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Whitehead, James, and the Ontology of Quantum Theory

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Abstract

I shall describe the beautiful fit of the ideas of Alfred North Whitehead and William James with the concepts of relativistic quantum field theory developed by Tomonaga and Schwinger. The central concept is a set of happenings each of which is assigned a space-time region. This growing set of non-overlapping regions fill out a growing space-time region that advances into the still-uncreated and yet-to-be-fixed future. Each happening has both experiential aspects and physical aspects, which are jointly needed to generate the advance into the future. This conception is useful in passing from the pragmatic interpretation of science to a putative understanding of the reality beyond phenomena, and of our role within it. James' ideas about attention and volition are naturally implementable within this framework, and make us into agents that can act efficaciously upon the physical world on the basis of felt values, rational reasons, and conscious understandings.

Prelude

Upon completing my article "The Copenhagen Interpretation" (Stapp 1972), which stressed the pragmatic character of that interpretation, I sent the manuscript to Heisenberg for his reaction. He expressed general approval, but raised one point:

> There is one problem I would like to mention, not in order to criticize the wording of your paper, but for inducing you to more investigation of this special point, which however is a very deep and old philosophical problem. When you speak about the ideas (especially in section 3.4) you always speak of human ideas, and the question arises, do these ideas "exist" outside of the human mind or only in the human mind? In other words: have these ideas existed at the time when no human mind existed in the world? ...
>
> I am enclosing the English translation of a passage in one of my lectures in which I have tried to describe the philosophy of Plato with regard to this point. The English translation was done by an American philosopher who, as I think, uses the philosophical

> nomenclature correctly. Perhaps we could connect this Platonic idea with pragmatism by saying: It is “convenient” to consider the ideas as existing outside the human mind because otherwise it would be difficult to speak about the world before human minds have existed.

These remarks highlight the fact that standard quantum philosophy adheres to the Copenhagen pragmatic stance of erecting science upon human knowledge. Yet science encompasses cosmology, and also our attempts to understand the evolutionary process that created our species. If we want to address the basic question of the nature of human beings then we need more than a framework of practical rules that work for us. We need to see the pragmatic anthropocentric theory as a useful distillation of an underlying non-anthropocentric ontological structure that places the evolution of our conscious species within the broader context of the structure of nature herself. We need an ontology within which the pragmatic theory is naturally embedded.

That is a big order! Fortunately, however, there already exists an ontology that provides a good starting point. It is the ontology proposed by Alfred North Whitehead. In the following I shall describe the fusion, as I conceive it, of relativistic quantum field theory with what I take to be the key ideas of Whitehead. Then I shall demonstrate how the ideas of William James about attention and volition can be implemented in this framework.

1. Introduction

> Nature and Nature’s laws lay hid at night.
> God said, ‘Let Newton be!’ and all was light.
>
> Alexander Pope

> In our description of nature the purpose is not to disclose the real essence of phenomena, but only to track down as far as possible relations between the multifold aspects of our experience.
>
> Niels Bohr

These two quotations highlight the question: What is the proper task of science? Is it to describe nature herself and her laws, as Alexander Pope proclaimed was already achieved by Isaac Newton? Or should the goal of science be curtailed in the way recommended by Niels Bohr (1958, p. 71) who asserted that

> . . . the formalism does not allow pictorial representation along accustomed lines, but aims directly at establishing relations between observations obtained under well-defined conditions.

Difficulties of representing reality along accustomed lines do not automatically preclude every kind of rational conceptualization. Perhaps an uncustomary idea will work. Even Newton's mechanical conception was not customary when he proposed it. If advances in science reveal the incompatibility of the empirical evidence with customary pictorial representations, then perhaps the construction of a new vision of reality is needed, instead of meek resignation to the construction of mere practically useful rules. Of course, direct empirical validation may become elusive insofar as the needed conceptions carry us beyond the realm of human experience. Hence, increased reliance upon rational coherence will presumably be required.

To operate most effectively in the physical world, one needs an adequate conception – compatible with science – of oneself operating within that world and upon it. Optimal functioning is impaired if you are armed only with blind computational rules, severed from a rationally coherent conception of yourself applying those rules.

There is, of course, no guarantee that our species can come up with an adequate conceptualization of our mindful selves acting in and upon the world. And even if such a conceptualization were uncovered, there is no assurance that it is unique. However, neither the fear of failure nor the specter of non-uniqueness constitutes a sufficient reason to refrain from at least trying to find some rationally coherent way of understanding our conscious selves embedded in the reality that surrounds and sustains us.

Due undoubtedly, at least in part, to the impact of Bohr's advice, most quantum physicists have been reluctant even to try to construct an ontology – a conception of what really exists – compatible with the validity of the massively validated pragmatic quantum rules pertaining to the structure of human experience. However, due to this reticence we are faced today with the spectacle of our society being built increasingly upon a conception of reality erected upon a mechanical conception of nature now known to be fundamentally false. Specifically, the quintessential role of our conscious choices in contemporary physical theory and practice is being systematically ignored and even denied. Influential philosophers, pretending to speak for science, claim, on the basis of a grotesquely inadequate old scientific theory, that the (empirically manifest) influence of our conscious efforts upon our bodily actions, which constitutes both the rational and the intuitive basis of our functioning in this world, is an illusion. As a consequence of this widely disseminated misinformation, "well informed" officials, administrators, legislators, judges, educators, and medical professionals who guide the development of our society are encouraged to shape our lives in ways predicated on known-to-be-false premises about "nature and nature's laws".

Bohr's pragmatic quantum philosophy emphasizes the *active* role that we human beings play in the development of our scientific knowledge. But pursuing this approach can easily lead to an overly anthropocentric conception of reality. A rational escape from this parochialism is provided by the work of the eminent philosopher, physicist, and logician Alfred North Whitehead. In his main opus "Process and Reality" of 1929 (Whitehead 1978) he created a conception of natural process that captures the essential innovations wrought by quantum theory in a way that allows the human involvement specified by quantum theory to be understood within a fundamentally non-anthropocentric conception of nature as a whole.

Whitehead struggled to reconcile the findings of early 20th century physics with the insights and arguments of the giants of Western philosophy, including, most prominently, Plato, Aristotle, Descartes, Leibniz, Locke, Hume, Kant, and William James. But although Whitehead had the hints about "abrupt quantum jumps" and "objective tendencies for these jumps to occur" that came from early quantum theory, and although he was familiar with Einstein's special and general theories of relativity, he was not acquainted with the important and sophisticated developments in relativistic quantum field theory represented by the mid-20th-century works of Tomonaga (1946) and Schwinger (1962).

I shall describe here a conception of reality that stems primarily from the ontological ideas of Werner Heisenberg (1958), one of the principal founders of quantum theory, expressed within an ontological construal of von Neumann's (1955) formulation as revised by Tomonaga and Schwinger to bring it into accord with the physical requirements of the theory of relativity. This relativistic quantum ontology is in close agreement with many key ideas used by Whitehead. Emphasizing these connections will flesh out the rational ontological construal of relativistic quantum field theory.

