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Essay review

Quantum processes: A Whiteheadian interpretation of quantum field theory

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1. Introduction

Quantum processes: *A Whiteheadian interpretation of quantum field theory* is an ambitious and thought-provoking exercise in physics and metaphysics, combining an erudite study of the very complex metaphysics of A.N. Whitehead with a well-informed discussion of contemporary issues in the philosophy of algebraic quantum field theory. Hättich's overall goal is to construct an interpretation of quantum field theory. He does this by translating key concepts in Whitehead's metaphysics into the language of algebraic quantum field theory. In brief, this Hättich–Whitehead (H–W, hereafter) interpretation takes "actual occasions" as the fundamental ontological entities of quantum field theory. An actual occasion is the result of two types of processes: a "transition process" in which a set of initial possibly-possessed properties for the occasion (in the form of "eternal objects") is localized to a space–time region; and a "concrescence process" in which a subset of these initial possibly-possessed properties is selected and actualized to produce the occasion. Essential to these processes is the "underlying activity", which conditions the way in which properties are initially selected and subsequently actualized. In short, under the H–W interpretation of quantum field theory, an initial set of possibly-possessed eternal objects is represented by a Boolean sublattice of the lattice of projection

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operators determined by a von Neumann algebra $\mathscr{R}(\mathscr{O})$ associated with a region $\mathscr{O}$ of Minkowski space–time, and the underlying activity is represented by a state on $\mathscr{R}(\mathscr{O})$ obtained by conditionalizing off of the vacuum state. The details associated with the H–W interpretation involve imposing constraints on these representations motivated by principles found in Whitehead's metaphysics. These details are spelled out in the three sections of the book. The first section is a summary and critique of Whitehead's metaphysics, the second section introduces the formalism of algebraic quantum field theory, and the third section consists of a translation between the first two sections. This review will concentrate on the first and third sections, with an eye on making explicit the essential characteristics of the H–W interpretation.

2. Critique of Whitehead's metaphysics

In general, Whitehead holds a relational view of space–time. Spatiotemporal properties are not given prior to the creation of an actual occasion, but are realized along with other properties during the process of becoming. Furthermore, actual occasions are associated irreducibly with non-overlapping space–time regions ("irreducibly" in the sense that an occasion does not have spatiotemporal parts). Lastly, Whitehead claims that the spatiotemporal properties of occasions are characterized by those of Minkowski space–time.[1] The task then is to articulate a relational view of Minkowski space–time that is based on an extended event ontology and that is amenable to the concept of becoming. In the first section of the book, Hättich identifies three problems with this task. The first two are specific problems that have to do with reconciling causal features associated with Whitehead's notion of becoming with the structure of a relativistically informed extended event ontology. To resolve these, Hättich suggests a modification of Whitehead's ontology. The third problem is a general worry over the compatibility of the notion of becoming with Minkowski space–time.

2.1. Causality, becoming and Minkowski space–time

Associated with an actual occasion E is its "actual world", which consists of the "causal past" of E, namely, all relevant determining factors for the initial constituents of E. In accord with the notion of becoming, E's actual world must be determined before E is created. Under Whitehead's description, E is determined by a particular manifestation of the underlying activity, call the latter ω, and this particular manifestation is determined by the restriction of ω to the actual world of E.[2] Whitehead's "doctrine of actual worlds" is the stipulation that "... different

[1] More precisely, Minkowski space–time represents the spatiotemporal properties of actual occasions for our current "cosmic epoch".

[2] According to Whitehead, the underlying activity at some stage in the world-process "envisages" all already actualized occasions, and thereby is restricted to particular manifestations that then determine individual occasions that become at the next stage.

occasions arise from different causal pasts'' (Hättich, p. 14); i.e., no two occasions have the same actual world. The motivation for this doctrine apparently comes from Whitehead's desire to model the causal past of an occasion E on its causal past in Minkowski space–time, namely, all points in Minkowski space–time that can be connected to (the region associated with) E via future-directed timelike or lightlike curves. However, that Whitehead was willing to allow for exceptions to this correspondence leads Hättich (p. 71) to identify the following problem, which I will refer to as the ''Actual World Determination'' problem:

> *Actual World determination problem*. What determines the actual world of an occasion? More generally, suppose Σ is a spacelike hypersurface in Minkowski space–time representing some stage in the world-process. What determines how occasions to the past of Σ are partitioned into distinct actual worlds?

