

INFORMATION AND EXPLICATION: FROM WAVE FUNCTION TO CONSCIOUS THOUGHT

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Abstract: An atom is characterized mathematically as an evolving superposition of possible values of properties and experimentally as an instantaneous phenomenon with a precise value of a measured property. Likewise, an organism is to itself a flux of experience and to an observer a tangible body in a distinct moment. Whereas the implicit atom is the stream of computation represented by the smoothly propagating wave function, the implicit organism is both the species from which the body individuates and the personal mind its behavior explicates. As with the wave computation that underlies the atom, the substance of the implicit organism is not matter but information. And like projection from a superposition of potential values to a single outcome in a precise and fleeting moment, the organism actualizes only one of the many possible behaviors calculated in the ongoing presence we know as consciousness.

Keywords: Time; Complementarity; Coherence; Memory; Signal

INTRODUCTION

J.S. Bell's problem with quantum theory was not so much the indeterminism inherent to the quantum transition as the necessity of a fundamental transition in the first place. Must we divide the world into a "wavy" part -- a set of possible values of physical properties described by a wave function -- and a "classical" or tangible part composed of well-defined values of properties? The necessity for a measurement or observation to extract momentary definitude from an otherwise inexpressible reality introduces an ambiguity into physics at odds with the classical ideal (1987, 188).

Bell was of course well aware of the need for a quantum theory, in contrast to which classical theory is mere approximation. The failure of classical theory at

the very small scale provided the impetus for Planck's discovery in 1900 that energy is emitted in countable or "quantum" units. Soon thereafter Einstein recognized that the photoelectric effect requires treating photons as particles, contradicting the wave theory of light then predominating on the basis of electrodynamics. In 1924 de Broglie completed the case for a new theory by explaining electrons, among the building blocks of matter, in terms of waves.

If an electron is sent through an opening in a metal screen to a photographic plate, classical theory explains the impact area as a function of the size of the hole: the smaller the hole, the smaller the potential area of impact on the plate. This is indeed the case but only to a point. Beyond that point the smaller the hole, the *greater* the area of the plate accessible to the electron. If the screen has two holes, classical physics predicts simply an enlarged area of the plate upon which the electron can strike. Instead, as quantum theory predicts, the electron's possible landing point is restricted to a series of bands well known in classical physics as the signature of wave interference. As the procedure is repeated many times with many more electrons, the interference pattern is gradually fleshed out. The electron comes across as a wave.

On the basis of the Schrödinger equation, wave mechanics provides the dynamics of quantum systems. "There is no hint in the mathematics," as Bell points out, "of particles or particle trajectories" (1987, 187). This creates a dilemma, for once we recognize that the quantum analysis is more fundamental than the classical analysis, we have no means of restoring the classical world. Wave mechanics can predict everything the electron does *except* at the moment it manifests on the plate as a point-particle. The mathematics explains the wavelike distribution of points emerging on the plate as electrons are successively fired at it but not the *particularity* of each electron when it arrives. And without particularity, there are no definite properties out of which to make a tangible world.

Suppose we wish to explain the properties of the plate struck by the electron. Is it not made of atoms and their components? If we calculate the behavior of all those atoms on the basis of wave mechanics, according to which all their variable properties are distributed across potential values, we will never arrive at a solid object capable of registering an electron as a particle. Although classical physics approximates the more fundamental description, by itself quantum physics is

insufficient. This is why Bohr invoked the principle of complementarity (Faye and Folse 2017, 20). Rather than simply replace classical mechanics with wave mechanics, we assume a classical world in the form of a measuring device and resign ourselves to the alternating use of the opposed classical concepts of "particle" and "wave" in order to describe the phenomena that arise in the course of experimental interactions with quantum systems (Folse 1985, 116). Conspicuously missing from Bohr's approach was a metaphysical commitment. What is the reality of the unmeasured atom? Bohr does not say.

Bell disliked complementarity and called it "contradictariness" (1987, 190). If an elephant, he noted, is described from one angle as a head and the opposite angle as a tail, the descriptions are in no way contradictory. Particle and wave, on the other hand, are incompatible, as if the animal in question is an elephant from one angle and a duck from the other.

Though Bell, like many theorists, sought an alternative to Bohr's interpretation of quantum theory, the resolution of the quantum conundrum follows precisely from the principle of complementarity -- with the proviso that the elephant in the room is *time*.

As with light, matter comes across as either waves or particles depending on temporal context. On the basis of quantum theory we infer a background time in addition to the familiar moment-to-moment foreground. The unbroken presence of background time is implicit in the Schrödinger equation, the solution of which is a *continuously* propagating wave function. By contrast, foreground time is the *momentary* present extracted from continuous presence when, for instance, an electron strikes a photographic plate. So long as its motion is unbroken, the electron has only a superposition of potential values of properties. The act of striking the plate, however, cannot help but project the electron into a distinct moment with a definite position. The plate, on the other hand, need not interact with another object in order to exist *as such* because its scale guarantees the continual interaction of its constituent elements. This is why the indicator on a measuring device always points in a single direction as opposed to two or more directions at once. Neither a measuring device nor an observer can exist as such without a succession of distinct moments bearing definite properties.

In its default state the electron is wavelike insofar as each of its properties -- distributed across a range of potential values -- is a function of wave computation.

Whether natural or the result of intentional human measurement, interaction breaks the wave against the rock of temporal particularity. Upon that rock is built the tangible world of the senses. As the distinct moment is no more real than the ongoing presence from which it emerges, the unmeasured electron in wavelike superposition is as real as the particulate electron of the tangible world.