In order to both clarify this quantum ontology and bring it into correspondence with the Whiteheadian framework I will begin by quoting Whitehead's clear enunciations of those key ideas. On the other hand, I make no claim to encompass every pronouncement of Whitehead, who wrote long before the work of Tomonaga and Schwinger. Indeed I shall always take the quantum theoretical findings as preeminent, and use only those assertions of Whitehead that mesh nicely with, and flesh out, the ontological construal of the quantum formalism that springs naturally from the formulation of von Neumann, as brought into accord with the precepts of the special theory of relativity by the works of Tomonaga and of Schwinger.

A core issue for both Whiteheadian process and quantum process is the emergence of the discrete from the continuous. This problem is illustrated by the decay of a radioactive isotope located at the center of a spherical array of a finite set of detectors, arranged so that they cover the entire spherical surface. The quantum state of the positron emitted from the radioactive isotope is a continuous spherical wave which spreads out continuously from the center and eventually reaches the spherical array of detectors. But only one of these detectors will fire. The total space of possibilities (the entire sphere) has been partitioned into a discrete set of subsets (defined by the part of the sphere covered by the various individual detectors) and the prior continuum of potentialities is suddenly reduced to some particular part of the whole specified by the prescribed partition.

But what fixes, or determines, this particular partitioning of the continuous whole into these particular discrete parts? The orthodox answer is that "the experimenter decides". Yet if the experimenter himself is made wholly out of physical particles and fields then his quantum representation by a wave function must also be a continuous function. How can a smeared-out continuum of classically conceivable possibilities be partitioned into a set of discrete components by an agent who is himself a continuous smear of possibilities? How can the definite fixed boundaries between the discrete elements of the partition emerge rapidly from a continuous quantum smear?

None of the founders of quantum theory could figure out how this can happen in a way compatible with the successful rules of quantum mechanics, nor has anyone since. Von Neumann (1955), in his rigorous formulation of the mathematics of quantum theory, calls the partitioning action an "intervention": It is an intervention into the continuous deterministic evolution of the physically described aspects of the universe controlled by the Schrödinger equation.

In orthodox quantum theory *and in actual scientific practice*, the "discreteness" problem is resolved by what Heisenberg and Bohr call "a choice on the part of the experimenter". Von Neumann calls the manifestation of this choice in the physical world by the name "process-1". I shall call by the name "process-0" the process that *selects/chooses* the particular partitioning of the physically described world specified by von Neumann's process 1.

It seems clear that this partitioning cannot arise from the physically described aspects of the world alone: Continuous smears acting in accord with the smoothing Schrödinger equation (von Neumann's "process-2") cannot create a discrete partitioning in finite time. However, the experimenter feels that his consciousness plays a role. So if the physically described aspects alone cannot do the job, and it feels like our conscious efforts are helping, then why not try that idea out? Consciousness is, after all, the only remaining element available in our ontological arsenal. But how can we understand, coherently and rationally, how consciousness can act on the physically described world? The plan of the subsequent Sect. 2 is this:

1. Specify, in Whitehead's words, what I take to be his key ideas.

2. Put them coherently together to form the space-time aspects of Whiteheadian processes.
3. Describe the basic structure of an ontologically conceived relativistic quantum field theory à la Tomonaga and Schwinger.
4. Put these elements coherently together to form the space-time picture of quantum processes.
5. Note the identity of these two space-time pictures.
6. Note some further identities, and propose a unified non-anthropocentric Whiteheadian quantum ontology, based on these connections, and on Whitehead's notion of "feelings".

The ontology is still not completely specified. But it is far more structured than a general pan-psychism. It specifies distinctive conditions pertaining to space, time, causation, the notion of the "now", the physically and psychologically described aspects of nature, and the nature of conscious agents. The empirically validated anthropocentric concepts of contemporary orthodox pragmatic quantum theory become thereby embedded in a general non-anthropocentric theory of reality.

2. A Non-Anthropocentric Whiteheadian Quantum Ontology

2.1 Some Key Elements of Whitehead's Process Ontology

I shall now state what I take to be Whitehead's key principles, expressed in Whitehead's own words, taken from his book "Process and Reality" (PR, Whitehead 1978). Whitehead's first principle is that the world is built out of actual entities or actual occasions (PR, p. 18):

> "Actual" entities – also termed "actual occasions" – are the final real things of which the world is made. ... The final facts are, all alike, actual entities, and these actual entities are drops of experience, complex and interdependent.

Whitehead accepts James' claim about the drop-like (atomic, indivisible) character of experience (James 1911, p. 1061):

> Either your experience is of no content, of no change, or it is of a perceptible amount of content or change. Your acquaintance with reality grows literally by buds or drops of perception. Intellectually and on reflection you can divide them into components, but as immediately given they come totally or not at all.

Whitehead builds also upon James's claim that "the thought is itself the thinker" (James 1890, p. 401):

> If the passing thought be the directly verifiable existent, which no school has hitherto doubted it to be, then that thought is itself the thinker, and psychology need not look beyond.

Thus, the "actual entities" are the "drops of experience" themselves, not some soul-like entities that know them. Your awareness of your "self" must be an aspect of your thoughts, and there is no rational need for, additionally, something besides or beyond the reality that is *that awareness itself.* What we need is an understanding of (1) how and why these thoughts cling together in "streams of consciousness" that have the internal structures that they appear to have, and (2) why these streams of consciousness have the kinds of relationships to other such streams of consciousness that our conversations with other persons suggest they have. These two kinds of properties need to be explained, of course, but they are to be understood not as properties of "matter" as matter was classically conceived, but rather as coordinated properties of dynamically related collections of "actual entities".

Whitehead draws a basic distinction upon which his ontology is based: "continuous potentialities" versus "atomic actualities" (PR, p. 61): "Continuity concerns what is potential; whereas actuality is incurably discrete."

Another Whiteheadian precept is that actual entities decide things (PR, p. 72): "Actual entities ... make real what was antecedently merely potential." And (PR, p. 43): "Every decision is referable to one or more actual entities ... Actuality is the *decision* amid potentiality." Moreover (PR, p. 24): "Actual entities are the only *reasons.*"

Another of Whitehead's key ideas is that each (temporal) actual entity is associated with a region of space (PR, p. 68): "Every actual entity in the temporal world is to be credited with a spatial volume for its perspective standpoint ..." This "perspective standpoint" is the place from which the actual entity views the past.

A closely associated idea is that these regions "atomize" space-time (PR, p. 67): "The actual entities atomize the extensive continuum. This [space-time] continuum is in itself merely potentiality for division." Similarly (PR, p. 62):

> The contemporary world is in fact divided and atomic, being a multiplicity of definite actual entities. These contemporary actual entities are divided from each other, and are not themselves divisible into other contemporary actual entities.

