The Role of Mind in the Human Brain

Introduction

The aim of this talk is to provide a rationally coherent physics-based understanding of the manner in which our conscious thoughts can influence our physical actions. An incidental aim is to expose the profoundly ill-informed understanding behind the quip that "The claim of quantum physicists that consciousness is related to quantum mechanics comes from the idea that because quantum mechanics is a mystery and consciousness is a mystery, maybe the two are related."

I begin with a brief historical review of the relationship between classical and quantum physics.

By *classical* physics I mean the physical theory that originated in the seventeenth century work of Galileo and Newton, and that reigned as the basic scientific theory of nature until it was displaced during the first half of the twentieth century by quantum physics. The basic idea of classical physics was to build a conception of nature around a "physical description" of the world, and "physical laws", where a physical description is a description in terms of mathematical properties attached to space-time points, and physical laws are laws that relate different aspects of a physical description to each other.

The laws of classical physics entail the principle of *The Causal Closure of the Physical*. This principle asserts that at any instant of time *t* the aspects of the physical descriptions tied to points in the very near past of *t* completely determine the aspects of the physical descriptions tied to points in the very near future of *t*. Applied at all times *t,* this principle entails that for any time *t*, the very near past of *t* completely determines every physically described property for *all* future times *t*. Classical physics is consequently said to be "deterministic".

Science deals, however, primarily with what we *know* and *can know*, and hence with such things as our thoughts, ideas, and feelings. These realities are described in psychological terms, rather than in physical terms. However, the principles of classical physics do not specify the general relationship between the things described in these two different languages.

Consequently, classical physics is not a complete scientific theory. The aim of this paper, broadly speaking, is to explain how the changes introduced by quantum theory remove this deficiency of classical physics.

Because classical physics entails the causal closure of the physical, its application is restricted in principle to situations in which any role played by mind, or consciousness, is redundant: its application is restricted to situations in which mind can do nothing in the physically described world that is not done already by the physical properties acting alone in accordance with the classical physical laws. Thus our minds, in situations covered by classical physics, must be treatable as passive witnesses to what the physically described aspects of nature are doing by themselves.

Niels Bohr was one of the principal founders of quantum mechanics. The title of his second book (Bohr, 1958) on the subject is *Atomic physics and Human Knowledge*. The title emphasizes the central importance in quantum theory of the linkage, within that theory, of physical description to human knowledge. That point was re-enforced by following famous assertion by Heisenberg (1958a, p.100):

> The conception of objective reality of the elementary particles has thus evaporated not into the cloud of some obscure new reality concept but into the transparent clarity of a mathematics that represents no longer the behavior of particles but rather our knowledge of this behavior.

Human knowledge is, within quantum theory, not a stand-alone metaphysical notion. It is intricately woven into the pragmatic structure of the theory. The general idea that science should be useful to man was emphasized already by Francis Bacon, and the idea is an integral aspect of pragmatism, as the following assertion (Dipert, 2004) indicates:

> The penultimate goal of thought is to have correct representations of the world, and these are ultimately grounded for the pragmatist in the goal of effective action in the world.

Bohr (1958, p.73) speaks of the "free choice of experimental arrangement for which the mathematical structure of the quantum formalism offers the appropriate latitude." What he is alluding to here is the fact that (orthodox) quantum theory *demands interventions* into the purely physically described evolution. These interventions seem to be coming from our minds and have,

according to quantum mechanics, observable influences on the course of the physically described events. This brings quantum physics into alignment with the ideal of science, that it should provide a rationally coherent framework that ties the physical descriptions to our knowledge in a way that allows us to act effectively in the world.

The Effects of the Uncertainty Principle

According to classical physics, as it existed in the year 1900, the physically described aspects of the world corresponded to a collection of particles and fields. Each particle was postulated to have, at each instant of time *t,* a precisely defined position in space and a precisely defined velocity. But the efforts by physicists to understand the data pertaining to real particles, such as electrons, protons, and hydrogen atoms, led to the replacement of these idealized point particles by smeared out clouds of "possibilities" or "potentialities". These clouds could not be squeezed down to the classical ideal of point particles, due to the constraint imposed by Heisenberg's uncertainty (or indeterminacy) principle. Moreover, even initially "tiny" clouds of minimal size generally do not remain "tiny". Evolution according to the appropriate quantum mechanical law, the Schroedinger equation, generally causes initially tiny clouds to expand into large rarified clouds. Because big physical objects are just collections of elementary particles (and their associated fields) this tendency to spread out can carry over to a large object, such as, for example, a living cat. Under certain conditions, the cloud associated with, for example, a cat would necessarily evolve, insofar as the Schroedinger equation was universally valid, into a combination of two very different clouds, one representing a dead version of Schroedinger's cat, and the other representing an alive version. (The oft-cited environmental decoherence effect does not undo this doubling, it merely makes an experimental demonstration of certain interference effects between these two components, which can be demonstrated *in principle*, virtually impossible to realize *in practice*.)

