# Review
# Kuhlmann, Lyre, and Wayne:
# Ontological Aspects of Quantum Field Theory

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What does quantum field theory (QFT) tell us about the furniture of the world? The seventeen essays gathered in the four parts of *Ontological Aspects of Quantum Field Theory* address this question from different angles and with different objectives. Together they form a wide-ranging and up-to-date volume which makes an important contribution to an on-going discussion and which, due to the comprehensive introduction by the editors, can be of interest not only to experts but also to novices.

The essays in the first part, *Approaches to Ontology*, explore different philosophical frameworks in which the ontology of QFT could fruitfully be examined. Despite their differences, they all agree that traditional ontologies, in particular substance-attribute ontology, are unsuitable for QFT. Peter Simons begins by pointing out why substance-attribute ontology, applied set theory, fact ontology, occurrent ontologies, and trope theory are inadequate ontologies for QFT and then puts forward his own suggestion: factored ontology. The main idea of this ontology is to posit basic features (so-called 'factors') and to view objects as suitable combinations of some of these factors. He presents an outline of a version of a factored ontology, called PACIS, which he and his collaborators have developed over the last fifteen years and which they have – in their view successfully – applied to different domains in the natural and the social sciences. Given this success, Simons is confident that this framework will also prove fruitful in the case of QFT. However, he does not give any further argument for this claim and does not make an attempt at formulating a concrete factor ontology of QFT. He merely puts forward his framework as a conceptual tool and leaves it to the philosopher of physics to work out an interpretation of QFT in its terms.

Johanna Seibt begins with some methodological reflections on philosophical ontology in general and then launches a sustained attack on what she calls the ‘substance paradigm’, the presupposition that there are substances that figure as carriers of properties. On her view, substance-attribute ontologies are untenable both for their internal difficulties and their incompatibility with QFT; and she dismisses alternatives based on tropes or Whiteheadian processes as incoherent. As an alternative she suggests so-called ‘axiomatic process theory’. The leading idea of this theory is to deny that all concrete individuals are particulars – an assumption that is motivated by the substance paradigm and that still occupies center stage in Whitehead’s account – and postulate so-called ‘free processes’ as basic entities. Free processes are concrete in the sense that they are spatiotemporally occurrent but they are not particulars. As Simons, Seibt merely puts forward her framework as a suggestion without presenting a worked-out ontology of QFT.

In his comment on the former two essays Meinard Kuhlmann first compares the two frameworks and then draws attention to problems they face. The main problem with Seibt’s account, he argues, is the lack of a satisfactory explicit description and a definition of the assumed basic processes, which leaves us in dark about what free processes really are. More generally he holds against process theories that they cannot explain the obvious, namely that there are static things in the world that do not change. He then criticises Simons’ account as not parsimonious at all and therefore devoid of explanatory power. Simons’ ontology allows for 3072 fundamental combinations of factors. This, Kuhlman argues, is far too much: why not just take everything in the world as fundamental? Furthermore, he doubts that factored ontology can help us to understand how the world might look like according to QFT because its categories have no connection whatsoever to the formalism (or any other aspect) of QFT.

Sunny Auyang takes the question of how field theories refer to entities in the world as her starting point. She distinguishes two basic ways of referring to something, reference by description and direct reference, and points out that these presuppose different ontologies. Direct reference presupposes an ontology of individual entities with numerical identity. Descriptive reference works against an ontological background of bundles of qualities. Interestingly, both types of reference occur in QFT, from which she draws the conclusion that the ontology of QFT is much more complex than one might think.

The second part of the book, *Field Ontologies for QFT*, is dedicated to a discussion of Paul Teller's suggestion (put forward in his 1995 book) that the basic entities of QFT are quanta, which, unlike classical particles, lack 'primitive thisness'. In the course of his discussion of QFT Teller also dismisses a naive understanding of QFT – one which takes field configurations to be represented by field operators – as entirely wrongheaded. Andrew Wayne aims at resisting this judgement and argues that, suitably developed, this naive way of thinking about the quantum field can provide a valuable basis for an interpretation of QFT. He does not provide a worked-out interpretation, but presents some preliminary results in this direction which center around the notion of vacuum expectation values (VEVs). These values have the essential feature that they offer a characterization of all information contained in the quantum field operators. The central claim of Wayne's VEV interpretation of QFT is that VEVs for field operators correspond to field values in physical systems with quantum fields.