Apparently, this is a problem only to the extent to which Whitehead is willing to allow ''determining factors'' for occasions to propagate along spatiotemporally discontinuous trajectories.[3] Otherwise, as Hättich (p. 18) points out, one could claim that the spatiotemporal properties of actualized occasions determine how they get partitioned into actual worlds and subsequently how they determine the spatiotemporal properties of yet-to-be-born occasions.

The second problem Hättich raises is what may be called the ''Causal Independence'' Problem (p. 71). Occasions are supposed to become in causal independence, and this conflicts with the requirement that the space–time regions of those yet-to-be-born occasions they determine be non-overlapping. For instance, the space–time region $\mathcal{O}_1$ of a yet-to-be-born occasion E_1 is determined by already actualized occasions in E_1's actual world, and similarly for the region $\mathcal{O}_2$ of another yet-to-be-born occasion E_2. $\mathcal{O}_1$ and $\mathcal{O}_2$ furthermore must be non-overlapping. But the processes that produced occasions in E_1's actual world at some stage in the world-process (i.e., on some spacelike hypersurface Σ) must be causally independent, not only from each other, but also from those that created occasions in E_2's actual world on the same Σ. Hence:

> *Causal independence problem*. What guarantees created space–time regions are non-overlapping, given that the processes that created them are causally independent?

[3] Hättich sees a larger problem, claiming that, for Whitehead, ''... there are no spatiotemporal, let alone spatiotemporally continuous, processes which link cause and effect'' (p. 17). This is because the process of becoming (in either its ''transition'' or its ''concrescence'' forms) is intrinsically non-spatiotemporal. But this may be to conflate cause–effect relations between already actualized occasions and yet-to-be-born occasions, with the process of becoming of yet-to-be-born occasions. Arguably, the former cause-effect relations are legitimately spatiotemporal (given by the uniform structure of Minkowski space–time), and it is these relations that figure into the determination of actual worlds. (Note that this uniform structure need not be given by a pre-existing substantival spacetime; rather, it may be described as an absolute dynamic relatedness that is imposed on all occasions in our current cosmic epoch.)

2.2. Resolution and comments

Hättich's resolution of both of the above problems is to introduce "bifurcating" activities into Whitehead's ontology (p. 73). Under Whitehead's account, at each stage in the world-process the actual worlds of the yet-to-be-born occasions of the next stage determine particular manifestations of the underlying activity, and these particular manifestations are distinct from each other—each functions to determine a unique occasion associated with a unique spacetime region disjoint from the rest. Under Hättich's modified account, at each stage in the world-process there is just a single undivided activity by means of which a single undivided process creates all the space–time regions that will be associated with the yet-to-be-born occasions of the next stage. The outcome of this process is, in general, a single undivided activity spread over all the regions. This undivided activity then "bifurcates" into particularized activities associated with individual regions and unique occasions-to-be-born. The timing of the bifurcations of the single underlying activity determines the extent to which the yet-to-be-born occasions may be correlated with each other, thereby resolving the Causal Independence Problem. According to Hättich, this account also resolves the Actual World Determination Problem in so far as the single undivided activity at a given stage in the world-process determines a single actual world for all yet-to-be-born occasions at the next stage. This single actual world determines regions and occasions without having to be further divided itself. The "dividing" is now done by the bifurcating activity. As Hättich explicitly states, this account requires a rejection of Whitehead's doctrine of actual worlds, namely, it rejects Whitehead's requirement that no two occasions have the same actual world.