It is agreed by everyone that no one would ever observe both the living and dead versions of Schroedinger's cat. Hence the problem arises as to how to understand the discrepancy between (1), the form of the physical representation provided by quantum mechanics, and (2), what we human beings actually experience.

The orthodox solution begins with the fact that quantum theory converts elements that classical physics described as "things" into "actions". Thus the state of the world, or of any subsystem, is represented in quantum theory by an "operator", called a density matrix, which can act mathematically upon, and be acted upon by, other operators. If A, B, C. and D, are four operators, then ABCD represents the operator/action formed by letting D be acted upon by C, and then letting the resulting operator be acted upon by B, and then letting the resulting operator be acted upon by A. An important combination of operators is the cyclic combination in which the right-most operator of a sequence acts (back) upon the left-most element. This cyclic structure, for the sequence ABCD is called Trace ABCD. It is evident that Trace ABCD =Trace BCDA etc. The trace of any operator is a (generally complex) number.

Quantum theory is designed to give relationships between the physical description ρ that it provides for the state of a system, and a human experience, under the condition that the human agent performs a measurement on that system that gives an experiential feedback of a certain kind. Suppose the agent performs an action that will give a distinctive recognizable feedback 'Yes' or 'No' according to whether or not a particle, as classically conceived, appears to be, after the measurement, in a certain specified spatial region R. Associated with this physical property (namely that the classically conceived particle is in region R) there is, in quantum theory, an operator P that satisfies PP=P (and hence is called a "projection operator") such that the predicted probability that the feedback will be 'Yes' is given by the formula

$$<P> = \text{Tr } P\rho / \text{Tr } \rho,$$

where ρ is the operator (density matrix) that represents the system upon which the measurement action is performed. This formula connects the physical description of the system that is being examined to an empirical (i.e., experiential) feedback from the probing action that the agent performs. A dynamical connection between a physical description and a conscious experience is thereby specified. This connection is active. After the probing action is performed the probed system is asserted to be either in the subspace corresponding to the answer 'Yes' or in the subspace corresponding to the answer 'No'. Most quantum states do not lie in either of these two subspaces, and hence the probing action induces the famous "quantum

jump" from the state prior to the probing action into either the 'Yes' subspace or the 'No' subspace. The probing action thus influences the physically described state of the observed system. An important question thus arises: what determines which of the infinite number of mathematically possible probing action the agent will perform?

Contemporary quantum theory has at this point a causal gap: the known laws fail to fix which of the infinite number of mathematically possible probing actions the experimenter will perform, and when, if at all, he will perform it. This is the circumstance alluded to by Bohr's mention of the "free choice of experimental arrangement for which the mathematical structure of the quantum formalism offers the appropriate latitude." This freedom of choice, coupled with the effects of this choice upon the physically described state of the probed system, opens the door to the possibility of *effective human action* in the physically described world, with the effective action chosen on the basis of what the person knows and values.

It should be noted that the statistical elements enter orthodox quantum mechanics only in connection with the *answers* to the questions, not with the choice of which questions will be posed! It is completely compatible with contemporary physics to postulate that the choices of which probing actions will be performed, and when they will be performed, can be influenced by realities such as rational reasons and felt valuations, treated as instigators of actions, rather than as mechanically determined side effects of physically described properties. The logical priority of the physical vis·a·vis the experiential, which characterizes classical physics, does not necessarily carry over to quantum theory.

The Physical Reality as "Potentia" for the Occurrence of Psycho-Physical Events

Heisenberg (1958b, Ch. 3) suggested that if one wants to go beyond quantum theory considered merely as a set of practical rules (for making predictions about future experience on the basis knowledge cleaned from feed-backs from earlier probing actions) then the physical state should be interpreted as a "potentia" for an "event" to occur. The word "potentia" means "objective tendency", and the "event" is an occurrence or action with both a psychologically described aspect and a physically described aspect.

The psychologically described aspect is an increment in knowledge, whereas the physically described aspect is a sudden reduction of the prior state ρ of the physically described system to the part of that prior state that is compatible with the increased knowledge. Thus each "event" is a co-occurring pair consisting of an increment in knowledge and a reduction of the physical state to the part of the prior state that is compatible with the increased knowledge. These psycho-physical events are the glue that links the experiential aspects of nature to the physical aspects.