In this paper I explore the distinction between quantum and classical in terms of space and time. I then apply the resulting insights to the nature of life and consciousness, in the process providing a unified picture of the physical and the mental in accord with the twofold nature of time. Finally, I establish that in the absence of perfect knowledge of the nature of life, the default theory accords with quantum mechanics rather than classical mechanics.

PRESpace AND SPACE-TIME

Seeking an escape from complementarity, Bell was intrigued by David Bohm's interpretation of the quantum formalism. Bohm avoided the problematic transition from the wave function to a classical state simply by inserting the particle into the wave state. Since these particles are never observed, they constitute "hidden variables" and are therefore immune to verification. Worse, Bohm endowed his so-called particle with only one property, that of position. All other variable microphysical properties -- such as energy, momentum and spin -- are attributed to the wave function (Lewis 2016, 56). Since the wave function also captures the property of position, why separate out that one property and render the particle into a sort of reified position? With a temporalized complementarity, we have no need for a determinate position somehow hidden in the folds of the wave function. Instead we recognize that the particle *is* the wave function but in the context of the instantaneous present and that the wave function *is* the particle but in the context of ongoing presence.

Nor is there any need for spontaneous discontinuities inserted into the wave function, as proposed by Girardi, Rimini and Weber, another of Bell's preferred alternatives to complementarity (1987, 202-09). Discontinuity is inherently alien to wave propagation, a strictly external factor that decouples the quantum system from underlying temporal continuity. Precisely in its *departure* from the ongoing presence of the smoothly propagating wave function is the quantum system characterized by definite values of properties.

The wave function occupies an imaginary mathematical place known as

configuration space, which consists of three dimensions for each particle in a system (Ney and Albert 2013, 10, 15). For a quantum system of a million particles, its wave function thus occupies a configuration space of three million dimensions. In terms of ordinary space, wave propagation takes place nowhere in particular. Yet the wave function can affect activities anywhere, a capacity dramatically revealed in the correlation of particles remote from each other in ordinary space. The lesson of nonlocal entanglement is that the whole system, as governed by the wave function, is the primary reality while measurable particles distributed across classical space are secondary. Only upon external interaction, e.g. with a measuring device, does the quantum system lose its wave coherence and devolve into an ordinary set of spatially separated particles.

Though in classical mechanics configuration space is merely a conceptual aid for understanding complex systems, in quantum mechanics there is no description without it (2013, 17). Because a quantum system undisturbed by environmental interaction has no definite properties in classical three-dimensional space, configuration space is as close as we can get to a quantum system in its default or unmeasured state. Since the wave function accurately computes the probable outcomes of measurements, it presumably represents something real. But how can it be real when the space it occupies is imaginary?

A place that takes up no space is incomprehensible except in terms of time, specifically the background time of ongoing presence. This is why the wave function propagates continuously and why definite objects in discrete instantiations of the background time are the exception not the rule. Bohm, whose terminology transcends the limitations of his idiosyncratic interpretation of quantum theory, links wave computation to *implicate* order as opposed to the familiar *explicate* order of classical space (Bohm and Hiley 1993, 374). Implicit in every tangible system is the potentially infinite-dimensional order of the wave function.

The priority of implicate to explicate order is captured in Wheeler's concept of prespace. This is where the mathematics of configuration space takes on physical meaning. Starting from any location in ordinary space, by diving into it, so to speak, we arrive eventually at the Planck length, 10^{-33} centimeters or the size of a photon. To snap a picture in this region would require setting the shutter speed at maximum, which is 10^{-43} seconds or Planck time, the duration required

for a photon to travel a Planck length. Beyond this interior boundary neither space nor time is susceptible to measurement, rendering meaningless both the Cartesian coordinate system and the concept of particle.

Temporality is implicit in prespace. Precedence is after all not only ontological but temporal. The basic unit of time, according to Bohm and Peat, is not expressible in space-time measurements (1987, 114). Prespace knows nothing of coming or going, only ceaseless presence. Prior to space-time is the ongoing implicate background of all that is measurable.

Nothing tangible can be found in prespace, only the wave function computing potential properties in superposition. In contrast to prespace -- the zero extension of infinite dimensions -- a particle of light or matter requires a tiny amount of extension. When sufficient time has elapsed from the zero-point of prespace to allow for photons and electrons and atomic nuclei, a microphysical system is susceptible to explication. But the quantum leap is not necessarily triggered until sufficient duration has elapsed from the ever-present starting point for large-scale objects to come into being as such. According to Zurek, a sugar molecule requires 10^{-9} seconds to exist not just at the atomic scale but *as a sugar molecule* (Zeh 2010, 106). While quantum systems can exist either continuously in potential states or discontinuously in definite states, the scale of a sugar molecule by necessity propels it from ongoing presence to a succession of distinct and fleeting moments.

With each explication the wave function resets on the basis of the newly defined quantum properties. From this point the possible states of the microphysical system again multiply until the emergence of scale triggers another explication, that is, a particular moment distinct from the ongoing present. On and on it goes, each explication resetting the wave function at the time-zero of prespace from which it expands across possible states until sufficient time has elapsed for a determinate system to emerge in yet another instantiation of the ongoing temporal background.