This account of bifurcating activities is not without its concerns. First, on the surface it might appear that the problem of how actual worlds are determined has been replaced with the problem of how, at any given stage in the world process, the single undivided activity "envisages" all already actualized occasions. Under Whitehead's original account, envisagement could perhaps be explained in terms of already determined actual worlds (i.e., the way the underlying activity envisages already actualized occasions is conditioned by the actual worlds they enter into). But under Hättich's account, envisagement becomes a bit more mysterious. Under Hättich's account, particular manifestations of the underlying activity are still responsible for the determination of yet-to-be-born occasions, but these particular manifestations are not determined by actual worlds (as Whitehead would appear to require); rather, they are products of the bifurcation of the single underlying activity. And these bifurcations seem ultimately to be determined by the space–time regions that the single underlying activity has created at some stage of the world-process over which it is then "spread". The question then becomes: What determines how the act of envisagement creates these regions (what determines their number, location, extent, etc.)?

A second concern is with the motivation for Hättich's modified account of bifurcating activities. If this motivation is to allow "non-local" determining factors into Whitehead's ontology, then one could argue that it does not require the

rejection of the doctrine of actual worlds. Note first that non-local correlations between spacelike separated events in Minkowski space–time find homes in relativistic quantum mechanics and quantum field theory. Moreover, even in classical (non-quantum) field theories for fields with well-posed initial value problems, there is a sense in which an event E to the future of a spacelike Cauchy surface Σ is determined by all events on Σ, whether they are elements of E's causal past or not. In particular, constraint equations can be viewed as non-local determining factors for the evolution of a field off of a Cauchy surface (see, e.g., Earman, 1995, pp. 125–126). The suggestion then is that perhaps Whitehead's doctrine of actual worlds can be retained (and a realistic interpretation of the Minkowski spacetime structure that informs it) by adopting a notion of "determining factor" that is weaker than one derived from causal determinism.

2.3. Problem with universal becoming

The third problem Hättich discusses in the first section of the book is the compatibility of a concept of universal becoming with the structure of Minkowski space–time. Hättich argues that the concept of universal becoming in Whitehead's metaphysics (as captured, for instance, in Whitehead's depiction of the world-process as a "creative advance into novelty") requires a distinguished foliation of space–time, each leaf of which represents a given stage. But since Minkowski space–time structure is what is empirically given, Hättich concludes that the distinguished foliation of space–time required by universal becoming must be in-principle unobservable.

2.4. Comments

In debates over the nature of becoming in Minkowski space–time, advocates of relativistic becoming point to the fact that a relation of becoming can be defined on Minkowski space–time. Their opponents attempt to argue that such a "scientific image" of becoming fails to do justice to "manifest images" of becoming (see, e.g., Callender, 2000). Hättich takes this as a serious criticism that Whitehead must address: He acknowledges that a relation of becoming can be defined on Minkowski space–time, but he suggests that this relation does not accurately represent Whitehead's notion of universal becoming (p. 21). On Hättich's account, Whitehead's particular manifest image requires that we be instrumentalists with respect to Minkowski space–time, and realists with respect to an in-principle unobservable distinguished foliation of space–time. One could argue that this is a problematic reading of Whitehead.

First, one might argue that Whitehead would object to in-principle unobservable elements of ontology. In particular, universal becoming is too prominent in experience to be scientifically described by in-principle unobservable structures. One might further argue that Whitehead would not have objected to the scientific image of becoming as a relation defined on Minkowski space–time. In *An Enquiry*

Concerning the Principles of Natural Knowledge, he reconstructs Minkowski space–time from an ontology of extended events via the method of extensive abstraction. This method is supposed to provide us with mathematical representations of the elements of our ontology (which are given directly in experience), thereby preventing disconnects between the scientific image and the manifest image. Hence, arguably, Whitehead would have been satisfied with a becoming relation definable on Minkowski space–time, so long as it could be derived via the method. As far as I am aware, he did not do this; although one would expect him capable of doing so. It should not be forgotten that Whitehead began his career as a mathematical physicist, having published, in addition to *Enquiry*, a relativistic theory of gravity as an alternative to general relativity. Thus Whitehead might well have been satisfied with a scientific image of relativistic becoming that only differs from the manifest image due to scale: the fact that c is so large allows us to view becoming as a creative advance into novelty that, for all practical purposes, all contemporaneous occasions engage in.