Von Neumann's Shift of the Heisenberg Cut

The original "Copenhagen" interpretation of quantum mechanics separated the physically described world into two parts: (1), the system being probed, which was described in the mathematical language of quantum mechanics; and (2), the rest of universe, which is treated as the "observer", whose experiences pertaining to the observed world are described in the language of classical physics. This observing portion is supposed to include both the human observers and their macroscopic measuring devices, conceived and treated in the way that classical physics conceives and treats macroscopic objects. This approach works well, insofar as one is content to regard quantum theory as merely a set of practical rules for making predictions about outcomes of our physical probing actions. But it becomes problematic when we move into the realm of nanotechnology with ever smaller measuring devices, or into the domain of cosmology where there are no repeatable preparations. We want to use it to explore quantum effects in our brains, and to study the relationships of our conscious thoughts to our physically described brains.

Von Neumann tackled these problems by considering an idealized situation in which there is a sequence of measuring devices, each probing the output of the device that precedes it in the sequence, and by then following the causal chain first into the retina of the observer, and then into the optic nerves, and then ever deeper into the brain until at last the entire brain of the observer is treated quantum mechanically, along with the rest of the physical universe. Because quantum mechanics was formulated from the outset in terms of the two different descriptions, the physical and the psychological, with only the former tightly attached to space-time points, the logical structure continues to be maintained even when the entire physically

described world is treated quantum mechanically. At that ultimate stage von Neumann gives the name "abstract ego" to the carrier of the psychologically described aspects. The theory at that stage describes the entire physical world quantum mechanically, with each psycho-physical event representing a quantum mechanically specified dynamical linkage between the mind and the brain of a conscious agent. The real psychological events that populate our streams of conscious experiences are thereby allowed to play the dynamically active role that they intuitively seem to us to be playing, but now within the framework imposed by the quantum mechanical formalism.

Within this logical framework there is no logical need to restrict the role of active conscious agent to human beings. However, von Neumann's analysis shows that it will be extremely difficult to distinguish, empirically, between non-human macroscopic physical systems that are acting as agents, and hence causing collapse events to occur, and those that are not. However, our interest here is in the case of human beings, whose reports of their experiences we can reasonably elect to treat on a par with our own reports of our own experiences.

The Four Processes

Von Neumann identifies two processes. His *Process 1* is his name for the physical aspect of the action of posing a specific question. The question can be reduced to a set of Yes-No questions, and each 'Yes' answer is supposed to be, at the psychological level, a recognizable experiential feedback. The physical aspect is

Process 1: The Choice of Question

$$\rho \rightarrow \rho' = P\rho P + P'\rho P' , \qquad \text{with } P' = (1 - P_.)$$

Von Neumann's *Process 2* is

Process 2: The Schroedinger Evolution

$$\rho(t_2) = (\text{Exp} - iH(t_2 - t_1))\ \rho(t_1)\ (\text{Exp} + iH(t_2 - t_1)),$$

where H is the Hamiltonian, here assumed to be time independent.

Process 3: Nature's reply

$$\rho' \rightarrow P\rho P \ \textit{or}\ P'\rho P' \quad (\text{'Yes'}\ \textit{or}\ \text{'No'})$$

The probability of reply 'Yes' is Trace Pρ/Trace ρ.

Quantum theory does not determine which one of the infinite set of possible projection operators P will appear in process 1. I call the process, whatever it is, that chooses this P and the time *t* that the process 1 action occurs, by the name "Process Zero". The fact that process zero is not determined by contemporary quantum theory constitutes a "causal gap" in that theory, and entails an apparent (or potential) breakdown of the principle of the causal closure of the physical. In any case, this theory entails a two-way causal linkage between the mind and the brain of the agent:

Brain affects mind via process 3, and

Mind affects brain via process 1.

Template for Action

Any intentional physical action, such as raising one's arm, requires sending a temporally correlated sequence of neural signals to the muscles. So it is plausible that there is, in association with each intentional action, a corresponding spatio-temporal pattern of neural or brain activity that if sustained for a sufficient period of time will tend to cause that action to occur. I call this spatio-temporal pattern of brain activity a *template for action*. The projection operator P associated with this intentional action should preserve this template for action, and eradicate all possible patterns of brain activity that are incompatible with it.

Process 1 and the Conversion of an Intentional Thought to a Bodily Action

An experimenter's action of setting up a particular experiment is an action directed at the goal of receiving an intended feedback. It is represented in

quantum theory by a psycho-physical event. The psychological aspect is the felt intention to receive the intended feedback. The physical aspect is the "query" or "question" represented by the process 1 action specified by the projection operator P that reduces the state of the brain to the part compatible with the template for the intended action.

