Withering Away, Weakly

Abstract. One of the reasons provided for the shift away from an ontology, for physical reality, of material objects & properties towards one of physical structures & relations (Ontological Structural Realism: OntSR) is that the quantum-mechanical description of composite physical systems of similar elementary particles entails they are indiscernible. As material objects, they ‘whither away’. We inquire into the question whether recent results establishing the weak discernibility of elementary particles pose a threat for this quantum-mechanical reason for OntSR, because precisely their discernibility prevents them from ‘whithering away’. We argue there is a straightforward manner to consider the recent results as a reason for OntSR rather than against it. Finally we argue that the relativistic quantum field provides an even better reason for OntSR.

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1 Whither Elementary Particles?

According to our best scientifically informed philosophical views, everything in the universe, from the body of Albert Einstein to the brain of Angelina Jolie and from the ideas of Ludwig Wittgenstein to the music of Igor Strawinsky, ultimately either consists of or supervenes on pieces of *interacting matter*; without interacting matter there is nothing whatsoever, perhaps not even space-time. According to our best scientific theories, every piece of matter in the universe is composed of *elementary particles*, ultimately quarks, leptons and bosons. Hence everything in the universe ultimately either consist of or supervenes on elementary particles. This makes elementary particles truly and uniquely *fundamental*.

According to quantum mechanics (QM), elementary particles are *unlike* tiny indivisible pieces of rigid matter in motion, occupying a definite location at every instant of time, colliding with other particles. This much is pretty certain. In good Popperian spirit, we know pretty certain what an elementary particle is *not*.

But what *are* elementary particles? What are they *like*? We must know.

QM tells us more, if only a little: elementary particles possess some properties, such as mass, charge and magnitude of spin. Yet all other properties are denied to them, unless we perform measurements on them. Just after measurements are performed on them, in the laboratory, they acquire some additional properties. But only for a split second. After measurements have ended, the properties pop out of existence. And they pop back into existence upon measurement and only upon measurement, unpredictably. Elementary particles are somewhat like colourless, amorphous entities in a box that obtain a shining colour and assume a definite shape as soon as someone opens the box. Sheer magic. *Real* magic. Elementary particles never occupy any definite location. They are neither somewhere nor everywhere. Yet there is a non-vanishing probability to find them anywhere upon measurement, also outside boxes with the thickest of walls, just after you put them in there. Furthermore, elementary particles behave *as if* they were tiny billiard balls in some respects when they find themselves in certain particular circumstances, created by us; and they behave *as if* they were tiny waves in some respects when they find themselves in other particular circumstances, also created by us. This is called ‘the wave-particle duality’. But, as Feynman knew, to introduce a word for something does not mean you understand it. They are like little schizophrenics it seems — although the proposal to call them ‘wavicles’ rather than ‘particles’ to express this has not caught on, as have Nicholas Maxwell’s proposal to call them ‘propensitons’ and Lévy-Leblond’s to call them ‘quantons’. Admittedly naming is not the same as understanding, but a different word just to signal that the quantum-mechanical particle-concept is very *unlike* the classical particle-concept we
once knew, used and loved seems an excellent idea.

When sets of what Dirac called similar elementary particles are considered (i.e. having the same few properties they do possess), they lose their individuality, as a consequence of the symmetrisation postulate of QM, according to which permuting them does not yield a situation that is physically discernible from the unpermuted one. Ever since Weyl brought it up about eighty years ago and Margenau emphasised it about twenty years later, philosophers of physics have been arguing that this means that QM refutes Leibniz’s venerable principle of the identity of indiscernibles (PII), for when we can have composite physical systems consisting of indiscernible particles, then PII is refuted because PII precisely forbids the existence of indiscernible objects. So elementary particles are indiscernibles, precisely as Schrödinger begged us to believe. After having taken cognizance of this, Quine bluntly concluded that ‘matter evidently goes by the board’. When we take Einstein’s insights into the nature of space and time into account, and wed QM to his Special Theory of Relativity by cutting away infinities that arise in the process (renormalisation), particles no longer live eternally. They can be annihilated and created. We can do it and we do it, in what Casimir has called ‘the cathedrals of the 20th Century’: the high-energy particle accelerators that have the size of cities, those magnificent symbols of the pursuit to unravel the mysteries of the cosmos. By the way, the effect named after Casimir showed that quantum-physical empty space (the vacuum), i.e. without ‘particles’, is not a void but a plenum, seething with fluctuations; when you accelerate a ‘particle-detector’ through empty space, it registers something, as Unruh first demonstrated — presumably vacuum fluctuations. Long before talk of virtual reality became common, virtual elementary particles swarmed the stage of physics, in a limbo between definite existence and definite non-existence that still no one understands. And when elementary particles are localised somewhere, in space, at some point in time, upon measurement in a laboratory, they are not localised anywhere according to someone who happens to drive by the laboratory on her bicycle — for localisation is not Lorentz-invariant, as Wigner pointed out long ago. Bafflingly, a quantum theory of localisable particles in Minkowski space-time turns out to be mathematically impossible altogether, as Malament demonstrated. The marriage between QM and the special theory of relativity seems the death-knell of the already meagre quantum-mechanical concept of a particle-concept.

