Things Ain't What They Used To Be*

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It doesn't mean a thing to me
It doesn't mean a thing to me
And it's about time you see
Things ain't what they used to be

Parsons and Ellington

1 These Foolish Things

A world of things or a world of relations? **Things** have traditionally exposed scientific development to trouble. Think phlogiston. Think luminiferous ether. **Things** have been at the root of many problems in the foundations of physical theories. Think spacetime points. Think quantum particles. Yet things seem to be necessary for relations to make sense. How could there be a world *without* things; without particular objects or individuals? How could there be relations without things *standing* in those relations? So long as there are things, there are relations between them and, it seems, logically *dependent* on them so that where there are relations there must be things too.

In this essay we will argue, contrary to this common line of thought, that the assumption that the world is composed of 'things' is wrong (or at least problematic) and that jettisoning it might plausibly lead to advances in physics. That the world is fundamentally made up of things is surely an example of a belief "so ingrained" that (with some exceptions) it has become an "unquestioned dogma" (though a perfectly understandable one).

The search for things (of an ever more elementary kind) has been fruitful in many ways, and will presumably always have a role to play given that they provide our 'access' to the world in a very general sense. However, not only have specific choices for the fundamental things repeatedly been overturned throughout the history of science, aspects of

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our most fundamental theories imply a picture in which the fundamental ontological level (the 'ontological basement', to borrow Paul Davies' phrase) is occupied by primitive, *irreducible* relations. What is called for, we argue, is a reconceptualisation of our 'thing-world' in terms of a fundamentally relational ontology, which is perhaps better called 'structural' to avoid the troubling slide to relata (though structures too are usually conceived of as being composed of and dependent on elements).

Viewing the world as structurally constituted by primitive relations has the potential to lead to new kinds of research in physics, and knowledge of a more stable sort. Indeed, in the past those theories that have adopted a broadly similar approach (along the lines of what Einstein labeled 'principle theories') have led to just the kinds of advances that this essay competition seeks to capture: areas "where thinkers were 'stuck' and had to let go of some cherished assumptions to make progress". Principle theory approaches often look to general 'structural aspects' of physical behaviour over 'thing aspects' (what Einstein labeled 'constructive'), promoting invariances of world-structure to general principles. As Einstein puts it himself:

> These employ not the synthetic, but the analytic method. The starting point and basis are not constituted out of hypothetical constructional elements, but out of empirically discovered, general characteristics of natural processes (principles), from which follow mathematically formulated criteria that the individual processes or their theoretical models have to satisfy. (A. Einstein, Time, Space, and Gravitation. *Times (London)*, 28th November, 1919.)

However, the notion that the principles have to be 'filled in' by individual processes (of thing-like character: Einstein's 'hypothetical constructional elements') is where the trouble starts. It is just such elements that tend to be overturned in scientific revolutions, and just such elements that tend to be underdetermined by the observational data. Einstein followed such principle-theory approaches because he wasn't convinced by the available (quantum) filling, nor did he have a better alternative to hand. In place of a 'realistic', construction in terms of quantum particles (or singularities in a classical field) Einstein was forced to employ decidedly *unrealistic* rigid rods and clocks:

> *Sub specie aeterni* Poincaré, in my opinion, is right. The idea of the measuring rod and the idea of the clock coordinated with it in the theory of relativity do not find their exact correspondence in the real world. It is also clear that the solid body and the clock do not in the conceptual edifice of physics play the part of irreducible elements, but that of composite structures, which must not play any independent part in theoretical physics. But it is my conviction that in the present stage of development of theoretical physics these concepts must still be employed as independent concepts; for we are still far from possessing such certain knowledge of the theoretical principles of atomic structure

as to be able to construct solid bodies and clocks theoretically from elementary concepts. (Einstein, Geometrie und Erfahrung. Erweiterte Fassung des Festvortrages gehalten an der Preussischen Akademie der Wissenschaften zu Berlin am 27. Januar 1921. Berlin: Julius Springer, 1921—translation by Don Howard.)

We can agree that rods and clocks are not primitive, but that does not mean filling in by some kind of elementary things. Measurements of time and distance, in order to be invariant, must be of an irreducibly relational form, correlating (gauge-variant) quantities.[1] While the gauge variant quantities have a 'thingish' quality about them, they are strictly unphysical and realised only via a choice of gauge (which, again, involves a primitive correlation between them).