Suppose an electron is hurtling toward an atom embedded in a metal plate. While the plate is repeatedly explicating due to the interaction of its component atoms, the electron remains in its implicate or wave-mechanical state. As it nears the plate, however, its wave function is thrown into conflict with that of the target atom. Whereas the continued momentum of the electron is included in its wave function, the atom says otherwise. The only way to resolve the conflict is to

explicate the configuration space of wave computation -- a kind of *virtual* space - - into the actual space of the classical world. The wave function is like a bubble expanding across a myriad of possible values of quantum properties. The conflict of two or more systems is the pin that pops the bubble.

The quantum transition, inevitably triggered in matter-rich regions by the emergence of scale, also occurs when the expansion of the wave function from prespace to virtual space brings neighboring systems into conflict, the resolution of which requires the explication of virtual space into classical space at an instant, i.e. space-time. Until the distinct moment of explication, there is only the indeterminate presence of implicate order. Whether due to scale or conflict, the progression from prespace to virtual space to classical space corresponds to the emergence of fleeting presence from ongoing presence.

THE COHERENT ORGANISM

We take pride in the coherence of modern systems -- from the circuitry in our phones to the regulated traffic in our cities to the physical and legal infrastructure of international trade -- until we consider that nature built its great civilizations in the dark, so to speak, without the benefit of systematic intelligence. If a bacterium is a village, a cell of the human body is a metropolis. Yet no one, as far as we know, designed any of its structures. Imagine a city that came into being without the guidance of self-aware intelligent agents, all the appliances and plumbing and wiring in each and every building, as well as the buildings themselves, generated and maintained spontaneously. Granted, nature had much more time to construct its cellular, organismal and ecological systems, but how did such a thing as the biosphere come into being in *any* amount of time?

The situation would be considerably less perplexing if the coherence inherent to wave mechanics somehow recapitulates in the classical world. As determined by its wave function, a many-particle quantum system is an indivisible whole not subject to analysis in terms of autonomous parts. Perhaps something similar enables the cell to operate as a unified whole and thereby prevents its myriad chemical reactions from going off the rails.

Ordinarily the power of maintaining the integrity of the whole system is attributed to the genome. Yet the genome is itself part of the process in need of ordering. DNA is "subject to a continual onslaught of molecules that bind it -- the

enzymes that untangle, unwind and then replicate DNA; the molecules that mark which genes are active and which are silent; and the proteins that pack the lengthy molecule into a manageable size... How the cell decides to activate a certain gene, for example, involves a complex assembly of molecules in the right place at the right time" (Singer 2016).

If the quantum mechanical wave function is a natural form of computation, perhaps organisms self-organize on the basis of an evolved form of wave computation. We may conjecture that a species of wave computation -- a descendent of the kind of computation described in quantum mechanics by a wave function -- accounts for the ability of biological systems to emerge not from a set of blueprints and prefabricated parts but from seemingly nothing.

This line of thought, however, immediately encounters a problem. Because interaction with surroundings continually destroys the coherence of a quantum system, the inherent holism of the wave state fails to endure in the macroscopic domain under ordinary conditions. Though a Bose-Einstein condensate illustrates nicely the ballet-like movements of correlated electrons in the absence of electrical resistance, it requires a temperature of no more than a few hundred billionths of a degree above absolute zero, preserving coherence over observable time-spans by preventing environmental interaction. Whether superconductivity is achieved through extreme cold or the application of extreme pressure and laser-generated heat (Grant 2018), that which maintains quantum coherence at the classical scale negates even the possibility of biology.

If nature provides a backdoor by which the holism of wave computation trespasses onto the classical domain, it might be the spontaneous emergence of complex organization in the context of environmental gradients such as temperature, pressure, charge, etc. Rather than mechanically forced, the emergence of convection cells in heated water, for instance, follows from the natural tendency to close down temperature gradients. Heated from below, water is subject to a gradient between the source of heat and the cooler air above and around it. To efficiently convey heat out of the water, a system of convection cells brings vast numbers of molecules into coherence. As long as heat can be exported to the surrounding air, energy flows and matter cycles, defining each "cell" of the system (Schneider and Sagan 2005, 111, 121). Thus environmental interaction, which destroys coherence at the microphysical level, enables it in the case of self-

organized systems. Like convection cells, living cells dissipate heat while drawing in the energy needed to maintain the cycles of chemical reactions on which they depend. Systems of spontaneous complexity retain coherence by staying out of equilibrium with the environment while interacting advantageously with it.

Strictly speaking, lasers are not built by engineers but self-generate when exposed to sufficient energy. Pumping energy into a block of densely packed "solid state" material yields at first the predicted random emission of light from scattered atoms. Unpredicted -- at least on the basis of classical physics -- is the laser threshold, a level of energy input beyond which atoms in great numbers spontaneously oscillate in phase and emit, as one, a coherent beam of light. According to Mae-Wan Ho (2008, 149), the same effect applies to the living cell. Energizing a cell stimulates coherence among its densely packed components, enabling the right molecules and enzymes to come together for a chemical reaction exactly when and where needed. Against the constant background of molecular and macromolecular jiggling, the standard "lock and key" model of the interaction of enzyme and substrate is suspect. Perhaps, writes Ho, a signaling molecule to its target protein is like a tuning fork to a piano string (2008, 134-36).