3. Characteristics of the H–W interpretation

In the third section of the book, Hättich provides a translation between key Whiteheadian concepts and objects appearing in the formalism of algebraic quantum field theory. This translation serves as the basis for the H–W interpretation of quantum field theory.

The basic object of the algebraic formalism is a von Neumann algebra $\mathscr{R}(\mathscr{O})$ of local observables associated with a space–time region $\mathscr{O}$.[4] Properties of a physical system associated with $\mathscr{O}$ can then be represented by projection operators P_i associated with the self-adjoint elements of $\mathscr{R}(\mathscr{O})$ via their spectral decomposition. States are represented by linear functionals on $\mathscr{R}(\mathscr{O})$ that satisfy the requirements for a probability measure over each resolution of the identity $\{P_i\}$. The essential ingredients of Whitehead's metaphysics include "actual occasions", "eternal objects", and "underlying activities". In a nutshell, an actual occasion is the product of a "transition process", whereby its associated underlying activity localizes a set of possibly-possessed eternal objects to a space–time region, and a subsequent "concrescence process", whereby the underlying activity selects, in an inherently indeterministic way from among this initial set, those eternal objects that are actualized to create the occasion. Under the H–W translation, "eternal objects" are represented by projection operators on $\mathscr{R}(\mathscr{O})$,[5] and the "underlying activity" associated with an "actual occasion" is represented by a state on $\mathscr{R}(\mathscr{O})$ obtained by

[4]More precisely, the basic object is a correspondence $\mathscr{O} \mapsto \mathscr{R}(\mathscr{O})$ between (open, bounded, connected) regions $\mathscr{O}$ of Minkowski space–time and von Neumann algebras $\mathscr{R}$.

[5]For the sake of simplicity, I will skip over some nuances. Hättich actually suggests that an eternal object be represented by an equivalence class of projection operators up to Poincaré transformations (p. 170). This is due to his claim that there are no appropriate objects in algebraic quantum field theory that can be used to represent universals.

conditionalizing off of the vacuum state.[6] A "transition process" is then represented by the restriction of the vacuum state, first to the lattice $\mathscr{P}(\mathscr{O})$ of projection operators determined by a von Neumann algebra $\mathscr{R}(\mathscr{O})$ (during what Whitehead calls the "dative phase"), and then to a Boolean subset of $\mathscr{P}(\mathscr{O})$, call it **B** (during the "conformal phase").[7] A "concrescence process" is then represented by a collapse of the resulting state; i.e., a final restriction of it to a pure state associated with one of the elements of **B**. The probability measure defined by the state on **B** is interpreted as assigning single-case ontic propensities to the elements of **B**, and the "concrescence process" describes the actualization of these propensities.

The H–W interpretation based on this translation has four essential characteristics: (1) it adopts an ontological interpretation of probabilities; (2) it subscribes to a form of contextualism; (3) it rejects the Eigenvalue–Eigenstate Rule; and (4) it adopts a rule that picks out, for any given system in a given state, a set of possibly-possessed properties.

3.1. Ontic probabilities and collapse

Under the H–W interpretation, probabilities defined by states on $\mathscr{R}(\mathscr{O})$ are always interpreted as ontic. Moreover, H–W is a collapse interpretation—it refers to a process whereby ontic probabilities are actualized.

