Objects or Events ?

Towards an Ontology for Quantum Field Theory

Abstract

The recent work of P. Teller and S. Auyang in the philosophy of Quantum Field Theory (QFT) has stimulated the search for the fundamental entities of that theory. In QFT, the classical notion of a particle collapses. The theory does not only forbid classical, i.e. spatiotemporally identifiable particles, but it makes particles of the same type conceptually indistinguishable. Teller and Auyang have suggested competing ersatz-ontologies which could account for the (loss of the particles(: Field quanta *vs*. Field events. However, both ontologies suffer from serious defects. While quanta lack numerical identity, spatiotemporal localizability, and independence from basis-representations, events - if understood as concrete measurement events - are related to the theory only statistically. I propose an alternative solution: The entities of QFT are events of the type (Quantum system S is in quantum state ((. The latter are not point events, but Davidsonian events, i.e. they can be identified by their location inside the *causal* net of the world.

1.Preface

In recent analytical work on ontology, ontological problems raised by modern physics are mentioned casually at most. This corresponds to a widespread neglect of analytic ontology by people studying the ontological consequences that follow from physics theories, e.g., from Quantum Field Theory. In this paper I shall argue that, despite the spirit of mutual disregard of ontology and physics, exchange of ideas between those fields can be beneficial. Some of the moves in the development of pure ontological conceptions do seem to address the ontological problems that arise in physics theories. Ontological conceptions, such as the ones developed by P. Strawson 1959, W.V.O. Quine 1960, D.M. Armstrong 1989, and D. Davidson 1969, may be interpreted as (responding(to problems of ontology discussed in the recent work on QFT by P.

Teller 1995 and S. Auyang 1995.

The emergence of increasingly abstract types of objects in the physics domain, seems to coincide with the replacement of spatiotemporal localizability as the essence of identity - as it appears in P. Strawson´s conception of particulars - by W.V.O. Quine´s logical criterion of identity. This criterion allows for fundamental entities other than objects in space and time, and thereby opens the door for spatiotemporally non-localizable entities like quantum (particles(. If we reject, however, space and time as supplying the primary criterion of identity, the problem immediately arises of how to account for cases in which theories employ entities that cannot be distinguished by means of their theoretical predicates, as it is the case for quantum (particles(. In this case, Quine recommends to turn to the Universals relative to which these entities are indistinguishable. This means, however, in the case of Quantum physics that types of quantum states have to count as the physical entities and this is in conflict with the intuition that physics theories deal with concrete physical systems.

According to D.M. Armstrong, the things we deal with in ordinary discourse and in scientific theories are states of affairs, i.e. instantiations of Universals. Since quanta are indistinguishable entities, i.e. they cannot be distinguished independently of their being different instantiations of the same excitation mode, this idea fits the quanta-interpretation of QFT, as advocated by P. Teller.

In contrast to the quanta-interpretation of P. Teller, S. Auyang thinks that spatiotemporal identity proves to be the only form of identity applying to concrete things (Teller´s quanta, according to Auyang, do not only suffer from being indistinguishable, but also from the fact that quanta-representations of physical states are basis-dependent). In the domain of QFT, however, spatiotemporally identifiable classical objects do not exist. It is not objects, but concrete physical events that make up the quantum field. Unfortunately, it turns out to be inappropriate to identify the entities of QFT with Auyang´s events, because what Auyang means by (events(are either the events of measurement which are related to the theory merely by statistical relations, or they are general descriptions of a type of events (e.g. the presence of a number of a certain sort of quanta). In the latter case, however, they are not concrete physical entities.

There remains, however, another solution. This is to take the fundamental entities of QFT to be events, without identifying them by their spatiotemporal location. Instead these events can be identified by virtue of their causal location, in the manner suggested by D. Davidson. In other words, these events would be identified by their causal past and future. The only (invariant) candidates that fit into this scheme, in my view, are the whole quantum states of physical systems. But what about the quanta ? They lose their ontological status and re-appear as (basis-dependent) conceptual representations of physical events (whole quantum states). As exemplars of Davidsonian states of affairs they are not physically real, but represent different conceptual perspectives that can be taken on some physically real event.