While the basic idea defended here (a fundamental ontology of brute relations) can be found elsewhere in the philosophical literature on 'structural realism' (especially [6]), we have yet to see the idea used as an argument for *advancing* physics, nor have we seen a truly convincing argument, involving a real construction based in modern physics, that successfully evades the objection that there can be no relations without *first* (in logical order) having things so related. We will sketch an argument in this paper that is sufficiently general to apply to fundamental physics as a whole.

2 All The Things You Are

Clearly, eliminating things as the fundamental ontological category (out of which the world is composed) will not really alter our everyday interactions with the world: we will still drink tea out of teacups, and not some flimsy structural counterparts thereof. Moreover, at least in terms of our direct experimental dealings, it will be things that form the objects of discourse and thing-language that is used to speak about them. However, when, e.g., the experimentalist speaks of a click in a counter or a spark on a screen or a number on a dial, he is really speaking elliptically about a component in a relation (a relation in disguise). But before we begin our case for clearing things out of the ontological basement, we'd better firm up just what we have in mind by the term.

What are things? The question lies, in many ways, at the heart of most of the central debates in metaphysics. "Thing" usually refers to something *concrete*: an individual entity with a definite location in space and time that takes on properties, and so on. In other

[1] The argument involves diffeomorphism invariance: physical quantities at points don't have physical meaning, because of the freedom to perform diffeomorphisms. As Peter Bergmann colourfully writes, "A world point (identified by its coordinate values or, perhaps, by its geometric properties) gets mapped on a definite world point only if the field is fixed; clothed with different fields it will get mapped on different world points" ([3], p. 53). But relations between 'clothed' quantities can localise other quantities in a relative way.

words: a *subject*.[2] We will understand the notion in this sense. Things *qua* subjects are quantified over in models characterising a theory's possible solutions. Hence, we might find $\langle \mathcal{M}, A, B, C \rangle$ (where A, B, C are functions of $x \in \mathcal{M}$ and will map to some value space, usually $\mathbb{R}$). Of course, quantum mechanical no-go theorems, such as Kochen and Specker's, already place considerable pressure on this notion of thinghood (at least as something that applies to all objects at all times in a *non-contextual* way), since complete, consistent simultaneous value assignments to the properties of a quantum system are not possible given certain reasonable (functional) constraints.

We are used to the notion of a *relative* or relational property via the distinction between primary and secondary qualities. A secondary quality (of a surface for example), such as being green, is just a property that demands a relationship between the coloured object and the observer (including background 'viewing conditions'): greenness involves appearing green under the right conditions. However, relational properties are still properties that things possess, as subjects.

Our approach might appear at first sight to be a defence of plain vanilla relationism, which classically boils down to the view that space and time are dependent on configurations of material objects. The metric field in general relativity [GR] seems to support this perspective, given that it shares characteristics associated with matter and determines the shape of the universe (via mass distribution). However, we wish to go further than this. Whilst the relationist position does treat some of the world's furniture relationally (as in the case of material objects over the existence of an independent spacetime), it still relies heavily on things to do this. It's things that support the reduction of relational structure.

Structuralism as we are proposing it, does away with this kind of reductive move. Whereas relationalism will seek to reduce one type of thing to the relational properties of others, we treat the relational structure as irreducible (in all but an unphysical sense, to be explained below). Rather than 'objects' and 'structure', we have only the uninstantiated structure. This position has several advantages: it neatly sidesteps the (moribund) debate between relationism and substantivalism; it fits several strands of interpretively difficult contemporary physics; and it also provides a context in which to forge a new approach to physics.

3 We'll Be Together Again

Most, if not all, of the revolutionary episodes in physics have happened when some piece of the theoretical framework was found not to have a counterpart in reality. What was thought to be a substantial thing, was found not to be observable (even in principle),

[2] We should point out that philosophers have have (thanks to Hume) a notion of a thing that does not require any 'thick' or substantial notion of a thing *underlying* properties: instead one can view things themselves as constituted by a *bundle* of properties held together by a 'compresence' relation. However, even in this case the standard subject-predicate form of description will apply.

or could be eliminated without disrupting empirical aspects.[3] The stability of relations over relata has formed one path to structural realism, but this leaves us with the problem mentioned at the outset: how can there be relations without related *things*? It would be like having a handshake without the hands! Formally: if $R(x, y)$ then x and y are clearly bundled up in the relation. For example, let R be the taller-than relation. Then this is given by the set of ordered pairs of things, such as <Magic Johnson , Danny DeVito>, <Everest , K2>, <Empire State Building , Tower of Pisa>, and so on. This brings us finally to our main case for rejecting 'object-oriented physics' (a phrase due to Steven French).