A primary idea in Whitehead's philosophy is his notion of becoming, or process (PR, p. 21):

> The many become one, and are increased by one. In their natures, entities are disjunctively "many" in process of passage to conjunctive unity. This Category of the Ultimate replaces Aristotle's category of "primary substance".

Thus, in Whiteheadian process the world of fixed and settled facts grows via a sequence of actual entities. The past actualities generate potentialities for the next actual entity, which is tied to a new space-time standpoint from which the potentialities created by the past actualities will be prehended (grasped) by the current entity. This basic autogenetic process creates the new actual entity which, upon the completion of its creation, contributes to the potentialities for the succeeding actual entities.

Nature's process assigns a separate space-time region to each actual entity, and this process fills up, step by step, the space-time region lying in the past of the advancing sequence of space-like surfaces "now", as indicated by Figure 1.

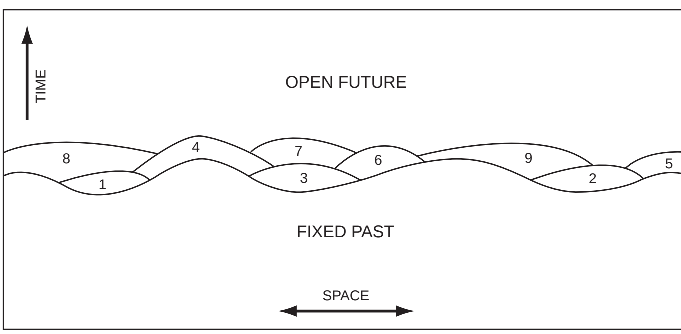

Figure 1: Space-time aspects of the Whiteheadian process of creation.

The bottom wavy line represents the (spacelike) three-dimensional surface "now" that separates – at some stage of the process of creation – the space-time region corresponding to the fixed and settled past from the region corresponding to the potential future. Each new actual entity has a standpoint space-time region, which gets added to the past, thereby pushing slightly forward the boundary surface "now". The small regions with numbers indicate the standpoints of a succession of actual entities, each representing a step in the creative process.

This conception of a growing actual space-time region – filled with (the standpoints of) the growing set of past actual entities – that advances into the potential open future constitutes a resolution to the famous debate between Newton and Leibniz about the nature of space. Newton's conception, described in the *Scholium* in his main work, "Principia Mathematica", was essentially a *receptacle* conception, in which space is an empty container into which movable physical objects can be placed. By contrast, Leibniz argued for a *relational* view that space is naught but relations among actually existing entities: Completely empty space is a nonsensical idea. Whitehead's *actual* space-time is filled by actual atomic (indivisible) entities, thus it is not empty. On the other hand, there is also a yet-to-be-filled space-time future which, however, is still a mere potentiality.

Whitehead's idea of a growing "past" can be contrasted with a corresponding idea in non-relativistic quantum physics. There, the growing "past" lies behind an advancing (into the future) sequence of constant-time instants "now", as illustrated in Figure 2. In non-relativistic quantum theory (NRQT) the fixed past advances into the open future in a layer-cake fashion, one temporal layer at a time. Each quantum reduction event occurs at some particular time "now", *but over all of space.* In von Neumann's NRQT this event produces the new quantum state $\Psi(t)$ of the universe at the instant labeled by time t. Here t specifies a continuous three-dimensional surface in the four-dimensional space-time continuum, with all spatial points lying at the same time t.

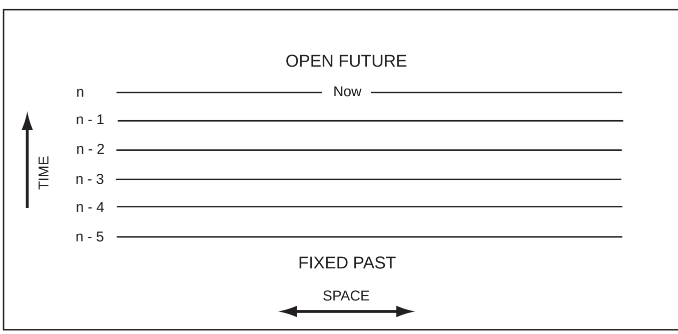

Figure 2: Representation of the space-time structure in non-relativistic quantum theory. At each one of a sequence of constant-time surfaces an "intervention" occurs in association with an abrupt jump to a new quantum state Ψ(t).

2.2 From Von Neumann's NRQT TO RQFT According to Tomonaga and Schwinger

In the relativistic relativistic quantum field theory (RQFT) of Tomonaga and Schwinger the NRQT state $\Psi(t)$ is replaced by $\Psi(\sigma)$. In contrast to t, σ specifies a continuous three-dimensional surface in the four-dimensional space-time continuum, with every point on that surface space-like-separated from every other point (i.e., no point on the surface can be reached from any other point by moving at the speed of light or slower).

The Whiteheadian space-time structure represented in Fig. 1 represents also the space-time structure of a sequence of discrete actualization events in Tomonaga's and Schwinger's formulation of RQFT. In this case, the sequence of space-like surfaces "now" represents the relativistic generalizations of the sequence of fixed-time surfaces upon which, in the non-relativistic formulation of quantum theory, the quantum state (of the universe) is (re-) defined just after each quantum jump in the sequence of quantum jumps.

In the relativistic case, the bottom wavy line in Fig. 1 represents some initial surface σ, an initial "now". In the dynamical evolution of the quantum state this surface pushes continuously forward first through the space-time region labeled 1. This unitary evolution, via the relativistic generalization of the Schrödinger equation, leaves undisturbed the aspects of the state $\Psi(\sigma)$ associated with the rest of the initial surface σ.

When a new quantum "reduction" event occurs, it acts *directly* (via projection) only on the new part of the surface, the part represented by the top boundary of region 1. But this direct change causes *indirect* changes along the rest of the surface σ due to quantum entanglements. These "indirect changes" produce the "faster-than-light" effects which Einstein called "spooky actions at a distance".

The evolutionary process then advances the surface "now" through region 2, then through region 3, etc. After each successive advance into the future, a quantum reduction event occurs. It is associated with a mathematical "projection" that acts directly only on the new part of the current surface "now", but indirectly (via entanglement) on the entire surface "now" (at least in principle).

2.3 Similarities Between Whitehead's Ontology and an Ontologically Construed RQFT

Beyond the identity of RQFT and Whitehead's ontology regarding the space-time development indicated in Fig. 1, there are further correspondences. The first concerns the matching of the Whiteheadian connections between "objective potentia" and "subjective knowledge" with Heisenberg's (1958, p. 53) quantum ontology:

> The probability function combines objective and subjective elements. It contains statements about possibilities or better tendencies ("potentia" in Aristotelian philosophy), and these are completely objective, ... and it contains statements about our knowledge of the system, which of course are subjective in so far as they may be different for different observers.