(2) Strawson´s Objects

According to Strawson, spatiotemporal localizability is the essence of identity. In any talk about ordinary experience we have to refer to particular objects (or particulars) the identity of which is given by recourse to spatiotemporal localizations. This unique role of spatiotemporal localization, as Strawson thinks, is not a contingent matter of fact, but expresses that the concept of a particular is intrinsically tied to a spatiotemporal conceptual schema.

Our preferred way of identifying particulars is material localization, i.e. we identify things (directly) by demonstrative reference (Strawson 1959, p.19) or (indirectly) by relating them to already identified things according to their relative location in a comprehensive spatiotemporal framework (Strawson 1959, p.22). This is why material objects are the paradigmatic particulars (Strawson 1959, p.55 and 87). What is more, the concept of a particular entails the idea of an all-embracing spatiotemporal frame.

To know a particular is to know an individuating fact about this particular, and those facts are, in the first place, spatiotemporal facts. Even if a particular is not itself a spatiotemporally localizable thing, any individuating fact about the particular must be construed by relating it to some other localizable particular (e.g. a particular thought is perhaps not a spatiotemporally localizable thing, but in order to be counted as a particular, it has to be tied to a localizable person at a particular time). The system of spatiotemporal relations is the privileged stage of empirical reality (as opposed to reality relative to some story or to some theory).

In order to be able to use a unique spatiotemporal scene at different times, we need solid reference bodies which we can re-identify at different times. But even if we keep track of bodies through time by continuous perception, we will never perceive more than qualitative identity of bodies through time. Therefore, our system of identification of particulars entails an irreducible non-empirical element: the idea of numerical identity (or: (primitive thisness() of material reference bodies through time, irrespective of and beyond qualitative identity. Therefore, the very use of the concept of a particular ultimately depends on the belief that material things have the property of primitive thisness (Strawson 1959, p.35). Exactly this belief, however, has to be abandoned in the case of quantum particles. Quantum particles simply have no primitive thisness. According to QFT, they are (quanta(, i.e. excitation modes of a quantum field that cannot be identified independently of their being instantiations of some typ of field excitation (cf. Teller 1995, p.20).

(3) Quine´s Instances

According to Quine, our epistemic access to objects is not a matter of perception, but of linguistic reference. Perceptual experience satisfies the truth conditions of (observation) sentenes, but does not single out particular types of referents for the general terms occuring in those sentences. Particulars are singled out by linguistic acts, and through these linguistic acts some domain of reference that fits the truth conditions is selected as an interpretation of a general term. Importantly, since satisfaction of truth conditions does not single out a domain uniquely, the act of reference is partly conventional: Any selected domain of reference can be replaced by some other domain without thereby changing any empirical matter of fact that could substantiate a preference for the selection of a particular domain (Quine 1981, p.16f.).

Quine´s objects are instances (or values) of the theoretical variables occuring in the canonical notation of scientific (and ordinary) discourse. Since satisfaction of truth conditions is a logical condition, not necessarily tied to such material characteristics as spatiotemporal localization, the limits of Quine´s ontology are considerably less restrictive than Strawson´s: n-Tupels of real numbers count as particulars that are as perfect as material bodies. The fact that material bodies are, in a sense, the preferred referents of our ordinary discourse has nothing to do with any necessary preconditions of our knowledge of the world, but rather contingently characterizes the home language to which we are adapted.

Nonetheless, there are limits. The limits are drawn by the logical condition of identity. For particulars to feature as well-defined instances of some variable, there must be some factual criteria according to which we can decide whether sentences such as a=b are true, where a and b are descriptions (or names) of some exemplars of this type of particulars.

All of Quine´s examples of failing identity have in common that, in theory, the number of the supposed types of particulars is not uniquely determined. (E.g. the number of spatial locations corresponding to two different physical events depends on the reference frame; therefore, spatial locations are (entia non grata((Quine 1960, p.253)). Thus, objects which are not countable are excluded from Quine´s ontology. What about those cases, however, in which the number is uniquely determined, but is not a number of distinguishable things ?