The Quantum Zeno Effect

It is a consequence of quantum dynamics that sufficiently rapid repetitions of the same process 1 action can, by virtue of the so-called quantum Zeno effect, cause the template for an intended action to be held in place, in the face of strong opposing physical forces, for much longer than would otherwise be the case. Such an extended holding-in-place of this template for action will tend to make the intended action occur. Thus a control of the repetition rate of a sequence of process 1 actions translates into an influence on the bodily actions of the agent.

If the properties that characterize the density matrix $\rho(t)$ and the projection operator P are themselves characterized by classically conceived parameters pertaining to the state of the brain then the time scales relative to which "rapid" is defined will be these classically specified time scales.

Thus, if a strongly felt intention corresponds to rapid repetition of the associated process 1 action, then the net result of implementing the quantum mechanical effects of the process 1 actions will be a prolongation, relative to what follows from a classically conceived neural dynamics, of the temporal duration of the pattern of brain activity that is the template for that strongly felt intentional action.

The process zero, whatever it is, that determines the form and the timings of the process 1 actions is *not* the quantum mechanical process, process 2 (the Schroedinger equation) that governs the time evolution of the quantum state of the system. That quantum state, according to orthodox ideas---particularly those of Heisenberg---specifies only the potentialities/probabilities for the actual events, but neither the form nor the timing of the *actual* events themselves. The Schroedinger equation, which is a quantum mechanical analog of the equations of motion of classical mechanics, makes no reference at all to idea-like realities such as intentions or mental concepts.

But it is not evident this same limitation must apply also to process zero. *Insofar as process zero allows the repetition rate for a sequence of similar process 1 actions to be influenced by conscious intentions, quantum mechanics provides a fundamental-physics-based way for our conscious intentions to inject the physical correlates of mental concepts into the physically described universe.*

Quantum mechanics rationally accommodates, therefore, a two-way causal linkage between mind and brain, whereas the concepts of classical mechanics provide no rational foundation for a causal connection in either direction.

Quantum mechanics leads, consequently, to a radical revision of the conception of man. Whereas classical physics reduces man to a machine, quantum mechanics allows man to be an injector of physical counterparts of mental concepts into the structure of the physically described world. Physical counterparts of mental concepts can be identified and honed into brains by trial and error learning. (cf. Stapp, 2007)

The Form and Timing of the Process 1 actions

We now look more closely at question that orthodox quantum mechanics does not answer: What determines *when* a process 1 action will occur, and *what* the associated projection operator P will be? That is, we turn to the problem of understanding the possible workings of process zero.

The *when* question pertains to the representation of process 1 in space-time.

Von Neumann's analysis was based on non-relativistic quantum mechanics. According to orthodox non-relativistic quantum mechanics, each collapse event occurs at an instant of time, and changes the state $\rho(t\text{-})$ that represents the extended-in-space system just before time t to the state $\rho(t)$ that represents the system at the instant of time t. The horizontal lines in the figure shown below represent the instants at which the state of the extended-in-space systems suddenly changes.