It is becoming almost a truism amongst those working on quantum gravity that the relational revolution ignited by special relativity's dethroning of uniform motion has spread to include locations too. But still the relationality is defined with respect to *elements*. For example, even when Lee Smolin speaks of relational variables "created by the system itself, as it evolves" that "do not exist *a priori*, but are defined in a context of relationships created by the dynamics of the system" ([8], p. 1082), he nonetheless understands the system to be composed of "a population of diverse elements" (ibid.). But the central point we wish to make is that the notion of elements here ends up looking like that philosopher's nightmare, the 'bare particular'! A something we know not what waiting to receive its relational properties, whereupon it magically becomes a part of a physical structure. Instead, taken to its logical conclusion, the thesis of relational localisation (based in the gauge and diffeomorphism invariance of our theories) implies that at a fundamental level, things (such as Smolin's population of elements) do not exist. If anything, things are epiphenomena, by-products of more fundamental purely relational quantities.

Our first principle is that observables characterise what our theories are about: whether we can actually perform an operation to determine their values or not, they provide the ontological foundation telling us what kinds of thing exist in worlds that satisfy the theory. In a physically realistic theory, we should not wish to include 'external' components (other than for convenience). When we do make observations, they are inevitably local (or approximately so), for reasons of practical necessity. But also, these observables have to be of a form that renders them invariant under general coordinate transformations. Quantities defined at spacetime points will not be of this form, so some other means of localising is demanded and given that we wish to avoid external, unphysical elements, this should be done using physical degrees of freedom.[4] Hence, we see that the observables will be of a form involving relations between physical quantities. Now, though we speak of related quantities, this should not be taken to presuppose the priority of the individual quanti-

[3] Philosophers of science call the view that this will *continue* to occur, he 'pessimistic meta-induction'.

[4] The idea is an old and venerable one: Einstein postulated a "reference mullusc", DeWitt a "reference fluid" (consisting of an elastic medium holding a field of clocks), and more recently Rovelli suggested a "material reference frame" ("a 'realistic' local material reference system" also consisting of a field of clock-carrying particles). These all aim for the same basic goal: an invariant way to localise quantities. In each case, however, the 'physical' reference system is only elevated a little way above the external, absolute objects they are seeking to replace in that the reference frames themselves are treated as external material objects (things!).

ties. Rather, the relation is the *sine qua non* of the quantities, but not vice versa. The reason for this is simple enough, though seems not to have been appreciated: the quantities qua independent things are not invariant (that is, unphysical). To imbue them with robust ontological status (on a par with the gauge invariant quantity) is to dabble in something like a physicist's version of a bare particular.[5] We can perhaps diagnose this in terms of the language we use which, based so strongly on subject-predicate form, forces us into speaking in terms of correlations, coincidences, relations, and so on, and this leads us to fall into the trap of thinking in terms of things standing in such relationships. Hence, traditional relationalism can't help us (and, indeed, can only hinder us) in the interpretation of the relational observables we find in spacetime theories since the things grounding the relations are themselves unphysical.[6]

The only other person we know of that has considered the deep implications of the kind of structural, correlational view that gauge invariant spacetime theories appear to imply is John Earman ([4], pp. 15-6). As he points out, the notion of physical observable we described above does not sit well with either of the usual interpretive suspects: neither absolutism/substantivalist nor the relational alternatives seem able to cope. The root of the problem, again, is that both substantivalism and relationalism invoke the traditional distinction between subject and predicate, viewing spacetime points (or regions) or material bodies respectively as subjects (things) bearing various properties. He goes so far as to suggest that the gauge-invariant content of GR might demand the introduction of a new ontological category that he labels a "coincidence occurrence" that encodes the idea of co-realizing values of pairs of gauge-variant quantities. He concludes: "my feeling is that spacetime theories satisfying [substantive general covariance] are telling us that traditional subject-predicate ontologies, whether relational or absolute, have ceased to facilitate understanding" (p. 16-17). We heartily concur! However, we feel he doesn't go quite far enough, since he speaks of the co-realization of the values of dynamical (i.e. physical) quantities—seemingly buying into the 'no relations without relata' objection. But this ignores the problem that one can't make physical sense of the quantities independently of the correlation that they form so that it is wrong to speak of them as dynamical variables.