Inexplicable from the standpoint of classical mechanics is the ubiquity of spontaneous oscillations synchronized across living tissues (2008, 159). Why, when a scent is detected, do oscillations in the olfactory bulb synchronize with breathing? Why must neuronal activities in the motor centers of the brain be in phase with the coordinated movements of muscle cells in limbs (2008, 239)? Why must the emission of "biophotons" correlate with cell cycles (2008, 193)? Why bother unless such correlations facilitate an underlying organic coherence? In the case of Asian fireflies flashing together in perfect time and crickets chirping in unison, the holistic state extends to entire communities (2008, 160).

Though predictable in the long term, a healthy heartbeat demonstrates fluctuations in smaller time-scales. A sick heart, by contrast, is likely to be strictly mechanical in its rate of beating. Ho suggests that the dynamic rhythm of the healthy heart indicates coherence with processes going on throughout the body (2008, 164-66). Moreover, the emotional state of the organism is correlated with both the speed and pattern of its heartbeats (2008, 171-76). If emotion expresses the irreducible wholeness of the organism, so does consciousness. Ho suggests that general anesthesia, the efficacy of which is a total mystery for classical

biology, operates by suppressing the organism's innate coherence (2008, 237).

Hydrogen bonds involved in protein-folding are made and broken in less than a nanosecond. To do useful work, these fluctuations must be coherent. Otherwise they would cancel out, as predicted by statistical mechanics (2008, 36). What kind of classical mechanism could possibly account for such coherence? The same protein that coagulates in the presence of picric acid in a laboratory solution is resilient inside a cell (2008, 216). Energy released from molecular storage is far more efficient in a cell than a laboratory (2008, 11). Does our ability to "summon energy at will" result from a fantastic biological mechanism or the holistic coherence of the organism?

Bohm's defines implicate order as "active information" that projects into the explicate order of tangible existence (Bohm and Hiley 1993, 35). After enfolding back to implicate computation the quantum system unfolds again in a slightly different conformation upon measurement or other interaction. Whether particles or anything built from them, a permanent object is merely classical approximation (1993, 357). I propose that the action of unfolding and refolding reflects the nature of time. Implicate order yields to explicate order because the potential values of properties in the wave function instantiate as the determinate properties of an observable material system, and explicate order returns to implicate because the distinct moment vanishes into the past, leaving only wave computation in the underlying ongoing present.

At the microphysical level a wave function explicates as, say, an atom, which then folds back into its default state as a wave function. Since the macroscopic world, by necessity, also instantiates repeatedly from the ongoing present, the same back and forth action applies. What, then, does a convection cell revert to when the distinct moment passes? Unlike dust, a convection cell is no random agglomeration of atoms but a complex system with an implicit form of organization irreducible to classical mechanics. A convection cell ought to fold into an associated implicate order just like an atom enfolds to the implicate order corresponding to its type. When background time once again instantiates, the convection cell is tangible in the context of a distinct moment, which of course immediately passes, leaving only the implicate convection cell, and so on.

Because the definite properties possessed by an atom in a distinct moment establish the new starting point from which wave computation carries on, each

explication is incorporated into the continuous time underlying the wave function. The continuity of background time thus facilitates a natural form of memory. As fleeting and rapidly recurring explications play out in space-time, information builds up in the implicate order. The meaning of nature's memory is the indestructibility of wave-mechanical information. Far from annihilating information, the latest explication merely reshapes it, stimulating implicate evolution in conjunction with outer tangible evolution.

SPECIES AS IMPLICATE ORGANISM

A machine is made of parts that cohere according to a blueprint. Not only is each operation tightly constrained so as to perform a specific function but every procedure is always carried out in the exact same sequence of steps. As Daniel J. Nicholson points out (2019, 108-26), none of these characteristics apply in the case of a living cell. In no way do genes provide a basis for cell architecture, which remains globally stable despite the perpetual flux of its components. Far from a rigid product of pre-existent design, a protein is free to fold into whatever shape is appropriate for a given context. Rather than following pre-determined steps in a precise order, cell behavior is probabilistic. Even when they share the same genes, cells respond uniquely to the same input. The cell balances between structural stability and functional flexibility "by continuously turning over and reorganizing its constituents into different macromolecular complexes with diverse functional capabilities, which assemble and disassemble in order to meet the ever-changing demands of the environment" (2019, 123).

Given the absence of mechanical constraint, how does a cell maintain its functions? On this point Nicholson is silent. He does, however, provide a clue. Because a machine can be turned off and even disassembled and later reassembled, its structure can be abstracted from time. This is not the case in regard to the cell, which operates on the basis of stabilized process (2019, 112). A single temporal thread links not only every operation within an organism but every operation of its ancestors all the way back to the first bacteria. Temporal continuity opens up the possibility that memory, the influence of the remote past over the present, is integral to biology.

A natural form of memory is central to the model of living organization developed by Walter Elsasser. Lesser known among the pioneers of quantum theory, Elsasser nonetheless played a key role in its formulation. As a graduate

student at the University of Göttingen, he proposed the experiment that verified de Broglie's hypothesis of matter waves. He pointed out that the lattice-like structure of a crystal contains an array of slits narrow enough to scatter electrons that are fired through it. The experiment, performed in 1927, revealed the predicted interference pattern, demonstrating the wave nature of electrons in their default state (APS 2010).

In contrast to Mae-Wan Ho, whose inspiration was Schrödinger's book, *What is Life*, Elsasser approached biology from the standpoint of complementarity, which Bohr intended as a means of illuminating not only quantum but living and cognitive systems (Whitaker 2006, 189). Whereas Schrödinger postulated a "code-script" of species-specific developmental information bound to an "aperiodic crystal," i.e. DNA, Elsasser realized that complementarity, in the context of an organism, implies a *contrast* between information and tangible structure, that is, between mind and body. In Elsasser's view, just as the momentum and position of an electron are mutually exclusive, our picture of the organism as a whole -- in accord with Bohr's "generalized complementarity" -- is obscured by the detailed analysis of its physiochemical properties (Elsasser 1998, 8-9).