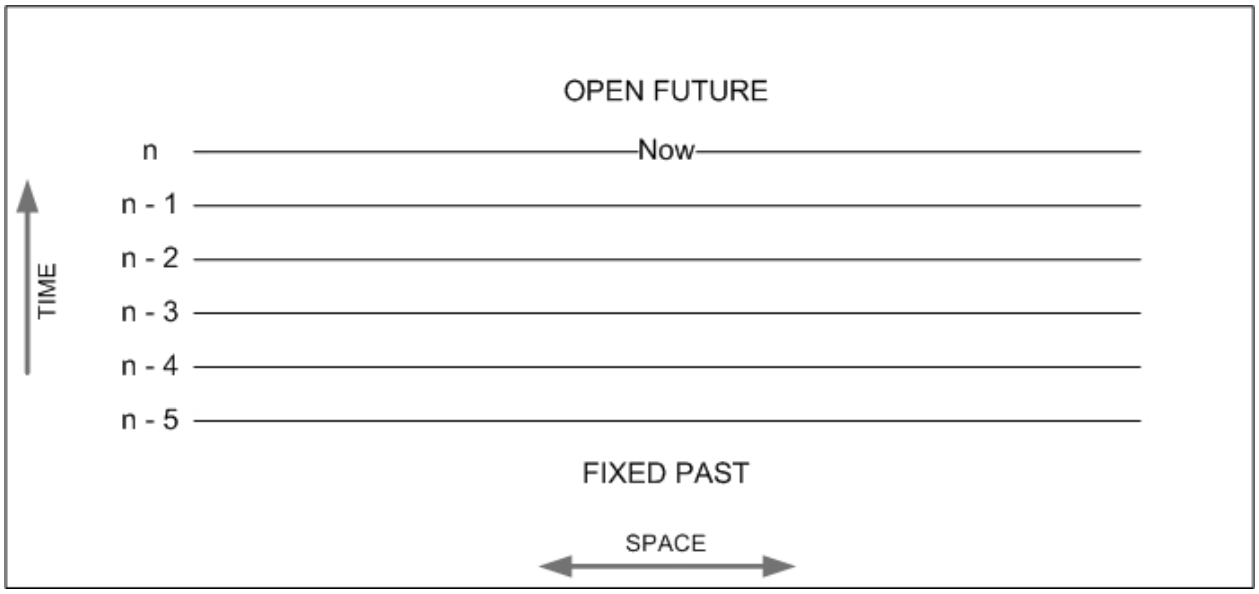

Figure 1. A space-time diagram showing as horizontal lines the instants at which the evolving state $\rho(t)$ suddenly changes to a new (reduced) form. During the intervals between these times the state $\rho(t)$ evolves according to von Neumann's process 2, the Schroedinger equation.

Von Neumann's 1932 non-relativistic formulation was converted to a relativistic form during the middle of the century independently by S. Tomonaga (1946) and by J. Schwinger (1951). In this relativistic formulation the state of the system was associated not with an instant of time t, but rather with a space-like surface σ. A space-like surface σ is a continuous three-dimensional surface in space-time such that every point on the surface is space-like separated from every other point on the surface. A succession of collapse events can be assumed to occur on a succession of space-like surfaces σ such that each coincides with its predecessor except on a small patch, over which a surface σ is displace slightly into the future relative to its predecessor, as indicated in Figure 2

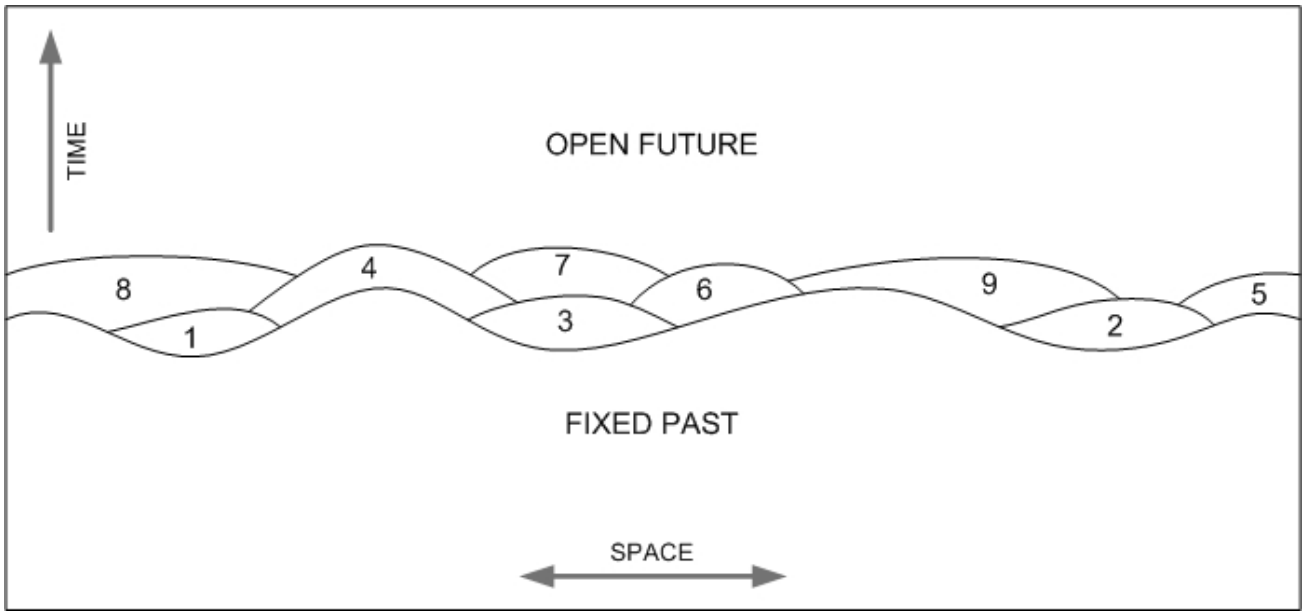

Figure 2. The collapse events occur over a sequence of space-like surfaces σ each of which is locally shifted slightly forward in time relative to its predecessor. In the intervals between these surfaces the state ρ evolves in accordance with the relativistic quantum field theory (RQFT) generalization of the Schroedinger equation.