Quine mentions the example of incomes occuring in any fictional theory of economics. There, we do not take it to be necessary theoretically to distinguish different people with the same income theoretically. In such a case we should, according to Quine, talk of different incomes, not about different people having the same income (Quine 1969, p.55). Not people, but possible values of income should be the objects of discourse. Thus, we are told to sacrifice the intuitive objects of our discourse in order to take a general term as representating a more adequate object of discourse.

If we apply this advice to the case of QFT, we have to stop talking about quanta in favour of talking about types of quantum states. They are the Universals which are instantiated by indistinguishable quantum (particles(. The world of QFT would then be inhabited by Universals. For Quine, this would be nothing to quarrel with, since any distinction between particulars and Universals itself merely reflects an individual preference for some (home language(or the other. In physics, however, we have to search for some ersatz-ontology which could account for the loss of classical particles. Whether a type of entities is able to account for the loss of classical particles depends on its capacity to feature in explanations of how properties of classical particles (e.g. the appearence of identifiable particle trajectories (cf. Dieks 1990, p.137/38)) can re-emerge in classical limit situations. Since it is far from clear how the conceptual gap between classical particles and quantum Universals could be bridged, Universals cannot be accepted in the role of an ersatz-ontology for classical particles.

2.Armstrong´ s States of Affairs

Quine´s treatment of scientific ontology has favoured the admission of abstract objects as perfectly acceptable existents. The distinction between concrete and abstract objects, according to Quine´s view, reflects a philosophical superstition with regard to the supposed naturalness of a particular language which Quine hopes to reveal as the result of familiarity.

The second important move in ontology, compared to the more empiristic ontological thinking of Strawson, is Quine´s awareness of the consequences following from the occurence of indistinguishable objects in scientific theories. Where indistinguishable objects occur, it seems to be legitimate, according to Quine, to take the universals, with respect to which the objects are indistinguishable, to be the objects of discourse.

Such realism with respect to Universals (even if the commitment is merely a formal one, as in Quine´s case) is objectionable, Armstrong says. According to realism, as understood by Armstrong, two indistinguishable objects are objects that are built up by the same set of Universals, and therefore actually appear to be one rather than two. Therefore, realism, according to Armstrong, reduces the problem of indistinguishable objects to triviality. Armstrong´s alternative conception is a revitalization of (universalia in rebus(: What one has here, are neither distinct particulars, distinguished from each other by their respective primitive thisness, nor universals existing independently of their instances, but states of affairs that instantiate Universals (Armstrong 1989, p.95).

Yet, how can the objection which Armstrong raises against realism be avoided ? Should not states of affairs instantiating the same bundle of Universals count as one state of affairs ? According to Armstrong, qualitatively identical states of affairs can be bundled up in different ways from a certain set of Universals (Armstrong 1989, p.93) and thereby be different things. But which ever interpretation the clause (in different ways(may receive in various domains of discourse, there are no (different ways(in which two quanta can be instantiations of the same quantum state. There can be two of them despite the fact that they cannot be distinguished by any theoretical or experimental means.

It is now time to explain what the theoretical requirements are for choosing a quanta-interpretation of QFT. What does it mean that quanta are indistinguishable and what are the problems of their interpretation ?

(5) The Quanta-Interpretation and its Problems

Elementary particles, in general, do not have exact spatiotemporal trajectories. Therefore, it is impossible to re-identify them by means of their trajectories. This is a consequence of Heisenberg´s uncertainty relation: quantum particles cannot have a definite spatial localization and a definite momentum at the same time; this, however, would be the condition for the existence of a well-defined trajectory.

Yet, it is not the failing trajectories that make quantum particles indistinguishable. They are conceptually indistinguishable (Dieks 1990, p.140). To get at this meaning of (indistinguishable(, it matters whether a particle label occurs essentially in the theory. The question is whether a particle label makes a difference in any situation described by the theory, i.e., whether it *numerates* (has the role of a proper name) or merely *counts* (plays the role of an arbitrary number sign in some enumeration). In elementary particle theory, the labels merely count.