Just as coordinates provide a useful gauge allowing us to identify spacetime locations, with no physically objective reality, so *things* and *thing-talk* act as a kind of 'gauge fixing of the world'.[7] It is possible that evolutionary mechanisms determined the specific gauge

[5]There is a curious parallel here with the measurement problem in the context of EPR experiments on spin-singlets: before a measurement is made, the components of the singlet are in a kind of limbo. But the crucial difference in the gauge theory case is that the limbo is not one of probabilistic uncertainty over which value will be found; rather it concerns unphysical structure in the sense that no reality (other than a purely formal one) can be ascribed to it whatsoever.

[6]We might also add, at this point, that the idea that quantum gravity involves a (traditional) relationalist stance has also become something of a recent dogma. Our proposal is also intended to counteract this.

[7]Technically speaking, a gauge will be a function of a parameter space (changing as one varies the location in this parameter, or base space): we have no idea what the appropriate base space would be for the 'thing

fixing that characterises the human cognitive framework. It does not seem outlandish to suppose that alternative cognitive frameworks (and perceptual faculties) would 'gauge fix' in a different way, while still preserving the same relational structures.[8] Hence, the choice of things seems to be more variable than the structure exhibited by things. Rather than having an undifferentiated blooming, buzzing confusion, by fixing on things we can navigate the world. The thing-gauge acts as an identification map between a dictionary of thing words or concepts and aspects of world structure.[9]

Lest the reader suppose that a gauge fixing couldn't possibly have the kind of physical significance we are suggesting here, we would point to the case of the (arbitrary) gauge fixing used to pick a prime meridian or zero on the Earth—this makes longitude a (global) gauge symmetry.[10] Once selected by George Airy in 1851, Greenwich determined the evolution of multiple aspects of human life—it continues to do (albeit now using the International Reference Meridian) as the zero for GPS technology. Given its physical arbitrariness, one can easily imagine different choices for the meridian, but that would have led to slightly different human behaviour. If one did choose to do this, then one would of course have to specify one's numbers relative to a choice of prime meridian for them to be physically meaningful.

4 There'll Be Some Changes Made

We don't expect the physics of things to vanish, but we do believe it has a useful role to play in fundamental physics involving what are usually thought of in traditional relationalist terms (such as relative locality). What kind of physics can be expected to flow

gauge'. Hence we don't claim the analogy is without its problems!

[8]Interestingly, this line of thought has impressive pedigree in the form of Poincaré (where he speaks of "enunciations" in place of our coordinates): "Since the enunciation of our laws may vary with the conventions that we adopt, since these conventions may modify even the natural relations of these laws, is there in the manifold of these laws something independent of these conventions and which may, so to speak, play the role of *universal invariant*? For instance, the fiction has been introduced of beings who, having been educated in a world different from ours, would have been led to create a non-Euclidean geometry. If these beings were afterwards suddenly transported into our world, they would observe the same laws as we, but they would enunciate them in an entirely different way. In truth there would still be something in common between the two enunciations, but this is because the beings do not yet differ enough from us. Beings still more strange may be imagined, and the part common to the two systems of enunciations will shrink more and more. Will it thus shrink in convergence to zero, or will there remain an irreducible residue which will then be the universal invariant sought?" ([7], p. 334). His response to his question is also along the lines we suggest here: "What now is the nature of this invariant it is easy to understand, and a word will suffice us. The invariant laws are the relations between the crude facts, while the relations between the 'scientific facts' remain always dependent on certain conventions" (ibid, p. 336).

[9]This view clearly presupposes that 'the real world' (which we are understanding as a structural entity) does not have distinguished striations carving it up into 'natural' things.

[10]The process is a little more complicated than this suggests, since one must map the Earth's surface to a standard unit 2-sphere and then pick an orientation, a zero-point pole, and *then* a prime meridian.

from a physics without things? Given the space remaining, we don't propose to offer any new framework in which to conduct such physics. Instead we briefly point to somefew examples that seem to fit the general mould.

The first is an ongoing attempt to revise the mathematical foundations that might link up with the physical picture we have offered. In particular, category theory offers an alternative foundation to mathematical structure (and therefore, a potential alternative means of representing physical theories). The idea is to view such structures (usually viewed as set theoretic entities composed of elements) as objects in a category characterised by the morphisms (arrows) between objects. In this way, it is the arrows to and from objects that receive prime billing. John Baez [1] has shown how one can set up appropriate categories for GR and quantum field theory by invoking the appropriate morphisms. The categories are $nCob$ and $Hilb$, n-dimensional manifolds and mappings (cobordisms) between them and Hilbert spaces and mappings (linear operators) between them. As Michael Atiyah has shown, one can understand a topological quantum field theory (a diffeomorphism invariant quantum field theory, without local degrees of freedom) as a morphism between these categories (known as a 'functor'). We mention this to point out that there is a mathematical foundation available with features rather closely aligned with the physical ideas we have presented—*cf.* [2].