The conceptual structure of the theory remains unchanged: the physically defined state ρ(σ) represents not "actuality" itself, but merely a set of objective tendencies pertaining to the occurrence of the next psycho-physical event. It is these *events*, which are registered in consciousness, that are regarded as the objectively existing actualities.

Process Time

The time represented in Figures 1 and 2 can be called "physical time": it is the time that appears in our presently existing physical theories. But the evolutions and events represented in these figures pertain directly only the features of reality associated with known physical aspects. We are now concerned with a process that is not determined by the known physical aspects. This latter process, process zero, is *not* process 2, and it could involve feature of reality, namely the psychologically described realities, that are not among the physical factors that determine the potentialities. It is

not evident that process zero evolves between two successive events in lock step with process 2. In view of our present lack of knowledge of the nature of this process it is prudent to *allow* its dynamics between two successive events to be independent of the dynamics of process 2. This amounts to introducing a second time in which the process zero is taken to occur. I call this time "process time". Process time and physical time are linked at the surfaces σ of Figure 2 associated with the actual events, but during the intervals between events they can be *allowed* to develop independently.

Incorporating Whitehead

So far I have merely spelled out the logical consequences of accepting the fact that brain dynamics *at the microscopic scale* is subject to the uncertainty principle, and the fact that the uncertainties at the microscopic scale will tend to be magnified by the brain dynamics as one moves up to the macroscopic scale. This requires a remedy that will bring the consequences of the full theory into alignment with human experience.

Insofar as one seeks a rationally coherent conception of what is actually happening, as opposed to a mere set of practical rules, the orthodox remedy (associated with works of Heisenberg and von Neumann) postulates a reality built of psycho-physical events, with the evolving quantum physical state ρ interpreted as a "potentia" for the occurrence of the next event. The psycho-physical events provide the glue that links the quantum mathematics to human experience, and the interpretation of ρ in terms of potentialities for the occurrence of events then follows naturally from its statistical significance.

The idea of a reality built around psycho-physical events, and of 'potentialities' for them to occur, is the core of a conception of reality advanced also by Alfred North Whitehead, who was stimulated by quantum mechanics but developed this core idea by linking it to the ideas of the major figures of western philosophy. The central focus of Whitehead's attention is precisely the structure of what I have here been calling "process zero", namely the process that decides key questions about the *actual* specific form of the next event. Because of the difficulty of deducing the workings of this process zero directly from empirical data alone, any suggestions based on deep philosophical considerations are welcome, even though the scientific test of their worth will be their success in producing a rationally coherent

and useful understanding of the connection between the psychologically and physically described aspects of the scientific endeavor.

The discussion that follows is inspired by the ideas in Whitehead's 1928 book *Process and Reality*, regarded, however, as an elaboration upon the Tomonaga-Schwinger formulation of relativistic quantum field theory discussed above.

The Process of the Creation of Relational Space-Time

Isaac Newton erected his (classical) physical theory on the idea of a space-time continuum as a *receptacle* within which the material stuff of the universe was placed. Space and time were described as if they existed on their own, independently of the matter that was placed in the framework they provided. Leibniz criticized this idea of space conceived independently of the matter it contained, and argued for the notion that space was naught but a system of *relationships* between the material elements of nature. Newton's conception was better suited to his idea of gravity as an instantaneous force. However, Newton actually rejected the idea that gravity had no carrier, and Einstein's 1915 theory of gravity was called "General Relatively" because it generalized his earlier "Special Relativity", which regarded space-time as a codification of a system relational (i.e., relative) connections, as opposed to being a pre-existing receptacle.

Whitehead opted for a relational conception of space-time that exists in actualized form only to the extent that it has been created by "actual occasions", which is Whitehead's name for what I have been calling (actual) events. Each such event is associated in Whitehead's scheme with a particular region of space-time from which it views all of the events that precede it in the process of the creation of actual(ized) reality. These event-associated regions are supposed to be non-overlapping regions whose union grows, and progressively fills more and more of the space-time continuum.

This Whiteheadian conception of a growing actualized and compartmentalized space-time fits well with the picture of a growing fixed-and-settled past and a shrinking (yet-to-be-filled-with-event-associated-regions) open future indicated in Figure 2. A more detailed discussion of

this connection between Whitehead's ontology and Tomonaga-Schwinger relativistic quantum field theory is given in chapter 13 of Stapp (2007).

In Figure 2 the sequence of events is considered to be well ordered. However, an important feature of relativistic quantum field theory is that the ordering in which space-like separated process 1 events occur has no effect on the prediction pertaining to the future process 3 events. Thus although imaging that the events occur in a definite sequential order is conceptually helpful, the theory is appropriately independent of the order of the occurrence of space-like separated events.