In a many-particle representation, a system of n particles (here particles X and Y) can be described by a superposition of product states ((x_i(and (y_i(are bases for the one-particle Hilbert space H):

$$(= (c_{ij} \ x_i \ (\ y_j$$

x_i represents some eigen-state of the first particle, X, y_j some eigen-state of the second particle, Y. It seems as if the product state entailed single particles in the form of the particle labels x_i and y_j. But quantum statistics has shown that the situations where the first situation presents X in state x_i and Y in state y_j, and the second situation presents Y in state x_i and X in state y_j, have to be counted as only one state. Permutation of particles in the state space does not alter the situation that is represented. Thus, it follows that a n-particle bosonic system (e.g. photons) has to be represented by a symmetric wave function and a fermionic system (e.g. electrons) by an antisymmetric wave function (van Fraassen 1991, p.383):

Bosons: $(= (c_{ij} \ (x_i \ (\ y_j \ \ (\ \ y_j \ (\ x_i)$

Fermions: $(= (c_{ij} \ (x_i \ (\ y_j \ \ (\ \ y_j \ (\ x_i)$

These two sorts of state-representations are essentially characterized by the property that a permutation of particle labels does not alter the state. The conceptual indistinguishability of the particles is shown by the fact that it is not possible to assign one-particle states to single particles of the n-particle state. Thus, it is not possible to distinguish the particles by their states. The labels of the particles do not play the role of names, they merely present a conventional enumeration.[1]

The Fock space formalism of QFT draws a conclusion from these properties of quantum statistics. Since quantum statistics does not provide any means of distinguishing between an assignment of properties to particles, X and Y, and the reversed assignment, the Fock space formalism allows only for symmetric and antisymmetric state descriptions as representations of actually occuring states.

A Fock space is a Hilbert space spanned by the basis vectors (n_1, n_2,..., n_i,..., n_k($_A$, each representing a finite number n_i (occupation number) of Bosons or Fermions with the corresponding eigen-value a_i of the observable A. Insofar as the Fock formalism does not enable one to tell which particle has which property, but only which pattern of properties is exhibited by a certain physical system, it (cuts off(the surplus structure of the many-particle Hilbert space description. It (explains(quantum statistics by removing the idea of a particle provided with property-transcending individuality (or (primitive thisness((Teller 1995, p.12)) and replaces it by quanta[2], objects which cannot be *numerated.* Quanta, as Teller writes, (can only be aggregated((Teller 1995, p.29); in the same way a certain amount of dollars in a bank account can be aggregated (and distinguished from another sum of dollars), but it does not make sense to numerate the individual dollars that make up the amount. There are simply no distinguishable individual dollars in the account.

Quanta (=excitation states or field modes), like electrons or photons, are in general not spatiotemporally individuated; they are properties (or appearences of properties) of the whole

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[1] The conceptual indistinguishability of quantum particles can also be expressed in the language of possible experiments: There is no experiment by means of which one would be able to distinguish situations originating from each particle by some permutation of the particle labels. The expectation values for all possible physical measurements are independent of the order of the particle labels in the description of the state of the system.

[2] Quanta are occurences of definite excitation states (eigen states), relative to a chosen basis.

quantum system. The transition to another basis representation changes the sort of quanta involved. Even if electrons and photons are not numerable, they are still *countable*. Since any eigen-state of a system can be characterized by a set of occupation numbers n_1, n_2,... , quanta are countable particulars with well defined physical characteristics, which can be used as building blocks for the specification of the state of any quantum system. Therefore, they seem to provide an ideal ersatz-ontology replacing the classical particles.[3]

There is one major problem with the proposed replacement of particles by quanta:

<u>How can the quanta-interpretation be reconciled with the existence of superpositions of exact number states which are in fact states with an indefinite number of quanta ?</u>

The Fock space does not just include the different eigen-states characterized by definite occupation numbers, but also superpositions of those eigen-states which represent states with an indefinite number of quanta. How can a physical system, characterized by an indefinite-number state relative to the chosen basis, be interpreted as some composition of quanta ?