Another similarity refers to the transition from "potentiality" to "actuality" as expressed by Heisenberg (1958, p. 54):

> Tthe transition from the 'possible' to the 'actual' takes place during the act of observation. ... The observation itself changes the probability function discontinuously; it selects of all possible events the actual one that has taken place. Since through the observation our knowledge of the system has changed discontinuously, its mathematical representation has also undergone the discontinuous change and we may speak of a "quantum jump".

2.4 Compatibility with Einstein's (Special) Theory of Relativity

In the foregoing account I took the structure of RQFT as foundational, and Whitehead's words as supplemental. For Whitehead, of course, philosophical principles were foundational, and physics derivative. However, with regard to the coordination of his actual entities to space-time and, in particular, to the reconciliation of his ontology with the "theory of relativity", Whitehead repeatedly emphasized that the structure that he described did not follow from his general principles but appeared to be features of our particular epoch. That is, his descriptions of the space-time features of his "actual worlds", "contemporary entities", and "durations (the loci of unison in becoming)" were specifically designed to accord with *his idea* of the demands of the theory of relativity.

Particularly in connection with the idea of "unison in becoming (durations)" he brought in ideas from the theory of relativity associated with mere *conventional* choices of a coordinate system. In the classical-physics-based developments of the theory of relativity, the choice of a coordinate system – and hence of the locus of points "now" – is purely conventional, without ontological significance: "Now" is *not* associated with any act of "coming into being". The notion of "coming into being" has, of course, no meaning in the deterministic "block universe" conception of classical physics. Consequently, many different surfaces "now" can pass through a point in a classical picture without conflict. But an analogous multiplicity of loci of "unison in becoming" would create conceptual conflicts within the "open future" RQFT accommodated by Tomonaga and Schwinger.

Because of Whitehead's own admitted reliance on his (relatively primitive) conception of how the theory of relativity can be reconciled with quantum mechanics, it is reasonable to replace Whitehead's proposals, based on his quasi-classical ideas about relativity, by proposals concordant with the way quantum theory was actually made compatible with the theory of relativity during the late 1940s. In the logically simplest ontologicalization of Tomonaga-Schwinger RQFT, the space-like surface "now" advances always forward into the open future, and conceptual confusion and conflict is thereby avoided.

Quantum theory is designed to be a theory of predictions, and the predictions of RQFT conform to the demands of Einstein's (special) theory of relativity. The predictions do not depend upon which one of any two spacelike separated events occurs first in the sequential unfolding of actuality: Switching the sequential orderings of, e.g., the entities labeled 1 and 2 in Fig. 1 changes no prediction of the theory. Furthermore, by virtue of the detailed structure of the quantum rules, the indirect effect, via entanglement, of a quantum event occurring in one region upon predictions of potentialities pertaining to a faraway (spacelike separated) region cannot be used to transmit a "signal" (a controllable message) faster than the speed of light. (For more details see Stapp 2007, App. 5,6,7.)

2.5 The Psycho-Physical Building Blocks of Reality

In the Whiteheadian ontologicalization of quantum theory, each quantum reduction event is identified with a Whiteheadian actual entity. *In the quantum version*, such an actual entity performs two kinds of actions. An action of the first kind *partitions* a continuum into a collection of discrete *experientially distinct* possibilities. An action of the second kind selects (actualizes) one of these discrete possibilities and obliterates the rest. These two kinds of actions are represented mathematically in an abstract Hilbert space. They are associated with the feature of discreteness that Bohr (1962, p. 60) called "the element of wholeness symbolized by the quantum of action and completely foreign to the classical physical principles", and that James (1911, p. 1061) called the "buds or drops of perception" (see Appendix).

According to this ontology, objective or absolute actuality consist of a sequence of psycho-physical quantum reduction events, each similar to a Whiteheadian actual entity. This sequence of happenings creates a growing "past" of "fixed and settled facts".

Each fact is specified by an actual entity that has both a physical pole (aspect) and a mental pole (aspect), and a "standpoint" region in space-time from which it views reality. I take the *physical* aspect of the actual entity to consist of a physically/mathematically described *input* and a physically/mathematically described *output*. The physical input (output) is precisely the part of the physically described quantum state of the universe that is localized – just before (after) the jump – on the *front* boundary of the standpoint region associated with the actual entity.

The mental pole also consists of an input and an output. The mental inputs and outputs have the ontological character of "feelings". The mental inputs are drawn largely from the mental outputs of the prior entities, and the mental output of the current entity is the "bud or drop" of experience created by and at this current entity.

The process by which the mental and physical inputs are combined to produce mental and physical outputs involves aspects that Whitehead called appetites, evaluations, and satisfactions. Thus, idea-like qualities are asserted to be important in the dynamics of the basic process that creates the actual entities, and hence the growing world of actual facts.

The paradigmatic example of an actual entity is an "event" whose mental output is an addition to a stream of conscious events, and whose physical output is the actualization of the neural correlate of that mental output. Such events are "high-grade" actual entities. But Whitehead also allows simpler entities to exist that have lower-grade outputs. Thus, the Whiteheadian quantum ontology is essentially an ontologicalization of the structure of orthodox RQFT, stripped off any anthropocentric trappings, but supplied with a dynamical process that makes our thoughts dynamically effective. This approach takes the physically described and psychologically described aspects of contemporary orthodox RQFT to be exemplars of the elements of a general non-anthropocentric ontology.

This putative understanding of the way nature works is merely an outline, further details of which can be filled in when additional pertinent data become available. The theory is not implied by the currently available empirical data, but it gives a rationally coherent way to accommodate the discreteness aspects that Bohr and James identified.

The program to ontologicalize the pragmatic orthodox quantum mechanics of its founders, and of von Neumann, may seem misdirected. For how does this explicitly observation-dependent ontology apply to the formation of a track in a cloud chamber? The physical happenings in the chamber *seem* to have, fundamentally, very little to do with any act of observation: Our human involvement *seems* only incidental. Some physicists, therefore, conclude that the collapse events in cloud chambers are instigated by purely physically describable causes alone, and that this conclusion holds for brain events as well.

Von Neumann's analysis of measurements shows that for all practical purposes one can indeed assume that an appearing track comes into being without any dependence upon our human observations of it. Still, some sort of process-1 intervention is needed to make the quantum rules work in this paradigmatic case. If it be granted that the coming into being of a particular track is a quantum event which needs to be described not in terms of classical physics but in terms of quantum concepts, namely in terms of vectors in a vector space, and a choice of basis vectors (see Appendix), then the problem of what chooses the basis must be dealt with in some way.