Localization and Causation

Whitehead's basic idea is that each actual occasion is a psycho-physical happening that is associated with a physical space-time, but that is intrinsically a *psychological process,* as is indicated by his use of words such as 'appetite" and "satisfaction". This process draws upon psychological realities that have occurred its space-time past in a way similar to the way that the physical state $\rho(\sigma)$ of RQFT draws from potentialities created by physical events created in its space-time past. For example, suppose the next event is localized---as regards its physical aspects---on the patch p lying on the surface σ, with p located in the brain of some person, Its physical inputs can be taken to be the aspects of the physical state $\rho(\sigma)$ that are localized in this patch p on σ. But what are its psychological inputs?

The simplest hypothesis is that the psychological inputs are the psychological aspects of the events whose physical aspects contribute to the physical aspects of $\rho(\sigma)$ localized on the patch. This conception of the process is then in general concordance with the causal strictures of the theory of relativity. This psycho-physical process fills the causal gap in basic contemporary physical theory by doing what the Schroedinger process 2 does not do, namely determine, not merely the possibilities or potentialities for what might happen, but rather what actually does happens, or, more precisely, the projection operator P, and the timing, of the next process 1 action.

Coherent States of the Electromagnetic Field and Classical Description

Relativistic quantum field theory contains a special category of states of the electromagnetic field called "coherent states". They can be specified in term of the parameters used to describe classical electromagnetic fields. If the projection operators P that specify the process 1 are expressed as statistical mixtures of these special states, then the idea that our human involvement is classically describable becomes realizable strictly within the quantum formalism: Classical description then becomes an *aspect* of the quantum description, rather than a contradiction to it.

Connection to the "Consistent Histories" Approach

The approach to the completion of quantum theory outlined above can be illuminated by comparing it to the "consistent histories" approach initiated by Robert Griffiths, and endorsed by its serious use by Roland Omnes and by Murray Gell-Mann and James Hartle. The starting point of both approaches is the same, namely the formula that von Neumann would associate with a sequence of process 1 actions on some initial density matrix. The von Neumann formalism gives a formula for the probability associated with each possible sequence of 'Yes' or 'No' outcomes of the measurement-like actions. In the special cases in which every two different sequence of outcomes lead to two orthogonal final states the set of alternative possible histories (defined by the various sequences of 'Yes' or 'No' outcomes) are related in the ways specified by the rules of ordinary logic.

This linkage between physical theory and classical logic provides a rich field for theoretical studies, and brings quantum theory into closer connection to the features that would be exhibited by a classically conceived world. This theoretical richness is, however, also a liability, for the theoretical framework allows not only the sequence of process 1 actions that can be conceived to be what actually happens, but also, and completely on a par, an infinite continuum of other logically allowed sequences of process 1 actions, with no reason for supposing that some one particular discrete sequence will single itself out from the continuum of theoretically equivalent possibilities. Indeed, the theory is formulated so as to allow any possible sequence of process 1 actions to be actual, and gives no indication of what it is that picks

out as actual one particular sequence from the continuum of possibilities that the rules of quantum mechanics treat equivalently.

Omnes, who is a big supporter and developer of the "consistent histories" approach, is very explicit and emphatic about this difficulty. In Omnes (1994), p.506 he gives a summary of his conclusions in twenty-six theses. Thesis 9 asserts that "The theory is unable to give an account of the existence of facts!" This re-affirms what he said on page 502, in connection with a comparison between the Consistent Histories approach and the earlier orthodox one: "Both theories…fail when asked to give an explanation for the existence of facts." On page 516 he says: "Another feature of facts is still more striking. As long as one only thinks of them (rather than experiencing them), by envisioning them as so many possible phenomena, the representation works perfectly well. This representation however breaks down when one comes to their actuality." On page 504 he says: "Finally, there remains *the* problem, which is the existence of facts. It was somewhat hidden behind wave packet reduction in the older interpretation but, now that most other problems have been solved, or at least clarified, it stands pure and alone."

This problem is the problem of specifying the workings of process zero. The need for process 1 was clearly recognized by von Neumann, and the question of what picks the form and timing of process 1 is implicit in Bohr's talk about the "free choice" on the part of the experimenter. The notion of psycho-physical events is needed to tie the mathematical formalism to empirical data, and the mathematics implies that the state ρ acts as a potentiality for the occurrence of an outcome, but the entire scheme is an empty formalism if there is nothing that achieves what Bohr ascribes to "the free choice of experimental arrangement for which the quantum formalism provides the appropriate latitude." Omnes (1999 p.238) says: "One more revelation must be borne in mind,…the unbridgeable gap between theory and existence…Such is the new state of affairs that we now must face."