3.2. Contextualism

The H–W interpretation is characterized by a contextualism of the sort that rejects a 1-1 correspondence between self-adjoint operators and observables. This appears to ultimately be a consequence of an extended event ontology. According to Whitehead, an eternal object belongs indifferently to the whole space–time region in which it is ingressed. Hättich views this as a constraint on the way projection operators that represent eternal objects can be compatible: compatible operators must not only commute, but also must belong indifferently to the same space–time region $\mathscr{O}$.[8] This constraint on compatibility also affects the translations between H–W propensities and probabilities defined by states on $\mathscr{R}(\mathscr{O})$, and between manifestations of the underlying activity and states on $\mathscr{R}(\mathscr{O})$. A consequence of this is that the formalism of algebraic quantum field theory contains surplus structure when

[6] In Whitehead's metaphysics there is a distinction between the "underlying activity" as a general potential for universal process, and particular manifestations of it that act in the creation of particular actual occasions. Hättich suggests that the (universal) underlying activity be represented by the (unique) vacuum state and particular manifestations as states obtained from the vacuum by "conditionalizing" with a given element of some local algebra $\mathscr{R}(\mathscr{O})$. The motivation for this is the Reeh–Schlieder theorem, which entails that any given state can be obtained from the vacuum in this manner to as close an approximation as necessary.

[7] More precisely, Hättich allows for a restriction to a conjunction of sets $\bigwedge_i \mathscr{P}(\mathscr{O}_i)$ during the dative phase to allow for "non-separable" underlying activities.

[8] According to Hättich (p. 170), two eternal objects P_1, P_2 belong indifferently to the region $\mathscr{O}$ just when $P_1, P_2 \in \mathscr{R}(\mathscr{O})$ and $P_1, P_2 \notin \mathscr{R}(\mathscr{O}')$ for all $\mathscr{O}' \subset \mathscr{O}$.

it comes to the H–W translational scheme. Not all self-adjoint operators in $\mathscr{R}(\mathscr{O})$ represent eternal objects (viz., properties); not all probability measures defined by states on $\mathscr{R}(\mathscr{O})$ represent single-case propensities; and not all states on $\mathscr{R}(\mathscr{O})$ represent manifestations of the underlying activity.

3.3. Rejection of Eigenvalue–Eigenstate Rule

Recall that the Eigenvalue–Eigenvector Rule (EE, hereafter) is the claim:

(System in state ρ does (not) possess property P) $\Leftrightarrow$ ($\rho(P) = 1(0)$).

The H–W interpretation adopts the "only if" $\Rightarrow$ part of EE and rejects the "if" $\Leftarrow$ part (p. 158). Hättich views the "only if" part as necessary to uphold an ontic view for all probabilities (in light of standard logic and standard probability theory). His argument for rejection of the "if" part briefly runs as follows. First, Whitehead views "concrescence processes" as involving the "actualization of possibilities", namely, from an initial set of possibly-possessed "eternal objects", some select subset are actualized in the actual occasion. Hättich then argues that, given standard probability theory, the EE Rule is incompatible with the notion of the actualization of possibilities with respect to properties. Briefly, one can show that the set of possibly-possessed properties of a system that the EE Rule picks out does not form a Boolean algebra; hence a standard probability measure cannot be defined on it. Thus, if we define a property P as a possible property of a system in a state ρ to mean that $\rho(P)$ is a standard probability, then EE is incompatible with the notion that a system possesses its properties by means of an "actualization of possibilities". Hättich concludes that adopting such a notion of the actualization of possibilities with respect to properties, as well as the "only if" part of EE, requires rejection of the "if" part.

For comparison, recall that modal interpretations reject the "only if" part of EE and adopt the "if" part. Arguably, modal interpretations allow for the actualization of possibilities with respect to properties by allowing for some probabilities to be epistemic (namely, those defined on the set of possibly-possessed properties).

3.4. Rule for possibly-possessed properties and modal interpretations

In modal interpretations, one needs a rule for picking out, from the non-Boolean lattice of projection operators on a Hilbert space, a subset of possibly-possessed (viz always determinate) properties in such a way that avoids the Kochen–Specker theorem. In Clifton's (2000) modal interpretation of algebraic quantum field theory, the possibly-possessed properties of a system in state ρ on $\mathscr{R}(\mathscr{O})$ are elements of a set $\mathbf{B}$ that is uniquely determined by ρ and the set $\mathscr{P}(\mathscr{O})$ of projection operators on $\mathscr{R}(\mathscr{O})$. $\mathbf{B}$ is generated by the center $\mathscr{Z}(\mathscr{C}_{\rho,\mathscr{P}(\mathscr{O})})$ of the centralizer $\mathscr{C}_{\rho,\mathscr{P}(\mathscr{O})}$ of $\mathscr{P}(\mathscr{O})$ and defines a Boolean algebra.[9] In the H–W interpretation, the Kochen–Specker theorem is