According to Teller 1995, an acceptable interpretation of such states can be achieved, if one takes superpositions to be (propensities to reveal one of the superimposed properties under the right (measurement(conditions((Teller 1995, p.32). An indefinite-number state is the presence of a property which reveals itself in measurements in the form of the occurence of exact numbers of quanta, according to the probability measures given by the superposition. The acceptance of this proposal depends in the first place on the general acceptance of propensity-interpretations of superpositions in general. Even if this general acceptance is taken for granted, there is a more specific reason for rejection: The property specifying probabilities for the manifestation of certain collections of quanta cannot itself be a property <u>of</u> some definite collection. Thus, what is that property a property of ?

According to Teller, we can dissolve this difficulty, if we declare the indefinite-number state to be not a state of something independently existing, but rather a property that is exemplified by different types of quanta - the definite-number collections of quanta which appear in measurements (cf. Teller 1995, p.105).

[3] Cf. French/Redhead 1988 (p.238): (there are strong arguments for regarding the (quantized excitation(view of quantum particles as the correct one(.

I find this answer unconvincing. It is not the claim that a property is specified by propensities which is problematic here; neither is it the fact that the entities realizing this property through their occurence cannot be said to be the bearers of the property. The real problem is, in my view, that a statement according to which a quantum system has a property of that kind is explicated by recourse to entities the occurence of which cannot be predicted by the theory. The occurences of quanta, by which a superposition state is realized, are single measurement events, and the theory - according to our current knowledge - is not able to account for single measurement events. The ontology for QFT should not be built upon a type of entities the presence or absence of which is not a consequence of the theory. The fact that superposition states can only be assigned to the quantum system itself very much favours an interpretation according to which events of the type (quantum system S is in quantum state ((are the building blocks of QFT-ontology.

Neither classical particles nor ephemeral quanta seem to provide a reasonable ontological basis for QFT. Since classical particles are spatiotemporal individuals, but are not allowed by the theory, whereas quanta are allowed by the theory, but are no spatiotemporal individuals, the search should focus on things that fulfill both conditions. The latter are what Auyang 1995 calls the events that make up the quantum field.

3.The Event Interpretation and its Problems

The Fock space description of quantum systems can be developed by introducing the so-called lowering and raising operators. These operators, corresponding to some basis, carry a vector describing a definite number of quanta into a vector describing one fewer (or one more) quantum. If one chooses the position basis, the raising operator, ((x), associated with each space-time point takes the vector representing any state to a new state with one additional quantum located at x. The *quantum field* is just this association of an operator with each of the space-time points. Applied to concrete quantum states, (, the field operator, ((x, t), at space-time point, (x, t), determines expectation values (((((x, t)(((, e.g. the expectation value for an exact momentum state occuring at the point, (x, t).

Thus, the quantum field does not supply us directly with specific values of physical quantities - this is what distinguishes it from a classical, e.g. the classical electromagnetic field;

instead it is (something that charts the spatiotemporal relations of any of a large set of possible field configurations((Teller 1995, p.103).[4]

According to Teller, the idea that QFT is a genuine field theory essentially stems from its historical genesis (Teller 1995, p.69f.). Starting with a classical physical field, ((x, t), we can, by Fourier expansion, arrive at a formal description of the field in the form of classical harmonic oscillators, a(k, t), satisfying the classical oscillator equation (k is a coefficient of the Fourier expansion). Those oscillators, a, (and their complex conjugates, a() can then be interpreted as the raising and lowering operators, **a** and **a**(, relative to a momentum basis (where k is interpreted as momentum). The classical field description can then be replaced by the operator-valued field description (field quantization) of the form

$$\mathbf{(}^{(}(x, t) = (\ d^3\mathbf{k}\ \mathbf{a}(\mathbf{k}, t)\ e^{i\mathbf{k}x}.$$

(Field quantization(presents the classical field in a way in which the Fock space formalism can be applied. The corresponding Fock space is defined by vectors which are specified by occupation numbers for the various field excitations (field modes). Thus, even if we start from the quantization of the classical electromagnetic field, there is good reason to think of the Fock space formalism with its occupation-number states as the core of the theory. The (fieldtheoretic(description of QFT does not prevent us to think of quanta as the objects of the theory.