The crucial point here is that quantum phenomena appear to require the entry into reality of the elements of discreteness and wholeness associated with von Neumann's process-1 action, and that this effect cannot be adequately represented either within the conceptual framework of classical physics or its quantum generalization represented by the wave function evolving continuously in accordance with the Schrödinger equation. My proposal is that each such intervention is *in its logical form* like the interventions associated with human observations that orthodox quantum mechanics describes. This conceptualization requires the existence of realities that play, in a general context, the role played by human experiences in the orthodox formulation. But what is the ontological character of these more general realities? A significant achievement of Whitehead's ontology is a rationally coherent putative identification of their nature.

Whitehead calls the realities that are described by the mathematical formulas of physics by the name "physical feelings". In classical physics these realities are conceived to be tiny bits of mindless matter or mindless fields of force. In quantum physics, however, they are converted to features that act like potentialities – like objective tendencies – for psycho-physical events to occur. Whitehead's move of calling these realities "physical feelings" – which need to be combined with "conceptual feelings" and "memory" in order to rise to the level of "conscious feelings" – provides a uniform basis of "feelings" for the entire ontology. And this uniform basis allows the conscious feelings of the kind we know to emerge via a "dynamics of feelings" from an ontological substrate consisting of realities of one single ontological type.

It is admittedly difficult to conceive of a "feeling" that is not a "conscious feeling", for the latter is the only kind of feeling that we actually know, or know of. But if we accept that our conscious feelings are complex versions of simpler elements that can act dynamically upon other like elements and merge with them to form more complex elements of the same kind, then we have, I think, gained an important insight into what Whitehead was driving at with his choice of word. And we will have established a basis for understanding how consciousness can emerge from realities that are not conscious.

For the purpose of illustration, physicists sometimes use the phrase "the electron 'feels' the force exerted by the electric field" to convey the idea that the electron *responds* to the presence of the electric field, in a way intuitively akin to the way our thoughts respond to our feelings. Of course, in the case of the electron, the word "feels" has, for the physicist, no connotation pertaining to consciousness. The physicist is completely content to describe the interactions in purely mathematical language – which is all he needs or uses – without any concern pertaining to the ontological character of the stuff whose mathematical description he employs. Yet non-scientists tend to think of that stuff as classical "matter", even though the mathematics of quantum theory is incompatible with that idea. In the quantum description the "stuff" creates tendencies for the creation of more bits of stuff of the same kind.

The question of what it *is* that is described by the mathematics is a question that can properly be regarded as irrelevant for physics. But if one wants to provide a rational understanding of how our conscious feelings can emerge from the activities of our brains, then it becomes important to recognize that the mathematics of quantum theory does not describe motions of bits of classically conceived matter, but that it can be understood to describe properties of "feelings", conceived to be interacting qualities that are dynamically able to combine with other feelings to form output feelings of the same ontological kind. Under suitable conditions, these output feelings can be the complex sort of feelings that populate our streams of conscious experiences.

Thinking in this way, though based on physics, goes beyond physics: it is metaphysics. In this connection, James anticipated, presciently, scientists who would someday illuminate the mind-body problem (James 1892, closing words):

> ... the necessities of the case will make them "metaphysical". Meanwhile the best way in which we can facilitate their advent is to understand how great is the darkness in which we grope, and never forget that the natural-science assumptions with which we started are provisional and revisable things.

3. Jamesian Volition in Quantum Theory

In line with Whitehead's distinction of a physical pole and a mental pole of an actual entity, contemporary science divides our descriptions of the totality of all things into two categories: descriptions in physical terms and descriptions in psychological terms.

Physical properties consist basically of mathematically described properties localized at points or tiny regions of space-time. More generally, they are the properties dealt with by physicists in physics courses. (In other sciences, this applies as well if properties are non-problematically reducible to basic physical properties.)

On the other hand, according to James, the psychological properties consist of "thoughts, ideas, and feelings". These psychological elements are collected into separate "streams of conscious experiences", each associated, in orthodox psychology, with the subjective inner life of an individual human person.

3.1 Continuity and Causation in Classical Physics

Classical physics postulates that all physical processes satisfy a principle called the "causal closure of the physical". This principle asserts that the physical description, by itself, provides for a causally complete deterministic account. The complete physical description over all of space during any interval of time determines the physical properties over all of space-time. No effects of mind or consciousness on the physically described properties need be considered or acknowledged.

This feature of classical physics – the causal closure of the physical – leads to a puzzle expressed by James (1890, p. 138) as the observation that consciousness seems to be

> an organ, superadded to the other organs which maintain the animal in its struggle for existence; and the presumption of course is that it helps him in some way in this struggle, just as they do. But it cannot help him without being in some way efficacious and influencing the course of his bodily history.

James goes on to an extensive analysis of the entry of consciousness into our lives, and ends up by saying (James 1890, p. 144):

> The conclusion that it is useful is, after all this, quite justifiable. But if it is useful it must be so through its causal efficaciousness, and the automaton theory must succumb to common sense.

3.2 Orthodox Quantum Theory Is Not Causally Complete

In quantum theory there are two kinds of actions that are *not determined by the known laws of quantum theory*, yet are needed to make the theory work. The first of them, corresponding to a first gap in the rule of causal closure has been described by Bohr (1958, p. 73):

> The freedom of experimentation, presupposed in classical physics, is of course retained and corresponds to the free choice of experimental arrangements for which the mathematical structure of the quantum mechanical formalism offers the appropriate latitude.

Bohr's *dictum* that "in the great drama of existence we ourselves are both actors and spectators" (Bohr 1958, p. 81) means that our conscious choices determine conditions that affect subsequent physical properties. Von Neumann calls the physical correlates of these conscious choices process-1 *interventions*. They *intervene* in the orderly continuous process-2 evolution of the physical state of the universe controlled by the Schrödinger equation.

The decisions that select these actions are *free choices* made by conscious agents. They are the process-0 choices that, in actual scientific practice, determine the physically described partition, specified by a process-1 action, of the continuous quantum mechanically described physical world into discrete experiencible components. These choices act in a particular way, with an intent to elicit a conceived experiential feedback. They are made, in actual practice, by human agents. They are "free" in the sense that they are not determined, within orthodox theory, either statistically or in any other way. *This indeterminateness constitutes the first kind of causal gap.*

The second kind of causal gap is related to what Dirac called nature's choice of the *outcome* of the experiment. The intended outcome may or may not actually occur. The quantum state of the universe just prior to the agent's choice determines the *probability* for the intended feedback to occur, but it does not determine whether or not that feedback will actually occur. *This indeterminateness constitutes the second kind of causal gap.*

3.3 Filling the First Causal Gap

It is a mainstream "materialist" assumption in neuroscience that any effect of mind is causally reducible to the physically describable aspects of nature. This presumption is in no way a consequence of basic physical principles: It is neither demanded nor supported by contemporary orthodox physical theory. According to 20th century quantum physics, consciousness can *intervene* in brain dynamics in an essential and non-eliminable selection and actualization of physical actions that without this intervention would remain pure quantum potentialities.