[9]The centralizer $\mathscr{C}_{\rho,\mathscr{P}(\mathscr{O})}$ of $\mathscr{P}(\mathscr{O})$ is defined by $\mathscr{C}_{\rho,\mathscr{P}(\mathscr{O})} = \{P \in \mathscr{P}(\mathscr{O}) : \rho(PQ) = \rho(QP), \forall Q \in \mathscr{P}(\mathscr{O})\}$, and its center is given by $\mathscr{Z}(\mathscr{C}_{\rho,\mathscr{P}(\mathscr{O})}) = \{P \in \mathscr{C}_{\rho,\mathscr{P}(\mathscr{O})} : PQ = QP, \forall Q \in \mathscr{C}\}$. $\mathscr{Z}(\mathscr{C}_{\rho,\mathscr{P}(\mathscr{O})})$ is a commutative subset of $\mathscr{P}(\mathscr{O})$ and so generates a Boolean algebra $\mathbf{B}$.

avoided explicitly by adopting contextualism (i.e., a rejection of a 1-1 correspondence between operators and properties.[10] However, there is still a need in H–W to pick a set of possibly-possessed properties that will ingress in a region $\mathcal{O}$ to eventually produce an actual occasion. Hättich suggests a restriction of Clifton's Rule, namely, the set of possibly-possessed properties for an actual occasion with underlying activity represented by state ρ (at the beginning of the "conformal phase" of a "transition process") are *compatible* elements of the set **B**, as defined above (this is his rule DEF on p. 232). Compatibility, recall, is a consequence of an extended event ontology and requires not only commutativity, but also the characteristic of "belonging indifferently" to the region $\mathcal{O}$ (see footnote 8).

Thus in Clifton's modal interpretation of algebraic quantum field theory, possibly-possessed properties are given by elements of **B**, and probabilities defined on them are epistemic. In the H–W interpretation, the possibly-possessed properties are given by a slightly restricted **B**, and probabilities defined on them are ontic.

3.5. Comments

There are two aspects of Hättich's translation programme. First, there is Hättich's claim to have constructed a Whiteheadian interpretation of quantum field theory. But if the translation goes through, he may also be thought of as having constructed a quantum field theoretic interpretation of Whitehead.

To what extent is the H–W interpretation a viable quantum field theoretic interpretation of Whitehead's metaphysics? One slight concern is over the representation of the indeterminateness associated with concrescence processes by single-case propensities. Most interpretations of Whitehead view this indeterminateness as involving an element of intentionality, and it might be objectionable to equate the latter with stochasticity. Another concern is that Whitehead's concept of the "extensive continuum" gets short-shifted in the H–W translational scheme, under which it corresponds to Minkowski spacetime (pp. 30, 137). Hättich acknowledges that this is a simplification for the purposes of interpreting Whitehead's metaphysics as it applies to our present cosmic epoch, and that, in general, space–time is to be made distinct from the extensive continuum. The failure to make this distinction explicit becomes significant in a discussion on what Hättich perceives as a perspectivalism in Whitehead that is either in conflict with his doctrine of actual worlds, or made unnecessary by it (p. 205). Briefly, there are passages in which Whitehead claims that even if two occasions were to share the same actual world, they would have different perspectives on it, and thus be distinct in so far as their influences on yet-to-be-born occasions are concerned. Hättich suggests the doctrine of actual worlds either makes this perspectivalism puzzling (how could two occasions share the same actual world) or unnecessary (by reducing an occasion's perspective just to its actual world). One way to reconcile the doctrine of actual

[10] H–W contextualism is of course different from ontological or causal contextualism. The latter variants suggest a one–many map between operators and properties. H–W simply suggests that the correspondence between operators and properties is not a map (i.e., function) in the first place.

worlds with a non-trivial perspectivalism is to claim that the perspective associated with an occasion transcends its spatiotemporal properties: One might claim that actual occasions possess primitive thisness. Hence Whitehead can image two occasions alike in all spatiotemporal attributes (viz, sharing the same actual world) yet still distinct. And this distinctness (viz, primitive thisness) is determined just by an occasion's "location" in the extensive continuum. In representing the extensive continuum by Minkowski space–time, Hättich risks glossing over such issues of individuality.