In his attempt to establish "precise point to point predictability of every step in a reaction chain that is both necessary and sufficient for a particular biological outcome," Elsasser quickly discovered that even for an organism as simple as a haploid mold, the number of possible gene combinations for any given molecular compound is incomprehensible, beyond the capacity of "any conceivable computer in a finite period of time" (1998, xiii-xiv). Thus we cannot follow a causal chain from the operations of DNA to larger-scale cellular activity, much less the formation of tissues and organs. As Elsasser put it, the ultimate origins of the forms and instincts of an organism are "buried in unfathomable complexity" (1998, 3).

As Gould conceded, the idea that genes provide a recipe for the construction of an organism does not rest on evidence and was never intended to be a testable hypothesis (2002, 201-02). At no point has anyone conceived of an experiment that would generate a specific outcome if genetic reductionism is true. Elsasser compared the state of biology of his time (and ours) to the Ptolemaic theory of planetary orbits, a prematurely ordered pattern that obscures the true pattern

(1998, 16). The challenge of a genuine theory of the organism is to make sense of living organization in the face of inconceivable complexity. He proposed three principles upon which to base such a theory: ordered heterogeneity, creative selection and holistic memory (1998, 3-4).

"The organic chemist is not satisfied until he has achieved a homogeneous assembly of molecules, where apart from irrelevant differences each molecule is indistinguishable from the next. Evidently, the organism does not behave like a chemist..." (1998, 39). Rather than strive for chemical purity, a cell maintains overall order in the face of numerous types of compounds (1998, 40). If the global order of the cell cannot be reduced to local order on the basis of homogeneous and predictable compounds, it must be maintained at the level of the whole. With its trillion atoms, many of which are capable of combining in many ways, a cell selects from among incalculable numbers of possible molecular configurations the ones compatible with its overall pattern of activity (1998, 142). Because selections correspond to the class to which the cell belongs, different cell types make different choices. In most cases the basis of selection is the memory inherent to each cell type. Muscle and skin cells make different choices on the basis of the differing tasks they traditionally perform. Likewise, the organism selects states that are similar to previous states found in its species (1998, 110). For instance, during development from the egg, an insect makes its eyes out of skin cells while a vertebrate makes its eyes out of nerve cells (Gross 2002, 110). Though neither method defies the principles of mechanics, in neither case is the choice mechanically determined.

In the context of molecular instability and heterogeneity, holistic memory provides informational stability (Elsasser 1998, 43). Memory thus encompasses "not only cerebral memory but all informational stability in the organism that does not yield to an understanding in terms of mechanistic models" (1998, 89). Rather than implementing a program of action encoded in DNA, each organism follows its species-memory. Structures and behaviors result "from a selection, among the immense number of patterns available, of a pattern that resembles some earlier pattern of the same organism or of preceding (parental) organisms" (1998, 5).

This is not to say Elsasser denied the importance of genetic heredity. He proposed a two-fold system of heredity combining holistic memory with

"particulate memory" on the basis of genes. In keeping with Richard Semon's concept of memory, according to which the mind can call up a complete memory from a minimal cue (1921, 138), Elsasser regarded an activated gene as the cue from which an organism generates an entire structure. Though necessary, the protein produced by the gene is insufficient to reproduce the desired structure (1998, 45). Likewise, the alarm transmitted by amoeba when food sources dry up, rather than mechanically forcing the community to unite into a multicellular organism, merely triggers the habitual response to a food crisis, a response embedded in the implicate order or species-mind of the amoeba.

Elsasser regarded holistic memory as a "primary phenomenon of nature" akin to the conservation laws of physics (1998, 118). On the grounds that "the conservative property of organisms is their similarity to preceding states without intermediate information storage," he invoked the concept of "action at a distance" to account for the conservation of information across generations (1998, 110). Just as electromagnetic radiation needs no medium or "ether" to carry it across space, information needs no material medium to connect it between past and present organic activities (1998, 140).

In light of temporal complementarity, however, the idea of information transmitted at a distance through time is superfluous. An organism need not reach out across history to connect with an ancestor if past explications are enfolded into the ongoing present of implicate order. The past remains present because time is not limited to a succession of discrete instants. Underlying the moment-to-moment time of explicate order is the unbroken presence of implicate order, which cannot help but convey the past into the explicate present.

What is past from the point of view of space-time is present in the context of background time. Only for the explicate -- the distinct particle in a distinct moment -- does past equate to oblivion, as the absence of tangible form seems to indicate nonexistence. From the standpoint of implicate order, by contrast, the absence of explicate formation signifies the presence of *information*. At each moment we are informed by what seems, given our explicate bias, no longer to exist, though we know -- given the wave function at the heart of quantum physics -- that the tangible does not exhaust the real. Moreover, because the past has no particular location, implicate order can act anywhere. Like the wave function coordinating spatially remote elements of a many-particle quantum system,

holistic memory is innately nonlocal.