It is exactly her focus on (field quantization(that governs Auyang´s treatment of QFT. A field, ((t, x), Auyang claims, is (a dynamical variable for a continuous system whose points are indexed by the parameters t and x((Auyang 1995, p.48). Quantum fields are obtained by replacing the classical field variable by operators obeying certain commutator relations (Auyang 1995, p.50). Quantum fields, according to Auyang, (constitute the basic ontology of the world((Auyang 1995, p.50). Whereas spatiotemporally extended fields make up the primary stuff of the world, field quanta are portions of excitations by which a field may be characterized under cartain circumstances (when interaction can be ignored).

Why are field quanta not the entities of QFT ? According to Auyang, the prima facie

[4] On the same page, Teller argues: (The correct way to see the fieldtheoretic content is to see field operators as (analoguos to classical) field determinables and to see the field configurations in the expectation values given by applying field operators to specific states(.

entity of the theory is the quantum field. This entity could only be decomposed into more fundamental entities, if it *consisted* of them. However, since field quanta are not spatially localized, since they are not excitation states *at* a certain point of the field, but have to be assigned to the field system as a whole (Auyang 1995, p.159), they are no spatial parts of a quantum field. In short, they are not the sort of things of which the quantum field consists. Finally, the fact that basis transformations produce some other type of field quanta and the existence of indefinite-number states make it impossible to say that a field system *consists* of field quanta.

There is one more very general case to be made against field quanta. They cannot count as exemplifications of entities: (The requirement of identifiable reference suggests that what is usually called (particles(in quantum field theory are strictly speaking not entities. As quanta or field excitations, particles are like modes of waves and lack individual identity((Auyang 1995, p.123).

According to Auyang, the quantum field can be decomposed into parts; but these parts are not field quanta. They are field events. Since events are spatiotemporally located, field events, as opposed to field quanta, satisfy the condition of (having their own identity((Auyang 1995, p.122). For Auyang, who heavily relies on Kant´s philosophy, the concept of a particular is intrinsically bound to spatiotemporal localizability: (Field theories show the *concepts of entities and space-time are inseparable;* entities are individuated within a world that is spatio-temporal((Auyang 1995, p.123).

Now, it is hard to see how Auyang´s approach that makes so much of the possibility of depicting QFT by means of a position representation can lead to a generally viable ontological conception for QFT. If we are aware that QFT allows this representation no special privilege, the claim seems to be obscure that QFT - in the same way as classical field theories do - confirms that the identity of fundamental particulars is neccessarily given by their spatio-temporal localizability.

Moreover, it is difficult to be entirely clear about what Auyang actually means by (field events([5]. Auyang identifies field events with the *local field operators ((x)* (Auyang 1995, p.129). It is important to realize, however, that the local operators of QFT describe the dynamics of

[5] She claims, that events (do not endure and they have neither spatial nor temporal parts. We can regard them as the basic entities or basic individuals of the physical world((Auyang 1995, p.123).

quantum systems in a very general sense - as a kind of general dynamical condition that applies to arbitrary quantum systems. Therefore, a single field operator does not supply complete information about concrete physical systems; it does not specify any single concrete physical event, but at best a *type* of events. The description of concrete events prescribes the application of a field operator to a special state vector. The claim that the excitation of a certain mode of type i (Auyang´s example (Auyang 1995, p.129)) is an event, ($_i$ (x), is ambigious. Either Auyang means the *general* description of a type of events (but *this* is an abstract thing), or she means the concrete physical event, specified by measured values of physical quantities. But such definite values, as Auyang herself declares, are not something that could be assigned to quantum systems as their intrinsic properties. Quantum systems are separated from real measurement values by a veil.