If these quantum-physical considerations do not make a case for a revision of our fundamental ontology of material objects with properties, then nothing ever will revise it. At the truly and uniquely fundamental level of physical reality there are no individual material objects with properties and relations that derive from properties.
There are no individuals. There are no absolute discernibles. Let’s face it, *indiscernible* objects are no objects at all. Identity conditions break down. No identity, no entity. Quantification breaks down. We can talk no more — and *if* anyone wants to keep talking of physical objects nonetheless, then he must kiss goodbye standard mathematics and standard logics, must embrace an entirely different set-theory and logic, as Dalla Chiara, French an others know.6 All in all, elementary particles as material objects whither away. For whom science matters, everything must go. What will replace it?

Enter *ontological structural realism*. Elementary particles are *structures*. At the truly and uniquely fundamental level of physical reality there are only structures. Structures drive on relations. If structures have properties, these properties derive from relations. ‘Particles’ are no more than placeholders in structures. They don’t really exist. Only structures exist. Schrödinger: “Some philosophers of the past, if the case could be put to them, would say that the modern atom consists of no stuff at all but is pure shape.”7

So the ontological structural realist lives happily ever after? Not so fast. Recently his happiness has come under threat. But before we expound the threat (in Section 3) and try to allay it (in Sections 4), we first need to get clear on the relation between scientific realism and the metaphysical thesis of ontological structural realism (Section 2).

### 2 Scientific Structural Realism

When J. Ladyman introduced the distinction between Epistemological Structural Realism (EpSR) and Ontological Structural Realism (OntSR), and argued for OntSR, he called quantum mechanics (QM) to the witness-bench; other structural realists have endorsed this strategy, notably S. French.8 We briefly inquire into their relation to the general view of scientific realism. Here is a standard formulation of scientific realism.

*Scientific Realism* (ScR). Most of the posits of our theoretical scientific knowledge, unobservables notably included, exist mind-independently.

By ‘theoretical scientific knowledge’ we mean the propositional content of all well-established scientific theories and models. (Other kinds of scientific knowledge are not included here, such as how to conduct an experiment, how to test an hypothesis, and how to apply knowledge for the benefit of mankind, because they need not be included.) The presence of the adverb ‘mind-independently’ serves to emphasise that ScR stands opposed to *idealism*. The mentioning of unobservables in ScR serves to emphasise that they (or most of them) are included: ‘Most’ in ScR does not mean a restriction to observables only.9

*Scientific Epistemological Structural Realism* (ScEpSR). All our theoretical scientific knowl-
edge of the physical universe is knowledge of its structures.

The restriction to the physical universe (physical reality) leaves room for mental reality; it leaves room for a reduction of the mental to the physical, for supervenience of the mental on the physical, and even for a Cartesian substance dualism. ScEpSR makes no pronouncements on mentality and does not harbour any kind of (anti-)physicalism. For instance, the existence of (supervening) mental non-structural entities is compatible with ScEpSR.

Further, debates on and elaborations of structural realism generally have been focussing on physics, and not, for instance, on paleontology, zoology or astronomy, to mention a few branches of natural science only. This is understandable, because ScEpSR was intended by its modern originator, J. Worrall, as being ‘the best of both worlds’, in that it was supposed to be a metaphysically meagre realism so as not to fall prey to the pessimistic meta-induction over the history of science, but still a sufficiently muscular realism to provide success-arguments in its defence (e.g. Putnam’s ‘no-miracle argument’). Since the pessimistic meta-induction thrives on the history of physics, rather than on the history of paleontology, zoology or astronomy, the debate has therefore focussed on physics. We soon join in.