The possible values of the properties of a quantum system are computed in a gradually expanding virtual space until another system comes into conflict with it, forcing a decisive outcome for both systems in classical space. On this basis the wave function is updated to a new starting point, and its virtual space begins expanding again from the ever-present prespace origin. Likewise, the possible actions of a human being are computed in the virtual space known as mind. When circumstances -- whether physical or social -- require action, one of the possibilities is selected for explication. The results of the action enfold into the person's memory so as to inform future decisions in similar circumstances.

What operates consciously ought also to operate unconsciously for not only the organism as a whole but each of its cells, all of them engaged in a kind of organic variant of wave computation. That the choice ultimately selected in any given circumstance is generally the one that most resembles the choice made in prior similar circumstances in no way negates the importance of selection. Novel situations require creativity, and our personal freedom to create only extends what is already present in our internal systems all the way down to the cell.

Just as each type of particle or atom both reflects and reinforces the implicate order underlying it, every organism explicates its species and, in turn, adds to the pool of collective memory from which subsequent organisms will draw. As the organism explicates its species in its development and maturation, its behavior explicates its personal mind, that is, the implicate order built up over time on the basis of prior individual behavior.

COHERENT ONTOGENY

Like Elsasser, embryologist Paul Weiss cited Bohr's principle of complementarity as a useful starting point for the examination of the organism. As a theory of light requires the "coexistence of both a corpuscular and a wave concept," an organism must be understood not only in terms of the molecules comprising it but the "unitary dynamics" that orders their activity (1973, xiv, 33).

In contrast to a factory, where "both building and machinery are permanent fixtures," a cell consists of ephemeral structures "continuously or periodically disassembled and rebuilt, yet always each according to its kind and standard pattern." The only predictable thing in the cell is the "overall pattern of dynamics

which keeps the component activities in definable bounds" (1973, 39-40). This contrast between order in the large and disorder in the small is maintained throughout development from the egg. The basic rule of ontogeny is self-differentiation: out of the general comes the specific. The initial level of structure is the embryo as a whole from which substructures emerge, and so on, until individual cells -- formerly capable of taking on any role -- become determined according to type (Nüsslein-Volhard 2006, 14). Far from a mere "epigenetic" extension of genetic mechanisms -- an as-yet unspecified causal chain imposing genetic design onto tissues and organs and ultimately the entire living system -- ontogeny is strictly top-down, from whole to component.

This is exactly the opposite of the expected outcome if the chromosome contains, in Schrödinger's words, both "architect's plan and builder's craft" (Schneider and Sagan 2005, 13). That genes determine eye color or visual acuity in no way means they contain a recipe for building eyes. Genes, according to Weiss, are tools in the service of patterned dynamics. A genetic aberration, rather than creating a new pattern, only modifies an existing pattern. Drugs and viruses can also modify patterns of activity, and no one attributes to them the patterns themselves (1973, 62-64).

Despite Schrödinger's overemphasis on the material carrier of genetic information, his treatise on the nature of life contains a key insight. As Schneider and Sagan point out (2005, 15-16), Schrödinger was the first to apply thermodynamics to the study of organisms, deriving from this union a definition of life in terms of self-organized complexity. As we know from the second law of thermodynamics, energy tends to even out, eventually arriving at the maximum state of entropy or disorder. In contrast to his discussion of genetic order as the basis of organismal order and mutations as a source of disorder, Schrödinger "now turned to the question of order from *disorder*: how does the cell manage to *escape* the second law?" Not only does the organism build up order over time, but even when it dies, its form continues to propagate in its offspring. Unlike mechanically making copies of copies ad infinitum, which naturally fade over time with rising entropy, organic reproductions lose nothing of their fidelity no matter how many generations pass. Schrödinger concluded that species retain their integrity over time because organisms extract energy from their environment, which doubles as a sink for waste energy. So long as it remains out

of equilibrium with the environment -- that is, alive -- an organism can appear to contravene the second law by enhancing environmental entropy.

By pointing to self-organization via energy extraction as a defining factor of life, Schrödinger indicated the means by which wave computation could be leveraged into the large-scale classical world. If Bohr's generalized complementarity set the stage for a quantum-informed biology, living coherence enters the theater through Schrödinger's backdoor. Moreover, self-organized systems, including organisms, demonstrate not only coherence but a kind of "decoherence." Any system that organizes the flow of energy (and dissipation of entropy) exhibits both coherence and the potential to lose coherence in one way and not another. In the literature on nonequilibrium thermodynamics, the simplest example of this phenomenon is a bifurcation point, the point at which a system either collapses or evolves to greater complexity in order to maintain and even expand energy flows.

Einstein thought he had uncovered a serious problem in quantum theory when he and his colleagues, Podolsky and Rosen, realized it implies nonlocality. When the wave function of a many-particle system collapses, the properties of its particles take on correlated values regardless of their distance from each other, raising the specter of superluminal transference of information (Whitaker 2006, 226). Bohr responded by invoking quantum wholeness. In addition to the indivisible wholeness of measured system and measuring device, which prevents classical objectivity in quantum measurements, a quantum system is irreducible to distinct particles, meaning the elements of a many-particle quantum system have no independent existence (2006, 232, 239). Because electrons subject to a single wave function already express the same pool of information, the idea of sharing information between distinct entities -- at any speed -- has no meaning.

The chemical reactions studied by Belousov and Zhabotinsky vividly demonstrate the coordinating power of a thermodynamic system far from environmental equilibrium. In a reaction that generates wave fronts, 10^{20} molecules act in unity "as if choreographed or sending a message from one part of the reaction to another via some miniaturized form of telecommunications" (Schneider and Sagan, 2005, 98). The same barrier against superluminal speed of communication in quantum mechanics applies also at the molecular level. By necessity all the molecules caught up in a nonequilibrium system express a single

source of information.