Gordon Fleming agrees with Teller's characterisation of quantum particles as ones that lack primitive thisness; but he does not believe that this provides a sufficient reason for the move from the labelled tensor product formalism to a Fock space formulation. Surplus structure *per se* is not objectionable in physics and if we want to get rid of some particular piece of surplus structure we need an argument. But, according to Fleming, Teller does not have such an argument as it is not true that the excess formal structure comes at the high ontological costs that Teller maintains. As regards Teller's claims about quantum fields, Fleming is by and large in agreement with Wayne that the operator valued quantum field is in closer correspondence to the classical field than Teller admits.

Teller replies to these criticisms by articulating two further important differences between classical and quantum fields. First, unlike in classical physics where field configurations are contingent in that alternative sets of field values are possible, in the quantum context the actual configuration is necessary and no alternatives are possible. This is because the information the operator valued quantum field carries is, on Tellers reading, more like the information carried by Maxwell's equations as opposed to the information carried by one or the other configuration of the electromagnetic field. Second, quantum fields do not have the same causal efficacy as classical fields do. Classical fields, according to Teller, are causal agents in that they produce observable phenomena, while the operator valued quantum field has only something like structural efficacy, meaning that it does no more than specifying the structure of physically possible occurrences.

The third part of the book, *Relativity, Measurement and Renormalization*, begins with Jeffrey Barrett's contribution who points out that relativistic QFT (RQFT) does not help to solve the measurement problem. On the contrary, due to additional relativistic constraints and Malaments theorem (roughly: given certain plausible assumptions, there cannot be any detectable objects of finite size) a solution is even more difficult to obtain than in standard quantum mechanics. This is bad news. Since there is a close connection between proposed solutions to the measurement problem and one's ontological commitments, drawing ontological conclusions concerning RQFT without such a solution in mind would be misguided.

Hans Halvorson and Rob Clifton defend Malament's theorem against criticisms. They point out that the theorem seems most vulnerable in its tacit assumption that there is no preferred inertial reference frame and in the fact that it only establishes that there is no RQFT in which the particles are completely localizable while leaving the option open that they might be 'unsharply' localizable. Halvorson and Clifton block possible attacks on Malament's theorem by proving two no-go theorems, which show that these two assumptions are not needed to sustain the point against localizable particles. However, these results, as they are careful to point out, do not establish that a field rather than a particle ontology is appropriate to RQFTs. To rule out particle interpretations a further step is needed. They formulate necessary conditions for a RQFT to permit a particle interpretation and then show that no RQFT can satisfy these. However, not all is lost yet for the adherents of particles. As they point out in the last part of the paper, RQFT itself explains how the illusion of localisable particles can arise and how particle talk – although fictional, strictly speaking – is possible and useful even without a particle ontology.

Dennis Dieks deals with the problem of localized events within the framework of algebraic relativistic QFT (ARQFT). Although local operations are basic within this theory, it turns out to be difficult to accommodate the notion of an event taking place in a particular region of Minkowski space-time. This tension can be eliminated, Dieks argues, by adopting an interpretation of the theory based on familiar ideas from the modal interpretation of quantum mechanics. The result is a thoroughly perspectival account of quantum properties: a system's properties are only defined with respect to a frame of reference. Supplementing this with a basic decoherence condition, we find that definite physical magnitudes can be associated with each space time region, which are the localized events we were looking for.

Brigitte Falkenburg approaches the ontology of QFT from a Kantian point of view. The salient aspect of this point of view is that Kant, on Falkenburgs's reading, regards all properties, observable and unobservable ones alike, as relational and denies that there are any intrinsic properties. Falkenburg extends this view to QFT and argues that quantum fields have no reality 'on their own' and only exist as 'strongly coupled' entities.