Let us next combine ScEpSR and ScR. When knowledge implies truth, as few epistemologists would care to deny, then ScEpSR implies that all propositions of our theoretical scientific knowledge that posit something are true. This yields ScR, except for (the most-qualification and) the mind-independence. Indeed, one may consistently endorse ScEpSR and adopt idealism, and thereby reject ScR; this shows that ScEpSR does not imply ScR, although it does imply part of ScR. But for the general realist (anti-idealist) ScR does follow from ScEpSR, and even a more specific form of realism follows:

**Ontological Structural Realism (OntSR).** The universe consists of structures only and they exist mind-independently.

Conversely, if structures are all there is in the physical universe (OntSR), then all we can come to know of the universe by scientific inquiry is knowledge of structures. All theoretical scientific knowledge that we actually posses then must be knowledge of structures; this is ScEpSR.

Thus OntSR implies ScEpSR and although the converse implication fails, it goes through when ScEpSR is combined with ScR. So for the scientific realist (ScR), the difference between of ScEpSR and OntSR can be at most of little significance (if any), because conditional on ScR they imply each other:

\[
\text{ScR} \implies (\text{ScEpSR} \iff \text{OntSR}).
\] (1)
Hence debates among scientific realists whether an ontological or an epistemological variant of SR should be adopted are without substance. Substance would return if ScR were rejected; but then the debate between ScEpSR and OntSR could only be the traditional debate between idealism and realism.

The conclusion of the previous Section was that quantum physics, which is part of our theoretical scientific knowledge, is telling us that elementary particles are not material objects but structures. This is ScEpSR; and for the scientific realist (ScR) we then have OntSR by virtue of (1). But at the end of the previous Section we also mentioned a threat to the claim that elementary particles are not material objects, which eo ipso constitutes a threat to OntSR. We now turn to the basis of this threat.

3 Weak Discernibles

Recently S.W. Saunders has argued that similar particles can be saved from indiscernibility. They can be discerned by physically meaningful binary relations that are permutation-invariant; that is, by relations that are symmetric and either irreflexive or reflexive. This makes the particles weakly discernible, to follow Quine’s terminology. What is more, these relations are categorical in that they do not involve the quantum-mechanical probabilities. Call an object (in a set $S$ of objects) that is absolutely discernible — meaning that it has a property that no other object in $S$ — an individual (so that its ‘individuality’ resides in that property); call an object that is relationally discernible — meaning that it is discerned from all other objects in $S$ by a relation — a relational; and call an object that is neither an individual nor a relational indiscernible. Then elementary particles are not indiscernibles but relationals. We provide two examples of this and refer to the relevant literature for the general theorems.

Example 1. Consider a composite physical system of two fermions having spin $\frac{\hbar}{2}$ and finite-dimensional Hilbert-space $\mathcal{H} = \mathbb{C}^2$; then $\mathbb{C}^2 \otimes \mathbb{C}^2$ is the pure state space of the composite system. We have a set $\{1, 2\}$ of two particles-names (or labels) ‘1’ and ‘2’, over which the particle-variables $a$ and $b$ run. There is only a single admissible pure state (and therefore no admissible mixed states), which is the (unit ray of the) anti-symmetric singlet-state:

$$|\Psi\rangle \equiv \frac{1}{\sqrt{2}}(|z^+\rangle \otimes |z^-\rangle - |z^-\rangle \otimes |z^+\rangle) \in \mathbb{C}^2 \otimes \mathbb{C}^2.$$  

Consider the following physically meaningful and permutation-symmetric ‘Total-spin relation’ (in units of $\frac{\hbar^2}{2}$):

$$\mathcal{T}(a, b) \iff (\sigma_a + \sigma_b)^2 |\Psi\rangle = 12 |\Psi\rangle,$$  

where $|\Psi\rangle \equiv \frac{1}{\sqrt{2}}(|z^+\rangle \otimes |z^-\rangle - |z^-\rangle \otimes |z^+\rangle) \in \mathbb{C}^2 \otimes \mathbb{C}^2$.  