Because molecular motion is ordinarily uncoordinated, disorder in the small is a given, which is why classical thermodynamics was displaced by Boltzmann's statistical mechanics (Schneider and Sagan 2005, 47). Order in the large indicates that cellular activity is a form of self-organized complexity. Life is a *product* of evolution, specifically the evolution of energy-importing, matter-cycling, entropy-exporting chemical systems. A cell is a system of systems. Not everything within it can be treated as a functional mechanism but must be accepted "as is," its complexity a "fundamental and irreducible property" (Forgacs and Newman 2005, 1). Rather than a bundle of mechanisms, the cell arranges itself such that mechanistic principles serve its survival and reproduction imperatives (2005, 7). Left unchecked any mechanical process will eventually derail ontogenesis. What counts is the "multileveled determination of cells and embryos which ensures that each driving force is constrained... and that the whole complex of forces is subordinated to the survival and propagation of the organism" (2005, 50).

Cells are believed to differentiate into specific types according to their position in the embryo, which is signaled to each cell on the basis of concentrations of molecules known as morphogens (2005, 160-61). Since concentration gradients change gradually across the embryo, every cell is informed of its location. The cell is prompted, not forced, to act. Moreover, the way it transforms into the correct cell type for its location is equally unforced. Every tool at its disposal, whether involved in the process of unfolding the genome or copying the relevant genes or matching nucleic acids with amino acids or folding a polypeptide chain into a functional protein, must appear on cue in a complex dance far beyond the scope of mechanistic analysis. Despite its likelihood at some point of engaging mechanically in a cellular process, a protein's route to and from that point -- its very existence in the first place -- follows from the irreducible coherence of the cell and not as a simple consequence of chance and mechanism.

Far from mechanically forcing a cell onto the correct pathway, a morphogen gradient functions as a signal in exactly the same sense that words function as signals for human consciousness. Each cell must know what the signal means and act accordingly, presumably on the basis of whatever memory the morphogen triggers. According to Forgacs and Newman (2005, 134-38), movement of

embryonic cells along neural crest pathways cannot be explained according to intrinsic motility, surface features or chemical gradients. Moreover, cells grafted onto a new location seem to retain their memory of how to operate in the original location, moving opposite the cells native to the new location. Perhaps a hidden mechanism forces neural crest cells to detach from the neural tube and migrate to distant sites where they differentiate. Or maybe mechanisms are merely utilized in the course of organically coherent actions.

Ontogenesis becomes more resistant to mechanistic explanation as it proceeds. Not just the emergence of a circulatory system or an endocrine gland with its transmission of regulatory signals throughout the body but even tissue-specific properties such as muscle contractility and nervous electrical excitability and the secretion of solid matrices by bone cells involve a multitude of patterning processes far beyond the scope of a few "generic physical mechanisms." Though nothing biological "can occur without the participation of physical mechanisms, the high degree of structural and dynamical complexity of most living systems makes it exceedingly difficult, in general, to follow the workings of basic physical principles or appreciate their roles" (2005, 188-89). The heart begins as two parallel tubes that are eventually brought together and fused (2005, 192-93). Perhaps a mysterious set of mechanisms accounts for the whole process, and perhaps one day researchers will uncover them. Given the primacy of quantum over classical physics and the possibility of an evolved form of wave computation, however, the mechanistic assumption cannot be taken for granted.

CONSCIOUSNESS

By generating possible responses to a given situation, mental computation resembles the action of the wave function. Likewise, behavior resembles the explication of a superposition of possibilities into a single outcome. Ongoing presence and the distinct states that successively emerge from it comprise *time* in the quantum context and *consciousness* in the human context.

Bergson was the first to identify the complementarity of apparent opposites in consciousness. The experience of listening to music, he observed, entails both continuity and heterogeneity over time. The melody is always changing, but this heterogeneity in no way indicates discontinuity, only successive phases in the flow. As Milic Capek (1971, 120) puts it, continuity and heterogeneity are

"complementary aspects of one and the same temporal process." Quoting James to the effect that consciousness, like a bird, is easier to grasp at rest than in flight (1971, 121), Capek notes that we naturally associate consciousness with its explications, overlooking the continuous order implicit in the parade of distinct thoughts and emotions. The materialist imperative of reducing mind to brain is only the logical endpoint of confusing fundamental reality with its moment-to-moment unfolding. Against this reduction Bergson posited memory as the continued existence of the past in the present as opposed to a representation of the past produced by the brain (1911, 80-82). Bergson's proposal foreshadows the seamless emergence of memory from the temporal complementarity of continuous and discontinuous presence.

Perhaps, like the unified mechanics of the heavens and the earth, what applies in the conscious mind applies equally in the physical world. Implicate order builds up over successive explications, providing the basis for the characteristics of each type of quantum entity. Photons act like photons -- and electrons act like electrons -- because their properties built up over time into an embedded implicate order. Early in the history of the universe the basic properties of matter evolved into being, and afterwards events played out deterministically.