It is one thing to notice that the shift from classical mechanics to quantum mechanics involves the injection of conscious choices into the causal physical structure of the theory, and to observe that this opens a door to *possible* effects of minds upon brains. But it is quite another thing to spell out in detail how such an effect could actually occur. Let me discuss this issue with a simple example.

Suppose the idea "I shall now raise my arm" pops into your stream of consciousness, and this experience is colored by a strong feeling of *the positive value to you* of that contemplated action's actually occurring. It is concordant with normal experience to presume that this experience will often have a successor in which the core idea "I shall now raise my arm" is colored with a feeling of making an "effort to raise now my arm". The felt connection between "effort" and the "intensity of experience" makes it natural to suppose that the intensity of the effort is correlated with the rapidity at which the experiential events are occurring; that increased effort will be correlated to an increased rapidity of the sequence of actual entities associated with the idea of raising the arm.

Since the timings of Whiteheadian actual entities are not specified by the known quantum mechanical rules, this opens the door to the possibility that psychologically describable elements not reducible to physically described properties enter into the causal structure. But even if that were true the question would arise of how the conscious effort can influence what physically happens. How can a *conscious effort* to raise the arm "cause", in some sense, the physical arm to rise ?

What is the neural correlate of the experience of "making an effort to raise the arm"? Presumably, it is a pattern of neural activity that, if sustained over a sufficiently long time, will tend to cause, via the neural machinery, the arm to rise. This correlate typically has become established through trial-and-error learning involving the comparison of effortful intentional actions to their experiential feedbacks. I call such a pattern of neural activity a "template for action".

Let us suppose, in connection with the succession of actual entities discussed in Sect. 2.2, that the experience of an "effort to raise the arm" causes an immediate (within a few milliseconds) repetition of that experience, and that this causes another immediate repetition, and so on. This rapid sequence of actualizations of the associated "template for action" will tend – by virtue of the quantum Zeno effect (Misra and Sudarshan 1977) – to hold that template for action in place for longer than would otherwise be the case. This persisting excitation of the template for action will, by virtue of its defining property, tend to cause your arm to rise.

This effect is in exact agreement with the observations of James (1892, p. 227):

> I have spoken as if our attention were wholly determined by neural conditions. I believe that the array of things we can attend to is so determined. No object can catch our attention except by the neural machinery. But the amount of the attention which an object receives after it has caught our attention is another question. It often takes effort to keep mind upon it. We feel that we can make more or less of the effort as we choose. If this feeling be not deceptive, if our effort be a spiritual force, and an indeterminate one, then of course it contributes coequally with the cerebral conditions to the result. Though it introduce no new idea, it will deepen and prolong the stay in consciousness of innumerable ideas which else would fade more quickly away. The delay thus gained might not be more than a second in duration – but that second may be critical; for in the rising and falling considerations in the mind, where two associated systems of them are nearly in equilibrium it is often a matter of but a second more or less of attention at the outset, whether one system shall gain force to occupy the field and develop itself and exclude the other, or be excluded itself by the other. When developed it may make us act, and that act may seal our doom. When we come to the chapter on the Will we shall see that the whole drama of the voluntary life hinges on the attention, slightly more or slightly less, which rival motor ideas may receive.

Later in the same book, in a section entitled "Volitional Effort is Effort of Attention" James (1892, p. 417) expresses this even more concisely:

> The essential achievement of the will, in short, when it is most "voluntary," is to attend to a difficult object and hold it fast before the mind. ... Effort of attention is thus the essential phenomenon of will. ...
> Consent to the idea's undivided presence, this is effort's sole achievement. ... Everywhere, then, the function of effort is the same: to keep affirming and adopting the thought which, if left to itself, would slip away.

3.4 Empirical Support

Empirical support for this explanation of the way in which our consciousness affects our brain can be found in Stapp (2001) and Schwartz *et al.* (2005). But beyond the detailed experimental findings described in those works there is the enormous practical benefit of having a rationally coherent conception of nature, and our role in nature, that links our intuitive feeling that our intentional thoughts can influence our physical actions to a science-based understanding of how conscious intentional efforts can affect brain activities in ways that can, through learning or training, be correlated to experiential feedbacks. The vast literature on biofeedback, and the mounting evidence from nerve-activated prosthetics, attest to the utility of this conception of the mind-brain connection.

Insofar as one grants that a conscious experience is not simply an aspect of the activity of a brain that is completely expressible in terms of the physical concepts of (classical or quantum) physics but, instead, has qualities that cannot be expressed in terms of, or reduced to, the physical description of the world, one must specify whether these further properties are needed to fix the flow of physically described events, or whether, as in classical physics, the physically describable flow of events is completely determined by the physically describable aspects alone.

Consider a situation in which consciousness is represented by a module that can integrate and evaluate brain data and make selections, but has no causal effect on the physical machinery that implements or obeys the physical laws that by themselves determine all physical effects. One would then have to understand how this module *could be trained* to come into good alignment with the causal processes upon which it has no causal effect. There is certainly no automatic uniform concordance between the mental and physical descriptions, as the numerous examples of mismatches cited by proponents in mechanistic or materialistic conceptions of reality attest. If there is indeed no automatic concordance between conscious thoughts, ideas, feelings and physical actions, then how can the empirically occurring correspondences come into being without an action of the mental module upon the physical actions ?

Why, I must ask, would anyone ever want to postulate the existence of such an unnatural, awkward, and seemingly *impossible to comprehend* reality ? The empirically validated laws of current physics are applicable to warm, wet, and noisy brains and provide a way of understanding, within that context, a causal influence of mental effort upon brain activities that renders the empirically manifest phenomena of effortful and guided mind-brain interactions natural and understandable.

3.5 Comments

1. Every aspect of the preceding analysis is in strict accord with the orthodox laws of quantum physics. No rule has been stretched or altered. A causal gap in the theory has been filled in a natural way, by exploiting effects explicitly assigned by the theory to conscious free choices, and then applying the known causal laws.
2. The quantum Zeno effect is itself a decoherence effect, and it is not diminished by environmental decoherence. *Thus the decoherence*

argument against using quantum mechanics to explain the influence of conscious thought upon brain activity is nullified. Environmental decoherence does reduce pure quantum states to "mixtures", to a smear of quasi-classical states, but this neither resolves the problem of the discreteness of our experiences nor eliminates all macroscopic quantum effects.