5
where

\[ \sigma_1 \equiv (\sigma_x + \sigma_y + \sigma_z) \otimes 1 \quad \text{and} \quad \sigma_2 \equiv 1 \otimes (\sigma_x + \sigma_y + \sigma_z). \quad (4) \]

Relation \( T \) (3) demonstrably discerns the two fermions weakly and categorically.\(^{14}\)

**Example 2.** Consider a composite system of two arbitrary similar particles and infinite-dimensional Hilbert-space \( \mathcal{H} = L^2(\mathbb{R}^3) \). Let \( \hat{P} \) be the linear momentum operator and \( \hat{Q} \) the Cartesian position-operator acting in \( L^2(\mathbb{R}^3) \). Consider the following physically meaningful and permutation-invariant ‘commutator-relation’:

\[
C(a, b) \iff \forall \Phi \in \mathcal{D} : \left[ \hat{P}_a, \hat{Q}_b \right] \Phi = -i\hbar \Phi, \quad (5)
\]

where \( \mathcal{D} \subseteq L^2(\mathbb{R}^3) \otimes L^2(\mathbb{R}^3) \) is the domain of the commutator, and where

\[ \hat{Q}_1 = \hat{Q} \otimes 1 \quad \text{and} \quad \hat{Q}_2 = 1 \otimes \hat{Q}, \quad (6) \]

and similarly for \( \hat{P}_1 \) and \( \hat{P}_2 \), respectively. Relation \( C \) (5) discerns the two particles weakly and categorically.\(^{15}\)

We mention that the general proofs do neither rely on the projection postulate of QM nor on the standard property postulate of QM (a system has a quantitative property iff it is in an eigenstate of the corresponding operator), but they do rely on the uncontroversial conjunct of the last-mentioned (if in an eigenstate, then a property).

In all discernibility-proofs, one begins with the *numerical* diversity of having \( N > 1 \) named particles (\( N = 2 \) in the two examples above). If one were to account for this numerical diversity by appealing to the names of the particles only, say, and not to anything *physical* about these particles, one would be spreading the smell circularity. But one does no such thing. The numerical diversity is accounted for *physically*, that is, by means of physically meaningful and permutation-invariant relations, as in the two examples above.

Let us now see how these results bear on OntSR.

### 4 The Threat of Relationals

The French-Ladyman argument in favour of OntSR based on QM runs as follows.\(^{16}\) According to QM, an ontology of the truly and uniquely fundamental level of physical reality consisting of physical individuals must go, because similar elementary particles are indiscernible and indiscernibles are not individual objects. Then, when you want to be realist with regard to QM (ScR), you better become a ontological structural realist — OntSR or ScEpSR, that doesn’t matter (1). But we have just seen that, although
elementary particles are *absolutely indiscernible*, they are weakly *discernible*. This blocks the inference to OntSR for the scientific realist (ScR) it seems, because it seems that now ScEpSR is under threat.

Nevertheless, there is a way to infer OntSR, even in the light of the fact that elementary particles are discernible. This way opens as soon as we call to mind that structures consist of objects with relations; these objects are determined only in so far as they are determined by the relations in the structure.

This raises, however, a pertinent question: are properties of elementary particles like mass, charge and spin-magnitude, determined by relations? This question needs to be answered in the affirmative by the structural realist (ScEpSR, OntSR), because the presence of properties in structures is only permitted when they are determined by relations. The answer is provided by the symmetry-group of QM, which is the Galilei-group.17 The starting point of symmetry considerations is a *relation* between physical systems: one system being symmetric to another one, defined as there being a transformation (a map) that sends one to the other (active transformations); and: one description of a system being symmetric to another description of the same system, defined as there being a transformation (a map) that sends one description to another one (passive transformations). In physics the last-mentioned usually takes the form of an equation being covariant under the transformation of the physical magnitudes occurring in the equation. Notice we then have *three relations* here: an equation (which is a relation), the relations of covariance between equations (form-invariance), and physical magnitudes being related to transformed physical magnitudes. These transformations usually form a group. In QM the Galilei transformations form a connected Lie-group, which consist of the displacements and the rotations (they form the Euclidean group), and the Galilei-boosts (this can be extended by global phase-transformations of the state so as to obtain the Bargmann-group). The associated Lie-Algebra generates the Casimir-invariants, among which we find mass and spin-magnitude. These properties thus are determined by symmetry relations, which makes them acceptable for the structural realist.

Hence when you want to be realist (ScR) with regard to QM, you better adhere to OntSR after all. We conclude that the threat coming from the weak discernibility result has not only been allayed; this result has been transformed in an ally of OntSR.