Were it not for Schrödinger's backdoor, the story would end there. Emerging in regions of energy flow, self-organized systems resurrected quantum coherence at the large scale. In combination with implicate memory, explicate novelty enabled the complexification of such systems and the emergence of the bacterium, a stable and self-contained reproductive system of systems that lives by extracting energy from its environment and dissipating entropy. Much as wave computation determines the possibilities by which a quantum system might explicate, the mind of the bacterium determines possible responses to a given environmental input. In contrast to the wave function, however, the organism also determines the particular outcome of its computations. This is the hallmark of consciousness. Bacteria do not behave randomly; their actions do not mimic the randomness of wave function collapse. Swimming up a sugar gradient is not a random act but a strategy for absorbing high-quality energy to be degraded during work and ultimately exported back to the environment.

So long as sensory input leads directly to action, however, the ongoing presence of the organism is at best a kind of proto-consciousness. The significance

of the brain is that it makes room between input and output in which to allow for reflective decision-making (Bergson 1911, 21-23). Henry Stapp applies quantum mechanics to the question of how the brain carries out this task (1993, 133). Nervous tissue, as he points out, is calibrated such that each synapse has a roughly 50% chance of firing. With N action potentials pulsing through synapses, the quantum state of the brain is therefore a superposition of 2^N possible states. A pattern of actual neural firings is experienced as a conscious event, the mental correlate of a collapsing wave function. In both brain and psyche, among numerous possibilities only one is actualized (1993, 128).

This is not to say that brain and psyche are distinct objects. From the standpoint of temporal complementarity, psyche *is* brain but in the context of ongoing presence, while brain *is* psyche but in the context of a succession of fleeting moments.

The fact that the atoms comprising the brain are continually undergoing collapse from potential states to actual states in no way prevents the emergence of potentiality at a higher level of scale. All that is required is the cycling of energy through a self-organized system and that the elements of the system are generally poised between distinct possible actions. In this case, as Stapp notes, no matter how many elements the system contains, it operates as a unit in a wave-mechanical state. A conscious decision constitutes the collapse of potentiality to an actual outcome. Whereas the collapse of wave computation is random in the case of quantum systems, the collapse of potential behaviors into a single actual behavior in the organism is subject to nonrandom influence, whether memory in the case of familiar circumstances or intelligence in the case of novel circumstances.

The ongoing presence underlying wave computation serves as nature's template of consciousness. In turn, consciousness clues us in to the fundamental nature of time. The organism, with its nested hierarchy of self-organized chemical systems, adds self-nature to the impersonal wave mechanics of the atom. Just as the quantum system is determined by the wave function, the neurological system is *self*-determined by consciousness. In contrast to the random outcome that follows from the measurement of a quantum system, the evolved form of coherence is defined by the attainment of determinism in the explication of information. As macroscopic beings equally at home in the explicate order as well

as the implicate, we have the power not only to propagate possibilities, as in wave computation, but to project tangible actuality, as in measurement. I think, therefore I act.

CONCLUSION

We live in a world projected from a wave. The chief lesson of quantum mechanics is that reality is not confined to things that exist outside each other across space. More fundamentally reality is *inside*. Where everything exists inside everything else, space has no meaning. Purely temporal, the inside is presence, not static like a snapshot but in flux. Flowing presence is the basis of wholeness in both space and time, that is, the ground of both nonlocality and memory. As the body -- the outer self -- participates in the projection, the inner self rides the wave, projecting idea onto world.

Far from an early and imperfect forerunner of the computer-driven robots fashioned by human engineers, the organism is the missing link between quantum and conscious coherence. The mode of operation all along -- at every step in the evolution of physical and biological properties -- has been the simple act of folding and unfolding, information and explication.

Sometimes what explicates from the underlying informational order is itself a kind of information. As the words on this page attest, reflective human intelligence is a highly efficient generator of explicate information. When it happens in the body we call it a signaling molecule, something that carries meaning for a cell, telling it which set of implicate instructions to explicate and which can stay folded up. Harold Morowitz noted that adenosine triphosphate (ATP), the storehouse of energy in the body, is accompanied by several substances essential for energy transfer. Like ATP, each of these other substances also contains adenine, one of the four bases of DNA, despite the fact that "the adenine portion itself plays no part in the energy process. The whole idea seems information-rich, somehow rather too linguistic or poetic for the grind-and-extract business of biochemistry" (Schneider and Sagan 2005, 23).

I do not seem to be a machine. For this reason wave computation, the exploration of possibilities in virtual space, strikes a chord. Virtual space is so familiar it even has a name: imagination. My life is all about signals and meanings -- memory and emotion and striving -- not forces or laws or inviolable causal

chains. The electrochemical discharges in my brain, rather than define me, merely explicate me. Whereas the view of life from classical mechanics must explain away purpose as a mirage arising from passive mechanical processes, in the temporal-holistic view the *appearance* of purpose follows from its *actuality*. Presence seeks to perpetuate, to remain ongoing, in whatever form it currently explicates.

For centuries life has been conceived in terms of classical mechanics. Thus species evolved into being through a mechanical process of chance mutation and natural selection. The most obvious problem with this conjecture is that it makes no room for the self-existence and creative input of the organism. As it happens, the holistic nature of life is prefigured by the wave function, the ongoing determination of potential states at the very core of physical existence. Maybe this resemblance is mere coincidence, and our wish to see something more in it reflects the human tendency to find patterns in the static. Or maybe the coherence destroyed by explication has a way of coming back -- thermodynamically, biologically and psychologically. If an explanation of life is to be *true to life*, it must explain holistic coherence. In contrast to standard theory, the view from quantum mechanics achieves this aim and, for this reason, displaces the account from classical mechanics as the default theory, that is, the theory to beat.

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