Thus, either Auyang´s events are not the entities of QFT or they are not events in concrete physical systems. The probabilistic nature of the theory makes it impossible to take positions of a quantum field to be specified by measurement values. Point events, as described by Auyang, can therefore not solve the ontological problem of QFT.

4.Quantum States of Physical Systems as Davidsonian Events

As we have seen, quanta will not solve the ontological problem of QFT either. I have identified three main obstacles that lie in the way of an ontological status of quanta:

1. *failing invariance*: The description of quantum systems by occupation number-states is not invariant relative to basis transformations. In general, a basis transformation carries a definite occupation number state into a non-definite occupation number state;
2. *failing identity*: Field quanta instantiating the same excitation mode cannot be distinguished from each other, and in that sense (have no identity(;
3. *failing localizability*: Occurences of field quanta are generally not point events. Field quanta have to be ascribed to the whole quantum system; they cannot be spatio-temporally localized.

From those three obstacles, the third one seems to be the most resiliant. Neither spatio-temporally localizable objects nor point events provide us with a successful alternative. A way out could be to drop condition (c) and search for events which are not pointlike. In order to avoid the first and the second obstacle for *them*, these non-pointlike events should have some kind of identity other than that given by their spatio-temporal localizability. They should, moreover, be invariant to basis-transformations.

Events which are not (exactly) spatio-temporally localizable are such „earthly“ exemplars as earthquakes, marriages, and physical attacks that are classified as events in ordinary speech. In contrast to the highly idealized point events in physics, the identity of such events cannot be given by their spatio-temporal localization. Even if we accept that an earthquake is spatio-temporally located in some very rough and vague way, the identity of it is not fixed by its location. There may be many other events taking place inside the same spatio-temporal region. Thus, identity of time and place is not enough to ensure identity (Davidson 1980, p.178).

Davidson 1980 pleads for a *causal* identity criterion of events. Events, according to Davidson, are legitimate entities of the world, beneath objects, persons etc. if they satisfy the following criterion (where x and y are events):

(x=y if and only if ((z) (z caused x(z caused y) and (z) (x caused z(y caused z))

(Davidson 1980, p.179)

Thus, the identity of some event is given by its *causal location* inside the causal net of the world, i.e. by the totality of the causal connections with future and past events.

This idea can be transferred to the QFT-case in a rather straightforward manner. The fact that a certain physical system is in some definite quantum state can be interpreted as an event that is causally, yet not spatio-temporally, individuated. It seems natural to think of the quantum state of a physical system as something the identity of which is given by all its past and future interactions; if two systems, S_1 and S_2 , are in exactly the same quantum state, (, the corresponding events, E_1=((S_1) and E_2=((S_2), are not necessarily indistinguishable (as it would be the case for quanta of the same type); they can, however, be distinguished by the fact that E_1 is causally connected to some event, E, whereas E_2 is not. Furthermore, events of the type (system S is in quantum state ((satisfy the invariance condition; they are entities existing independenty of any particular basis representation.

A useful paradigm for the relation between events of the type (system S is in quantum state ((and a particular quanta representation (an occupation number state) could be the relation which Davidson claims that it exists between the *events* we refer to in ordinary speech and some *states of affairs* by which we represent such events (Davidson 1980, p.164f.). According to Davidson, events are the pieces of reality which can be represented by means of different states of affairs, depending on the focus we choose to characterize the event. For instance, we may choose to characterize events by means of the causal consequences they have. The pouring of a dose of arsenic into a glass of water may be represented by the state of affairs that is expressed by the sentence (John kills Agatha by poisoning(. Likewise, some occupation number state expresses a state of affairs representing the event that quantum system S is in quantum state (, relative to a chosen basis.

Quanta are, according to this view, not the building blocks of quantum reality, but they are (conceptual) building blocks used to construct representations of quantum reality. The stuff of which quantum reality is made is neither quanta nor point events, but Davidsonian events.

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