Gell-Mann and Hartle seem at first to move closer to the approach being discussed here. They speak of IGUSes. These are "information gathering and using systems", which are supposed "have interests" and "make observations", and "employ the fundamental formula", which is used to compute probabilities on the basis of present data, make predictions, control future perceptions on the basis of these predictions (i.e., exhibit behavior), …".

These IGUSes certainly seem to be a lot like us, but Gell-Mann and Hartle resist the very reasonable idea that the experiential realities *actually do something*: that they are more than just idle spectators. Yet if Gell-Mann and Hartle introduce no dynamics beyond what follows from contemporary quantum theory itself, then they would seem to be subject to the verdict of Omnes that their theory will not be able to distinguish the particular process 1 actions that actually occur from the continuum of logically possible ones in which they are imbedded.

Conclusions

It is completely reasonable and natural that experiential realities, which certainly do exist, should have a function in the workings of nature, particularly in connection with the course of events in our streams of consciousness. Classical physics was special and unnatural in this respect, in that it can be applied to the motions of macroscopic rigid bodies and to systems whose internal structures have little or no capacity to amplify the unavoidable effects of the uncertainty principle at the microscopic level into macroscopic physical differences, but it cannot be applied to systems that can magnify microscopic uncertainties into observably different macroscopic possibilities. The orthodox approach to this more general case, in which microscopic uncertainties spread to the macroscopic domain, has been to recognize that---insofar as one wants to have a conception that goes beyond regarding quantum mechanics as merely a set of practical rules for calculating expectations regarding future experiences from information gleaned from prior experiences---one should understand that the quantum mechanical state ρ represents not the actual facts, but merely a set of potentialities pertaining to future actual facts. Thus insofar as no actual event has occurred the splitting of, for example, the state ρ of Schroedinger's cat into two components would correspond not to a splitting of the cat itself, but only a splitting of the possibilities for what the cat-facts will be when the events that create the cat-facts eventually occur.

One key point should be emphasized: the mere amplification of uncertainties up to a macroscopic scale, although entailing unavoidable interactions with the environment, does not by itself bring about a reduction to one macroscopic state or the other. Some other process, not specified by contemporary quantum mechanics, must be added in order to specify the projection operator P and the timing needed to define the needed process 1.

Whitehead, as I propose to apply him, suggests that this selection process is essentially psychological, and involves, dynamically, the psychological aspects of the actual occasions whose physical aspects influence the physical aspects localized on the patch *p* of σ associated with the region of σ upon which P acts. This psychological process is not equivalent to the physically described process 2, for the latter represents the evolution only of the potentialities. That last statement is key: the process that specifies P, and when it acts, cannot be the physical process described by quantum mechanics---which includes classical mechanics as an approximation---because the quantum physical process generates the evolution only of the state ρ of potentiality, which is less than what is needed. Given that the purely physical process 2 cannot suffice, the notion that the needed choice is determined by a psychological process is the simplest possibility.

References

N. Bohr, (1958) Atomic Physics and Human Knowledge, Wiley, New York.

W. Heisenberg, (1958a) The Representation of Nature in Contemporary Physics, Daedalus 87 (summer) 95-108.

W. Heisenberg, (1958b) Physics and Philosopy, Harper, New York.

R. Dipert, (2004) Peirce's Deductive Logic: Its Development, Influence, and Significance. In Cherl L.Misak, editor, The Cambridge Companion to Peirce, pages 287-324. Cambridge University Press, Cambridge UK.

J. von Neumann, (1955) Mathematical Foundations of Quantum Mechanics, Princeton University Press, Princeton N.J. (Translated from the Springer 1932 German Original by Robert T. Beyers)

S. Tomonaga, (1946) On a Relativistically Invariant Formulation of the Quantum Theory of Wave Fields, Progress of Theoretical Physics 1, 27-42.

J. Schwinger, (1951) Theory of Quantized Fields I. Physical Review 82, 914-927.

Robert Griffiths, (2002) Consistent Quantum Theory, Cambridge University Press, Cambridge U.K.

R. Omnes, (1994) The Interpretation of Quantum Mechanics. Princeton University Press, Princeton N.J.

R. Omnes, (1999) Understanding Quantum Mechanics, Princeton University Press, Princeton N.J.

M. Gell-Mann and J. Hartle, (1990) in Proceedings of the 3rd International Symposium on Quantum Mechanics in the Light of New Technology, ed. by S.Kobayashi, H. Ezawa, Y. Murayama, and S. Nomura, Physical Society of Japan.

H. P. Stapp, (2007) Mindful Universe: Quantum Mechanics and the Participating Observer. Springer. Berlin Heidelberg New York.