3. The fundamental reason why the effect of conscious thought upon bodily action is explainable within quantum mechanics, but not within classical physics, is that orthodox quantum theory requires, as a key innovation, the causal input of our conscious choices. The logically needed process-1 physical choices have no causal roots in the physically described aspect of reality specified by the theory, but they are strongly correlated with sufficient reasons and other motivations describable in psychological terms. This configuration of causal connections suggests that consciousness is the cause, and the correlated process-1 action is the effect. This is the point of view that ties quantum theory most naturally and directly both to common sense and to our deepest intuitions, as well as to actual scientific practice, where the experimenter chooses on the basis of reasons and goals which of his or her options will be pursued. What thoughts could possibly induce any rational philosopher or scientist interested in the connection between mind and matter to close his or her mind to this seemingly so pertinent development of physics?

4. Contrasts to Whitehead

My use of Whitehead's conceptions is intended to flesh out an ontological construal of relativistic quantum field theory, not to explain Whitehead's philosophy. Thus I have picked out aspects of his work that fit contemporary relativistic quantum theory nicely, and elevate them from a set of pragmatic rules to a putative partial description of the reality in which our bodies and our streams of consciousness are embedded. But certain departures from Whitehead's scheme may be worth noting.

In Sec. 2.4 I have already discussed the deviations pertaining to spacetime structure that seem to be required to accommodate adequately the theory of relativity.

Whitehead regards the mental pole of an actual entity as primarily associated with the internal dynamics that creates the entity. I have taken a key feature of the completed entity to be the final whole experience, the bud or drop of experience that James describes in connection with humans, and have taken this to be *part* of the output of the entity. Whitehead achieves a similar effect when he speaks of the conceptual reproduction in a later entity of conceptual features of earlier entities that it prehends. But since I want to tie the physically described aspects of the output of an entity to those aspects that are represented in the mathematically described quantum state, I need to allow that the output be not confined exclusively to those mathematically described aspects. There is also a conceptual aspect that can be picked up by a later prehending entity and applied as a key part of the internal process of extracting from the smear of quantum potentialities the definite actual output. This integration by each entity of conceptual and physical aspects created by prior entities to produce a new definite actual component of reality is the central idea of the process discussed here.

Another departure from Whitehead stems from the fact that I do not see how a photon, for example, traveling through a vacuum, can be conceived of as a society of entities, at least insofar as these entities have smallish standpoints at which the photon becomes localized. That would seem to preclude well established interference effects such as the famous double-slit experiment. Similar experiments with neutrons going in two different ways around a football field are feasible. So if a photon or neutron is to be conceived of as a society of sequential (successive) entities, then the standpoints of these entities must apparently cover the entire spherical surface of the spreading wave front of the emitted particle. This leads to problems if one tries to deal with several simultaneously emitted particles.

I treat freely moving particles as "potentia" represented by the evolving quantum state, not as societies of actual entities. Only the "larger" physical systems are represented by societies of entities. For the defining characteristic of "larger" I refer to Heisenberg (19584, p. 54, my italics):

> ... the transition from the "possible" ot the "actual" takes place as soon as the interaction of the object with the measuring device, *and thereby with the rest of the world*, has come into play.

In the Whiteheadian framework we do not speak of "measuring devices" as such, but we do have large systems – physical objects – that do propagate as societies of actual entities, where the earlier entities that constitute the objects are succeeded by similar entities. These large objects *interact with the rest of the world* via gentle events that produce quantum decoherence. The first phase of the Whiteheadian process of creating an actual entity is to assess the entire already-created past. It is reasonable to suppose that an entity needs a sufficient linkage to the universe to be able to acquire a standpoint. Thus societies of entities that correspond to physical objects can reasonably be supposed to have appreciable linkage to their environment. This would allow individual elementary particles to propagate as potentialities rather than as societies of actual entities. If we note that the process of creating these events, corresponding to "measuring devices", does need conceptual inputs (mental poles) then we get an answer to Heisenberg's question mentioned in the Prelude: Mentality (conceptual aspects) extends all the way down, but not consciousness.

It is possible to avoid the awkward idea that each actual entity is localized and, hence, that the sequence of entities has to jump around the whole universe from tiny place to tiny place. The rules of RQFT allow the process-1 phase of a global entity to develop completely independent at non-overlapping sites scattered over the entire surface "now", and a later ("process-3") phase to then act globally over that entire surface and fix the outcome (more precisely, a whole set of outcomes) in conformity to the quantum statistical rules. This brings the process into concordance with the usual idea that time advances on a broad front. Thus 20th century physcis allows normal common-sense ideas to prevail in an understandable way without making conscious will an illusion.

Appendix: Connection Between Classical Physics and Quantum Physics

To understand the connection between classical physics and quantum physics, consider first a classically conceived system consisting of one single point particle confined to a large cubical box in ordinary three-dimensional space. Suppose we divide this box into a very large number N of tiny cubical regions. Then one way to represent some information about the system at some particular instant of time is to assign to each tiny cube a number "1" or "0" according to whether the particle is in, or is not in, that tiny cube at that instant. Thus, at each instant, all N boxes will be assigned a "0" except for one box, which will be assigned a "1". (A special rule can be introduced to cover the case where the particle lies exactly on a boundary.) Over the course of time this "1" will, due to the motion of the particle, occasionally jump from one tiny box to an adjacent one.

Information about the velocity of the particle can be added by introducing, for each of the little coordinate-space boxes just mentioned, a collection of M little boxes in a space that represents the velocity of the particle, or better, its momentum – which is the product of its velocity and its mass.

A *statistical* description of the system, as in statistical mechanics, shows particular analogies with quantum mechanics. Statistical mechanics covers situations where one wishes to make statistical predictions about future observations on the basis of the known equations of motion, when one has only statistical information about the initial conditions. In this case each little box represents a tiny region in the combined coordinate-momentum space – which is called *phase space* – and the initial number assigned to this box will generally be some number in between "0" or "1".

This number represents the initial probability that the combination of the location and the momentum of the particle lies in that tiny region. One can let the sizes of these little boxes become increasingly small, and finally go over to a continuous *probability density*. Then the classical equations of motion can be used to determine how this probability density changes over the course of time.

A typical measurement from the classical point of view is an action that answers the question: Do the position and momentum of the system at a time t lie in some specified region R in phase space? Given the initial probability conditions, the probability that the answer is "Yes" at time t is obtained by summing up all of the contributions to the evolved probability distribution that lie within the specified region R at time t of the observation.

In the simple case just described the observed system is just one single point particle. But the same discussion applies essentially unchanged to any physical system, including, in particular, the brain of a conscious human being. In that case, the space in which the little boxes lie is a space each point of which represents a complete classically conceived brain, and each little box represents a tiny range of values in this space. Each little box can represent a tiny region in which both the location and the momentum of every particle in the brain are very close to the values specified by a classically conceived and described possible state of the brain. According to the classical conception of nature, the actual state of the human brain at any particular instant lies in exactly one of these little boxes, and all but one box is assigned a "0". In a classically conceived *statistical* context a set of probabilities that sums to one can be distributed in any chosen (smooth) way among these small boxes, each of which can in principle be shrunk to an arbitrarily small size.