Quantum entanglement involves the notion that the total quantum system is not reducible to the properties of its subsystems, thus exhibiting a kind of 'relational holism'—*cf.* §6 of Healey's entry on Holism and Nonseparability in Physics: http://plato.stanford.edu/entries/physics-holism/. Formally, an entangled state (for an N-dimensional system) is 'non-factorizable' in the sense that $\Psi_{1,\ldots,N} \neq \Psi_1 \otimes \cdots \otimes \Psi_N$. Hence, there is a suggestion even in standard quantum mechanics that the world might not submit to being carved up in terms of individual things. Even here, however, some sense of spacetime frame is involved in the definition of the quantum theory, and so if one argues that quantum subsystems are not things, the underlying spacetime must seemingly be so understood in order to make sense of the distances in distant correlations.[11]

Finally, we note that Giovanni Amelino-Camelia's "detectors-first" methodology described in his essay for this competition, also provides an interesting potential example of the kind of structural physics we have in mind: http://www.fqxi.org/community/forum/topic/1442. Amelino-Camelia proposes that locations be given a relational def-

[11] Esfeld and Lam [5] argue that such relations in entangled systems can be understood as brute and unreducible to the intrinsic subsystem properties. In these cases too there is an external spacetime supporting the relations (and other state-independent properties). But then they do not believe that any part of current physics warrants the elimination of objects: "metaphysics should not be more revisionary than is required to account for the results of science, and in that respect, we do not see a cogent reason to abandon a commitment to objects" (p. 148). In this sense, they claim to tread a 'moderate' path towards structural realism. Ultimately, they propose that the 'object-property' distinction (where 'property' includes relations and structure) is not a fundamental ontological one, but a conceptual one, which sounds to our ears much like Earman's suggestion to dispense with the fundamentality of the subject-predicate distinction. A move, that we argued, recommends our further proposal to treat things as a kind of gauge fixing.

inition in terms of "detection at a given detector", with detection times likewise given by a material clock established at the detector site. Spacetime observables are then to be couched in such terms so that the notion of an independent spacetime framework becomes a redundant (though often convenient). Of course, this still leaves the detectors and clocks in need of an invariant physical definition, lest they simply replicate Einstein's unphysical rods and clocks. As we argued, to do so requires that we don't assign them physical reality independently of the irreducibly relational construct in which they are implicated, since so viewed they will not have physical locations or properties of their own. The cases he mentions in support of his view, will likewise form supporting cases for our view, though, again, combined with the proviso that the things (here 'detector' and 'detected') not be invested with independent existence: they are defined by the more fundamental invariant correlation they represent.

5 Until the Real Thing Comes Along?

Can we really be so confident that a world of primitive relations will be the final story? Is there something *necessary* about it, or does it simply provide a useful path? We have proposed that thing-talk is a convenient fiction: relations are the fundamental thing. We motivated this using invariance principles, but one can also see it perhaps more clearly by considering the role of observation in physics. Take the observation of the distance moved by some object, or the time elapsed of some process. To establish this requires that points be specified between which the lengths and time are defined. However, a purely formal specification of families of four numbers (the coordinate values) won't do (because of general coordinate invariance): one needs to *physically* locate the end points containing the lengths and intervals. This involves 'marking' the points using some other object or process, and thus forming a relation, allowing for the required determination.[12] But to view this as marking some pre-existing space is wrongheaded: the spacetime framework is built from such correlations. If physics continues to be based on this kind of framework—and there is surely something to the Kantian view that *experience* (an ineliminable stage of physics) demands a spatiotemporal framework—then a physics of primitive relations like this is surely required.

[12]Likewise, in quantum field theory one measures 'distance' from the vacuum state by using a similar physical setup of correlations, in this case collisions of various kinds. (One can specify general characteristics via the S-matrix, but even in Heisenberg's hands this S-matrix was supposed to be filled in by some physics of things, rather than viewing the S-matrix structure as a relational structure of which things can offer a representation.) This correlational form is presumably a general feature of empirical science, and underlying it is some notion of a spatiotemporal structure allowing for divisions between the object of study and the external means of testing or observing. But given diffeomorphism invariance, this usable spacetime structure must itself be bootstrapped into existence from physical quantities, which in order to make sense must have spatiotemporal properties. Thus the irreducibility of the relational structure in this case.

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