But we are not there yet. Until now we have been arguing against a Galilean space-time background, which is not the space-time of our universe. We must move to Minkowskian space-time of the Special Theory of Relativity (and then to the semi-Riemannian space-time of the General Theory of Relativity, although this last move will not be performed in this paper).
5 Epilogue: the Inscrutable Quantum Field

We propose to replace the quantum-mechanical arguments for OntSR with the following one, which we expound step-wise (when ‘from …’ appears between round brackets, this means that the current proposition follows deductively from …).

S1. A quantum-theory of particles against a Minkowskian background space-time is mathematically impossible (Malament’s Theorem).

S2. The Standard Model is formulated in the framework of Relativistic Quantum Field Theory (RQFT), which is a quantum-theory of fields on Minkowskian space-time. The ontological substances of RQFT are space-time and the quantum field, and not the particle.

S3. The Standard Model of (non-gravitationally) interacting matter is not a particle theory (from S2) and cannot be interpreted as a particle-theory (from S1, S2).18

S4. The vacuum of RQFT is unlike literally empty space-time, i.e. space-time without material particles (Casimir effect, Unruh effect, Reeh-Schlieder Theorem); it is a plenum seething with activity.

S5. The Standard Model currently is the best scientific theory of (non-gravitationally) interacting matter.

S6. The currently best scientific theory of matter and its interactions (save gravity) is not a particle-theory (from S4, S5).

S7. The currently best guess of the fundamental ontological substance of the universe is the relativistic quantum field (from S2, S6).

S8. The words ‘quantum field’ express first and foremost a mathematical concept, e.g. an operator-valued distribution attached to a space-time region, or an operator (acting on a non-separable Hilbert-space) attached to a space-time point.

S9. Setting the Teller-Maxwell interpretation of the quantum-field as a propensity-field aside (because re-naming is not the same as understanding), there is no way known of how to interpret — let alone how to depict — the mathematical concept of a quantum field physically; we only know how to use this mathematical concept to calculate cross-sections and other measurables.

S10. Consider the quantum field as a sui generis physical structure (in the light of S7, S8, S9).
S11. The universe consists of physical structures (from S4, S7, S10). This is OntSR.

This is the best argument for OntSR that we are able to muster at present. We do not claim that the expression ‘the quantum field is a *sui generis* physical structure’ (S10) is as clear and we want it to be, although we do have a reasonable grasp of the *structure*-concept that occurs in it and thereby are beyond mere re-naming. To make it as clear as we want it to be is a formidable project that lies beyond the scope of the current paper. Further steps have been set elsewhere.\(^{19}\) What we do claim is that when we return to Galilean space-time and restrict ourselves to QM, (i) we have a clear argument for OntSR (the adapted French-Ladyman argument of Section 4) and (ii) we have turned a *prima facie* threat to OntSR, namely the weak discernibility of elementary particles, into an ally of OntSR.
Notes

2Quine [1976b: 499].
3See Redhead [1995].
4Malament [1996], Halvorson & Clifton [2002].
5We therefore disagree with Chakravarty [2003], who claims that the quantum-physical considerations provide insufficient ground for rejecting a fundamental ontology of material objects and properties.
6See their contributions to Castellani [1998b].
7Schrödinger in Castellani [1998b: 203].
8Ladyman [1998], French & Ladyman [2003].
9For what unobservables are, see Monton and Van Fraassen [2003], and Muller [2005].
10Worrall [1989], who focussed on 19th-century physics.
11Saunders [2006], Muller & Saunders [2008], Muller & Seevinck [2008].
12Quine [1976a].
13See Muller & Saunders [2008: 503–504], for this terminology and its Quinean origins.
14For the general proof for \( N > 1 \) similar fermions in finite-dimensional Hilbert-spaces, see Muller & Saunders [2008: 535–536].
15For the proof for \( N > 1 \) similar particles in infinite-dimensional Hilbert-spaces, see Muller & Seevinck [2008], § 5.
16Ladyman [1998], French & Ladyman [2006].
17For details about what follows, see Castellani [1998a].
18Saunders [1995] and Wallace [2006] have attempted to squeeze particles out of the quantum field, but what results is such a diluted particle concept, restricted to spatial scales and energy-regimes and depending on global states of the field, that they have stretched the particle-concept beyond breaking-point.
19See the contributions of of S.Y. Auyang, A. Wayne, G.N. Fleming and P. Teller to the collection Kuhlman et. al. [2002].
References


Muller, F.A., Saunders, S.W. [2008]: ‘Discerning Fermions’, British Journal for the Philosophy of