In the quantum generalization of classical statistical mechanics the region R associated with an actual (conscious) observation cannot be represented by an arbitrarily small (or even sharply defined) region of the classically conceived phase space. The size of the – in principle fuzzy – region in phase space, defined in a suitable way, is a multiple of Planck's quantum of action. The intrinsic wholeness of each conscious thought renders the phase space of classical physics an inappropriate basis. The physical state of the brain is represented, rather, as a *vector* in an appropriate *vector space*, and each permissible conscious observation associated with that brain is associated with some set of mutually orthogonal (perpendicular) *basis vectors*.

Thus the basic mathematical structure needed for the conscious-observation-based quantum theory of phenomena is fundamentally incompatible with the mathematical structure used in the physical-measurement-based classical theory of phenomena. An irreducible element of wholeness is present in the former but absent from the latter.

The neural correlates of our conscious thoughts are, according to quantum mechanics, represented in a vector space of a very large number of dimensions. But the basic idea of a vector in a vector space can be illustrated by the simple example in which that space has just two dimensions. Take a flat sheet of paper and put a point on it. (Imagine that your pencil is infinitely sharp and can draw a true point and perfectly straight lines of zero width.) Draw a straight line that starts at this point, called the origin, and that extends out by a certain amount in a certain direction. That directed line segment, or the displacement from the origin that it defines, is a vector in a two-dimensional space.

Any pair of unit-length vectors that are perpendicular to each other constitute a *basis* in this two-dimensional space. (They are in fact an orthonormal basis, the only kind of basis that will be considered here.) Because any pair of perpendicular unit-length vectors rigidly rotated by any angle gives another perpendicular pair, there is an infinite number of ways to choose a basis in a two-dimensional space.

Given a basis, there is a unique way of decomposing any vector in the space into a sum of displacements, one along each of the two perpendicular basis vectors. The two individual terms in this sum are a pair of perpendicular vectors called the *components* of the vector in this basis. One such decomposition is indicated in Figure 3.

If V has unit length and A and B are the lengths of the components of V that are directed along these two basis vectors, then, by virtue of the theorem of Pythagoras, $A^2 + B^2 = 1$: the sum of the two squares is unity. This is what a sum of probabilities should be. Consequently, the concept of probability can be naturally linked to the concept of vectors in a vector

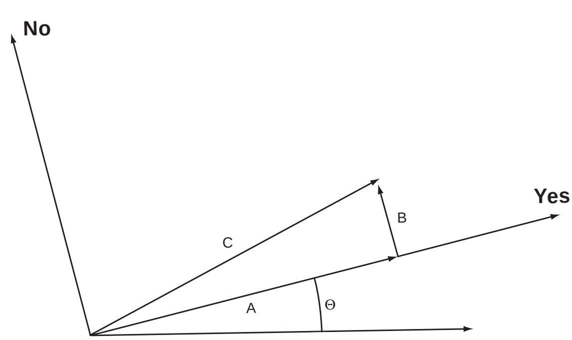

Figure 3: Decomposition of a vector V of length C, in a two-dimensional space, into components of lengths A and B directed along a pair of basis vectors that correspond, respectively, to the "Yes" and "No" answers to a possible process-1 question labeled by Θ.

space. The angle Θ specifies the different observational process that are possible in principle for vectors in this space, and the two corresponding basis vectors correspond to the two possible distinct outcomes, "Yes" or "No", of the observational process specified by Θ.

An N-dimensional vector has N dimensions instead of just two. This means that it allows not just two mutually perpendicular basis vectors, but N of them. As a mathematical idea this is well-defined. There are clearly an infinite number of ways to choose a basis in any space of two or more dimensions, hence an infinite set of elementary observational processes are possible in principle. For any N, and for any basis in the N-dimensional space, there is a unique way of decomposing any vector in that space into a sum of displacements each lying along one of the mutually perpendicular basis vectors.

Each possible observational process is, according to the basic principles of quantum theory, associated with such a choice of basis vectors. The N-dimensional generalization of the theorem of Pythagoras says that the sum of the squares of lengths of the mutually perpendicular components of the unit-length vector V that represents the quantum state of the physical system is unity. Consequently, the probability interpretation of the lengths of the components of the vector V carries over to the N-dimensional case. Vectors in a vector space provide, therefore, a way to represent in an abstract mathematical space the probabilities associated with the perceptual realities that form the empirical basis of science.

According to quantum theory, the alternative possible phenomenal outcomes of any process of observation are associated with a set of corresponding basis vectors. Each such basis vector is associated with an – in principle fuzzy – region in the phase space of the system that is being probed, hence acted upon. This region has a prescribed size, specified by Planck's quantum of action, and only certain kinds of shapes are allowed. Thus the mathematical entities corresponding to possible *perceptions* in quantum theory are very restrictive as compared to the completely general sizes and shapes of the phase-space regions that are allowed to represent measurable properties of classical physical systems. The transition to quantum theory imposes a severe restriction on observational realities, in comparison to the micro-structure that is deemed measurable in classical mechanics.

A quantum state of a system might be represented by a vector in a space with an infinite number of dimensions. Much of von Neumann's (1955) book is devoted to the fine points of how this could be done in a mathematically well-defined way. Although the number of basis vectors is infinite, it is countably infinite: The basis vectors can be placed in one-to-one correspondence to the numbers 1, 2, 3, ... This means that, given a basis, there is a unique decomposition of the state of the system into a countable set of elementary components.

The countability of the set of distinct or discrete possibilities is important. If you have a countable set of states then you could, for example, assign probability 1/2 to the first state, probability 1/4 to the second state, probability 1/8 to the third, and so on, and the total probability will add to one, as a sum of probabilities should. This kind of separation into a countable set of discrete elements, each finite, is not equivalent to the separation of a continuous line into infinitesimal points. There is an element of discreteness involved with observation in quantum theory that is essentially different from what occurs in classical physics, and from what can naturally be generated from von Neumann's continuous process-2, given by the Schrödinger equation, alone. The decomposition into discrete holistic components associated with a set of mutually perpendicular basis vectors in a vector space is the foundation of the relationship of quantum theory to empirical phenomena. This feature blocks the association of arbitrarily tiny regions R in phase space with observation.

This discreteness aspect poses a nontrivial, and I believe fatal, difficulty for many-world theories, which deny the entry of process-1 interventions. Scientific empirical data lie, in the final analysis, in our observations. But then what fixes the set of basis vectors that corresponds to some individual's observations? How can this correspondence, which involves discreteness and wholeness, be specified by a continuous microcausal physically described process-2 alone? Quantum theory is based on an elaborate mathematical machinery for introducing the irreducible element of wholeness, and this machinery is based on von Neumann's process-1 interventions. Leaving them out is contrary to the main thrust of quantum theory. The present approach accepts them as essential ingredients of the theory, and explores their consequences.

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