Nick Huggett raises the question of whether QFT can possibly be a candidate for a true theory. The status of QFT is problematic because full-fledged QFT is intractable and we have to take resort to perturbative expansions of free field solutions, and even these only yield results when supplemented with appropriate renormalization techniques. So it seems that this is grist to the instrumentalist's mill, who denies that general laws provide a literally true description of physical reality. Huggett argues that this impression, although plausible at first sight, is delusive. Based on a detailed analysis of how renormalization proceeds he puts forward the claim that we can be realists about QFT because the physics of the full-fledged theory is well captured by perturbative renormalization.

At the beginning of the fourth part, *Gauge Symmetries and the Vacuum*, Michael Redhead observes that physical theories often contain what he calls 'surplus structure', i.e. elements of mathematics that are connected to other parts of the theory but lack a direct link to reality. Gauge transformations are transformations that only act non-trivially on the surplus structure and reduce to identity on the parts of the formalism that have empirical content. Given this, how can gauge symmetries provide interesting information about the physical world? There are three answers to this question. First, one can move gauge potentials across the boundary of the surplus structure and interpret them realistically. This has the advantage that we can explain how gauge potentials bring about the relative phase shifts in the Aharonov-Bohm effect, but the disadvantage that the theory becomes indeterministic unless ad-hoc hidden variables are introduced that pick out one true gauge. Second, one can reformulate the theory in terms of gauge-invariant quantities. This has the consequence that the theory becomes non-local. Furthermore, the principle of gauge-invariance can no longer be used simply because there is nothing in the theory to which it could be applied. Third, and this is the answer that Redhead favours, one can allow non-gauge-invariant properties to enter the theory via the surplus structure and develop the theory by introducing yet more surplus structure such as ghost fields, antifields and so on. This is the route that has been followed in the development of field theory. However, it has the disadvantage that it leaves us with the puzzle of how to interpret these mysterious objects. Given that the gauge principle is arguably the most fundamental cornerstone in modern field theory, to clarify the nature of these objects is, according to Redhead, the most pressing problem in current philosophy of physics.

Michael Drieschner, Tim Oliver Eynck and Holger Lyre do not agree with Redheads assessment and defend the second of his options. They point out that the fact that the theory becomes non-local does not tell against the second option because, upon closer examination, all three options have non-local features. They then formulate an account of what they call 'prepotentials' (non-separable equivalence classes of gauge potentials in the entire space) and point out that these prepotentials are equivalent to the loop integrals used in the second approach. They then suggest that these prepotentials are the basic entities of gauge field theories.

Is the so-called ‘zero-point energy’ real? This is the question that Simon Saunders addresses in his contribution. He first puts this question into the context of the cosmological constant problem and then approaches it from a historical perspective by discussing in great detail the classical ether and Dirac’s negative energy sea. After this he examines the different roles that the Casimir effect has played in the context of arguments for the reality of the zero point energy. Finally, a discussion of zero-point fluctuations leads him to conclude that one should resist thinking that the zero-point energy is both real and unreasonably large. He then, returning to the cosmological constant problem, suggest to view the cancellation of the zero-point energy by the cosmological constant as a renormalization of the expectation value of the energy-stress tensor. This suggestion, if correct, would lend further support to the above conclusion.

Miklos Rédei discusses the nature of the vacuum with the framework of algebraic QFT (AQFT). One of the noteworthy features of this framework is its ontological silence: the axioms of the theory do not mention fields or particles at all. But this, as Rédei points out, does not imply ontological neutrality for two reasons. First, while AQFT is hospitable to a field ontology, it is, as a result of the theorems of Reeh-Schlieder and Malament, incompatible with an ontology based on localised particles. Second, AQFT can accommodate the principle of the common cause, which posits a common cause at the intersection of the backward light cones of two spacelike separated events. But it is still an open question whether there actually are such common causes in QFT.

The essays collected in this book do not present a definite and unanimous answer to the question of what there is according to QFT, but they are a very valuable contribution to the philosophical discussion of QFT, and on that certainly will be a reference point for future work in this field.