaving the physics out of it, at least one muddle can be avoided.

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