To what extent is H–W a viable interpretation of quantum field theory? Note first that Hättich's translational scheme is for the formalism of algebraic quantum field theory. In adopting this formalism, he follows the lead of much of the recent literature on philosophy of quantum field theory. Now, while the algebraic formalism does have its advantages, primarily in providing the means of representing sometimes vague concepts in clear terms and proving results about them in the form of precise theorems, it also has its drawbacks. While it is the formalism of choice for mathematicians interested in quantum field theory, it is not used by practicing physicists, primarily because non-trivial interacting field theories have yet to be given an algebraic formulation. For interacting field theories, the Lagrangian formalism is, for better or worse, the formalism of choice.[11] To avoid these concerns, let us therefore ask: To what extent is H–W a viable interpretation of *algebraic* quantum field theory? There are some reasons to doubt that this has been fully accomplished, all of which Hättich himself points out. First, there is a list of quantities that appear in the algebraic formalism that do not have Whiteheadian counterparts. This list includes

(a) some observables;
(b) some states;
(c) some probabilities;
(d) all operators with continuous spectra.

Item (a) might not be that problematic (given the success of other types of contextualism). But it is not clear if items (b) and (c) can be considered surplus structure, and certainly item (d) cannot in most applications. Then there are some technical problems with the H–W rules. The H–W rule DEF discussed above that determines the Boolean algebra **B** of possibly-possessed properties of quantum systems suffers from the same problem afflicting Clifton's original rule: In order for it to be non-trivially applicable, it requires states to be non-ergodic, and it is not known whether this is the case for the relevant states in question. Moreover, Hättich introduces another rule that determines the space–time regions (of yet-to-become

[11] In justifying his adoption of the algebraic formalism, Hättich raises two problems with the Lagrangian formalism: it suffers from the conceptual difficulties of Haag's Theorem and the fields that appear in it are not defined at points (pp. 108–109). Arguably, the latter difficulty can be remedied by smearing the fields, and the former difficulty is not unique to the Lagrangian formalism; in fact it takes on a precise formulation in the algebraic formalism.

occasions) that are created at a given stage in the world-process by the single undivided underlying activity (his REG, p. 227). This rule takes the form of a minimizing condition on the norm distance between the vacuum state (representing the underlying activity) and a product state defined in terms of the restrictions of the vacuum to all possible spacelike separated regions. Without going into details, the concern with this rule is simply whether or not the minimum it specifies exists in all cases.[12]

While these considerations make the H–W translational scheme problematic, they should not detract from the significance of Hättich's achievement. He has given us a detailed and rigorous discussion of topics that breach the gap between philosophy of physics and analytic metaphysics. His book should be fertile ground not only for philosophers of quantum field theory and Whitehead scholars, but for anyone interested in how physics and metaphysics can inform each other.

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[12]Note that the act whereby the single underlying activity at any given stage in the world-process determines the space–time regions of yet-to-become occasions may be taken as the act of "envisagement"; hence, REG might be seen as Hättich's answer to the question posed above in Section 2.1 of how the act of envisagement creates these regions, if the doctrine of actual worlds is given up. But, on the surface, REG cannot perform this service, since it assumes we can identify all possible spacelike separated regions of yet-to-become occasions. In fact, Hättich expressly introduces REG as a means of making the gap between his modified ontology, with its rejection of the doctrine of actual worlds, and Whitehead's original version "as small as possible" (p. 226), and not as a means of explaining the act of envisagement.